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Effect of Al-TiB Addition on the Mechanical Properties and Microstructure of Al-ADC12/NanoSiC Produced by Stir Casting Methods

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Abstract Addition of Ti-B grain refiner in Al-ADC12/nanoSiC composite results in improvement of tensile strength, hardness, and wear resistance through grain refinement. In this research, composite of Al-ADC12/nano SiC (0.15 %vf) with variations of TiB respectively (0.0), (0.02), (0.04), (0.06), dan (0.08) wt% were produced by stir casting. 10% of Mg were added to promote wettability between reinforce and matrix. It was found the best addition of TiB is 0.04 wt% Ti-B which results 135,9 MPa in tensile strength, 46 HRB in hardness, and $1.47x10^{-5}$ mm^3/s as wear rate. The increase in mechanical properties of composites mainly because of Al_3Ti acts as nucleants which initiates the grain refinement and the existence of $MgAl_2O_4$ phase indicates an interphase between nano SiC and ADC12 matrix. However, the increase of Ti-B addition after optimum number gives no significant results. High composition of iron and magnesium addition will form intermetallic phase β-Fe, π-Fe, and Mg_2Si.

1. Introduction

Aluminum which covers about 8% of the earth crust is known as one of the three most abundant metals in the earth after iron and copper[1]. It has a good mechanical properties and corrosion resistance both produced by casting or forging, therefore it has a wide applications in transportation. One being studied recently for the purpose of mass transportation is changing cast iron into composites as brake shoe[2]. ADC12 is aluminum with a main alloying element of silicon, copper, and magnesium[3]. These elements improved its casting properties: silicon will increase its flowability, copper reduce shrinkage and combination between silicon and magnesium will form precipitates that increase wear resistance[4,5].

Adding reinforce could enhance yield, tensile strength, and hardness without reducing ductility due to grain refinement mechanism called Orowan Looping[6]. Nano sized particle results in strong multidirectional interphase, good distribution of particles, and low porosity which will increase the ability to transfer applied load compared to micro sized particles[7]. Eventhough nano particles gives refinement effect, the addition of grain refiner gives more significant refinement effect due to innoculation mechanism[8–12]. The refinement takes place during the solidification stage and two phases which act as innoculant are TiB_2 and Al_3Ti which settle at α-Aluminum grain boundaries[13–14]. To achieve the full potential of composite, the SiC/Al interface must possess a strong adhesion through interdifussion by adding magnesium as wetting agent[15,16]. The good interphase of matrix and reinforce indicated by the existence of phase $MgAl_2O_4$ in the composite system[17]. In this work

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the effects of Ti – B addition were studied to find the ideal compositions provide the best mechanical properties.

2. Experimental

2.1. Synthesis of composite

The alloy was produced through stir casting method. Al-5Ti-1B master alloy were added as grain refiner. ADC12 with nominal composition (mass fraction): Si 10.5%; Fe 0.8%; Cu 2.33%; Mn 0.22%; Mg 0.22%; Zn 0.64% and Cr 0.04% was selected as the matrix, and combined with 0.15% volume fraction of nano silica as reinforce. In the making, aluminum was heated to its molten state in 800^{o}C, then magnesium was added to improve wettability between matrix and reinforce. Titanium boron was added in the form of rod, and nano silica was added the last after degassing process using Argon. Before poured in the molten aluminium nano silica was preheated in muffle furnace for an hour in 500^{o}C to remove moist and increase surface tension. The molten aluminum then stirred 600 rpm for 2 minutes. Before pouring, the mold had been preheated in 300^{o}C for 2 minutes and coated by zircon to reduce thermal shock.

2.2. Microstructural characterization

All cast were microstructurally characterized in the terms of grain size of matrix alloy using optical microscope. They were cut from the cast cylinder, polished, and etched using Keller reagent with standard metallographic technique. The specimen showing highest tensile strength then re-polished, and tested using SEM and XRD to check the phases and knowing the interphase between matrix and reinforce.

2.3. Mechanical properties characterization

All cast were prepared and tested to measure mechanical properties (tensile strength, hardness, wear rate). As another properties, density were tested using Archimedes' Theory. Tensile test was performed using Ogoshi universal testing machine and tested at room temperature. Some parts of sprue were cut into small pieces and grinded to get a fine surface and tested using Brinell. Wear test of the composite were conducted using pin-on-disk machine by sliding a specimen under dry condition.

3. Results and Discussion

3.1. Materials and microstructures

The microstructure of the composite with variation of Ti-B are shown in fig. 1 respectively. Seen in ADC 12 plain (without reinforce and grain refiner) all the structure are needle like, and with the addition of reinforce and grain refiner it all changed into spherical. Significant changes before and after addition of reinforce nanoSiC due Thermal Lag refinement. The nano particles of reinforce forced the α-Al to split and as the result, their grain size become smaller. As the proportion of grain refiner increase, the grains becoming finer and more spherical as seen in figure 1. (b-f).

