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Effects of garnet particles and chill casting conditions on properties of aluminum matrix hybrid composites

Haider Tawfiq Naeem[1+] Firas Fouad Abdullah[1]

1 Al-Muthanna University, 72001 Samawah, Al-Muthanna, Iraq

+Corresponding author: Haider Tawfiq Naeem, email addresses: haidertn@mu.edu.iq, dr.haider.naeem@gmail.com

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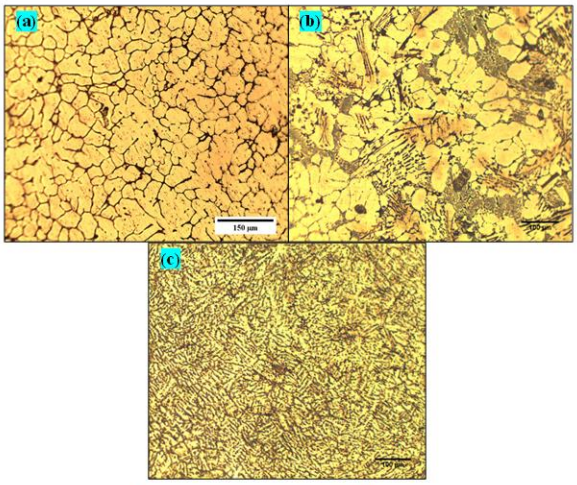
ABSTRACT: In recent years, the demand of high-performance and light-weight materials was increasing for industrial applications. The present research aims to study microstructural and mechanical properties of aluminum matrix hybrid reinforced 6-12 wt.% of garnet under the effects of materials chill casting during the manufacturing aluminum matrix composite. In this research work, metallic mold and no chills were used. In order to evaluate the quality of the chill end casting microstructure, hardness, and tensile tests were conducted on the prepared composite specimens. Aluminum matrix composites underwent the chill casting process have been examined using the optical microscope, scanning electron microscopy and X-ray diffraction. Microstructure outcomes of the casted Al-composites alloy indicated that having precipitations (Al_2Si, $AlCuMg_2Si$) and Garnet particulates hard within the Al-matrix. The results showed that the copper chill casting is the better one in terms of improving the mechanical properties because of its high volumetric heat capacity. Aluminum composite with addition of 9% Garnet composite produced via copper chill casting exhibits better mechanical properties.



The optical micrograph of the Al-samples

1. Introduction

Aluminum matrix hybrid composites with dispersion of two or more ceramic reinforcements have been widely used in various applications of automotive and aerospace sectors[1]. Aluminum matrix composite have light specific-weight, good resistance of corrosion with excellent thermal properties. These composites are becoming wide using as the high performance materials. Ceramic materials are generally used to reinforce aluminum-alloys with silicon carbide (SiC), titanium carbide (TiC), alumina (Al_2O_3), silicon oxide, TiB_2, ZrB_2, AlN, Si_3N_4 and SiO_2 [2,3]. These ceramic materials have high strength and high hardness. However, it displays brittle behavior and has low resistance to fracture which can be improved by modifying the reinforcement grain size, shape and by incorporating additional phases[4]. It has been widely reported that aluminum alloys can be readily developed with two or more reinforcement and recently there has been a growing interest in the use of hybrid composites. Particulate reinforced hybrid composites exhibit excellent isotropic properties[5]. Ghoncheh *et al.*[6] found that experiments carried out on a mold having high cooling rates have the solidification parameters such as nucleation temperature, recalescence undercooling temperature, and range of solidification temperature influenced by variation of cooling rates. Generally, the improvement in the overall properties of

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composites is made using the hybrid composites through adding insoluble reinforcements to the base matrix[7]. Many of studies focused on the utilization of various forms of artificial reinforcements in aluminum matrix alloys such as TiC, WC, SiC, SiO_2, Al_2O_3 etc. for getting the desired properties[8,9]. The composite hardness is improved using hard ceramic reinforcements. Saravanakumar, Sasikumar and Sivasankaran[10] started their investigation on hybrid composites by fabricating of Al-6063/Al_2O_3/Gr using liquid metallurgy technique, and then they have studied wear property using conventional tribometer apparatus for different parameters like sliding speed, applied loads as well the reinforcements effect addition of Gr (Garnet) is particularly useful and led to the improvement of the mechanical properties. Anju[11] has studied effect of particle size of Al-garnet composites on wear behavior showed enhancement for the wear property with Gr particles.

