CHARACTERISTICS OF ALSI7MG0.3/x-GNPS COMPOSITES MANUFACTURED VIA STIR CASTING METHOD

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ABSTRACT: Significant progress in graphene research has diverted interest to an emerging class of aluminium-based metal matrix composites. AlSi7Mg0.3 matrix composites reinforced with graphene nanoplatelets (GNPs) were fabricated via the stir casting technique. GNPs in varying amounts (0, 0.3, 0.5, 1.0 wt.%) were incorporated into the AlSi7Mg0.3 alloy via a mechanical stirring technique. Optical microstructures further analyzed the developed composites to discuss the microstructure evolution of alloys and composites. The hardness test was conducted to determine the strength of developed composites and supported by differential scanning calorimetry and X-ray diffraction. The results reveal the dendritic microstructure was decreased in the composites after adding various amounts of GNPs. The Vickers hardness value is significantly increased compared to as-cast alloy and the maximum hardness value (85.55 HV) was obtained for the AlSi7Mg0.3/0.3 wt.% GNPs. The outcomes demonstrate that incorporating a sufficient amount of GNPs into the AlSi7Mg0.3 alloy improves the hardness of the composite.

KEYWORDS: *AlSi7Mg0.3 alloy; Graphene nanoplatelets; Stir casting; Hardness*

1.0 INTRODUCTION

Metal matrix composites are the most valuable composite materials and have discovered applications in a variety of fields, including heat transfer, energy storage, good thermal resistance, excellent mechanical and more [1]. The properties of this metal matrix composite have attracted the attention of materials research throughout the worldwide in the establishment of novel materials for various industries, such as the automotive industry. Metallic materials, such as aluminium and its alloys, have been discovered to be more adaptable and have been employed in various applications. As a result, aluminium and its alloys have the most contribution to the formation of metallic structures in composites [2]. Meanwhile, aluminium-silicon alloys are frequently employed in engineering and construction because of their strong corrosion resistance, low density, and high strength [3–5]; however, their ability is limited. In recent years, its limited ability and strength gained the attention of researchers. They moved their focus to the practical application of composite materials, which allowed for the creation of inexpensive, lightweight, high-performance products that also possessed remarkable strength [6]. The reinforcing is the most widely used approach for modifying the properties of aluminium and its alloy to accommodate design requirements. Therefore, reinforcing components such as boron, silicon carbide, alumina oxide and nanocarbon are required to disperse across aluminium and its alloy to produce aluminium metal matrix composites.

Graphene has offered a wide range of potential applications in composite materials since it was discovered in 1994 by Geim et al., owing to its superior electrical, mechanical characteristics, and thermal conductivity [7-8]. In addition, graphene has recently demonstrated tremendous potential in matrix reinforcement because of its exceptional strength of over 1 TPa [9-11]. Graphene nanoplatelets (GNPs) are 2D multilayers of graphene with platelet-liked graphite nanocrystals and are efficiently used as reinforcement aluminium metal composites due to nano size and exceptional strength. These combinations significantly improve the mechanical characteristics of the composites. In addition, GNPs have better interfacial adhesion in composites owing to their higher specific surface area. Nonetheless, the large specific surface area leads GNPs to agglomerate when added within the composites because of the weak van der Waals force between the stacking layer of sheets [10]. Hence, dispersion and uniform distribution of GNPs reinforcement in aluminium alloys perform a crucial character and are still challenging in improving the properties of aluminium matrix composites. Most research used balling