The decreasing size of grain also proved by the calculation of *Single Dendrites Arm Spacing*, the number of SDAS decreased when the size of grain also decreased (figure 2). As seen in the microstructure there are few morphologies which indicates certain intermetallic phases, and it is predicted using phase diagram which is plotted from its chemical composition test result (OES) in table 1.The excess magnesium in the system derivates the ternary phase diagram Al-Mg-Si. The composition of each composite takes place around *quasi-binary* line reaction which results in formation of intermetallic phase primary Mg_2Si and eutectic Mg_2Si (binary and ternary).

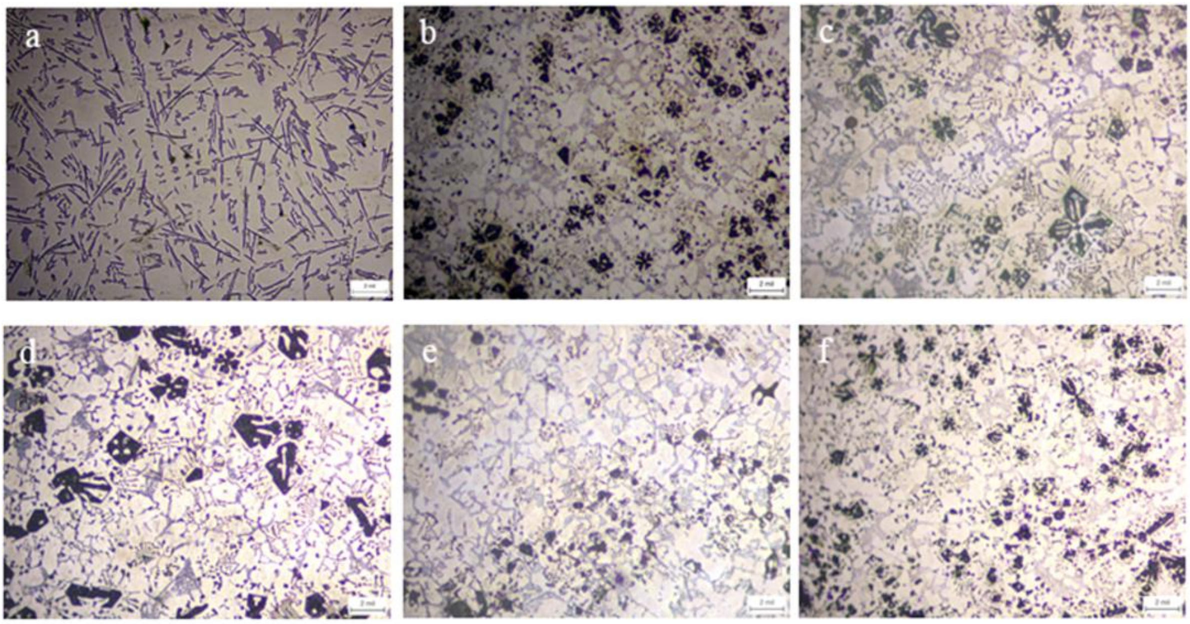

Figure 1.(a) ADC12, (b) 0.0 wt% Ti, (c) 0.02 wt% Ti, (d) 0.04 wt% Ti, (e) 0.06 wt% Ti, (f) 0.08 wt% Ti

Table 1. Chemical composition of composites

Composition	Silicon (Si)	Magnesium (Mg)	Iron(Fe)
Comp 1 (0.0 wt%)	7.21	>12	0,821
Comp 2 (0.02 wt%)	7.23	>12	0.913
Comp 3 (0.04 wt%)	7.20	>12	0.958
Comp 4 (0.05 wt%)	8.17	>12	0.950
Comp 5 (0.06 wt%)	7.20	>12	0.861

As the temperature decrease there will be a change in the morphology of the intermetallic phase. Primary Mg_2Si formed in the early reaction and mostly blocky and compact or snow-flakes shaped. Eutectic Mg_2Si will form after hand and the binary will form a chinese script and the ternary will form white dots around chinese script (figure 2). As the grain get finer, the SDAS reduced (figure 3). The formation follows reaction 1 and 2:

$$L \rightarrow L + Mg_2Si_p \rightarrow Mg_2Si_p + (\alpha\text{-}Al + Mg_2Si)_E \quad (1)$$

$$L \rightarrow L + Al + \beta\text{-}Al_5FeSi \rightarrow \beta\text{-}Al_5FeSi + Al + Si \quad (2)$$