Kumar, Sait and Subramanian[12] studied aluminum alloy boron carbide and garnet composites were fabricated by the stir casting process. They discovered that by increasing the amount of garnet in the aluminum alloy mixture, the tensile strength and hardness were increased. Also, the wear test analysis proved that the addition of reinforcements improve the wear property of composite.

Uthayakumar, Aravindanb and Rajkumarb[13] discovered that the addition of Graphite particles led to decrease the microhardness values but significantly improved the wear resistance of the aluminum composite specimens.

In recent years many researchers have worked on the combination of graphite with SiC and Al_2O_3 and it was found similar results. The study of Suresh and Hemanth[14] focused on the effect of chills on mechanical characteristics and wear properties of the composite. Whereas, Sharifi and Karimzadeh[15] investigated wear behavior of aluminum matrix hybrid nanocomposites by reinforcing of 1 wt.% Gr and 10 wt.% SiC with A356 using powder metallurgy technique to investigate the tribological properties.

Directional and fast solidification is one of a broadly reasonable method to refine the grain sizes and hence improves the mechanical properties of aluminum composite, which can be achieved by the application of chills.

In this research paper, the garnet was used as reinforcement with a matrix of Al-6000 alloys to produce new material alloys with optimum properties. Another goal of the research is to investigate the effect of the best chill castings. The application of chills will be used to improve the directional solidification and hence to achieve finer microstructure with improved mechanical properties.

2. Materials and methods

2.1 Materials

In the present study, commercially available Al-alloy (ASTM LM 13 as given in Table 1) piston alloy was used, which is a multicomponent Al-Si-Ni-Cu-Mg alloy with lower concentrations of Fe and Mn. In the present investigation low cost and naturally available hard ceramic Garnet (chemical formula of Gr is $Fe_3Al_2Si_3O_{12}$) are used to reinforcements Al-alloy. Garnet was added in the proportion of 6 wt.% to 12 wt.% in steps of 3 wt.% Table 2 shows the nominal of Al-composites samples.

Metallic chills of dimension 25 mm x 35 mm x 170 mm were used to investigate the influence of the directional solidification on characteristics of the composite. The effect is compared with composites developed without using chills. The used material provides superior casting characteristics thermo-physical properties. So, it is suitable for some of the industries such as the automotive industry.

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Table 1. Chemical composition of Al-alloys (LM13) during this study.

Element	Weigh Percentages (%)
Al	83.4
Si	10.89
Fe	0.53
Cu	1.3
Mg	2.32
Ni	0.51

Table 2. Nominal of aluminium composites alloys in this study

Elements	Gr	Mg	Si	Cu	Fe	Ni	Al
	Weight (wt.%)						
Al-C0	0	2.32	10.89	1.3	0.53	0.51	83.4
Al-C1	6	2.32	10.89	1.3	0.53	0.51	83.4
Al-C2	9	2.32	10.89	1.3	0.53	0.51	83.4
Al-C3	12	2.32	10.89	1.3	0.53	0.51	83.4

2.2 Experimental Procedure

2.2.1 Fabrication of the Composite:

Cost reduction is the key factor for wider application of aluminum hybrid metal metrics composites-(Al-HMMCs) in modern industry which can be achieved by cheaper reinforcements, simpler fabrication methods, and higher production volume. Thus, the fabrication process via a stir casting technique was used to develop the composites with greater bonding of reinforcement particles with the metal matrix. Stir casting method is well known for uniform distribution of the reinforcements because of stirring action and flexible for materials with different low melting temperature.

In the present study, a resistance furnace was used for melting the Al-alloy at about 850 °C.

Garnet (Gr) particles were preheated then added into the molten Al-alloy matrix, thereby the mixed Al-mixture poured into the different molds with and without chill. First mold which made of sand and also poured into different chills such as steel and copper is shown in Figure 1.

