Study on the Effect of Volume Fraction (Vf%) SiC Addition to The Characteristics of Mg-Al-Sr / SiC Composites Using Stir Casting Method

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Abstract. In this study a magnesium metal matrix composite fabrication process was carried out combined with Al-15Sr alloy which will create intermetallic phases of Mg17Al12 and Mg58Al38Sr4. Reinforce material that is used for this study is SiC with an amount of 2, 4, 6, 8 v%%. Stir casting is used as the fabrication method as it doesn’t require much maintenance and relatively cheap. Argon is used as a shielding gas so oxidation does not occur to magnesium and prevent combustion. The composite is then casted into a SKD 61 metal mold and then cooled so it can be characterized by the various tests it will go through. SiC is added as the reinforcement material in hopes to increase the mechanical properties of the composite. This can be seen when the composite go through a number of tests, including microstructure analysis, SEM, XRD testing, and various mechanical tests. Through this procedure is it then concluded that composite with 6 v% SiC is the optimum amount of reinforce material which results in UTS of 51.09 MPa, hardness of 73 HRH, impact strength of 0.0367 J/mm² and abrasion rate of 5.68 x 10⁻³ mm³/m.

Keywords : Magnesium based composite, Mg-Al-Sr, SiC, stir casting

1. Introduction
With the increasing use of energy resources, the industry continues to look for substitutes for conventional materials to increase efficiency and the use of lightweight materials to be one solution that cannot be avoided. Magnesium is a promising material for this problem.

Magnesium is one type of metal used to create blocks of machines with low mass. Magnesium is the metal that has the lowest density which is 1.738 g/cm³, only two-thirds of the value of light metal density is usually used, namely aluminum so that in terms of lightness, magnesium is a metal that is suitable for making high-efficiency fuel engine blocks of vehicles. In addition, the availability of magnesium in nature is very abundant [1].

However, for application to the engine block it cannot use pure magnesium because the mechanical properties of pure magnesium are not good enough to use. Magnesium is difficult to be cold worked due to the crystal structure of HCP, the process of increasing the strength of magnesium is by adding a mixture of other elements. The most common element used as a magnesium alloy for industrial applications is aluminum because it can increase strength, hardness and castability of magnesium. However, the heat resistance of the Mg-Al alloy is still low, so it is very susceptible to creep deformation [2]. One way to increase magnesium resistance at high temperatures is by refining grains [3]. Addition of strontium metal in Mg-Al alloys is able to soften microstructure and increase the strength and
resistance to the mechanical load of the alloy in high temperature applications. Addition of Sr can also be contributed to the increased creep strength of the alloy [4].

The addition of various types of reinforcement on magnesium alloys can improve mechanical properties such as fatigue and wear resistance [5]. In addition, monolithic metal alloys have a low modulus of elasticity if no reinforcement is added. This limitation can be overcome by combining harder ceramic particles into the metal matrix. When compared with aluminum matrix composites, research on magnesium matrix composites is still limited due to the nature of magnesium which is very reactive and easily oxidized when melted. The method of protecting molten magnesium usually uses fluxes and protective gases in the form of inert gases [6]. In this study a magnesium metal matrix combined with Al-15Sr alloy which is further reinforced by the SiC particles was fabricated.

2. Experimental method

2.1. Materials
In this research, pure magnesium 95% wt and 4.25% Al and 0.75% Sr was used as the matrix and micro sized SiC particle with 2, 4, 6, and 8% volume fraction was used as the reinforcement material.

2.2. Sample preparation
The magnesium ingot and 4.25Al-Sr (matrix) were cut into small blocks using the band saw. Magnesium and Al-Sr rod are weighted according to the mass balance calculation. Magnesium is cleaned with 96% alcohol in order to remove inclusion and oil that might be left on the surface from the cutting procedure. After that, the magnesium and Al-Sr are inserted into the furnace. Before the heater is turned on, the furnace is fluxed for 6 minutes with argon gas. The matrix was melted at 650°C in the furnace and before being poured into the matrix, the reinforce were pre-heated at 900°C in the muffle furnace to remove the moisture. After the pre heating process, SiC particle was inserted into molten Mg-Al-Sr and then stirred for 1 minutes to get a homogenous mixture. Then, they were poured into the mold and the mold will be opened after the composite has solidified. Finally, this composite sample will be used for further characterization [7].

2.3 Characterization
2.3.1 Chemical Characterization. Chemical characterization is performed using Optical Emission Spectroscopy (OES) to determine what elements were present in magnesium ingot samples and Mg-Al-Sr composite with with 2, 4, 6, and 8% Vf SiC. Chemical characterization using OES is generated the form of elements. Elements obtained are further discussed in relation to variations in the addition of SiC and the process of the stirring casting method.

