Materials Science and Engineering, Volume 37/2. (2012), pp. 43–50.

EFFECTS OF STRONTIUM ON THE MICROSTRUCTURE OF AL-SI CASTING ALLOYS

ANETT KÓSA [1], ZOLTÁN GÁCSI [2], JENŐ DÚL [3]
[1, 2]University of Miskolc, Institute of Materials Science, 3515 Miskolc-Egyetemváros
[3]University of Miskolc, Department of Metallurgical and Foundry Engineering, 3515 Miskolc-Egyetemváros,
femanett@uni-miskolc.hu, femtangz@uni-miskolc.hu ,ontdul@uni-miskolc.hu

The modification effect of Sr addition on the microstructure of Al-Si casting alloys (AlSi9Cu1 and AlSi9Cu3Fe) was investigated. The modification of eutectic in Al-Si casting alloys is a generally accepted process used primarily to improve mechanical properties by promoting the refinement of the inherently coarse and plate-like eutectic silicon phase. Furthermore, the combined effect of Sr addition and cooling rate was also studied in this paper because the microstructure of the eutectic is significantly affected by the cooling rate. The following measurements were used in this research: optical microscopy, measurement of secondary dendrite arm spacing, computer image analysis, scanning electron microscopy and electron microprobe analysis.
Keywords: Al-Si alloys, strontium, eutectic modification, cooling rate.

Introduction

Al-Si alloys are an important class of aluminum die casting alloys having wide ranging applications especially in the automotive industry, but even in the aerospace industry. The application area of an alloy is specified by the physical and mechanical properties of the casting, which are influenced by the chemical composition and microstructure. The two major microstructural components of the hypoeutectic Al-Si casting alloys are the primary α-Al solid solution dendrites and the Al-Si eutectic, therefore the mechanical properties mostly depend on the properties of these structural constituents [1–4].

The eutectic silicon crystallizes into a coarse, plate-like morphology during the formation of the eutectic, which is mechanically disadvantageous for the casting, because sharp corners concentrate stress, which can cause fracture during the use of the casting. The most commonly used modifier element is strontium because even a few hundred ppm of Sr can result a very fine, fibrous structure, furthermore it has a longer decay time than sodium. Strontium as a modifier element is added to Al-Si casting alloys to change this morphology, which causes a well-refined fibrous structure of the eutectic Si, thereby improving the mechanical properties of the casting [3–8].

The fine, fibrous eutectic structure can be achieved in two ways: either by the addition of modifying elements, such as Na, Sr or Sb; or by increasing the cooling rate, but in this case complete modification cannot be produced, thus the addition of modifier elements are essential [3–6].

1. Method

AlSi9Cu1 and AlSi9Cu3Fe low Sr containing alloys were used in the experiments. The alloys were melted in an electric furnace at 750 °C, as in industrial practice. Different amounts of Sr were added to the Al-Si alloys (Table 1) in the form of AlSr10 master alloy. After strontium addition an incubation time of 10 min was allowed. The alloys were poured into a thin cylindrical steel cup with a diameter of 30 mm (thermal analysis) and into a pre-heated (to 200 °C) permanent mould of tensile test rods with a diameter of 16 mm. Therefore the effect of the cooling rate was also investigated. The contents of Sr in testing samples were analysed by Spark Optical Emission Spectrometer and are listed in Table 1.

Casting series	Alloy	Samples	Calculated Sr, ppm	Analysed Sr, ppm
1.	**AlSi9Cu1**	1/1	20	**11**
		1/2	50	**41**
		1/3	100	**115**
		1/4	150	**152**
2.	**AlSi9Cu3Fe**	2/1	20	**17**
		2/2	50	**45**
		2/3	100	**105**
		2/4	150	**171**
		2/5	200	**222**
		2/6	250	**326**

Table 1. Concentration of strontium in test samples

2. Results and discussion

2.1. Effects of strontium and cooling rate on the microstructure

Figure 1 shows the effect of cooling rate on the microstructure, which is made much finer by applying rapid cooling. Secondary dendrite arm spacing (SDAS) was measured to define the cooling conditions with computer image analysis developed by the Department of Physical Metallurgy.