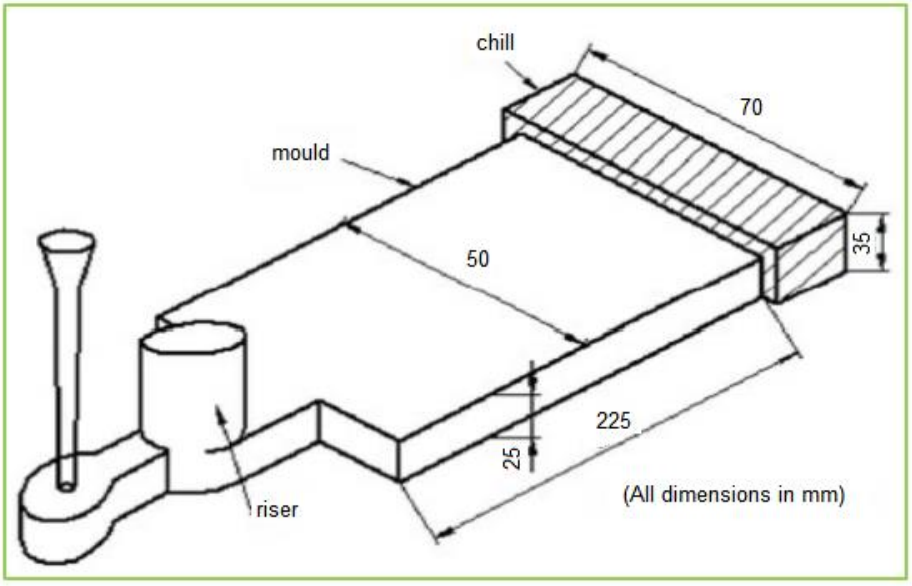

Figure 1. Scheme of sand mold.

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2.2.2 Mechanical Properties

Hardness tests were performed on the composites using Vickers hardness tester with a square-base diamond pyramid as the indenter. Ultimate tensile strength of the samples was tested using an electronic tensile testing machine based on ASTM standard. For a particular cast Al-HMMC, three specimens were tested and the mean value along with standard deviation of the mechanical properties reported. The micrographs of specimens were examined in the optical microscope and the scanning electron microscope. Chill end materials were machined on lathe to get the required dimensions.

3. Results and discussion

3.1 Microstructure and mechanical behavior

Figure 2 shows the optical micrograph and Figure 3 shows scanning electron microscope of microstructures of the different three aluminium samples. It shows the uniform distribution of the reinforcements and good bonding between reinforcement and matrix. Although the stir casting process is known for better bonding between Al-matrix and reinforces particles, it is not developed for mass production. The stir casting method is simple and convenient successful fabrication of the composite.

