Jurnal Mekanikal
June 2018, Vol 41, 1-7

Microstructure and Mechanical Properties of Hybrid Aluminum Composite with SiC Reinforcement

Muhammad Syameel Moktar, Hamidreza Ghandvar and Tuty Asma Abu Bakar*

School of Mechanical Engineering, Faculty of Engineering
Universiti Teknologi Malaysia
81310 UTM Johor Bahru
Johor, Malaysia

ABSTRACT

Aluminum matrix composites (AMCs) are widely used in automotive and aerospace industries. The material exhibits better mechanical and physical properties such as high hardness, good wear resistance, and also lighter in weight compared to the aluminum alloys. Aluminum metal matrix composites (MMCs) can be produced by two ways, either in situ or ex situ techniques. Each technique has its own advantages and limitations, in terms of wettability, mechanical properties and others. The purpose of this study is to produce and characterize the microstructure and properties of the hybrid aluminum MMCs, which were produced by combining in situ process using magnesium silicide (Mg_2Si) reinforcement *and ex situ process using silicon carbide (SiC) reinforcement. The experiments have been conducted by varying weight fractions of SiC (0, 5, 10 and 15%). The hybrid MMCs were produced through stir casting due to its simplicity and less expensive technique. The reinforcements' distribution and the fracture mode of the tensile samples were observed using the scanning electron microscope (SEM). Mechanical properties were measured using the Vicker's hardness tester and the tensile machine. The results had shown that aluminum MMCs without SiC has the best properties compared to the other samples. This happens due to improper wettability of SiC inside the matrix, SiC clustering and high porosity level when weight fraction of SiC was increased.*

Keywords: *Hybrid composites, stir casting, aluminum matrix, SiC particulates*

1.0 INTRODUCTION

Aluminum metal matrix composite (MMC) is a combination of aluminum alloy with other types of materials to achieve better material properties. The other materials are usually exhibit different mechanical properties compared to the aluminum such as higher melting point, higher hardness, better specific strength, excellent wear resistance and others [1]. This combination is expected to extend the service life of the structures and also to improve the performance of the structure, especially for operations at elevated temperatures. The material is called as hybrid composite, when there are at least three materials are present [1].

Two types of reinforcements are used in this project, which are magnesium silicide (Mg_2Si) and silicon carbide (SiC). Mg_2Si reinforcements are generated within aluminum matrix through reactions during solidification, also known as in situ method. Compared to conventional stir casting, in situ technique produces composites with clear interface, better wettability and more even distribution of reinforcements within the matrix.

*Corresponding email: tuty@utm.my

Besides, the in situ method provides reinforcements which are thermodynamically stable since they are the product of reactions within the molten matrix alloy [2]. The other reinforcement, SiC is introduced to the matrix through ex situ method, which addition from the external sources during stir casting. The reinforcement can be in three forms, either particles, whiskers, or long fibers [3]. In this project, particulate SiC is used since it is less expensive and provides isotropic properties compared to the other two reinforcements [4].

Stir casting is implemented to fabricate the hybrid aluminum MMCs due to its simplicity and lower in cost compared to other fabrication processes. There are several factors in stir casting need to be considered to obtain desired properties for the composites, such as the distribution of reinforcements within the matrix, the wettability of the matrix and reinforcements and porosity level within the MMCs [1]. Wettability in stir casting is the interface relationship between the matrix and the reinforcements. It can be defined as the ability of liquid to cover the solid surface, in this case, the reinforcement particles. In addition, wettability can be considered as measure of interface bonding between the matrix and the reinforcements, since different properties of materials within the composite cause discontinuities within the composite [5].

According to another study, the important parameters during stir casting are related to the stir casting technique carried out [6]. The parameters such as melt temperature, stirring speed and duration, reinforcement feed rate and mold temperature play important roles to ensure quality of the casted composite. It is also suggested to add magnesium to improve wettability between SiC particles and the matrix [6].

This paper discusses the characterization and mechanical properties results of the produced aluminum hybrid composites at different weight fraction of SiC within the samples (0, 5, 10 and 15%). Two types of mechanical tests were carried out, namely the *Vicker's* hardness and tensile tests.

