Please refer as:

Willy Handoko and Bondan T. Sofyan, *Modification of Microstructure of AC4B Aluminium CastAlloys by Addition of 0.004 wt. % Sr*, **Proc. 11th Int. Conf. Quality in Research**, Depok, 3-6 August 2009, ISSN. 114-1284, pp. 1049 – 1054.

Modification of Microstructure of AC4B Aluminium Cast Alloys by Addition of 0.004 wt. % Sr

Willy Handoko[1] and Bondan T. Sofyan[1]

[1]*Department of Metallurgy and Materials Engineering, Faculty of Engineering*
University of Indonesia, Depok 16424, Indonesia
Tel : (021) 786 3510, Fax : (021) 787 2350
E-mail : bondan@eng.ui.ac.id

ABSTRACT

Cylinder heads of motorcycles are produced by low pressure die casting (LPDC) process using AC4B aluminium cast alloy. Rejects that are often found in this component are misrun due to the inadequate fluidity of molten metal to fill up cavity of LPDC die. Fluidity of molten metal may be enhanced through modification of microstructure by adding Sr. This research studied the effects of Sr addition of 0.004 wt. % on the as-cast properties of AC4B alloys.

Addition of Sr was conducted by adding rod Al-10 Sr master alloy in the holding furnace. Injection temperatures of LPDC process were varied 680, 700 and 720 ^{o}C. Fluidity of molten metal was measured by spiral method, and porosity was observed through vacuum porosity tests. Tensile and hardness tests were conducted as well as observation on the microstructure of the materials in as-cast condition by using light microscopy and SEM (scanning electron microscope) equipped with EDS (energy dispersive spectroscopy).

Fluidity of AC4B aluminium alloys increases by addition of 0.004 wt. % Sr. The higher the injection temperature, the higher the fluidity of the molten metal. Addition of Sr seems to increase the porosity level, which then decreases the hardness of the alloy. However, the distribution of porosity is random, and no particular mode is able to detect. The presence of Sr modify the accicular Si eutectic into fine fibrous. Injection temperature seems to have little effects on the modification of mircostructure by addition of Sr.

Keywords

AC4B, Sr, low pressure die casting, fluidity, modification

1. INTRODUCTION

One foundry alloy that is popular for use in automotive application is AC4B aluminium alloy, due to its excellent castability and mechanical properties. Its excellent corrosion resistance and low cost of recycling are also important considerations from an environmental point of view. Aluminium alloy AC4B is essentially a hypoeutectic Al-Si alloy with two main solidification stages, formation of aluminium rich dendrites followed by development of silicon phase. Two major disadvantages of these alloys. The first is the sharp edges of the coarse acicular silicon phase that occurs in the microstructure, promoting crack initiation and propagation which leads to poor mechanical properties. Another disadvantage is their long freezing range, which leads to feeding difficulties in the interdendritic region, resulting in increased porosity [1].

Strontium is added to hypoeutectic aluminium-silicon alloys in order to transform the morphology of the silicon phase from acicular flakes to a fibrous rodlike form, thereby improving mechanical properties, especially fracture toughness and elongation [2]. At a given cooling rate, Sr decreases nucleation and growth temperatures of the (Al)-Si eutectic and this effect is higher the higher the cooling rate [3]. Addition of Sr does not affect primary deposition of (Al) but apparently modifies reactions occurring after the (Al)-Si precipitation. DTA work by Martinez *et al.* [3] confirmed that Sr addition has a direct influence only on the growth mechanism of the (Al)-Si eutectic. Small changes in overall eutectic kinetics due to Sr modification also results in subtle modification during final stages of solidification as well as in the precipitation of iron and manganese rich phases.

However, Sr addition is also associated with porosity formation. In this connection, Dahle *et al*. [4] suggested the change in the mode of eutectic nucleation – from that occurring near the a-Al dendrites in the Sr-free alloy, to that taking place within the eutectic liquid itself in the Sr-containing alloy. The mode in operation controls the distribution of the remaining liquid in the last stages of solidification when feeding becomes extremely difficult. This distribution, in turn, will define the connectivity of the feeding channels, and thus determine the resultant porosity profile in the solidified casting.

