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Effects of Combination of 0.02 wt % Sr and Ti on the Characteristics of AC4B Alloys Produced by Low Pressure Die Casting

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Abstract. Aluminium AC4B alloy is widely used in automotive industries for various components. However, when this alloy is used to produce motorcycle cylinder head by Low Pressure Die Casting (LPDC) process, high reject rate was often found due to shrinkage, porosity and misrun. Addition of grain refiner and modifier is an alternative for this problem, through the control of solidification process that results in grain refining and microstructure modification. This study was aimed to investigate the effect of combination of 0.02 wt. % Sr modifier with variation of Ti grain refiner on the characteristics of AC4B alloy and the reject rate of cylinder head components. The Ti grain refiner was varied 0.063, 0.083 and 0.108 wt. % Ti and added at the holding furnace prior to LPDC process. A series of test was conducted including hardness test from the thin and thick regions of the part, tensile test, fluidity test, vacuum test as well as observation of microstructure by using optical microscope and Scanning Electron Microscopy (SEM) equipped with Energy Dispersive X-Ray Analysis (EDAX). The results showed that the higher the Ti content, the higher the hardness for both thin and thick areas, the lower the fluidity of the molten metal. At the maximum level of Ti of 0.108 wt. % and 0.02 wt. % Sr, the reject rate was significantly reduced from 3.59 % to 1.38 %.

Introduction

Aluminium AC4B alloy (Al-Si-Cu) is one of the cast alloy that widely used in automotive industry such as for cylinder heads for the motorcycle. The component is produced by Low Pressure Die Casting (LPDC) process that usually faces problems such as leakage, shrinkage, misrun and porosity. One of the alternative to overcome this problem is by addition of modifier and grain refiner. Modification will change the structure of silicon phase from coarse plate into fine fibrous, which yields to higher strength and ductility [1, 2]. While the grain refiner, majorly as Al-Ti -based, will reduce the size of the Dendrite Arm Spacing (DAS), which increase the strength and helps feeding process during solidification of molten metal. For some time, grain refinement is believed to be caused only by the formation of peritectic Al_3Ti particles (I4/mmm, a=0.385 nm, c=0.429 nm), which act as the heterogeneous nucleants [3]. Another mechanism was proposed as the Growth Restriction Factor, in which the solutes segregate at the solid-liquid interface that restrict the growth of the solid and refinement of grains [4, 5, 6]. Combined addition of Sr and Ti may lead to poisoning, in which the effects of modification and refinement are both reduced [7, 8]. This research studied the combined effects of 0.02 wt. % Sr and varied addition of Ti to the characteristic of AC4B alloys produced through LPDC process.

Experimental Method

Melting of AC4B alloy was conduced in a reverbatory melting furnace at the temperature of 750-800°C, with the ingot to return scrap ratio of 55:45. After degassing by Argon at 350-400 rpm for 8 minutes, molten metal was poured into a holding furnace with the capacity of 500 kg. Flux Ti grain refiner (Coveral GR2815®) and Al-10Sr rod modifier was added into the holding furnace at 710 $\pm$ 10 ^{o}C and then stirred for 20 seconds by using Argon lance. Three alloys were made with 0.02 wt. % Sr combined with 0.063, 0.083 dan 0.108 *wt.* % Ti, as shown in Table 1. Some of the molten metal was taken for making samples of tensile test, chemical compositional test, and spiral gravity test. Molten metal was injected into a mould of two cavities of cylinder head heated at around 300 °C. Samples for hardness testing and microstructural observation were taken at the thin and thick areas of the cylinder head. Observation by optical microscope and SEM was performed on samples with standard preparation by using Tucker reagent (45 ml HCl + 15 ml HNO_3 + 15 ml HF (48 %) + 25 ml H_2O). Rockwell B hardness testing was in accordance with ASTM E18 with five indentations, while tensile testing followed JIS Z2201 standard.

Table 1. Nominal composition of the alloys (wt. %)

Alloy	Si	Cu	Mg	Sr	Ti	Fe	Mn	Ni	Pb	Sn	Cr	Al
Alloy 1	8.804	2.239	0.242	**0.020**	**0.063**	0.739	0.252	0.068	0.063	0.023	0.031	Balance
Alloy 2	8.883	2.462	0.276	**0.021**	**0.083**	0.851	0.257	0.072	0.076	0.045	0.036	Balance
Alloy 3	8.849	2.800	0.264	**0.018**	**0.108**	0.812	0.323	0.062	0.079	0.049	0.032	Balance

Results and Discussion

Fig. 1 shows the change in hardness of AC4B alloys after added with Sr and Ti, both in thick and thin regions of the part. At the same level of Sr, the addition of Ti led to the increase in hardness, from 50.26 HRB at 0.063 wt. % Ti to 52.48 HRB at 1.02 wt. % Ti. This is accordance with previous study by Hatch [9] which suggested that the effective level of addition of Ti to aluminium alloys is 0.02 – 0.15 wt. %. Similarly, the tensile strength and ductility are also higher with the addition of Ti (see Fig. 2). To understand how the combination of Sr and Ti affect the mechanical properties of the materials, the microstructures were observed and presented in Fig. 3.