2.0 METHODOLOGY

To prepare Al-20Mg_2Si-2Cu in-situ composite ingot, commercially ADC12 alloy, magnesium (ingot with >98.0% purity) and 2luminium (ingot with >98.0% purity) were used. In order to prepare the hybrid composite Al/ (Mg_2Si+SiC), firstly, the SiC particles (>99% purity, 10-30 μm) were peroxided at 800 ℃ for 2 h to obtain a better wettability. The mass fractions of SiC particle addition were set at 0 wt. %, 5 wt. %, 10wt.% and 15 wt. %, respectively. Secondly, about 300 g of Al-20Mg_2Si composite ingot was melted in a graphite crucible using the electric resistance furnace. Then the pre-heated SiC particles were added into the Al-Si-Mg melt at 750 ℃ with a stirring action. The stirring condition for the fabrication of Al/ (Mg_2Si+SiC) composite was: stirring speed of 500 r/min and stirring time of 15 min. Subsequently, after holding for 15 min, the composite melts were reheated to 720 ℃, and poured into steel die to produce cylindrical samples with 30 mm thickness. The flat tensile test bars were produced out of the solidified rods and prepared according to ASTM E8/E8M-13. Tensile tests were carried out using an *Instron* universal mechanical testing machine (5982), equipped with a strain gage extensometer, at a constant crosshead speed of 1.0 mm/min at ambient temperature. Metallographic specimens were polished through standard routines and examined using optical and SEM microscopy to observe the features of the Mg_2Si phase and SiC particles in the composites. The microstructure characteristics of the specimens were examined with a scanning electron microscopy (Philips XL40); coupled with energy dispersive spectroscopy (EDS), while the mean size of Mg_2Si particles was analyzed by a quantitative analysis system (i-Solution image analyzer). The phase constituents were analyzed using X-ray diffraction (XRD) (PHILIPS binary diffractometer with Cu-kα radiation application).

3.0 RESULTS AND DISCUSSION

3.1 Microstructural Studies

The SEM micrographs were taken for different hybrid MMC samples with the same magnification to compare the distribution of reinforcements within the composite. Figure 1(a) shows in situ composite with a good distribution of Mg_2Si particles within the aluminum matric. While the other SEM micrographs (Figures 1(b) – (d)) indicate uneven distribution of Mg_2Si and SiC reinforcements in the hybrid composites. Some of the areas on the samples are left without presence of reinforcements. Non-homogenous distribution of reinforcements is normal in stir casting [7]. From Figure 1(b), it is observed the Mg_2Si particles have more sharp edges than Mg_2Si in Figure 1(a). Sharp edges of Mg_2Si particles have potential to initiate cracks and causes lower strength of the composite [8]. According to Moses *et al.*, addition of SiC particles retards the freely growing aluminum grains [6]. This might also affect the nucleation of Mg_2Si within the hybrid composite.

From Figures 1(a) – 1(d), Mg_2Si particles are larger particles with dark grey color. Meanwhile, SiC reinforcements are light grey in color, with a small size particle. At higher magnification, it is also observed higher percentage of porosity when weight fraction of SiC is increase, it can be presented as the black color spots (Figure 2).