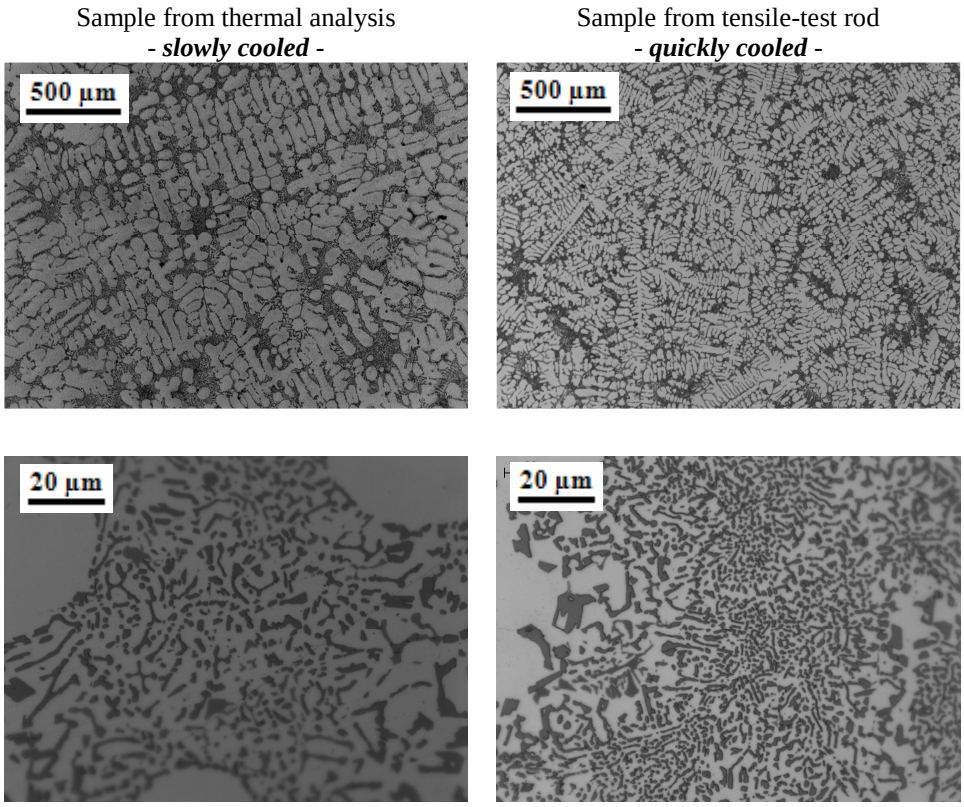


Figure 1. Effects of cooling rate on the microstructure of AlSi9Cu1 alloy containing 152 ppm Sr

The results (Table 2) show that there is an approximately two-fold difference between the SDAS of the samples from thermal analysis and from the tensile test rods, therefore this deviation works out to an eight-fold cooling rate difference by equation 1.

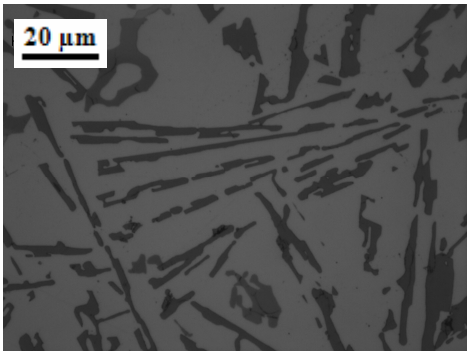
	SDAS, µm
Samples from thermal analysis (slowly cooled)	**47**
Samples from tensile test rods (quickly cooled)	**23**

Table 2. Average secondary dendrite arm spacing of the samples

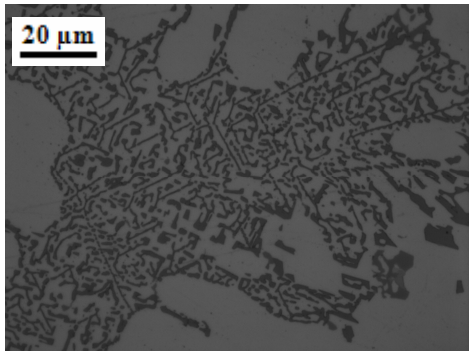
$$SDAS = konst\left(\frac{dT}{dt}\right)^{-\frac{1}{3}} \tag{1}$$