The aim of the present study is to understand the changes in the microstructure due to 0.004 wt. Sr addition to AC4B alloy produced by LPDC process. Fluidity of the molten metal and the resulting porosity was observed. Effect of injection temperature was also studied.

II. EXPERIMENTAL METHOD

An Sr-containing alloy was cast by using commercial AC4B as the base alloy and the resulting nominal composition is presented in Table 1. The charge materials consist of 70 % of ingot and 30 % of return scrap. These alloys were melted in an industrial furnace and gas bubble floatation process by using argon was performed for 8 minutes to remove trapped air from the molten metal. Master alloy Al-10Sr was added into the molten metal just before injection with the amount of 0.004 wt. % Sr. Injection temperatures were varied 680, 700 and 720 ^{o}C, and molten metal was injected into metal mould with resin-coated sand cores possessing the shape of cylinder head, therefore, it is expected that heat transfer in different position within the mould will be different. Hardness of the LPDC products was measured by using Rockwell B method with 1/16 inch diameter of indenter at 150 kg of load. Measurement was conducted around the studbolt region with 7 identation.

Fluidity test was conducted by using spiral mould with gravity method, in which molten metal was poured into the spiral mould, and the length of spiral was measured by using measuring tape. Microstructures at the tip of the spiral were observed to compare them with the LPDC structures.

Table 1. Nominal composition (wt. %) of alloys in this study

Alloy	Si	Cu	Mg	Fe	Mn	Sr	Al
Base	8.2	2.3	0.11	0.78	0.12	-	rem
Modified	8.9	2.6	0.13	0.88	0.13	0.004	rem

Tensile specimens were made by pouring molten metal into dog-bone-shaped metal mould in accordance with JIS Z2201, test piece no. 4. Hardness measurements were performed by Brinnel method at clamp area of the tensile specimens, by using steel ball indenter of 1/16 inch diameter. Seven indentations were taken for each hardness measurement.

Samples of each alloy were taken at three different positions of the cylinder head, representing area with high, medium dan low solidification rate, designated as area 1, 2, and 3, respectively. Samples were cut into 10 x 10 mm blocks for microstructural and microanalysis. Modification of microstructure was observed by means of a light microscope and LEO 420 SEM. Samples for microstructural analysis were prepared by etching with 0.5 % hydrogen fluoride.

III. RESULTS AND DISCUSSION

A. Effects of Sr on Fluidity and Porosity

Fluidity is an important factor in casting processes to reduce misrun. Results in Figure 1 show that at all injection temperatures, addition of 0.004 wt. % Sr increased fluidity of molten AC4B alloys. This is in correlation with previous studies that the role of Sr in solidification process is to decrease the eutectic temperature so that shorten the solidification range and resulting in higher fluidity [5]. Strontium is also known to reduce interfacial energy of molten aluminium that allows better fluidity [6]. As has been widely known, the higher the pouring temperature, the higher the fluidity of the molten metal. Another observation is that AC4B alloys containing Sr showed brighter silvery colour.

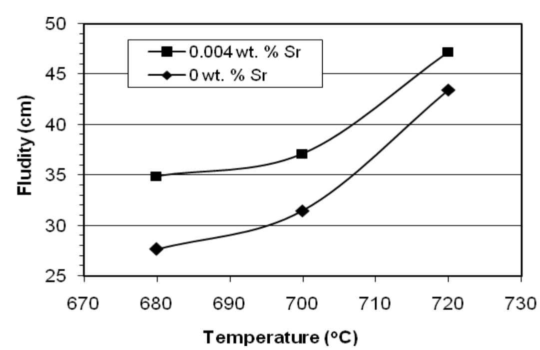

Figure 1. Effect of Sr addition and injection temperature on fluidity of AC4B alloys.