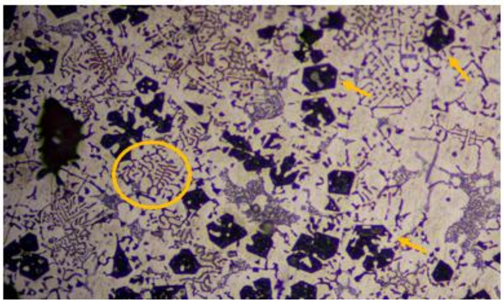

Figure 2. Intermetallic phase Mg_2Si primary (arrow) and eutectic (circle)

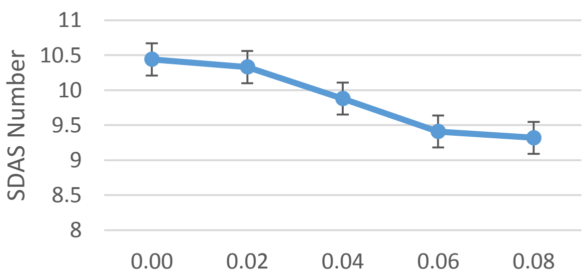

Figure 3. Effect of TiB addition to SDAS composite

The formation of intermetallic phases Al_5FeSi takes form needle like and sharp. This morphology reduces its toughness, and affects tensile strength. The other form of Fe intermetallic is π-Fe which looked like chinese script (figure 4).

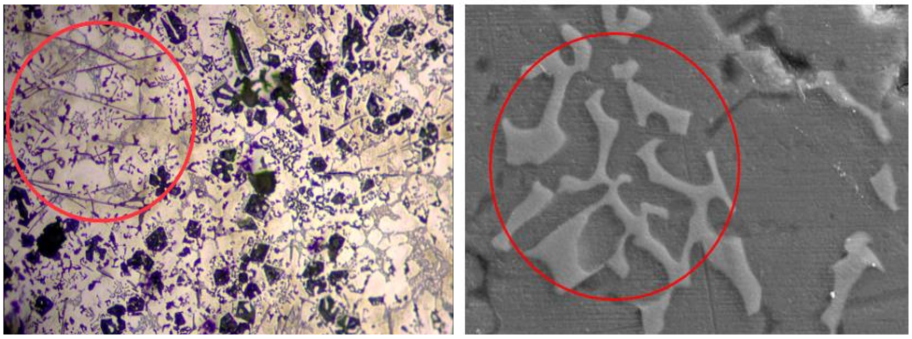

Figure 4. Intermetallic phase β-Fe (left) and π-Fe (right)

SEM and XRD results (figure 5) shows there are intermetallic phases and interphase between matrix and reinforce. Spinel ($MgAl_2O_4$) and titanium in the form TiB_2 and Al_3Ti confirmed by XRD test. The high percentage of oxygen compared to other elements in EDS result (table 2) indicated there is indeed a bonding between matrix and reinforced. There is no evidence on the existence of titanium or boron in the SEM, this is due to very small amount of them added to the system, but all of them showing high peak in the various location in XRD test. It indicates all of them fine dispersed in the matrix.

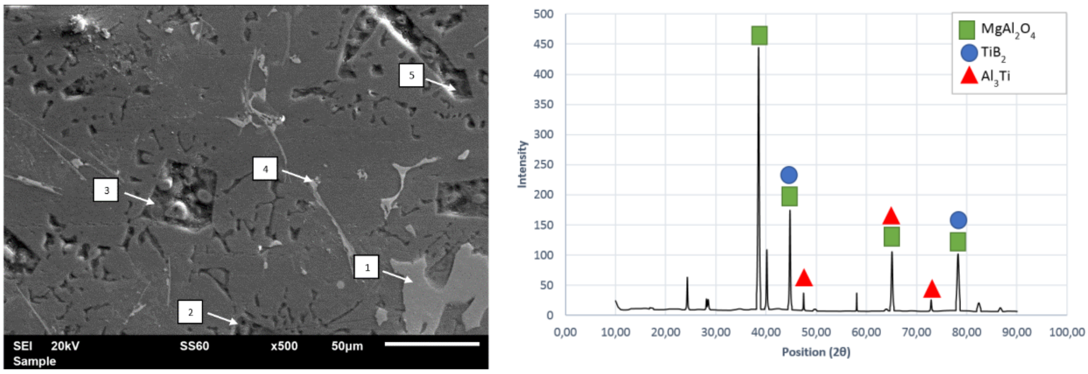

Figure 5. SEM image cast composite (left) and XRD result (right)

Table 2. EDS result cast composite

Region	Element (wt%)							Predicted Phase
	Al	Mg	Si	Fe	Cu	O	C	
1	95.75					4.25		α-Al
2	41.84	16.05	18.57			16.73		Al + Mg_2Si
3	1.41	24.72	26.73			30.82	12.18	Mg_2Si
4	68.29		8.71	9.15		3.69		AlFeSi (β-Fe)
5	54.88	0.93			16.64	3.57	17.28	Al_2Cu

3.2. Density and Porosity

All casts composites density are close to the pure Al (2,59 gr/cm^3). This is because the proportion of Ti-B added was too small, so there will be no significant differences in the term of density. The factor affecting differences between each composition is porosity. An increase of Ti-B addition results in reduction of porosity in cast composite as seen in figure 6. The addition of 0.06 wt% Ti-B gives the highest porosity among due to excess hydrogen which enter the molten aluminum during stirring. The existence of porosity in the system reduce tensile strength significantly[18].