milling [12] and sintering [13] for fabrication to achieve uniform distribution and avoid agglomeration. Meanwhile, the casting technique is a widely used process that involves liquid metal as a medium. However, the insertion of GNPs into molten metals results in non-homogeneous distribution, agglomeration, and cluster arrangement of the particles on the outer layer [14]. Hence, stir casting was brought into place to circumvent the common problem associated with normal casting techniques due to a more uncomplicated, cost-effective, and versatile fabrication technology than other approaches [15]. Chak and Chattopadhyay [16] analyzed the effect of various contents of GNPs (0.1, 0.3 and 0.5 wt.%) reinforced with Al7075 matrix alloy using a mechanical stirring-assisted liquid route where it justified that the microhardness of the 0.5 wt.% GNPs/Al7075 composites improved by 53.39% in microhardness compared to base Al7075 alloy. Hedayatian et al. investigated the graphene oxide reinforced Al6061 produced by stir casting and hot rolling as a secondary process on the mechanical properties [17]. The hardness test result showed the enhancement of 41% of composite samples with respect to the base Al6061 alloy. However, there is limited data in the literature on the stir casting technique on aluminium-silicon composites containing GNPs. In this approach, the liquid matrix metal is combined with the reinforcement particles and stirred under specified parameters to assist the dispersion of the reinforcement.

Hence, this study investigated the hardness of AlSi7Mg0.3 matrix composites strengthened by GNPs with various contents fabricated by stir casting. The results have been investigated with AlSi7Mg0.3 alloy without adding GNPs for comparison. In addition, the effects of GNPs reinforced AlSi7Mg0.3 matrix composites on the microstructure were evaluated as the outcomes of the study.

2.0 EXPERIMENTAL PROCEDURE

2.1 Composites preparation

In this study, the AlSi7Mg0.3 alloy ingot was used as a base matrix alloy with chemical composition as listed in Table 1, and GNPs (0.3, 0.5 and 1.0 wt.%) with a surface area of 500 m^2/g from Sigma-Aldrich was used as reinforcement Figure 1(a) and Figure 1(b) shows a scanning electron microscopy (SEM) image of the as-received GNPs and magnesium powder, respectively.

Table 1: Chemical composition of AlSi7Mg0.3 alloy

Si	Mg	Fe	Cu	Mn	Zn	Al
7.550	0.250	0.425	0.045	0.185	0.0035	Balance

An induction furnace fully melted 400 g of the base alloy in a graphite crucible up to 700 °C. The molten temperature was reduced and maintained at 650 ° for 5 minutes. The molten of the base alloy was stirred using three blades stainless steel stirrer at 500 rpm for 5 minutes. The stirring of the base alloy generates vortex formation in the melt. In order to enable GNPs to be effectively distributed in the alloy, pure magnesium powder (Figure 1(b)) with 1 wt.% was added to the mixture as a wettability agent. The mixture of GNPs and magnesium powder was wrapped in the aluminium foil and injected into the alloy molten at the bottom of the crucible by a plunger. The mixture was quickly stirred at 500 rpm for 5 minutes. The stirring forms a vortex within the molten, creating a pressure change within molten metal layers and forcing GNPs to be dragged inside, and resulting in a homogeneous mixture. The molten mixture was poured into the preheated mould at 150 °C to form the as-cast billet of composites after completing the stirring process.

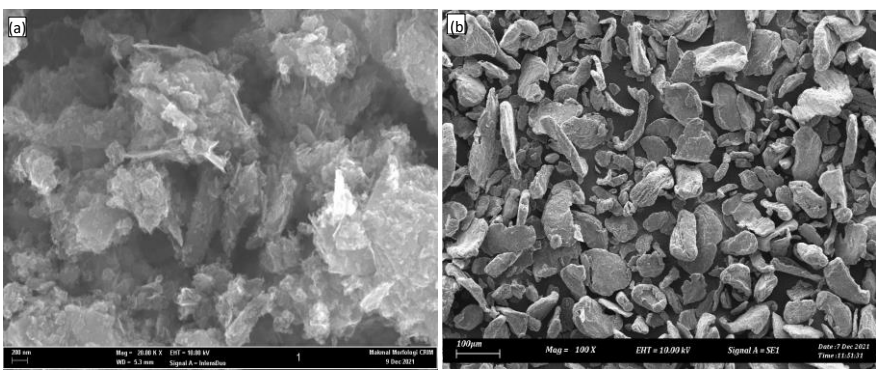

Figure 1: SEM images of as-received: (a) GNPs particles and (b) pure magnesium powder

