

Effect of Variation of SiC and Mg Mass Fraction on Mechanical Properties of Al-SiC Composite Using Stir Casting Method

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ABSTRACT

Al-SiC is a composite composed of AA6061 as a matrix and SiC as a reinforcement particle. The variation of mass added will affect the mechanical properties of the composite because Al-SiC is hardenable, which means that its mechanical properties can be improved by adding the reinforcement component. However, an excessive portion of SiC leads to a decrease in mechanical properties. The purpose of this study was to find the optimal composition of the addition of SiC into the aluminium matrix to gain maximum tensile strength and hardness. The mass fraction variation that would be used in this composite was the addition of 6%, 8%, and 10% SiC with the addition of 1% Mg as a wetting agent. The mixing process used the stir casting method. The process of adding SiC and Mg was carried out by melting the aluminium while stirring it for a certain time before it went to the furnace. The ASTM E8/E8M standard was used for observing the tensile strength of the specimens. Machining was carried out before testing. The specimens were also tested for hardness using the Rockwell hardness method. The result shows that the addition of SiC at the amount of 6%, 8%, and 10% SiC increased the ultimate tensile strength by 154.10 MPa, 175.01 MPa, and 198.14 MPa, respectively. Similarly, the hardness also increased up to 30.1 HRF, 48.1 HRF, and 66 HRF, respectively. Microstructure observation also confirmed that a 10% SiC fraction results in less defect and good wettability. The addition of 10% SiC and 1% Mg resulted in maximum tensile strength and hardness and the best microstructure.

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Keywords: Al-SiC, composite, mass fraction, stir casting

I. Introduction

In this modern era, many industries are trying to improve material properties. They compete to find materials and also higher technology, one of which is to make technology or materials that are lighter and more practical but have better mechanical properties. Composite is an alternative material that complies with these requirements [1]. In addition, some composites are corrosion resistance, design flexibility, durable [2], and fire resistance [3]. Many kind of composites: metal matrix [4]–[9], polymers-ceramic [3],[10],[11], metal-ceramic [12]. Normally, composite consists of a matrix filled with reinforcement material. There are three forms of reinforcement phase: fibre, flake, or particulate [13].

Al-SiC is a kind of composite that is made of Aluminum as a matrix, and SiC particles are added as reinforcement. The properties of Al-SiC are well known for their lightweight, high strength, high specific modulus, high fatigue strength, high hardness, low density, and good thermal conductivity [1]. It is reported that Al-SiC composite has a high mechanical property yet is lightweight [14].



The Al-SiC is commonly produced by stir casting [15]–[19]. This popularity of this method because stir casting is less expensive and has the ability for mass production [18]. Some attempts have been carried out to improve the mechanical properties of Al-SiC composite. There are three concerns: (i) design of the stirrer, (ii) addition of another element as a strengthening agent, and (iii) varying the SiC composition.

Of the first group, it is reported that adding the stirring speed was able to increase the hardness but decrease the tensile strength [19]. Sahu & Sahu [14] introduced a variety of stirrer designs (number of stirrers, impeller blades, position of stirrer to the base of the crucible, and stirrer speed). Optimization of the combination of those stirrer designs might be able to achieve higher strength, lighter weight, yet lower cost [14]. Another researcher introduced a vortex-free stir casting to avoid air trapping in the composite, which results in increasing tensile strength, hardness, and decreasing wear rate and porosity [20].

The second group of researchers is concerned with adding another element to the composite as a reinforcement. Krisna & Xavier [9] reported that adding graphite to the Al-SiC composite would increase the strength but decrease the density [20]. While the addition of fly ash on Al-SiC followed by heat treatment could increase the hardness and impact strength of Al-SiC/fly ash composite [5].

Another effort to improve the mechanical properties of Al-SiC composite was by increasing the SiC mass fraction in the composite. The strength and hardness of the Al-SiC composite can be increased by adding the SiC mass fraction as reinforcement. Maurya et al. [16] investigated the effect of adding SiC to Al6061/SiC metal matrix composite. They added a variety of mass fractions of SiC up to 5%. The result showed that the maximum tensile strength and hardness were achieved by 5%wt SiC [16]. Rahman & Rashed [21] added up to 20% of SiC with a tier of 5%. They found that the addition of 20% wt of SiC results in the maximum tensile strength and hardness [21]. The increase of tensile strength was linear with the increase of the SiC percentage except for 15% wt. The addition of evenly distributed SiC particles on the aluminium matrix makes the mechanical properties of Al-SiC better [22].