Figure 2 shows the intersection of vacuum porosity sample of the Sr-free and Sr-containing alloys. The presence of Sr seems to increase the amount of porosity. This has been shown by Amberg et al. [7] that modifier increase dissolution of hydrogen in molten metal, and decrease eutectic temperature that leads to longer period of solidification. The addition of 0.004 wt. % Sr increases porosity level from #5 to #7 in ASM standard. Figure 3 further confirms that the porosity increases in size and distribution by addition of Sr. This figure also shows that the porosity changes to transgranular and more rounded in the Sr-containing alloy.

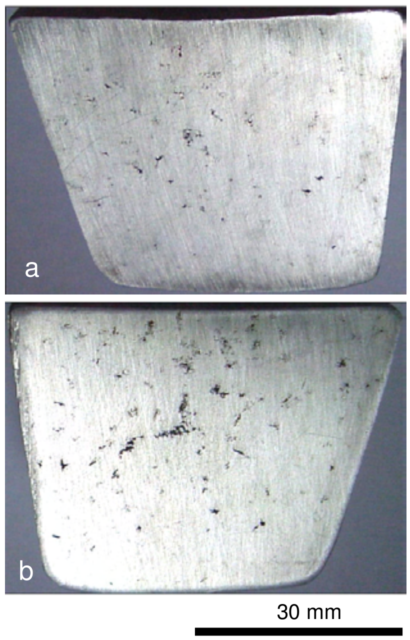

Figure 2. Porosity content in AC4B alloys with (a) 0 wt. %, and (b) 0.004 wt. % Sr.

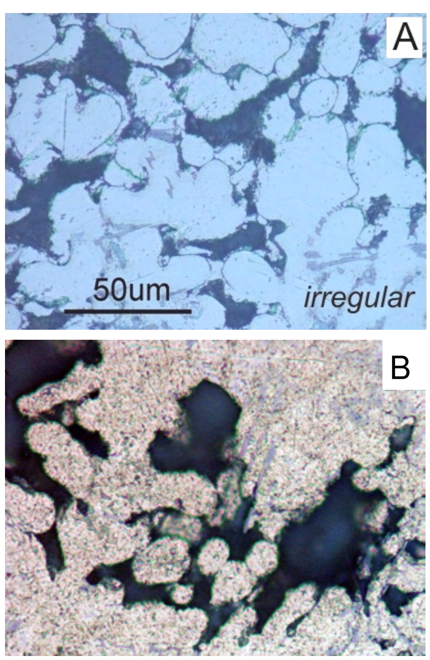

Figure 3. Morphology of porosity in (a) Sr-free, and (b) 0.004 wt. % Sr-containing AC4B alloys. Microstructures were taken from fluidity samples.

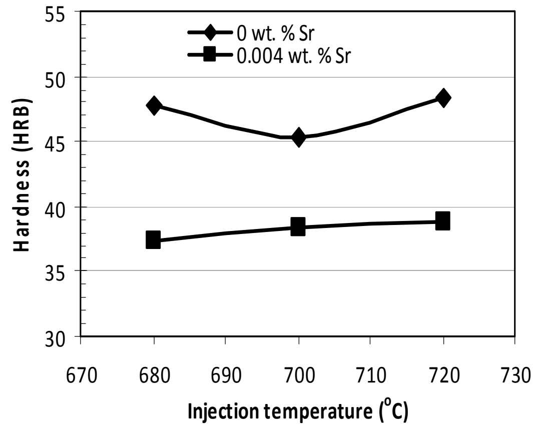

Figure 4. Effect of Sr content and injection temperature on the hardness of AC4B cylinder head.

B. Effects of Sr on Mechanical Properties and Microstructures

Figure 4 show the effect of 0.004 wt. % Sr addition on the hardness of AC4B alloys as LPDC products at different injection temperatures. It is clear that addition of Sr decreases the hardness for ~ 20 %, and there was no significant effect of injection temperature. This is in contrast with the tensile strength which shows slight increase for 0.8 % from 196.1 MPa to 197.8 MPa (Figure 5). This peculiarity was further observed by measuring the hardness at the clamp area of the tensile samples. The result is provided in Figure 6. The hardness shows an increase by addition of 0.004 wt. % Sr, in line with the tendency in tensile strength. Observation on microscopy on the LPDC products and the tensile samples showed that LPDC products possess more porosities than the tensile samples. Different mould materials may be the reason for the difference.