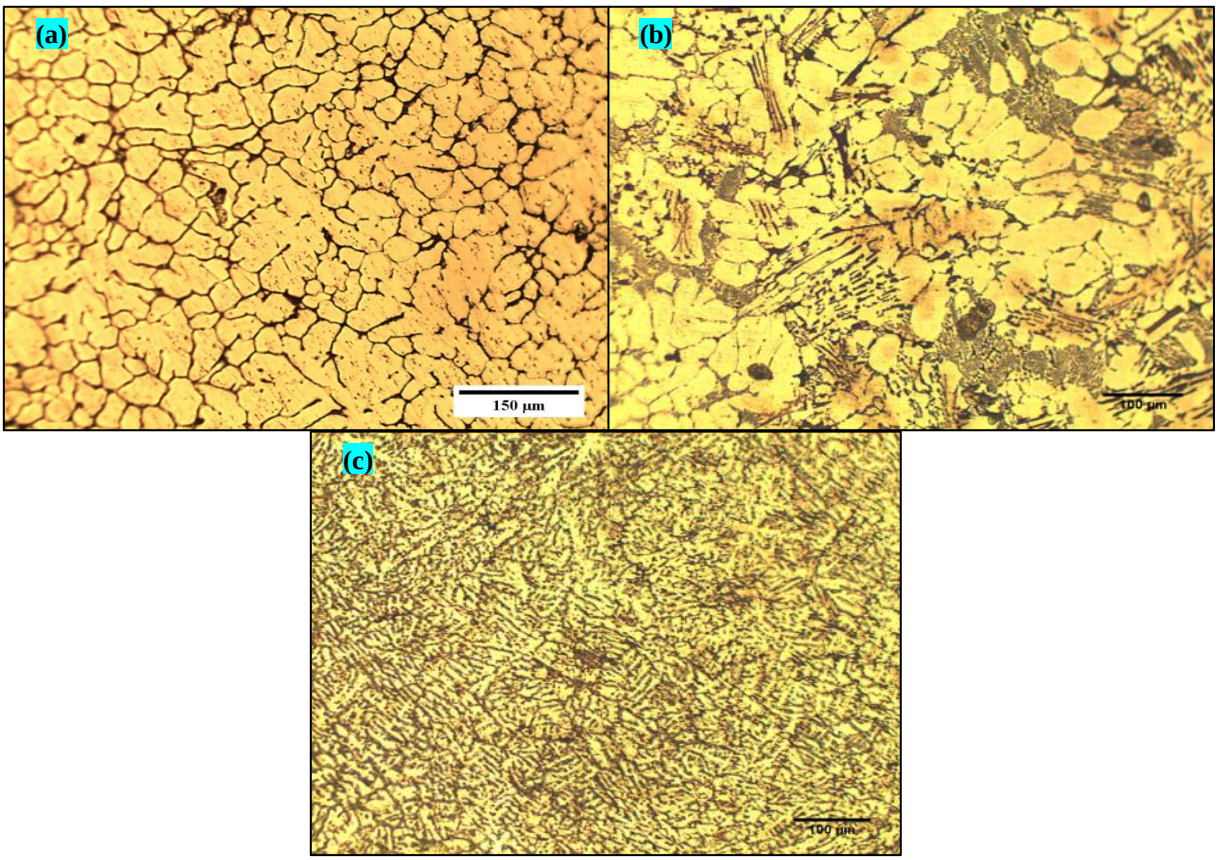

Figure 2. The optical micrograph of the Al-samples (a) Al-HMMC with 6% Garnet without chill, (b) Al-HMMC with 9% Garnet under mold of steel and (c) Al-HMMC with 9% Garnet under copper mold chill.

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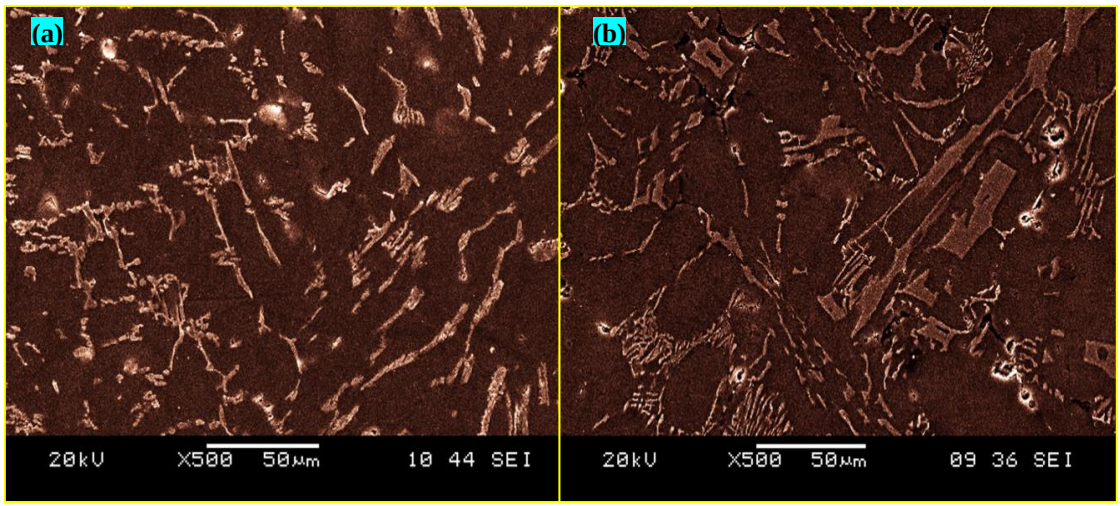

Figure 3. SEM images of microstructure of the Al-samples (a) **Al-C2** under mold of steel chilling and (b) **Al-C3** under mold of steel chilling.

