Characteristics of ADC12/nano Al₂O₃ composites with Addition of Ti Produced By Stir Casting Method

A Zulfia¹, Krisiphala¹, D Ferdian¹ B W Utomo² and D Dhaneswara¹

¹Departement of Metallurgy and Materials Engineering, Universitas Indonesia, Depok, 16424, Indonesia
²Astra Honda Motor, Cikarang Barat, 17530, Indonesia

E-mail: anne@metal.ui.ac.id

Abstract. The mechanical properties and microstructure of ADC12/nano Al₂O₃ matrix composites have been studied in this work. The composites were produced by stir casting method. ADC 12 as matrix composites was combined by Mg and Ti. The addition of Ti was varied from 0.02 to 0.08 wt-% as grain refinement wetting to improve mechanical properties such as tensile strength, hardness and wear resistance, while Mg addition was to promote wetting between ADC 12 and nano Al₂O₃. The optimum tensile strength was found at 0.04 wt-% addition of Ti with value of 132.5 MPa, further adding more Ti cause a poisoning mechanism that will hindered the grain refining process and reduce the tensile strength. The hardness and wear resistance of composites would also increase because of the refinement process and the added Magnesium in the material that will form Mg₂Si primary phases who have a high hardness value.

1. Introduction

In present day the use of a composites especially with a matrix of metal or called MMC have been increasing in various application. For example in the automotives region the need of a lightweight and high strength material for the brake pads can be realize by the use of a lightweight metals reinforced with a high strength ceramics instead of the conventional cast iron that is heavy and more expensive[1-2]. So this study focused on a lightweight metals that is Aluminium (ADC 12) reinforced with Al₂O₃ nano particles and was fabricated by a convetional stir casting to see the improvement of its mechanical properties[3]

The addition of high strength Al₂O₃ particles can gradually increase the mechanical properties of a low strength material like the ADC12 alloy. In addition, the Al₂O₃ can improve the grain quality as it can also be a nucleating agent for the α-Al and make the grain more finer and uniform [4]. The particle size can also influence the results because the addition of Al₂O₃ will make the material more brittle as the volume fraction of the addition increase. However, with smaller size of the particle it will reduce the volume fraction need to be added which in this study will use a nano size particle for the reinforcement[5].

One of the problems in the fabrication of metal matrix composite is the wetting between the reinforced with their matrix. The addition of Magnesium can increase the wettability of the matrix. The presence of oxide layer in the Al₂O₃ can make the penetration of the matrix difficult. So with Magnesium added it will react and make the spinell layer (MgAl₂O₄) that can make the penetration of matrix
easier[6]. Also Magnesium can increase the hardness of a material by forming a Mg2Si phase that have a high mechanical properties[7].

ADC12 which is an Al-Si alloy that have Si flakes microstructural morphology, the adding of Al-5Ti-1B master alloy as a grain refiner can further improve the mechanical properties of the material. The master alloy can produce a more uniform microstructure and a much finer grain than a plain Al-Si alloy[8] by forming an Al3Ti phases that will be acting as a nucleating sites for the α-Al[9] Nevertheless, high Ti content in a Al-Si system can trigger a poisoning mechanism in which the Ti will form a Ti5Si3 layer that can hinder the grain refining process[10]. So by adding variation of the master alloy it can show at what percentage it will have the optimum effect at refining the grain size and improving the mechanical properties.

2. Experimental

2.1 Making of ADC12/Nano Al2O3 Composites

Aluminum ADC12 with composition in Table 1 was melted at 800 °C in an electric furnace in the other hand nano Al2O3 particles were also preheated at 500 °C for 1 hour in a muffle furnace to remove moisture from the particles. After the aluminum melted, degassing was conducted to remove gas from inside the molten aluminium and followed by removing the slag from the surface of the molten aluminium. Then 10 wt-% of magnesium and variation of Ti from 0, 0.02 to 0.08 wt-% were added into the molten aluminium and stirred for 2 minutes. Meanwhile nano Al2O3 with 0.03% Vf was heating for 1 hour then poured into molten aluminium followed by stirring for 2 minutes to maximize the dispersions of the particles in the matrix. The cast composites then poured into tensile metal mold and underwent solidification.

2.2 Characterization of ADC12/Nano Al2O3 Composite

The mechanical properties of the composites were characterized by tensile, hardness, wear resistance and impact testing. GOTECH AI-7000 LA 10 machine was used to perform the tensile test with JIS Z2241 standard. Rocky Rockwell B was used to do hardness testing with ASTM E18-16 standard. Ogoshi machine was used to conduct the wear test. Samples for metallography observation were prepared by grinding with sand paper, polishing with TiO2 and polish cloth, and etching with keller reagent. Keller reagent has composition of 2 ml HF, 5 ml HNO3, 3 ml HCl and 190 ml aquadest. Samples were observed using OLYMPUS BX41M-LED optical microscope, scanning electron microscope (SEM) link to energy dispersive spectrum (EDS). For further analysis, XRay Diffraction was conducted to identify the phase present in composites.

| Elements  | Al   | Si   | Fe   | Cu   | Mn   | Mg   | Zn   | Cr   | Ni   |
|-----------|------|------|------|------|------|------|------|------|------|
| %wt       | 84.8 | 10.5 | 0.864| 2.33 | 0.233| 0.221| 0.637| 0.389| 0.0759|

| Elements  | Pb   | Sn   | V    | Na   | Bi   | Zr   | B    | Ga   | Ti   |
|-----------|------|------|------|------|------|------|------|------|------|
| %wt       | 0.0342| 0.0798| 0.0102| 0.0020| <0.0050| 0.0068| <0.0005| 0.0118| 0.0462|

3. Results and Discussion

3.1 Microstructural Observation and Phase Indentification of ADC12/nano Al2O3 Composite

The optimum grain refinement process occurs in the addition of 0.04 wt-%, the refining process occur because the Al3Ti phases which will become a nucleation site for the α-Al and produce a finer and much more uniform grain see Fig. 1. However, with the addition of 0.06 and 0.08 wt-% of Ti the grain become
larger because of the poisoning effect that is common occurred in the Al-Si system with a high Ti content. Ti will form Ti₅Si₃ layer with Si which have a higher affinity than Al.