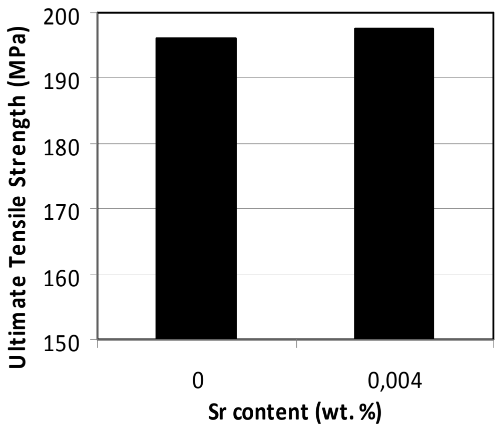

Figure 5. Effect of addition of 0.004 wt. % Sr on strength of AC4B alloy.

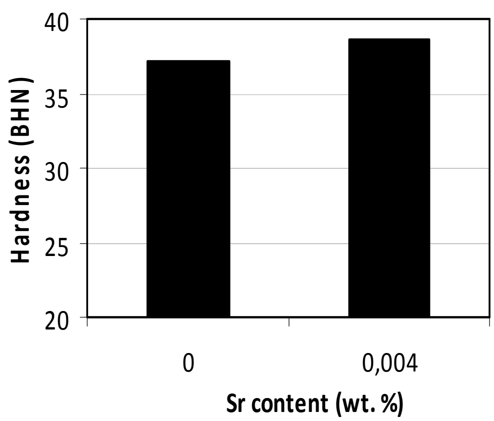

Figure 6. Hardness measured on tensile strength samples with different Sr content.

A series of microstructural analysis on the effect of Sr addition and injection temperatures is presented in Figure 7. These micrographs were taken from samples cast at 680 ^oC. In general, microstructure of AC4B alloys in as-cast condition consists of α-aluminium dendrites with interdendritic second phases. This is in correlation with the fact that solidification of hypoeutectic Al-Si starts with formation of α-aluminium dendrites, followed by eutectic reaction and formation of second phase particles, such as Mg_2Si and Al_2Cu. Aside from that, second phase particles containing Mn and Fe also form, such as Al_5FeSi (during slow solidification) and $Al_{15}(Mn,Fe)_3Si_2$ (during rapid solidification) [9]. As has been widely known, rate of solidification determines dendrite arm spacing (DAS), the higher the rate, the smaller the spacing, and this is confirmed in Figure 7.

Modification of microstructure by Sr can be clearly seen at position 3, which has the lowest solidification rate. Eutectic silicon structure was modified from coarse acicular into fine fibrous, similar to class C (modified) in accordance to ASM standard. At position 1, the microstructure is readily modified during high rate of solidification. Therefore, degree of further modification by Sr addition is not as apparent as that at positions 2 and 3. Quantitative measurement shows that modification also resulted in the decrease in DAS, which in turn increase the strength and hardness of the alloys. Observation revealed that varying injection temperature for 680, 700 and 720 ^oC did not affect the microstructure and level of modification of the alloys.

Detailed micrographs of AC4B alloys at position 1, which has the highest solidification rate, are presented in Figure 8. Identity of each phase was confirmed by EDXS analysis, tabulated in Table 2. Change of interdendritic structure due to modification is clearly revealed, in which the morphology of Al-Si eutectic transforms from acicular into fine fibrous structure. No alteration of morphology was detected in α-Al(Fe,Mn)Si phase (position 3 and 4). The small amount of Sr may be the reason for this. The pocket Al_2Cu structure was modified into massive blocks (position 1 and 2). This phase was initially well dispersed within the matrix, but upon addition of 0.004 wt. %, it tends to segregate at particular locations. This segregation may be caused by the lowering of eutectic temperature for $\pm$ 10 ^oC by addition of Sr, so that shorten remaining solidification time for Al_2Cu formation.