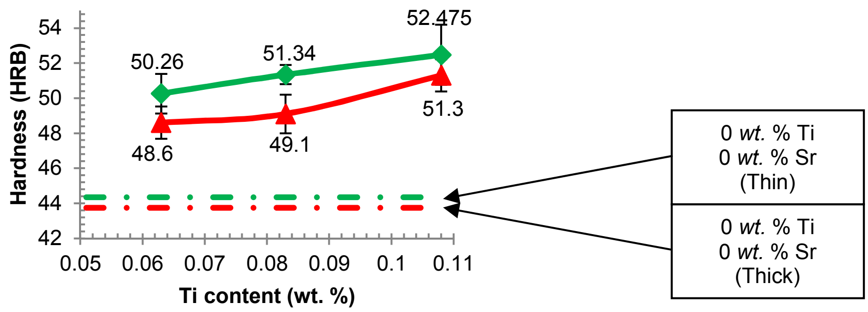

Figure 1. The effects of addition of 0.02 wt. % Sr and 0.063, 0.083 dan 0.108 *wt.* % Ti on the hardness of the AC4B alloys at thin and thick areas. The hardness of the samples without Sr and Ti addition is shown as the comparison.

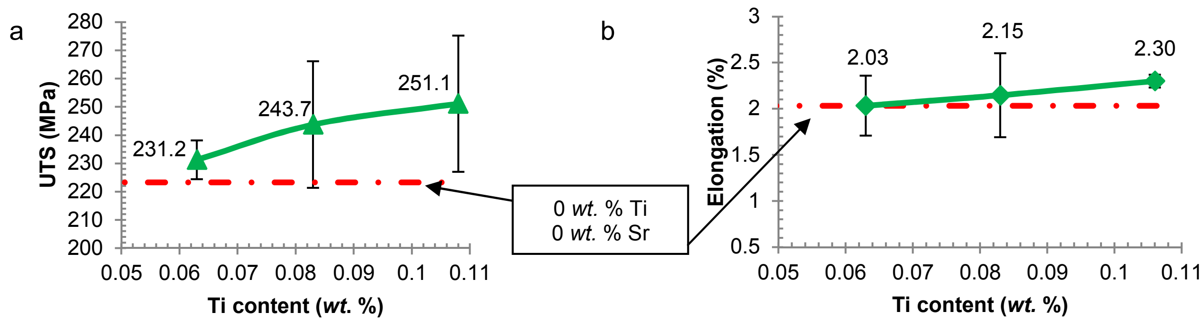

Figure 2. The effects of 0.02 wt. % Sr and Ti addition on the (a) tensile strength and (b) ductility of AC4B alloys. The strength and ductility of AC4B without addition of Sr and Ti is shown as comparison.

Fig. 3 reveals the dendritic structures of AC4B alloys cast through LPDC process. The addition of Ti grain refiner significantly reduces the Dendrite Arm Spacing (DAS), from 27.76 µm to 13.30 µm at thin area. The morphology of the silicon phase was initially coarse interconnected plates when no Sr was added. The presence of Sr modifies the silicon phase into fine fibrous structures which contributes to the ductility of the material. The finer DAS resulted in higher hardness and strength, because the grain boundaries inhibit the movement of dislocations [6], but the ductility of the alloy remained higher due to the modification of silicon phase. There is no indication of poisoning of Sr by Ti as proposed by Mohanty dan Gruzleski [10]. The Sr continues to be effective in modifying the silicon structures while Ti refining the α-Al dendrite. Detailed observation on microstructure revealed that with the constant composition of Sr of 0.02 wt. % and increased Ti of 0.063, 0.083 and 0.108 wt. %, the level of modification of the silicon phase increase from class B to D and E, respectively. Again, this indicates synergitic effects of Sr and Ti.