The X-ray diffraction analytic as given in Figure 4 manifests the XRD peaks of Al-Mg-Si-Cu-Ni matrix alloy with and without adding Garnet particles after applying the casting treatment processing. The XRD results for the stir casted Al-Mg-Cu-Si-Ni-9%Gr composite (**Al-C2 sample**), as presented in Figure 4a, exhibited many peaks which were alpha-Al, Al_2Si, $AlCuMg_2Si$ as well the peak of garnet particles. The XRD peaks of the stir casted Al-Mg-Si-Cu-Ni matrix alloy (**Al-C0**) sample is presented in Figure 4b. The peaks of **Al-C0** sample consisted of the alpha-Al and the high peak of Al_2Si. The peak Al_2Si was created due to the high dissolution percent of silicon within the Al matrix during the high temperature as results casting processing. Generally, it was observed that the cause of the presence of the Al_2Si, $AlCuMg_2Si$ compounds implicit alloying elements (Mg, Si, Cu and others) dissolution within the aluminum matrix, due to high temperature during the heat process.

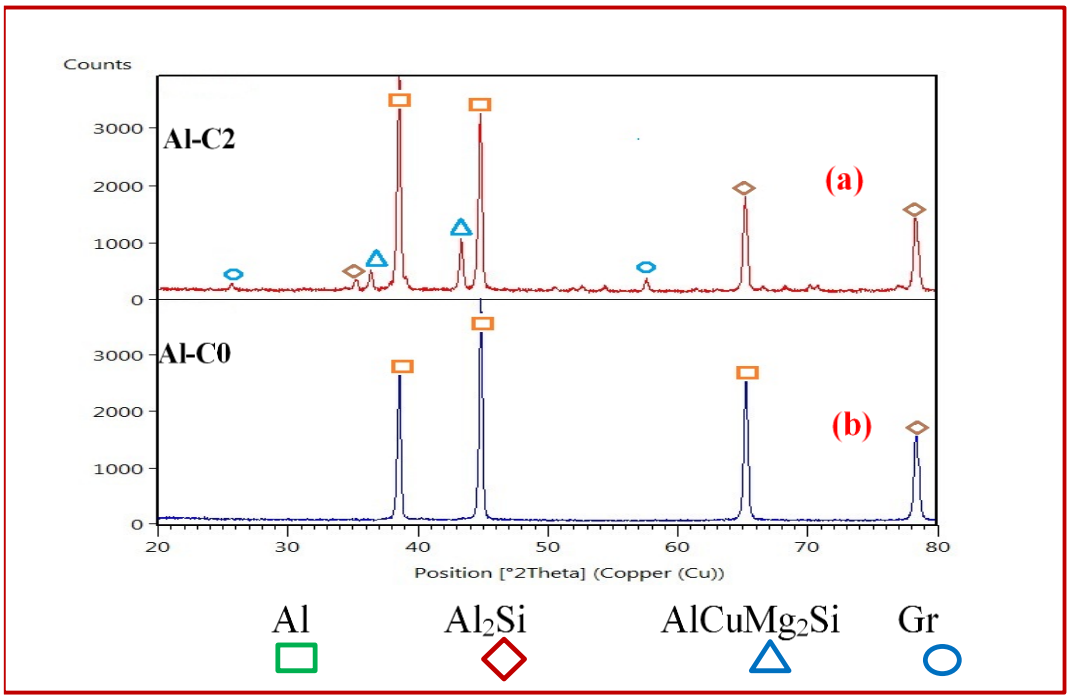

Figure 4. X-ray diffraction patterns of aluminium matrix composites (a) **Al-C2** (after adding 9% garnet) under mold of copper chilling and (b) **Al-C0** (without garnet particles).