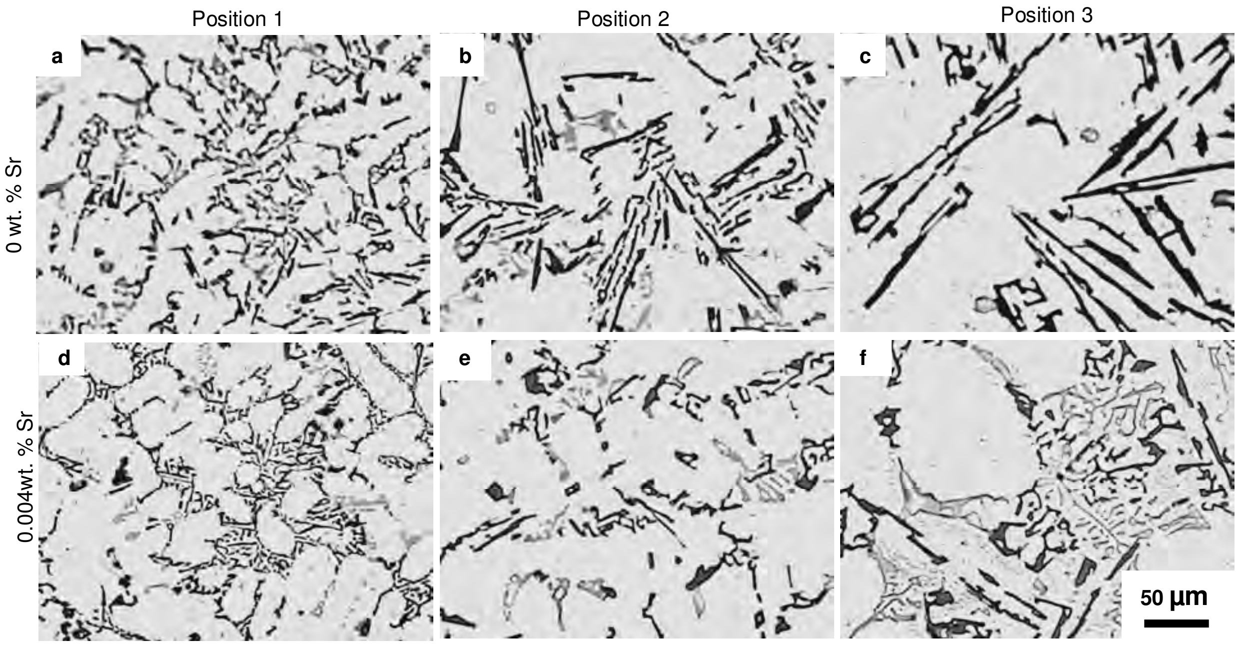

Figure 7. Effects of addition of (a-c) 0 wt. %, and (d-f) 0.004 wt. %, Sr on modification of AC4B alloys produced by LPDC process at 680 °C at different positions. Position 1, representing high solidification rate; position 2, representing medium solidification rate; and position 3, representing low solidification rate.

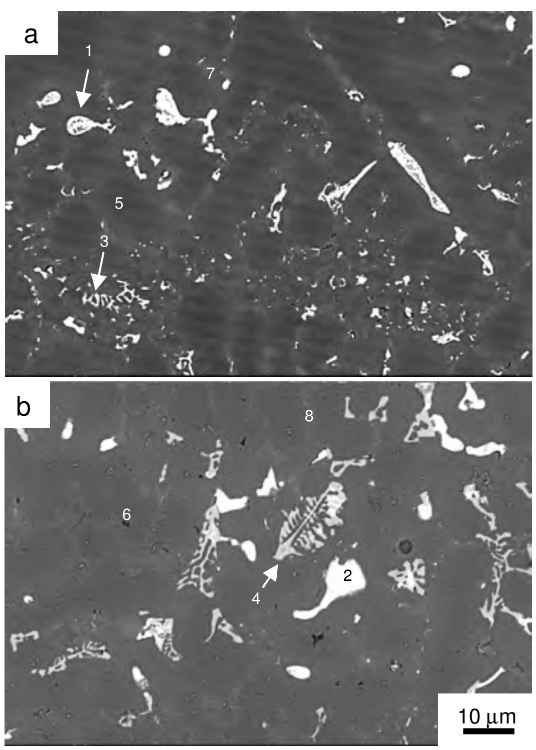

Figure 8. SEM micrographs of AC4B alloys added with (a) 0 wt. % Sr, and (b) 0.004 wt. % Sr, taken from position 1, which has the highest solidification rate.