2.2 Characterization and testing

The as-cast alloy and composites were characterized as per suitable ASTM standards. The microstructure evolution and mechanical properties of the GNPs reinforced aluminium alloy composites were determined. The samples were sectioned and prepared with standard metallographic procedures of grinding (600, 800, 1000 and 1200 grits), polishing until 1 μ diamond polishing suspension and etching with

Keller's reagent to get a clean surface for characterization. The microstructure evolutions were examined through optical microscopy. The hardness of the AlSi7Mg0.3 and AlSi7Mg0.3/GNPs composites were tested using the Vickers hardness machine (load=9.8066 N and dwell time=10 s). The samples were indented with 9 indentations on each sample, and the average data was recorded. Differential scanning calorimetry (DSC) was used to measure the thermal properties of AlSi0.7Mg0.3 and AlSi7Mg0.3/GNPs with a constant heating rate of 10 °C/min from 30 °C to 700 °C under N_2 gas flow to prevent severe oxidation.

3.0 RESULTS AND DISCUSSION

3.1 Microstructure evolution

Figure 2 shows the optical micrograph of the stir casting AlSi7Mg0.3 and GNPs-reinforced AlSi7Mg0.3 matrix composites. Figure 2 (a) shows the evolution to rosette-like α-aluminium grains after the stirring process, while Figure 2(b)-Figure 2(d) show the addition of GNPs to the matrix significantly retarded dendritic formation. However, with the GNPs addition from 0.5 to 1.0 wt.%, the non-uniform globular and rosette-like primary α-aluminium grains are increased, as shown in Figure 2 (c) and Figure 2(d). The irregular and non-uniform morphologies of the α-aluminium particles might have attributed to the presence of GNPs particle agglomeration in the AlSi7Mg0.3 alloy.

Figure 3 shows the optical microstructure images AlSi7Mg0.3 /0.3 wt.% GNPs samples were magnified at 50 and 100 times magnification. It shows the silicon eutectic surrounding the fine homogeneously dispersed spheroidal α-aluminium in the composites. In this instance, the GNPs serve as nucleation agents during the solidification of α-aluminium, although numerous methods have been suggested for decreasing the particle size by introducing reinforcement [18-19]. In addition, dendritic structures were fragmented into smaller globular or like-rosette and more uniform as a result of mechanical stirring action.

