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Distribution of trace elements in a modified and grain refined aluminium–silicon hypoeutectic alloy

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ABSTRACT

The influence of modifier and grain refiner on the nucleation process of a commercial hypoeutectic Al–Si foundry alloy (A356) was investigated using optical microscopy, scanning electron microscopy (SEM) and electron probe microanalysis technique (EPMA). Filtering was used to improve the casting quality; however, it compromised the modification of silicon. Effect of filtering on strontium loss was also studied using the afore-mentioned techniques.

EPMA was used to trace the modifying and grain refining agents inside matrix and eutectic Si. This was to help understanding mechanisms of nucleation and modification in this alloy. Using EPMA, the negative interaction of Sr and Al3TiB was closely examined. In modified structure, it was found that the maximum point of Sr concentration was in line with peak of silicon; however, in case of just 0.1 wt% added Ti, the peak of Ti concentration was not in line with aluminium, (but it was close to Si peak). Furthermore, EPMA results showed that using filter during casting process lowered the strontium content, although produced a cleaner melt.

1. Introduction

Excellent castability, low shrinkage, low coefficient of thermal expansion, low melting point, low specific gravity and good corrosion resistance are specifications which have made Al–Si alloys significantly popular and mostly used in foundries (Tenekedjiev and Gruzleski, 1990). It is well-known that strontium modifies the eutectic silicon (Hellawell, 1970) and TiB_2 refines primary aluminium (α-Al) in aluminium alloys (Johnsson and Bächerud, 1992). Simultaneous grain refinement of α-Al and modification of eutectic silicon can limit both modification and refinement (Liao and Sun, 2003).

In order to understand the effect of modifiers on the morphology of eutectic silicon, numerous studies have been carried out. Thall and Chalmers (1949) suggested that the modifier reduces the interfacial energy of the molten Al–Si/solid Si interface which was confirmed by Nakae and Kanamori (1997) by the sessile drop method. In addition, Davies and West (1963–1964) suggested that sodium absorbed onto the solid eutectic silicon/melt surface and thus retarded its growth, a result from poisoning of the growth sites of the eutectic silicon by the modifier. According to Thall and Chalmers (1949), aluminium was the 'leading' phase, but later the opposite was revealed (Flood and Hunt, 1981). Hamilton and Seidensticker (1960) introduced a mechanism for silicon growth by twinning known as the twin plane re-entrant edge (TPRE) mechanism later developed by Kobayashi et al. (1975) and Lu and Hellawell (1987).

Na has been traced in modified Si using EPMA and NanoSIMS (Simensen et al., 2007a,b). Clapham and Smith (1988) used atomic adsorption spectroscopy to demonstrate preferential segregation of Sr to the silicon phase in the Al–Si eutectic. This was confirmed by Nogita et al. (2006) by X-ray fluorescence, by Simensen et al. (2007a,b) using NanoSIMS and by Kim et al. (2004) using EPMA. Although adding Sr can improve the mechanical properties by modifying the eutectic morphology it can have an adverse effect by increasing the amount of porosity and inclusions. It is believed that due to high oxygen affinity of Sr it is almost impossible to prevent formation of inclusions. Liu et al. (2003) studied the nature of inclusions present in Sr-modified alloy, they even with a good degassing system could trace Al_2SrO_3 inside the castings which created more pores compared to unmodified alloys.

This work aimed to trace the α-Al grain refining and Si modifying agents inside the matrix and eutectic silicon. EPMA was used, to investigate quantitatively presence of Sr and Ti inside the silicon particle and aluminium phase, respectively, in untreated, modified, grain refined and simultaneously modified and grain refined A356 aluminium alloy. This was to help understanding of nucleation mechanism of α-Al and eutectic Si in the presence of grain

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Table 1
Statistical data collected using EPMA for samples A1 through A4 (from line scan of 60 μm for each sample) and B1 through B5 (from line scan of 80 μm for each sample). Data include average, standard deviation and maximum value for chemical composition of Si, Ti and Sr.

Samples	Si (wt%)			Ti (wt%)			Sr (wt%)		
	Average	STD	Max	Average	STD	Max	Average	STD	Max
A1	31.69	24.13	78.95	0.04	0.02	0.08			
A2	17.69	14.33	55.18	0.06	0.01	0.10			
A3	16.89	7.84	33.94	0.06	0.02	0.12	0.01	0.01	0.04
A4	16.68	9.20	36.69	0.07	0.03	0.17	0.01	0.01	0.02
B1	12.45	19.54	91.19	0.03	0.02	0.09			
B2	19.70	24.73	86.73	0.59	2.09	11.23			
B3	17.62	14.90	56.35	0.04	0.01	0.09	0.05	0.05	0.13
B4	20.35	15.20	70.20	0.04	0.02	0.11	2.11	1.97	4.92
B5	9.92	15.03	62.57	0.05	0.03	0.15	0.01	0.003	0.02

refiner and modifier. In addition, the effect of using filtration on the concentration of refining/modifying agents was investigated.