Moses et al. [23] studied the strengthening mechanism of the AA6061 matrix by adding SiC for wt% of 0, 5, 10, and 15. They found that the tensile strength increased by 119 MPa, 158 MPa, 192 MPa, and 188 MPa, respectively [23]. Increasing up to 10% of SiC effects increase the strength, while 15% results in reducing it. Hashim et al. [4] stated that hardness, tensile strength, and wear resistance increase with the addition of 10-15% SiC. If the addition of SiC is more than 15%, the hardness value will increase but will decrease other mechanisms [4]. Therefore, it is necessary to find out an ideal proportion of SiC which will produce optimal mechanical properties. The purpose of this research was to obtain the maximum tensile strength and hardness in Al-SiC composites by varying the composition of the addition of SiC.

II. Material and Methods

The aluminium was used as matrix material, and SiC particles were added as reinforcements to prepare composites in this study. We did not test the composition of the aluminium. However, according to the literature, the chemical composition of aluminium was presented in Table 1. The SiC as the reinforcement was in a powder form with a maximum grain size of 50 μm . The composite manufacturing used stir casting. This method was chosen because it is easy, simple, and low cost. Figure 1 shows a schematic of a stir casting process.

Table 1. The aluminium composition used as matrix material (wt%) in this experiments [21]

Elements	Fe	Si	Mn	Cu	Mg	Al
%	0.16	0.19	0.01	0.01	0.01	Balance

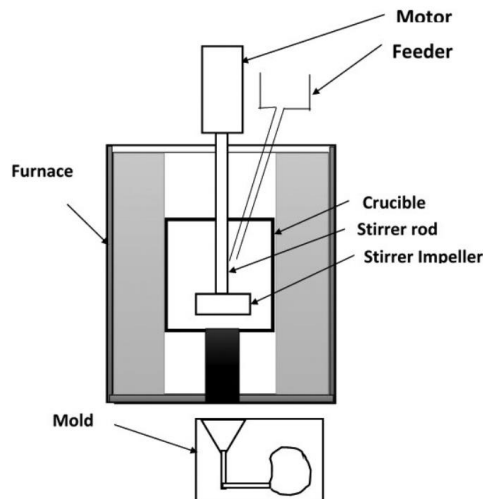


Fig. 1. Stir casting scheme [6]

The addition of SiC as reinforcement varied in amounts of 6%, 8%, and 10%. Magnesium (Mg) 1% was added as a wetting agent. The mould was made of steel and produced a solid cylindrical shape and produced 3 specimens at a time. Figure 2 shows an example of casting results. The amount of material to be smelted according to the weight ratio, based on the total weight of 650g. The detailed composition of the matrix (Al), reinforcement (SiC), and wetting agent (Mg) is presented in Table 2.

Table 2. Details of composite composition

SiC (wt%)	SiC (g)	Mg 1% (g)	Al (g)	Total (g)
6%	39	6.5	604.5	650
8%	52	6.5	591.5	650
10%	65	6.5	578.5	650

The amount of each element was weighted carefully using a scale. The crucible was coated with a mortar, and then started to heat up to 750 °C. Then aluminium was put in the furnace, while, preheating of SiC and Mg powder was in a different furnace. When aluminium was melted, pour the SiC and Mg powder into a smelting furnace, and stir it at a speed of 450 rpm for five minutes. Argos gas was blown into the furnace during the stirring and lifting process. Before pouring the melted into the mould, ensure to remove the slag on the melt. The mould was opened when it was already cold. An example of the casting result is presented in Fig. 2.

Tensile testing was carried out according to ASTM E8/E8M – 13a standards. The specimens were machined lathe to obtain standard dimensions. Each composition was

replicated thrice. Figure 3(a) shows a test specimen ready for tensile testing. The dimensions of the tensile test specimen can be seen in Figure 3(b).



Fig. 2. Casting result

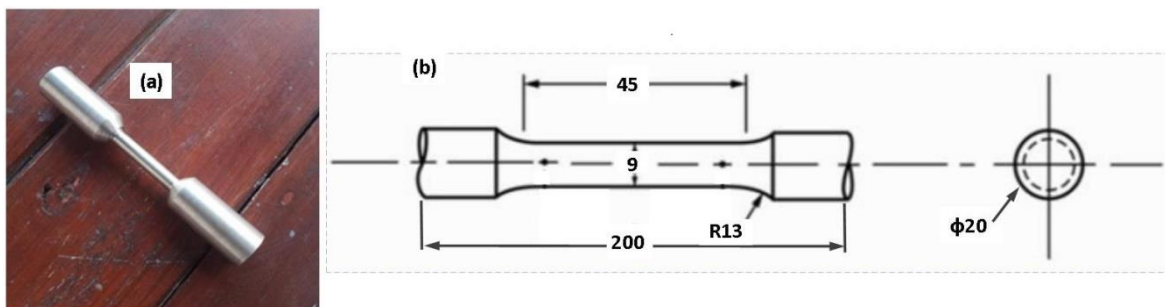


Fig. 3. Casting result after machining (left), and ASTM E8/E8M – 13a standards (right)