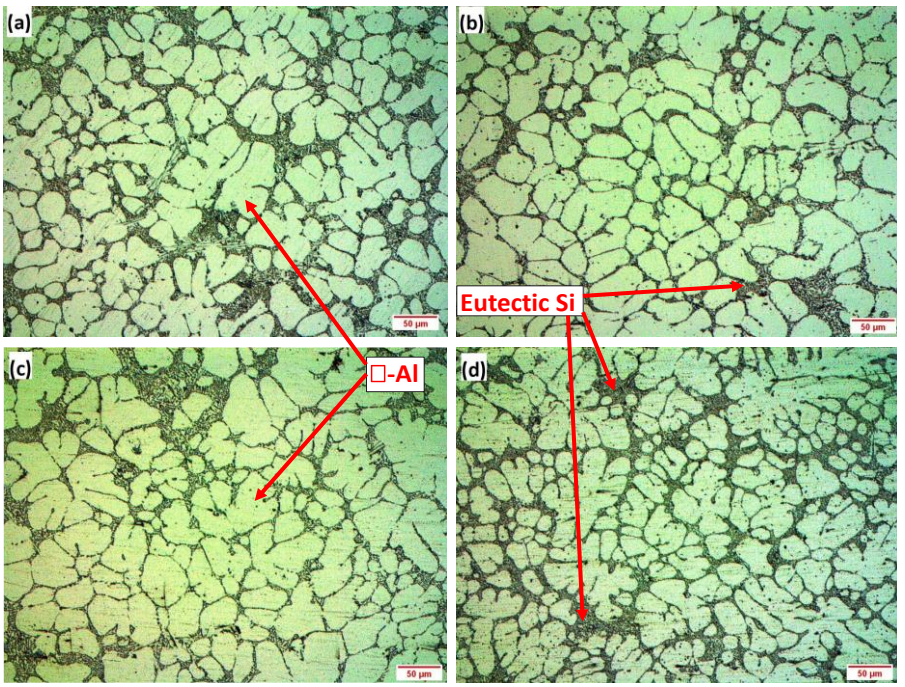

Figure 2: Optical micrographs of (a) AlSi7Mg0.3/0 wt.%GNPs, (b) AlSi7Mg0.3 /0.3 wt.% GNPs, (c) AlSi7Mg0.3/0.5 wt.% GNPs, and (d) AlSi7Mg0.3/1.0 wt.% GNPs

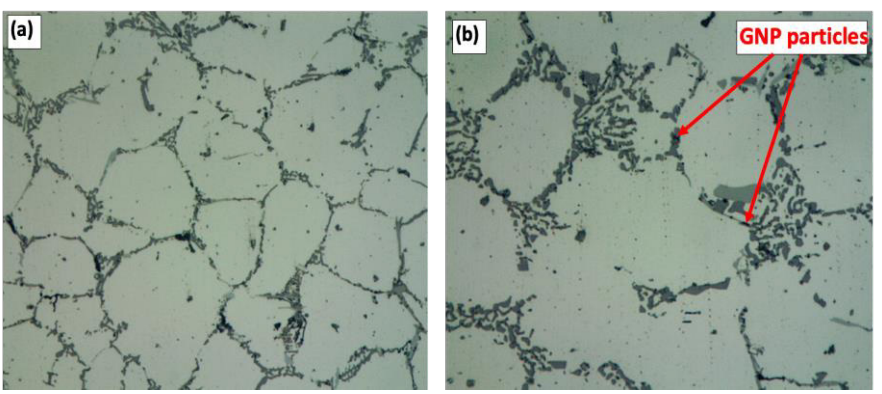

Figure 3: Optical microstructure of AlSi7Mg0.3 /0.3 wt.% GNPs at (a) 50x magnification (b) 100x magnification

3.2 Hardness properties

The results of the hardness of AlSi7Mg0.3 alloy and GNPs reinforced AlSi7Mg0.3 matrix composites are shown in Figure 4. The hardness of AlSi7Mg0.3/0.3 wt.% GNPs composite (85.55 HV) improved by 26.34% as compared with the AlSi7Mg0.3/0 wt.% alloy (63.01 HV), thereby

demonstrating the significant impact of GNPs on the alloy. The increase in hardness for AlSi7Mg0.3/0.3 wt.% GNPs can be attributed to the good homogeneous distribution of GNPs in the matrix.

In addition, when GNPs content increased from 0.5 to 1.0 wt.%, the hardness is decreased but still higher than AlSi7Mg0.3 alloy. It shows that the combination of GNPs strengthening and grain refinement of the AlSi7Mg0.3/GNPs composites microstructure is the main attribution to the hardness of the composites. It is also seen that even though AlSi7Mg0.3 is reinforced with GNPs with a low reinforcement ratio, the high aspect ratio of GNPs allows it to contribute significantly to the strength of the structure. However, the decreasing of hardness at a high amount of GNPs reinforcement is probably a result of the propensity to agglomeration and non-uniform dispersion and weakens the hardness properties of the AlSi7Mg0.3/GNPs composites [17]. Therefore, the presence of the correct amount of GNPs as reinforcement in the AlSi7Mg0.3 alloy is crucial to optimising the hardness properties of the composites.