2. Experimental

The A356 aluminium alloy ingot used for casting was supplied by Eurocast, with composition of Al–7Si–0.4Mg–0.1Fe–0.1Ti (wt%). Refiner and modifier additions to the melts were made using aluminium foil wrapped Al–4.2Ti–1.5B (wt%) (Al–3Ti–B) grain refiner and pieces of Al–10Sr–1Ti–0.2B (wt%) as modifier supplied by KBM Master Alloys B.V. Treated and untreated samples were produced using a bar-shaped copper mould containing 6 tensile bar cavities (each with 15 mm in diameter, and 320 mm in height). Mould was preheated up to 200 °C each time. Prior to the addition and pouring, the alloys were stirred and skimmed of surface oxide. Then, they were poured into the mould at 730 ± 5 °C. The additions were made inside the melting crucible 15 min before pouring the melt into the mould. Additives were wrapped by an aluminium foil and plunged into the melt. Then, melt was stirred promoting a homogenous liquid. In the first round, four different conditions were studied: A1: no addition, A2: 0.002 wt% Ti (as Al–3Ti–B), A3: 0.02 wt% Sr + 0.002 wt% Ti and A4: 0.02 wt% Sr. The second set of casting samples were cast by pouring treated alloys inside a small copper mould (a cylinder of 35 mm in diameter and 30 mm in height). Mould was preheated up to 200 °C. The additions made prior to the pouring were as follows: B1: no addition, B2: 0.1 wt% Ti, B3: 0.02 wt% Sr + 0.1 wt% Ti, B4 and B5: 0.02 wt% Sr. B5 was cast by a melt treated with ultrasonic vibrations during solidification and poured into the above-mentioned cylindrical copper mould using a Foseco Kalpur filter placed above the mould. This ceramic foam filter (with a diameter of 50 mm and with an average pore size of 20 pores per inch (ppi)) was used to remove large oxide particles and other unwanted inclusions.

For first set of castings, samples were prepared from small cylinders cut off from the bottom of (first-filled) tensile bars. For second set, metallographic samples were cut from the middle parts of the casting samples. Metallographic characterization of samples was carried out by usual standard grinding and polishing.

The concentration of Si, Sr and Ti for each sample has been analysed using EPMA. The EPMA measurements have been performed on a JEOL JXA 8900R microprobe with a wavelength dispersive

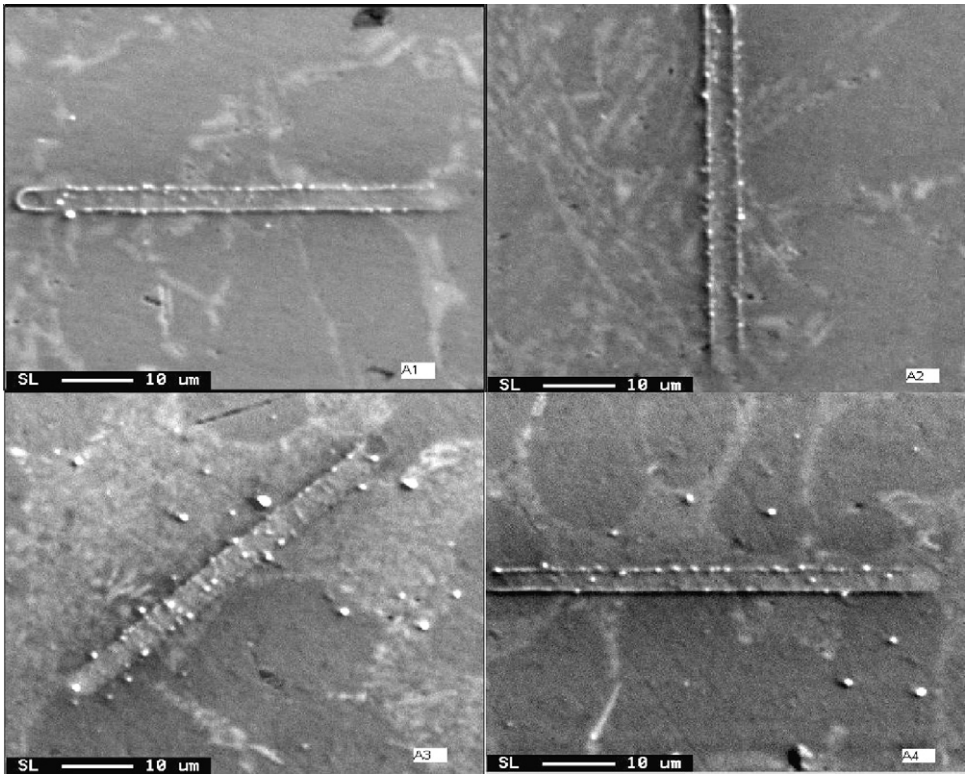

Fig. 1. Micrographs of A1, A2, A3 and A4 taken from the areas studied using EPMA.