Table 2. Microanalysis result on positions shown in Figure 8.

No	Element (wt. %)					Phase
	Al	Si	Cu	Fe	Mn	
1	81.60	5.73	12.67	-	-	Al_2Cu
2	84.55	2.41	13.04	-	-	Al_2Cu
3	57.00	6.50	0.62	32.40	3.48	Al(Fe,Mn)Si
4	61.00	6.29	0.57	30.19	1.94	Al(Fe,Mn)Si
5	7.91	92.09	-	-	-	Al-Si eutectic
6	29.97	70.03	-	-	-	Al-Si eutectic
7	98.32	1.68	-	-	-	Al matrix
8	98.59	1.41	-	-	-	Al matrix

CONCLUSIONS

1. Addition of 0.004 wt. % Sr to AC4B alloys processed by LPDC increases the porosity level from 5 to 7 (ASM scale), and reduces the hardness of LPDC products at all injection temperatures.
2. Addition of 0.004 wt. % Sr to AC4B alloys processed by gravity casting as tensile samples, increases tensile strength and hardness. Porosity in tensile samples was found less than in LPDC products.
3. Addition of 0.004 wt. % Sr increases fluidity of AC4B alloy. Increase in injection

temperatures also increases fluidity of the alloys.
4. Addition of 0.004 wt. % Sr modifies the silicon eutectic from acicular to finer fibrous in class C (modified).
5. Injection temperatures do not have significant impact to the microstructure and mechanical properties of the alloy.

ACKNOWLEDGMENTS

This research was partly funded by Ministry of National Education, the Republic of Indonesia through Hibah Bersaing XIII scheme.

REFERENCES

[1] W. LaOrchan, J.E. Gruzleski, “Grain Refinement, Modification and Melt Hydrogen – Their Effects on Microporosity, Shrinkage and Impact Properties in A356 Alloy”, *AFS Transaction*, Vol. 39, pp. 415-424, 1992.
[2] C.M. Dinnis, M.O.Otte, A.K.Dahle and J.A.Taylor, “The Influence of Strontium on Porosity Formation in Al-Si Alloys”, *Met. Mat. Trans. A*, Vol. 35A, pp. 3531-3541, November 2004.
[3] E.J.Martinez D., M.A. Cisneros G., S. Valtierra, and J. Lacaze, “Effect of strontium and cooling rate upon eutectic temperature of A319 alloy”, *Scripta Mat*., Vol. 52, pp. 439 – 443, 2005.
[4] A .K. Dahle, J. Hjelen and L. Arnberg, *Proc. 4th. Decennal Int. Conf. on Solidification Processing 1997*, University of Sheffield, UK, 1997, p. 527.
[5] P.R. Beeley, *Foundry Technology*, London, Butterworth, 1972.
[6] J.E. Gruzleski and B.M. Closset, *The Treatment of Liquid Aluminium-Silicon Alloys*, Illinois, AFS, 1999.
[7] L. Arnberg, L. Backerud, and G. Chai, *Solidification Characteristics of Aluminium Alloys: Vol. 3, Dendrite Coherency*, Sweden, AFS, 1990.
[8] J. Lozano, P. Asensio, and S. Beatriz, Effects of addition of refiners and/or modifiers on the microstructure of die cast Al-12Si alloys, *Scripta Mat*., Vol. 54, pp. 943-947, 2006.
[9] L. Bakerud, G. Chai, J. Tamminen, *Solidification Characteristics of Aluminium Alloys: Vol. 2, Foundry Alloys*, Stockholm, Skan Aluminium, 1990.