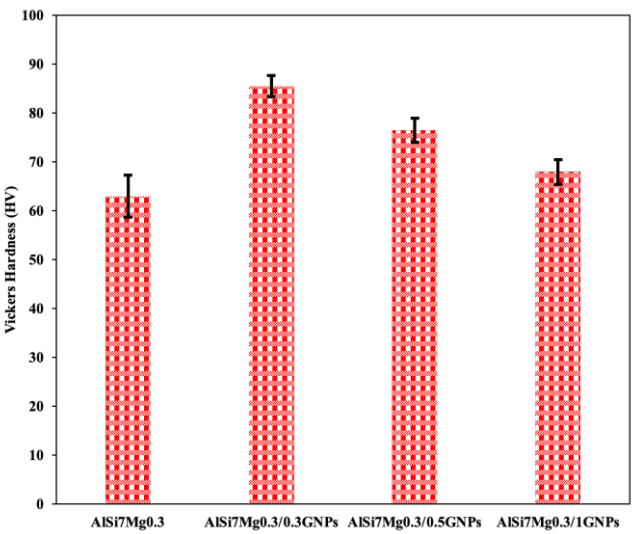

Figure 4: Effect of GNPs different weight fractions on hardness.

3.3 DSC analysis

Figure 5 presents the differential scanning calorimetry (DSC) for AlSi7Mg0.3 with different amounts of GNPs. In each curve, there is a major peak curve (marked by arrow A) due to the nucleation of α-aluminium. The temperature of nucleation at peak A (endothermic peak) decreases with increasing the amount from 0 wt.% to 0.5 wt.% of GNPs. However, the peak is increasing again at 1.0 wt.% of GNPs. The

endothermic area in Figure 5 for the small area of 0 wt.% GNPs resulted in the large fine network of eutectic silicon around the aluminium dendrites as shown in Figure 2 (a). In contrast, the large area for 0.3 wt.% and 0.5 wt.% indicate that few eutectic silicon formed a network around α-aluminium. However, the area for 1.0 wt.% of GNPs is reduced, and there is an increase in the eutectic silicon network around the dendritic. In addition, intermetallic formations are caused by either absorbing or supplying heat. Hence, scanning calorimetry (DSC) can accurately measure these heat exchange amounts; hence the analysis using this approach provides insight into the intermetallic developments inside the composites.

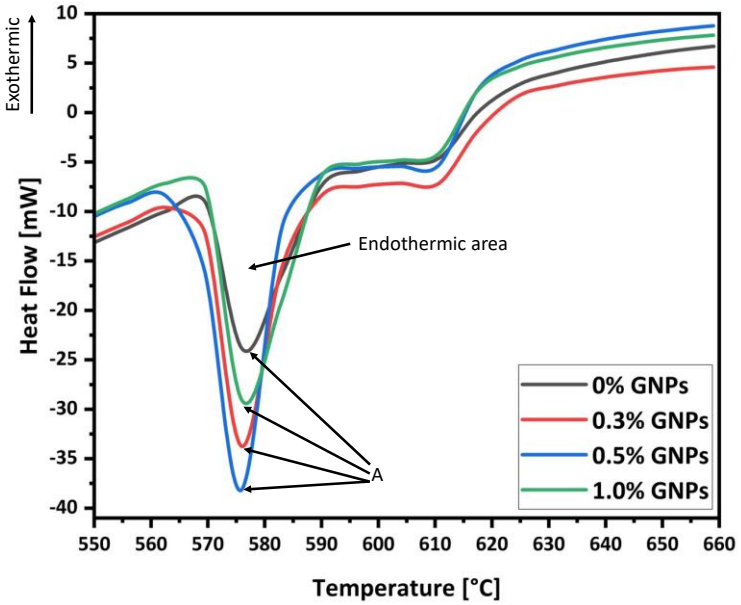

Figure 5: DSC AlSi7Mg0.3 alloy composites different amounts of GNPs.