2.3.2 Mechanical Characterization. Each sample is subjected to destructive testing (tensile, impact, hardness, and wear testing). Prior to destructive test, each specimen were tested to find its actual density using Archimedes Theory. The tensile test was done using GoTech machine based on JIS Z2241 at room temperature. The impact test was tested using the Charpy method at room temperature. The hardness test was done using Brinell test with HRH type. The wear was done by Ogoshi by sliding a specimen into harder material for 100 meter sliding distance.

2.3.3 Microstructural Characterization. Firstly all of the samples are grinded and polished. After sample preparation is done, the microstructure characterization is done using optical microscope to view microstructure, SEM with EDX integration to see topography of specimen in 3D and analysis, and XRD to confirm the presence of substances in the material.
3. Results and discussion

3.1 Chemical Composition

OES (Optical Emission Spectrometry) is a test to confirm the presence of elements in magnesium as-cast or non reinforced magnesium also magnesium composite quantitatively. So that, we will know the effect of the casting process on the metal characterization.

Table 1. Chemical composition of Mg as-cast and Composite Material.

| Element | Composite 1 (2% SiC) | Composite 2 (4% SiC) | Composite 3 (6% SiC) | Composite 4 (8% SiC) |
|---------|----------------------|----------------------|----------------------|----------------------|
| Mg      | 94.6                 | 95.2                 | 94.8                 | 91.7                 |
| Al      | 3.99                 | 3.18                 | 2.83                 | 4.17                 |
| Be      | 0.00025              | 0.00022              | 0.00016              | 0.00019              |
| Cu      | <0.0001              | <0.0001              | <0.0001              | <0.0001              |
| Mn      | 0.0106               | 0.0089               | 0.0069               | 0.0092               |
| Zn      | 0.0263               | 0.0195               | 0.0170               | 0.0222               |
| Ag      | 0.00058              | 0.00045              | 0.00041              | 0.00061              |
| Ca      | 0.0062               | 0.0065               | 0.0076               | 0.0164               |
| Cd      | <0.0001              | <0.0001              | <0.0001              | <0.0001              |
| Sn      | 0.0330               | 0.0286               | 0.0220               | 0.0221               |
| Sr      | 0.0904               | 0.08                 | 0.08                 | 0.0888               |
| Si      | 1.11                 | 1.29                 | 2.07                 | 3.7                  |

Table 1 above show the chemical composition of the material. There are a difference in the amount of added elements which strays from the mass balance, instead there are another elements that were not supposed to be in the composite, which is Ti, Be, Cu, Mn, etc but with tiny amount. Even though, these elements would not give significant effect on the characteristics itself. According to calculation, as you increase the number of reinforcement particles it will decrease the wt% of magnesium.

3.2 Microstructure

The observation used digital optical microscope with 200x, 500x, and 1000x magnification. Observations using optical microscopes show the microstructure of MgAlSr / SiC composite materials. The main phase observed in the microstructure is $\alpha$-Mg in the grain which is flat and brightly coloured. Observations using optical microscopes did not clearly show the presence of the intermetallic phases of Mg$_{17}$Al$_{12}$ and Mg$_{58}$Al$_{38}$Sr$_{4}$ in the generated microscope.

In Figure 1 there are arrows of different colors, where the blue arrow shows the $\alpha$-Mg phase, the orange arrow shows dendritic which is estimated to contain the Mg$_{17}$Al$_{12}$ phase and the Mg$_{58}$Al$_{38}$Sr$_{4}$ phase and the white arrow shows the amplifier namely SiC [8]. In pure Magnesium as seen in figure 3, grain boundaries can be seen and their size is much greater than the grain boundary size of Mg-Al-Sr composite. This is due to the Aluminum content which will refine the Magnesium grain due to the presence of other phases namely the intermetallic phase of Mg$_{17}$Al$_{12}$ and Mg$_{58}$Al$_{38}$Sr$_{4}$ [9].
3.3 SEM and EDS
SEM and EDS tests were performed using magnesium composite with 6% Vf to represent all of the composite sample.