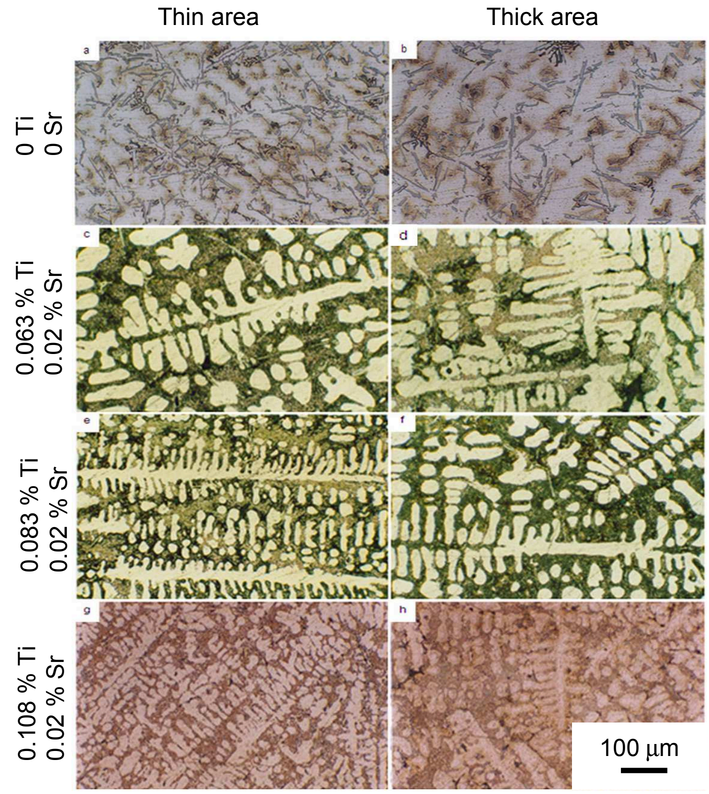

Figure 3. Microstructures of AC4B alloys (a-b) without addition of Ti and Sr, and with combined addition of 0.02 wt. % Sr and (c-d) 0.063, (e-f) 0.083, (g-h) 0.108 wt. % Ti, at the thin and thick areas of the samples.

The refining of DAS by Ti follows the theory of solute paradigm theory by Johnsson [11]. The solute elements restrict the grain growth by segregating to the newly formed solid surface. The ability of solute element in restricting grain growth can be calculated by Growth Restriction Factor (GRF) [11]. The GRFs of AC4B alloys with 0.02 wt. % Sr and 0.063, 0.083 and 0.106 wt. % Ti are 76.914, 83.373 and 90.069 respectively. The values are directly related to the decrease of DAS by addition of Ti.

Fig. 3 (g) was observed in detail by using SEM/EDX and the result is available in Fig. 4 and Table 2. The phases which are labeled as phase 1 and 2 were indicated as Al_2Cu and Al(Fe,Mn)Si, respectively. These two phases are among the first two phases form during solidification [13]. Some Sr was found segregated at phase 4 and 6, the Al(Fe,Mn)Si and the silicon phase. The segregation of Sr into silicon is believed to be at the faceted <111> plane of the silicon, which disturb the growth due to formation of twinning planes [10]. Nucleants may form during solidification caused by the presence of Ti [13]. However, no $TiAl_3$-nucleant was found in this study, which might be due to the limitation of detection in SEM. Or, it can be interpreted that the mechanism of growth restriction by solute elements is more dominant.

The combined effects of Sr and Ti on the fluidity of molten AC4B is presented in Fig. 5. The addition of 0.02 wt. % Sr significantly increase the fluidity from 40.1 cm to 65.6 cm. When more Ti was added then the fluidity reduced. Titanium may promote the nucleation of $TiAl_3$, which results in mushy zone during pouring and shorten the solidification range. Therefore, the more Ti added to the molten metal, the lower the fluidity.

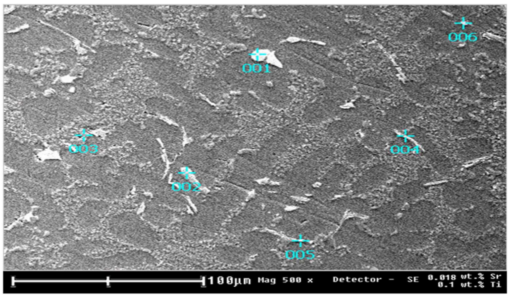

Figure 4. Microstructure of AC4B alloy with 0.02 wt. % Sr and 0.108 wt. % Ti viewed by SEM. The microanalysis was conducted at position 001 – 006 and the results are provided in Table 2.

Tabel 2 Microanalysis on position shown in Fig. 4, of the AC4B alloy with 0.02 wt. % Sr and 0.108 wt. % Ti.