Figure 6 displays the X-ray diffraction (XRD) to overview the phase compositions of these composites and AlSi7Mg0.3 alloy. According to these findings, the existence of GNPs in solid compositions was evaluated by a peak detected at 2θ values of about 44.73 ° and 56.21° for 0.3, 0.5 and 1.0 wt.%, respectively. These findings confirm the presence of GNPs, which exhibit no degradation in crystal structures due to processes such as oxidation. Thus, these solid combinations exist as a result of physical interactions. Intermetallic phases of Mg_2Si at 28.45°, 47.32°, and 65.12° for AlSi7Mg0.3 alloy and GNPs/AlSi7Mg0.3 composites. However, there is an absence peak of aluminium carbide (Al_4C_3) as a formation of an intermetallic reaction between carbon and aluminium. The absence of aluminium carbide is owing to the

extremely low concentration of the phase and the overlap with associated peaks of a similar form [20]. In addition, the intermetallic phase of AlFeSi at 34.060° and 78.27° was detected in both alloy and composites. These Fe-rich phases can act as causes of fractures that create stress concentration during plastic deformation, degrading the mechanical performance of AlSi7Mg0.3 alloys. However, the presence of Mg_2Si may have enhanced the hardness behaviour of the composites.

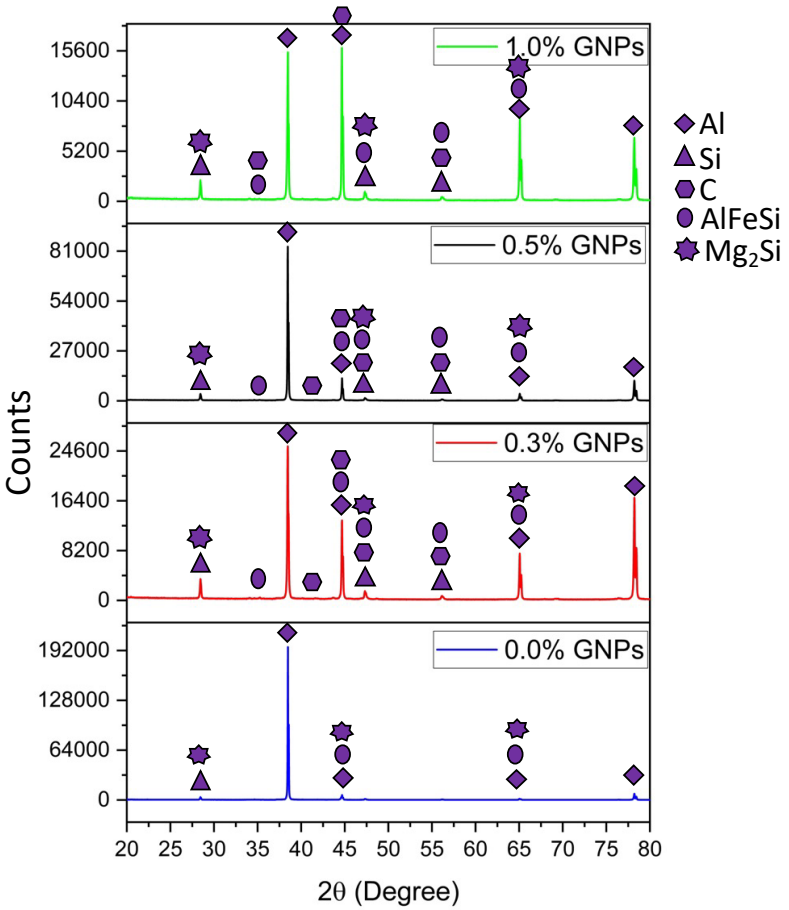

Figure 6: DSC AlSi7Mg0.3 alloy composites different amounts of GNPs.

4.0 CONCLUSIONS

In this study, GNPs reinforced AlSi7Mg0.3 composite with various amounts of GNPs were effectively produced using the mechanical stir casting process. Microstructures of primary α-aluminium in liquid casting were developed to be almost spheroidal and rosette-like shaped with mechanical stirring. Incorporating the reinforced elements into the matrix was assisted by the force convection under vortex conditions

that occurred during the stirring process. While the hardness improvement after adding GNPs was increased by 26.34% for 0.3 wt.% GNPs compared to alloy. However, the strength decreased significantly after 0.5 wt.% GNPs due to the increase in agglomeration. The further investigation is needed to verify the behaviour of the GNPs reinforced AlSi7Mg0.3 composites under the thixoforming or heat treatment process as a secondary process.

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