Hardness testing was carried out using the Rockwell method. This test was carried out on an F scale using a 1/16 inch indenter ball and using a load of 60 kgf. Before the hardness test, the specimens were polished using 200 to 600 grit sandpaper, then polished using an autosol and velvet cloth. The next step is the etching process using an etchant, which is composed of 2 ml HF, 3 ml HCl, 5 ml HNO₃, and 190 ml H₂O. The data collection process was carried out with 10 experiments for each specimen. Figure 4 shows the hardness testing specimens.



Fig. 4. Hardness testing specimens

Microstructure testing was carried out using a *Scanning Electron Microscope* (SEM) and an optical microscope. The optical microscope BX451M was used, which has a fine focus movement of 100 μm and minimum graduation of 1 μm . SEM HITACHI TM3030Plus was employed for insight microstructure observations. It has a magnification capacity of 120,000 \times and a filament image resolution of 640 \times 480 pixels and 1,280 \times 960 pixels.

III. Results and Discussions

Tensile test

In this study, tensile testing was carried out with ASTM E8/E8M. Figure 5 shows the value of the tensile strength of the Al-SiC composite chart. It is obvious that the more the wt% SiC, the stronger the composite is.

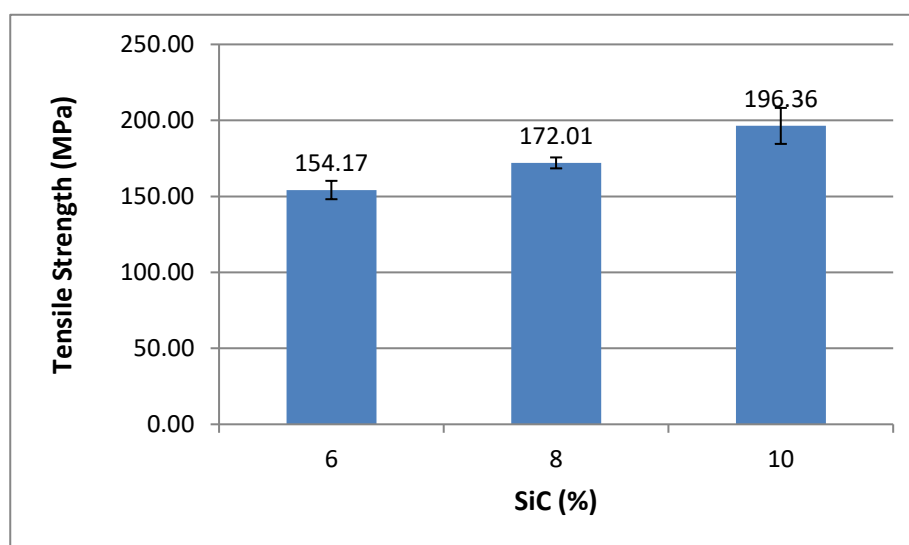


Fig 5. The value of the tensile strength of the Al-SiC composite chart

It can be seen that the highest tensile strength value is the Al-SiC composite of 10% SiC. Increasing the percentage of SiC in aluminium makes the composite stronger. It proved that SiC as the reinforcement agent in the aluminium matrix worked properly. It is also supported by stirring which results in a well-mixed and well-distributed composite. Equally distribution of SiC particles can improve the mechanical properties of the composite [4].

According to Zamheri (2011) [24], the addition of % volume fraction into molten metal affects changes in viscosity. The larger the volume fraction percentage will give a homogeneous mixture spread, and the particle deposition in the matrix becomes larger [24]. SiC reinforcing particles greatly affect the mechanical properties (hardness) and the microstructure of the tested material. Mohamed and Abdallah (2018) explained that SiC could increase the overall strength of composites as well as corrosion resistance and wear resistance [21].

According to Sadi, et al. [25], porosity is a defect in the form of fine cavities formed by gases trapped during the mixing process with stirring and shrinkage during solidifying [25]. Porosity is also formed by interfacial reactions because oxygen causes water vapour to appear on the surface of the SiC reinforcing particles. Porosity is very difficult to get rid of completely but there are ways to reduce it. One way is to add argon gas during casting because argon can inhibit the entry of air into the aluminium so that the gas content (air) in

the aluminium does not change. The decrease in tensile strength of the composite can also be caused by poor wetting of the composite and its reinforcement. Poor wetting can cause porosity in the interface layer which causes the stresses between the matrices to not flow properly [26].