![Figure 1](image1)

**Figure 1** Microstructure of ADC12/nano Al₂O₃ composites (200x): (a) ADC12; (b) ADC12/nano Al₂O₃; (c) 0.02 wt-% Ti; (d) 0.04 wt-% Ti; (e) 0.06 wt-% Ti; (f) 0.08 wt-% Ti

As it can be seen by the solidification path of the materials in Figure 2, the microstructure of the composites mainly contains of α-Al, Si eutectic (blue circle), Mg₅Si primary (red arrow) Mg₅Si quasibinary (yellow circle), and Al-Fe-Si intermetallics (green circle). The microstructure in Figure 1 can be seen Mg₅Si phases formed in the system because of 10 wt-% Mg the addition. It was shown in figure 1e and 1f Mg₅Si primary will form in the microstructure and have a blocky like morphology. Mg₅Si primary have a high hardness value that can improve the hardness of the material but can become a site for crack initiation, so more of the Mg₅Si primary phases form the more brittle the material can become[11].

![Figure 2](image2)

**Figure 2** (a) Ternary diagram of Al-Mg-Si alloys and the solidification path (b) Ternary diagram of Al-Fe-Si and the solidification path

ADC12 is a material that commonly have a high Fe content, so in this study it can be seen that the material have the Al-Fe-Si intermetallics. This intermetallics can cause poor mechanical properties because it have low elongation and can reduced the ductility of the material[12]. The Mg₅Si phases of primary and quasibinary were also found in the SEM-EDS examination in Fig.3. Besides the Mg₅Si phase, Al-Fe-Si phases are also found and this phases can lower the output of the mechanical properties.
Figure 3 Microstructure of ADC12/nano Al$_2$O$_3$ composites with 0.04 wt-% Ti analysed by SEM and EDS Examination

The phases present in ADC12/Nano Al$_2$O$_3$ with 0.04 wt-% Ti analysed by XRD is shown in Fig. 4, the phases are MgAl$_2$O$_4$, Mg$_2$Si, and Al$_3$Ti. The spinel layer MgAl$_2$O$_4$ proven good interface bonding between the matrix and the reinforcement, it is formed by the addition of Mg in this study at 10 wt-%. Al$_3$Ti is also detected and prove that a refining process occurs as the Al$_3$Ti became a nucleation sites[13].

Figure 4 XRD Pattern of ADC12/Nano Al$_2$O$_3$ compsoites with 0.04 wt-% Ti addition

3.2 Mechanical Properties of ADC12/Nano Al$_2$O$_3$ Composite

The results of the tensile test is shown in Figures 5 and 6. It can be seen that the addition of 0.03 % Vf Al$_2$O$_3$ nano particle can improve the tensile strength of the material from 98.36 MPa to 114.87. This is caused by the high strength of Al$_2$O$_3$ particles that will increase the mechanical properties of the ADC12 matrix[14]. The addition of Ti content as was discussed before can also improve the tensile properties of a material by making the grain smaller and more uniform. The optimum tensile strength was achieve at 0.04% of Ti addition with a value of 132.48 MPa, it is also have the smallest grain compared to the others. Furthermore addition will decrease the tensile strength because of the poisoning effect occurring in the material, and it was seen in Figure 1e and 1f many Mg$_2$Si primary were form because of the excess Mg. Mg$_2$Si primary phases can lowered the elongation of a material by being a site for crack initiation.
Figure 5 Effect of Ti addition on (a) Ultimate Tensile Strength (UTS) and (b) Impact strength of composites

The addition of nano Al₂O₃ increases the hardness of the material, it is because Al₂O₃ has a high hardness so the hardness of the composites will also improved. Ti addition can also increase the hardness of a material because of the smaller grain it will produce. In the addition of Ti at 0.06 and 0.08 wt% occur the poisoning mechanism and the grain it produces is larger, but the hardness of the material still increases because of the Mg₂Si primary that forms[15-16]. The highest value of hardness 41.3 HRB. The effect of adding Ti in the composites can be seen in Figure 6(a).

The addition of Al₂O₃ and Ti can also improve the wear resistance of material[17]. It can be seen also in Figure 6(b), that the harder the composite the lower its wear rate becomes. The optimum value of wear rate is at 0.96 x 10⁻⁵.

Figure 6 Effect of Ti addition on (a) Hardness (UTS) and (b) Wear rate

The impact value that was obtained are 0.0163; 0.024375; 0.02375; 0.01875; 0.017 corresponding to the increase of Ti addition. The addition of Ti slightly increase the impact value because of the finer grain increasing the energy the material can absorbed. The more brittle the material the impact value also decreases.

4. Conclusion

1. The addition of Al₂O₃ nano particle and Ti improves the mechanical properties of the material such as its tensile strength, hardness, wear resistance, and impact value.
2. The addition of Ti will form Al₃Ti phases in the microstructure that will become a nucleation site for α-Al and reduce the size of the grain so the mechanical properties will also improved.
3. Poisoning effect will occur by adding more than 0.04% wt Ti because of the high Si content in the material.

4. By adding 10 wt-% Mg will create a thin layer of MgAl$_2$O$_4$ that contributes to the improvement of mechanical properties of the composites but also form the Mg$_2$Si phases that can make the material brittle.

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