Samples from thermal analysis
- slowly cooled -

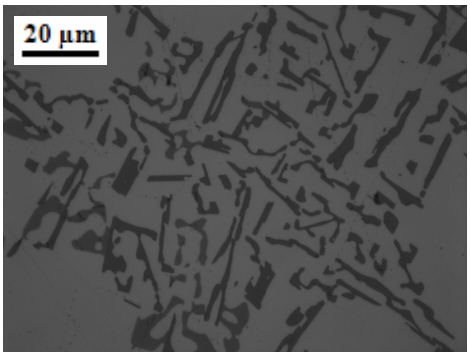
Samples from tensile-test rod
- quickly cooled -



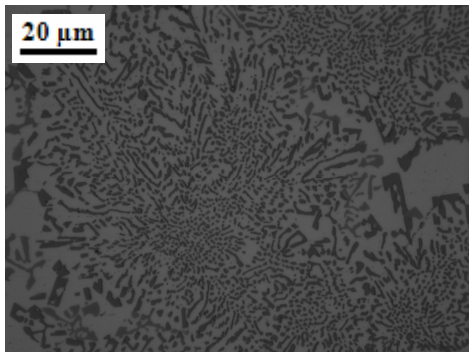
a) 2/1: **17 ppm Sr**



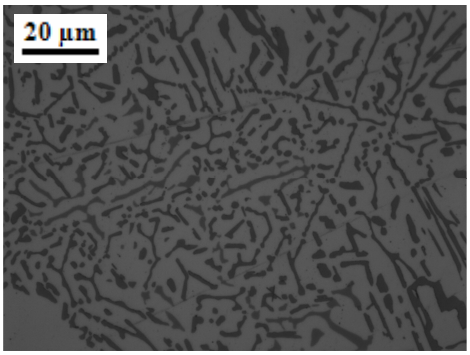
b) 2/1-SzP: **17 ppm Sr**



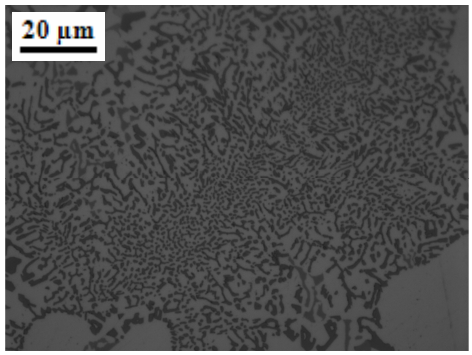
c) 2/2: **45 ppm Sr**



d) 2/2-SzP: **45 ppm Sr**



e) 2/3: **105 ppm Sr**



f) 2/3-SzP: **105 ppm Sr**

Figure 2. Effect of Sr on the eutectic microstructure of AlSi9Cu3Fe alloy

The micrographs of the quickly cooled samples (from the tensile test rods) and the slowly cooled samples (from the thermal analysis) of AlSi9Cu3Fe alloys are compared in Fig 2. In both cases the refinement of eutectic silicon induced by the strontium is clearly visible, and in the case of tensile test rods it can also be observed that the faster cooling rate results in an even finer eutectic microstructure at the same Sr level.

The microstructure of the additional samples was also examined, but significant differences in the extent of the modification cannot be observed in the samples containing more than 105 ppm Sr.

2.2. Quantitative metallographic characterization of eutectic Si particles by computer image analysis

The extent of the modification of the samples was quantified by three parameters – area, roundness and number of particles – which were measured with Leica computer image analysis. Figure 3 shows the change in these parameters depending on the strontium content. Solid lines show the change in the value of the slowly cooled samples from the thermal analysis and dashed lines show the quickly cooled samples from the tensile test rods.

It can be clearly seen that the average value of area (Figure 3a) and roundness (Figure 3b) of Si particles decreases, while the number of Si particles (Figure 3c) increases with increasing strontium content, so the eutectic becomes finer. Furthermore, it was observed that the modification effect is significant even at very low Sr content, and then it stabilizes at a specific value.