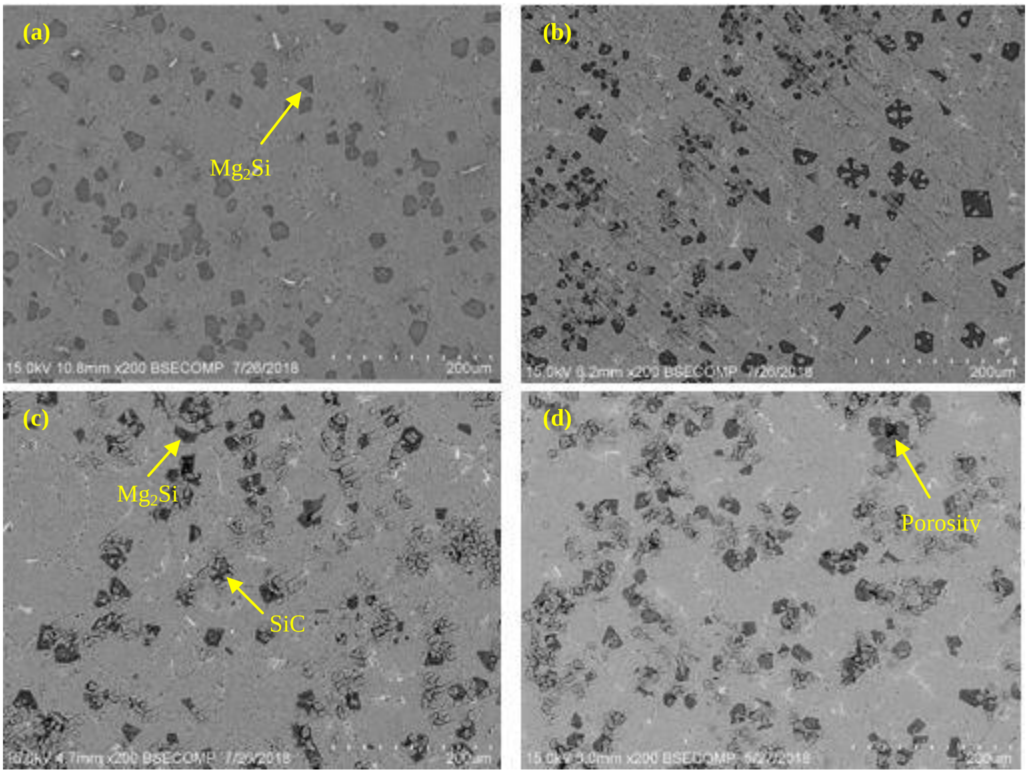

Figure 1: SEM micrographs of hybrid MMCs with SiC content;(a) 0 wt.% SiC (b) 5 wt.% SiC © 10 wt.% SiC (d) 15 wt.% SiC

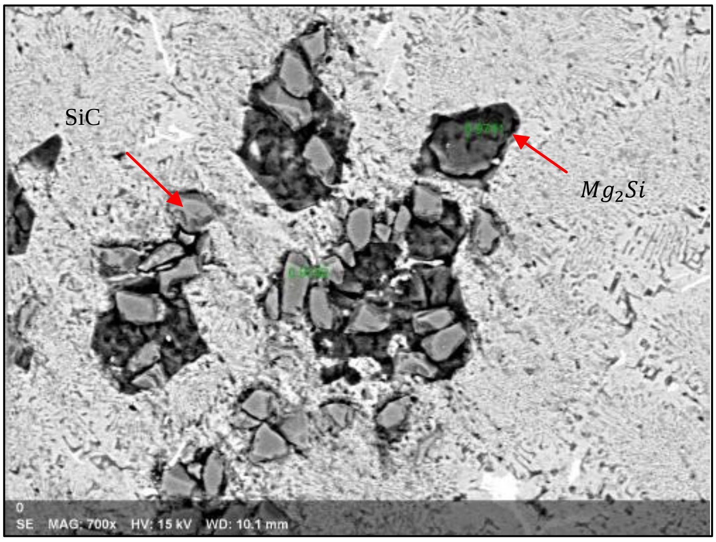

Figure 2: Validation of reinforcements' presence using Energy Dispersive X-Ray(EDX)

3.2 Mechanical Properties

Two types of mechanical tests have been carried out on the hybrid composite samples, *Vicker's* hardness test and tensile test. For hardness test, eight different locations were tested to get the average hardness values. The in situ composite recorded the highest hardness value compared to the others as presented in Table 1. According to a reporting from one of the journals, it was concluded that the hardness of the hybrid composite will increase and then decreased with further addition of SiC [9]. This happens due to higher porosity percentage with further addition of SiC. Figure 3 indicates the presence of porosity located just beneath the SiC reinforcements and it gives low hardness value. Porosity can happen due to several factors. Firstly, it occurs during addition of SiC reinforcements that introduces air bubbles inside the molten matrix. The viscosity of the melt traps the air bubbles until it is fully solidified. The second factor is due to particle removal during metallographic sample preparation such as grinding and polishing.