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Vickers hardness values of the Al-Mg-Si matrix under the different chill casting conditions (in Figure 5). It was observed that Al-composite samples which have the highest Vickers hardness values were underwent the copper chill casting compared to mold steel chill and mold without chill. The recently studies[16-18] proved that the use copper chill end (in the casting process) was not only favors in the directional solidification but also enhances solidification. The rapid cooling rate was helping to get finer structures and improved mechanical properties as investigated in this study. It is seen that the casted Al-HMMC samples under copper chill has a significant increase of Vickers hardness value. The major reason for increasing of Vickers hardness due to the actions of mold copper chill end and also to the presence of garnet particles (Gr) were coherent grains and their uniform distribution within Al-matrix alloy composite samples.

The ultimate tensile strength of Al-matrix composite samples under the different of mold-chills casting process shown in Figure 6. It was obvious that Al-composite with 9 wt.% garnet (using copper chill casting) has the high tensile strength. This high of tensile is due to increasing the weight percent of Gr. It was observed that tensile strength of Al-matrix composites reinforced with garnet is higher than the Al-matrix alloy without addition Gr particles. Recently studies by Nityanand and Prasad[19] and Bandekar and Prasad[20] referred to the advantages of the copper chill casting coupled with the reinforcement of Gr particles within Al-matrix alloy. However, the current study proved that copper chill casting condition with using Gr particles as reinforcement led to the very fine, uniform and coherent grains of microstructural (as aforementioned in Figure 2c) in addition to the obtaining improvements of mechanical properties of Al-matrix composites samples.

It has observed that the values of hardness and tensile were significant decreasing for Al-HMMC composite sample after added 12 wt.% Gr particles. This the decrease is due to that aluminum matrix become a semi-brittle matrix and, then, has a less ductility property thus losing strength.

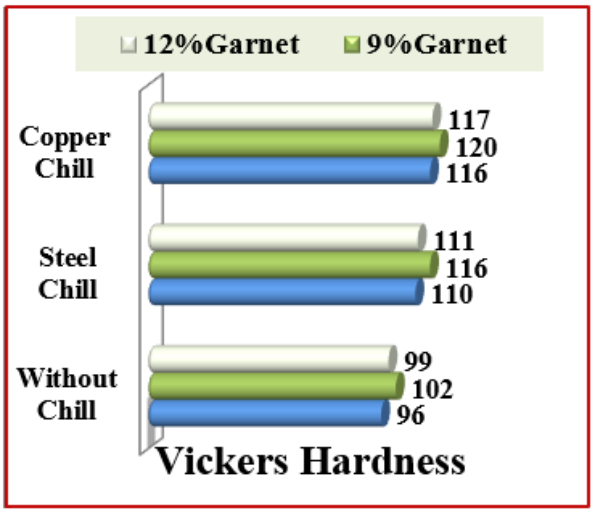

Figure 5. Vickers Hardness of the chill cast composites at various of Garnet.

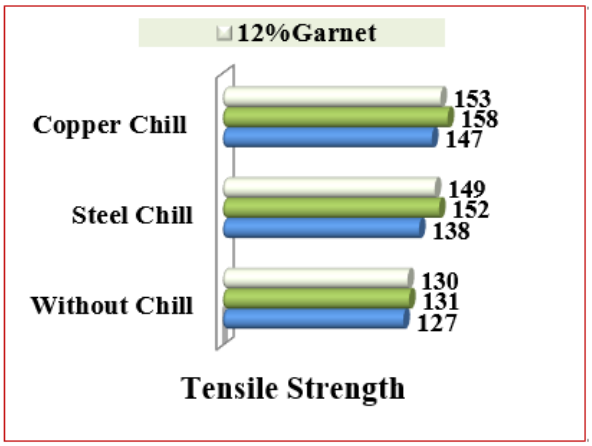

Figure 6. Ultimate tensile strength of the composite samples with respective to various of Garnet for different chill materials.

4. Conclusions

Al-Si-Ni-Cu-Mg alloy composites were successfully synthesized with garnet ceramic particles using the stir casting method under different chilling casting. Microstructural analyses showed that grains were uniform distributed, and they have a good bonding with the Al-matrix.

The results presented that the casted Al-matrix composite fabricated via copper chill block has significant high Vickers hardness and tensile strength values. The outcomes showed that the adding of Garnet particles and using copper chill casting have strongly effects on properties of aluminum metal matrix composites samples.

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