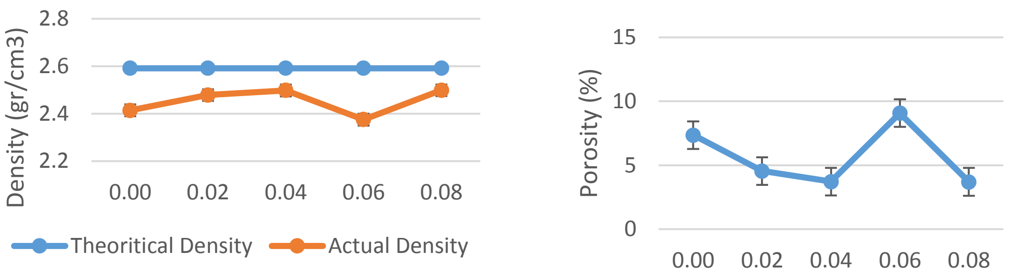

Figure 6. The effect of Ti-B to the density (left) and porosity (right) of composite

3.3. Tensile and Elongation

Porosity in the cast relates to tensile strength, higher percentage of porosity results in low number of tensile strength. Therefore the addition of 0.06 wt% Ti-B gives the lowest UTS (figure 7). Porosity does affect the ability of material to transfer applied stress.

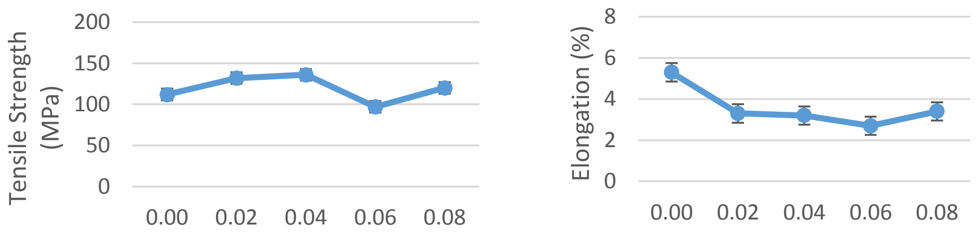

Figure 7. Effect of Ti-B to tensile strength (left) and elongation (right)

3.4. Hardness and wear rate

As the Ti-B added increase, the hardness of cast increase as well (figure 8), but after certain addition, it will give no significant result. The ideal addition is 0.04 wt% therefore addition 0.06 and so on, they give no increase in hardness. Hardness of material relate to the wear rate of the material, as seen variation 0.04 gives highest hardness thus gives the lowest wear rate.

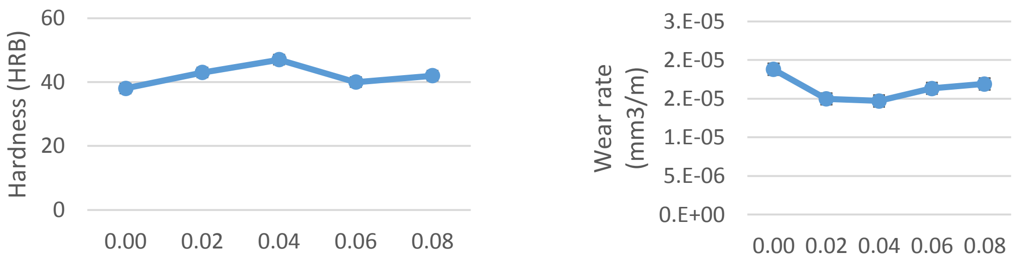

Figure 8. Hardness (left) and wear rate all cast (right)

4. Conclusion

Metal matrix composite can be produced using stir casting method, and the optimal addition of Ti-B which results in highest mechanical properties is 0.04 wt%. It reach highest tensile 135.97 MPa, 46 HRB in hardness, and 3.72% porosity. The addition of grain refiner changes the morphology of primary phase α-Aluminum from coarse dendritic to fine spherical grain which is attributed to grain refinement. Segregation of TiB_2 and Al_3Ti in the system act as inoculant near primary phase α-Aluminum.Addition of magnesium may create intermetallic phases Mg_2Si, and the high percentage of iron creates intermetallic phases β-Fe and π-Fe. The existence of spinel ($MgAl_2O_4$) indicates an interphase between matrix and reinforce which optimized the tensile stress distribution.

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