Table 1: *Vicker's* hardness results

Sample	Base	Al-5 wt.% SiC	Al-10 wt.% SiC	Al-15 wt.%SiC
Hardness (HV)	83.7	82.5	79.2	78.5

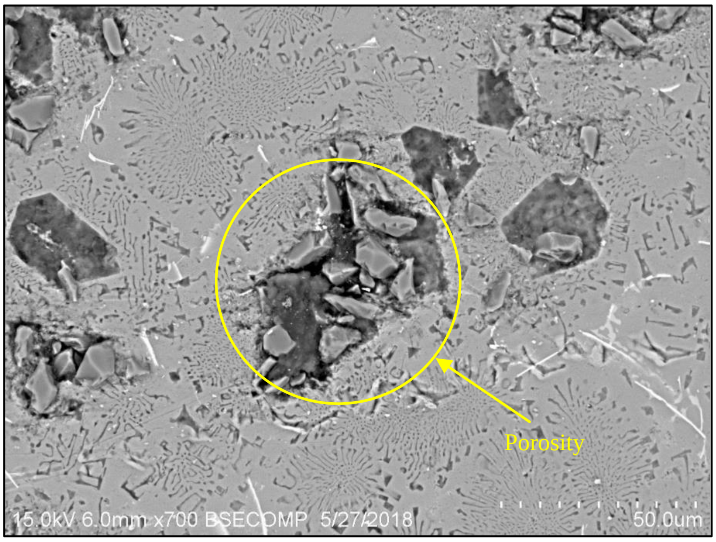

Figure 3: The presence of porosity in hybrid Al composite with 15 wt.% SiC

For tensile test, the tensile strength data is presented as in Table 2. The in situ composite recorded the highest tensile strength compared to the others. According to Rahman and Rashed, low tensile strength is due to SiC clustering [10]. Supposedly, the SiC reinforcements are tend to support the load applied on the matrix through direct strengthening mechanism. The mechanism supports the composite by transferring the applied load from the matrix to the SiC reinforcements through their interface. Hence, good interface between the matrix and the reinforcements is required so that the load can be transferred effectively [11].

Table 2: Tensile strength results

Sample	Base	Al-5.wt.% SiC	Al-10.wt.% SiC	Al-15.wt.%SiC
Tensile Strength (MPa)	77.45	53.58	67.61	34.11

Figure 4 shows the stress and strain curve for the in situ and hybrid composites with different volume fractions of SiC. The in situ composite (base) exhibits more ductile properties compared to the others. The tensile results demonstrate that the increase in SiC particles transforms the ductile properties to brittle properties. This is due to the presence of higher percentage hard particles SiC within the composite [6].

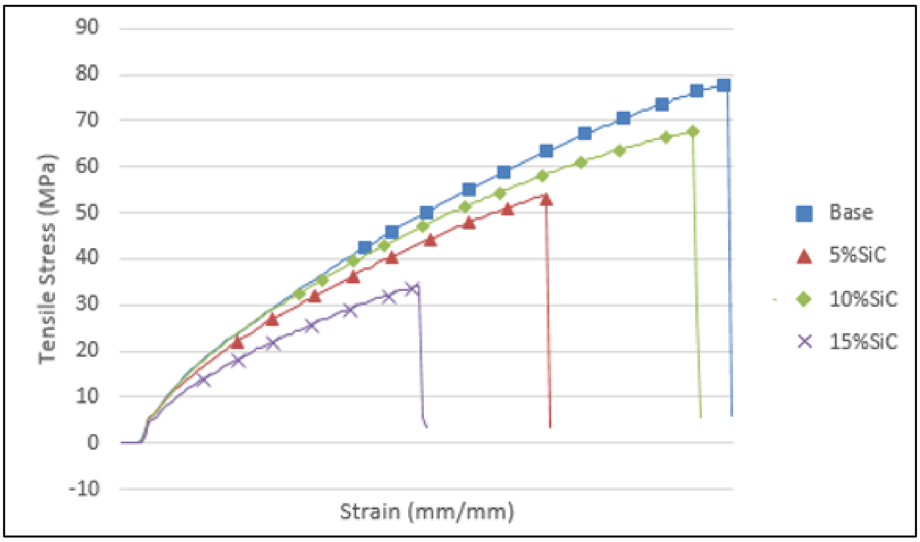

Figure 4: Stress-strain curve for all samples

Figure 5 shows the features of the fractured samples from tensile test. Figure 5(a) shows a good wettability between Mg_2Si and the matrix. This ensures that Mg_2Si reinforcements to provide better support for the matrix when the tensile load is applied. Meanwhile, Figures 5(b) and 5(d) show improper wettability between SiC and the matrix. It shows a clear cleavage occurs on both hybrid composites, which the material breaks at its weakest bonding. Figure 5(c) shows a better distribution of reinforcements, since the voids or porosity are less obvious on the fractured surface of this sample. It records the second highest tensile strength after the in situ composite.