Table 2. The EDS result of Mg-Al-Sr.

| Point | Wt (%) | Mg | Al | Sr | Si | O  |
|-------|--------|----|----|----|----|----|
| A     |        | 95.67 | 4.33 |    |    |    |
| B     |        | 89.85 | 9.97 |    | 0.18 |    |
| C     |        | 68.12 | 6.04 |    | 19.91 | 5.78 |
| D     |        | 84.79 | 6.06 | 1.28 | 3.64 | 4.23 |
| E     |        | 78.52 | 7.15 |    | 8.55 | 5.78 |
| F     |        | 83.45 | 5.41 |    | 6.4 | 4.74 |
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Based on the Figure 2 and Table 2 above, it shows some elements like Mg, Al, Si, and O which probably formed some compounds; MgO an Al₂O₃. MgO was formed due to the magnesium properties which is very easy to react with air. In point A it shows α-Mg. In point B, according to the elements that are present shows that it forms Mg₁₇Al₁₂. Point C shows the reinforce particle SiC. Point D shows MgAlSr alloy. Point E and F shows MgAlSi composition.

3.4 XRD

XRD is a test to find out what phases are formed in composite microstructure. In this research, magnesium composite with SiC 6% Vf was observed to represent all the composite samples.

![XRD graph](image)

**Figure 3.** The XRD result of Mg-Al-5Ti-B/nano Al₂O₃ 0.20% Vf.

Based on the data obtained, there are seven identified compounds, namely Mg₂Si, SiC, SiO₂, AlMgSi, Al₂O₃, Al₁Sr and SrO. Compounds that have high diffraction peaks are SrO and Al₂O₃. This is different from the results of SEM observations and micro-observations showing precipitates formed in the Mg-Al-Sr / 6 Vf% SiC composites are estimated to be Mg₁₇Al₁₂ and Mg₅₈Al₃₈Sr₄. From the XRD results above, it can be seen that the intermetallic phases formed are Al₁Sr and AlMgSi. This difference is caused by non-equilibrium cooling during the metal solidification process which results in a difference
from the results of the calculation rule. AlMgSi is formed because of the high amount of Si content. SiO2 is formed from the pre-oxidation of the SiC particles [10]. The main phase of Mg, and SiC have higher intensity than that of the secondary phases and they make up 55% of the composite. Which is 25% higher than the secondary phases which makes up 45% of the composite.

3.5 Mechanical Properties

3.5.1 Tensile and Elongation

![Figure 4](image)

Based on the Figure 4, the highest tensile strength achieved in the addition of 6% Vf SiC and the lowest is 2% Vf SiC. The increase of tensile strength is due to the addition of SiC and AlSr which act as a barrier from dislocation. The increased amount of SiC will increase surface area and create more interface between matrix and reinforcement material. The increased tensile strength between pure magnesium and magnesium alloy is caused by the formation of the phase Mg17Al12 which will cause the grain size to reduce as seen in the microstructure [11].

According to the data acquired on figure 4, the impact value of the matrix will decrease with the addition of SiC particles, this is caused by the increased hardness of the material [12].

3.5.2 Hardness, Wear rate, and Impact

![Figure 5](image)

Figure 5. (a) Hardness, (b) Wear rate.
According to the Figure 5, as the SiC particles is increased, the hardness of composite increase as well. The maximum hardness is obtained by adding 8% Vf SiC. The hardness will influence wear rate of composite, the harder material the lower its wear rate, and it shows that 8% Vf SiC had the lowest wear rate. The hard particle will minimize the matrix from the shear stresses [13]. This happens because of the presence of a reinforcer, where SiC particles and intermetallic such as Mg2Si will make dislocations difficult [14].

3.5.3 Density and Porosity

![Figure 6](image)

Figure 6. (a) Density and (b) Porosity of composite material.

Density test using Archimedes principle results in the actual density of the composite. The result of the actual density are compared with the theoretical density, which is obtained from calculation. From the comparison of density percentage of porosity can be obtained. According to the Figure 6, all of the stirred casting samples showed an actual density value much lower than the theoretical. The addition of 4% Vf SiC has the largest amount of porosity. It can be caused by gases that are trapped in the molten metal, which can come from turbulence during casting [15].

4. Conclusion

Composite MgAlSr with SiC amplifier can be fabricated using the Stir Casting method. The least amount of porosity and agglomeration in this study was obtained in variable 3 with the use of SiC as much as 6% Vf. Increasing the amount of SiC amplifier will improve the mechanical properties of the MgAlSr composite. The optimum mechanical properties obtained have a UTS value of 51.09 MPa, hardness value of 73 HRH, impact value of 0.0367 J/ mm², and wear rate of 5.68 x 10⁻³ mm³/ m. The phase formed in the MgAlSr composite according to micro-observations is the α-Mg phase, β (Mg₁₇Al₁₂) and Mg₅₈Al₃₈Sr₄ phases. The XRD results show that the phase formed in the MgAlSr / SiC composites is α-Mg, AlMgSi, and Al₅Sr. This difference is caused by non-equilibrium cooling.

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