Moses, et al. [23] also studied the AA6061 matrix with SiC strengthening for wt% of 0, 5, 10, and 15, and got the results that mechanical properties such as hardness and tensile strength increased by 33%, 133%, and 65.2%, respectively [23]. From this study, the most optimum result was the addition of 10% SiC, and the addition of 15% SiC decreased the other mechanical properties.

Hardness Test

Hardness testing was carried out to determine the hardness value of the Al-SiC composite. The average hardness value is taken from 10 different points to get more optimal results. Figure 6 shows a graph of the Al-SiC hardness value with mass fraction variations of 6%, 8%, and 10%. It can be seen that the more mass fraction of SiC used, the hardness value increase. Figure 6 shows the lowest hardness value using 6% SiC with a hardness value of 30.15 HRF, while the highest hardness value uses 10% SiC with a value of 66 HRF. This indicates that adding SiC to aluminium will increase the hardness. Following the result of Krishna & Xavier [9], the more SiC mass fraction in the aluminium matrix, the hardest the composite be. In different matrix materials, such as AMMC, the addition of SiC also increased the hardness. However, an excessive of SiC added to the matrix would the hardness. Rahman et al. [21] found that the maximum hardness is obtained at a percentage of 10% SiC. This is following the most optimum hardness value of this research with 10% SiC.

Bandil et al. [8] also conducted experiments to determine the density, hardness (HRB), wear, and corrosion resistance of Al-SiC composites. They found that the density of Al-SiC will decrease with increasing SiC booster if it is added to more than 12%, and corrosion hardness increases to 12% and then decreases when more than this amount. Wear resistance also increases with the addition of SiC up to 12% in Al-SiC composites [8].

Inegbenebor et al, [27] investigated the Al-SiC composite particles through the stir casting process and explained that the addition of Mg and SiC can increase the wettability of aluminium, increase the hardness value, and reduce grain boundaries. SiC is very hard compared to aluminium. If SiC is added to aluminium, it will increase the hardness [28]. Research conducted by Rahman [21] also states that adding Mg as a wetting agent can increase wettability and hardness.

Several things cause lower hardness values, including porosity due to gas trapped during the melting to pouring process, shrinkage during solidification, and poor interface between the matrix and the reinforcement. Porosity can occur as a result of the composite manufacturing process where air from outside the melt, especially at the surface, is trapped when mixing during melting. The pressure difference between the top and bottom of the melt causes the composite particles to be sucked into the melt together with air and other impurities. Porosity can also occur due to air bubbles trapped in the molten Al-SiC MMC during the casting process [28]. Porosity can also occur due to the agglomeration of SiC particles. Agglomeration is a size enlargement process in which the size of the initial material in the form of fine particles will be combined or bonded to each other, resulting in a porous structure that is much larger than the starting material [29].

Fig 6. Al-SiC hardness values with mass fraction variations 6%, 8%, 10%.

The presence of dimensional defects will reduce the mechanical properties of the composite, such as decreasing the value of strength and hardness. One of the most important things in a composite regarding the improvement of its mechanical properties is the matrix with the reinforcing interface. If the interface between SiC particles and aluminium is not good enough, then the load cannot be completely distributed by aluminium to SiC. The poor condition of the reinforcement interface with the matrix is caused by the difference in the thermal coefficient between aluminium and SiC. This can also cause a decrease in the mechanical properties of the composite [28].

Microstructure Observation

Observation of the microstructure using an optical microscope can show conditions that show the mechanical properties and characteristics of the Al-SiC composite by observing the visible elements so that the image or data seen on the optical microscope can be used as the main support for the evidence that the Al-SiC composite improved mechanical properties. Observation of the microstructure on an optical microscope can also show deficiencies or defects in the results of adding SiC to Aluminum and Mg as a wetting agent. Figure 7 is the result of observing Al-SiC using an optical microscope with 100× magnification.