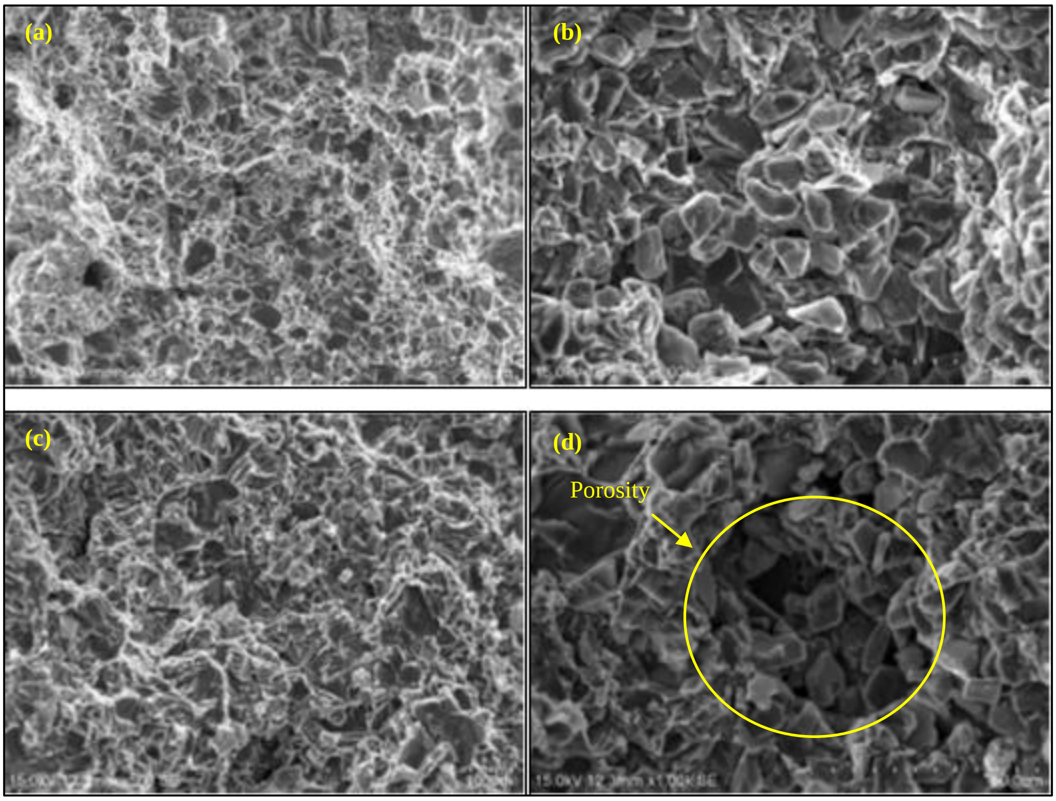

Figure 5: SEM micrographs of fractured in situ and hybrid MMCs with SiC content (a) 0 wt.% (b) 5 wt.% (c) 10 wt.% (d) 15 wt.%

4.0 CONCLUSION

A combination of two types of reinforcements, Mg_2Si (in situ) and SiC (ex situ) is expected to produce better mechanical properties. However, the mechanical results have shown that the in situ composite (without SiC particulates) has better properties compared to the hybrid composite samples. The challenges encountered are during the production of the composites, which is the stir casting technique. There are several parameters needed to be improved, such as maintaining the stirring speed to ensure continuous formation of the vortex within the melt and also SiC feeding rate. Low stirring speed will cause uneven distribution of reinforcements, while high feeding rate will cause the congestion of SiC to settle into the melt and eventually results in SiC clustering.

ACKNOWLEDGMENTS

The authors gratefully acknowledge this research project under a GUP research grant (Vote No. 13H72).

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