Due to the differences between the cooling conditions (thermal analysis and tensile test rods) the curves of the average area and number of Si particles are well separated from each other. The modification effect is more intensive for the quickly cooled samples. The deviation of the cooling conditions does not cause such large differences in the values of the roundness. The curves of the slowly cooled samples show that there is no change in the values of the average area of the Si particles above ~100 ppm Sr, where the area of the Si particles stabilizes at ~10 μm^2, while the area of the Si particles stabilizes even at ~50 ppm Sr at the value of ~10 μm^2 for the quickly cooled samples. The value of the roundness stabilizes at ~2.5 for both Sr contents (50 and 100 ppm Sr).

The area of the Si particles decreases precipitously to ~50 ppm Sr content, which is made even steeper by the increase of the cooling rate, as can be seen from the shape of the curves. (Figure 3a)

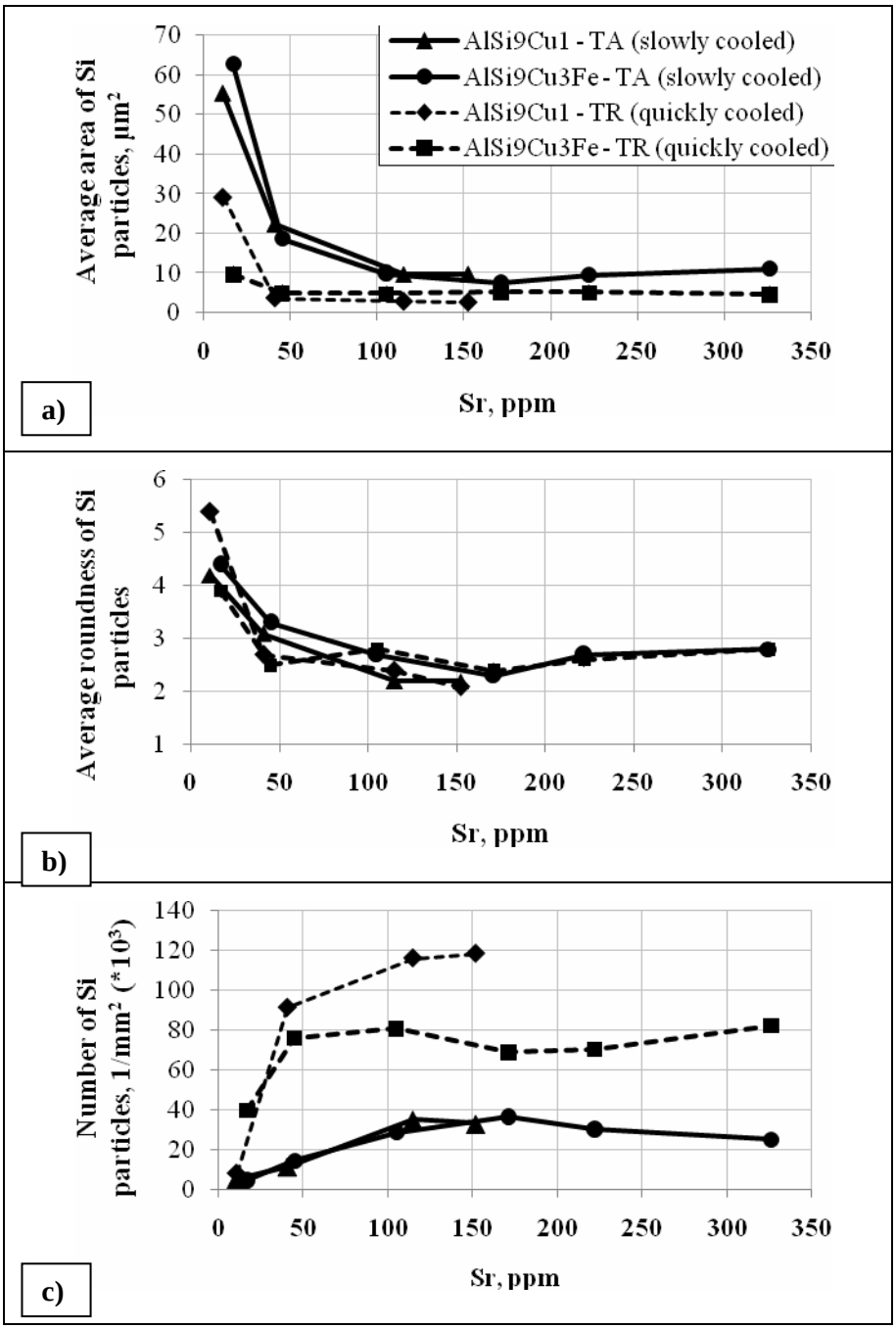
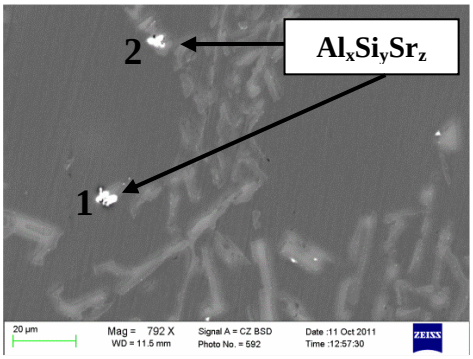