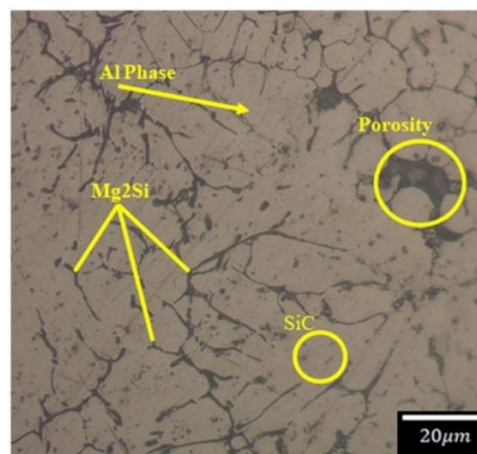


Fig 7. Composite with 10% SiC viewed through an optical microscope with 100× magnification

Figure 7 shows that many SiC particles are scattered on the aluminium matrix, but it can also be seen that the Al-SiC composite has porosity. This porosity can be caused by trapped gases during the mixing process of aluminium with SiC and can also occur due to shrinkage of grain boundaries. To minimize the porosity, the addition of argon gas can be used during the process of mixing aluminium with SiC. The addition of argon gas during the stirring process can prevent the bond between molten aluminium and atmospheric air to reduce the risk of porosity in the composite [7].

Figure 8 presents a comparison of Al-SiC composites with mass fraction variations of 6%, 8%, and 10%. It can be seen from the micro observations with 10% SiC variation seen that more SiC particles are scattered on the aluminium matrix. This causes the tensile strength value and composite hardness value to increase.

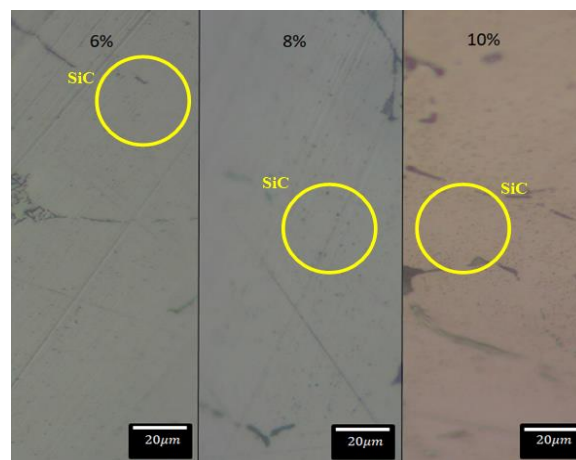


Fig 8. Comparison of Al-SiC with mass fraction variations of 6%, 8%, and 10% with 500x magnification.

SEM Observation

SEM observation aims to see the characteristics of the bond between the matrix and reinforcing particles. It can be seen in Figure 9 that the SiC particles get a good wetting.

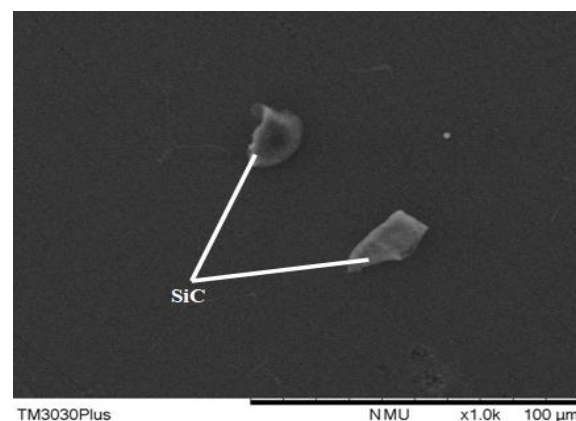


Fig. 9. SEM photo of Al-SiC with 1000x magnification

In Figure 9, it can be seen that the SiC particles are well wetted. This shows a good interface between the matrix and SiC as a reinforced. The interface that occurs in the composite is caused by a chemical reaction on the SiC surface with the aluminium matrix.

With the chemical reaction, wetting will occur better to minimize defects that may occur [30]. The addition of Mg as a wetting agent also has an effect because Mg can bind oxygen so that no oxygen inhibits the binding of SiC with the matrix. The addition of Mg affects the formation of an interface layer that can improve the mechanical properties between the matrix and the reinforcement. There is also no visible porosity around SiC. The addition of Mg as a wetting agent and the addition of argon gas during the mixing process can reduce the probability of voids around the SiC particles, which causes porosity. If the wetting composite is not good, then what will happen is increased mechanical properties are not optimal, and also many voids are formed and making the porosity level high.

IV. Conclusions

Three conclusions can be drawn from this research. Firstly, the addition of SiC affects increasing the mechanical properties of the Al-SiC composite, especially on the tensile strength. The highest tensile strength value is 196.36 MPa with a 10% SiC mass fraction. Secondly, the addition of SiC affects increasing the mechanical properties of the Al-SiC composite, especially the hardness. Al-SiC composites have the highest hardness value of 66 HRF with a 10% SiC mass fraction. Last but not the least that from the observation of the microstructure, the most optimum addition of SiC to aluminium AA6061 is the addition of 10% SiC, because more SiC is dispersed in aluminium so that the tensile strength and hardness values are more optimal.

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