No	Composition								Colour	Possible phase
	Al	Si	Ti	Sr	Cu	Fe	Mn	Mg		
1	25.73	0.75	-	0.16	38.41	0.44	-	-	white	Al_2Cu
2	23.32	12.34	-	0.68	1.98	17.07	3.14	-	light grey	Al(Fe,Mn)Si, $FeAl_3$
3	28.26	17.51	0.46	3.73	0.64	0.23	-	0.49	grey	Si crystal
4	29.32	9.27	0.63	1.95	1.48	9.26	4.83	0.52	light grey	Al_3Ti, Al(Fe,Mn)Si
5	49.51	0.81	-	-	3.49	-	0.27	-	dark grey	α-Al
6	38.76	3.79	-	3.04	4.19	3.92	-	2.71	dark grey	Mg_2Si, Si crystal

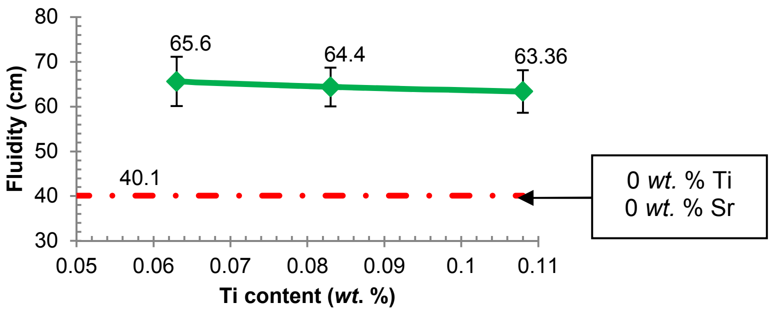

Figure 5. Effects of combined addition of 0.02 wt. % Sr and Ti to the fluidity of AC4B alloys. The fluidity of a standard AC4B is presented for comparison.

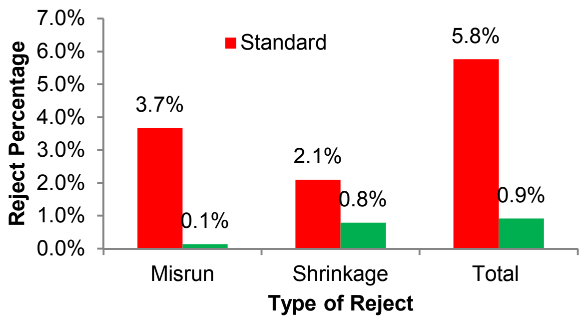

Figure 6. Comparison of reject percentage due to misrun and shrinkage in cylinder heads, by using standard and 0.02 wt. % Sr and 0.108 wt. % Ti modified AC4B alloys.

Trial at industrial scale was conducted by adding 0.02 wt. % Sr and 0.108 wt. % to the molten AC4B alloy. The total number of cylinder heads produced during the trial was 764 pieces for each of the standard and the modified alloy. The reject percentage is shown in Fig. 6. It is clear that the addition of both Sr and Ti siginificantly reduced the reject rate from 5.8 % to 0.9 %. The misrun trimmed down from 3.7 % to 0.1 %, only one part was found to have misrun in the modified alloy. The shrinkage was down from 2.1 % to 0.8 %. It is worth noted that shrinkage was observed more than the misrun when Sr and Ti was added. The addition of Sr successfully increase the fluidity to reduce the misrun, but the the shrinkage due to modified solidication should be watched out in more detail. The reduction in shrinkage by Ti and Sr addition is caused by the feeding ability of the molten aluminium. Feeding is the balancing of the contracted aluminium volume that solidify by supplying molten aluminium. With smaller dendrite size, contracted volume will be reduced and more easily fed [8].

Conclusions

The results of the study can be concluded as follows:

- The addition of 0.02 *wt.* % Sr and variation of Ti of 0.063, 0.083 and 0.108 *wt.* % increases the hardness, tensile strength, ductility and level of modification of silicon phase.
- The constant composition of Sr of 0.02 wt. % and increased Ti of 0.063, 0.083 and 0.108 wt. % leads to the decrease in fluidity and DAS and the rise in the level of modification of the silicon phase from class B to D and E, respectively.
- The combination of modification and grain refinement resulted in modified structures, which are fibrous with fine dendrite, with the maximum characteristics were achieved at 0.02 wt. % Sr and 0.108 *wt*. % Ti.
- This study did not find specific interaction between Sr and Ti. The Sr was found to be segregated at silicon phase and Ti was not found in the form of nucleant. It is suggested that Ti refines the dendrite through solute growth restriction mechanism.

Acknowledgement

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