Figure 3. Effects of Sr on the parameters of the eutectic Si particles

2.3. Scanning electron microscopy and EDS analysis

A strontium-containing compound phase – probably $Al_xSi_ySr_z$ – was identified in sample 1/4 from AlSi9Cu1 alloy containing 152 ppm Sr (Figure 4), which is significant, because Sr bounded in compound does not expound the modification effect on the eutectic silicon. [9, 10] Oxygen was also measured in the sample, so the compound phase probably appeared in oxide form.



Element	Wt%		At%	
	1.	**2.**	**1.**	**2.**
Al	**36.3**	**53.06**	**41.17**	**57.29**
Si	**29.61**	**17.03**	**32.27**	**17.66**
Sr	**23.09**	**17.39**	**8.06**	**5.78**
O	8.23	7.94	15.73	14.46

Figure 4. SEM image of the $Al_xSi_ySr_z$ IMC phases and their chemical composition

The sample containing 326 ppm Sr from AlSi9Cu3Fe alloy was also observed by SEM, but the strontium-containing compound could not be identified despite the higher concentration of Sr. The reason is that the AlSi9Cu3Fe alloy contains much more impurity elements, such as lead, which also appear white on the SEM images, so this makes it difficult to find the Sr-containing compound phases.

Conclusions

AlSi9Cu1 and AlSi9Cu3Fe casting alloys with different amounts of strontium addition were examined in this study. The combined effects of strontium and cooling rate were also investigated. The following conclusions can be drawn from the experimental results:

1. The increase of the cooling rate has a significant effect on the eutectic microstructure; the quicker the cooling, the finer the eutectic at the same strontium concentrations.

2. The modification effect of Sr is very intensive up to a certain value then stabilizes after reaching it. This value is 100 ppm in the case of the slowly cooled samples (from the thermal analysis), while it is 50 ppm for the quickly cooled samples (from the tensile test rod). Above these values further strontium addition does not cause further refinement of the Al-Si eutectic.

3. An $Al_xSi_ySr_z$ intermetallic compound phase was detected in the microstructure of the test sample containing 152 ppm Sr. The amount of strontium bounded in this compound is unable to participate in the modification process.

Acknowledgement

This research was carried out as part of the TÁMOP-4.2.1.B-10/2/KONV-2010-0001 project in the framework of the New Hungarian Development Plan. The realization of this project is supported by the European Union, co-financed by the European Social Fund.

References

[1] Warmuzek, M.: Aluminum-Silicon Casting Alloys; Atlas of Microfractographs, ASM International, 2004.

[2] Kaufman, J. G.; Rooy, E. L.: Aluminum Alloy Castings; Properties, Processes, and Applications; ASM International, 2004.

[3] Dahle, A. K.; Nogita, K.; McDonald, S. D.; Dinnis C.; Lu L.: Eutectic modification and microstructure development in Al-Si Alloys, Materials Science and Engineering A 413-414, (2005), p. 243-248.

[4] Chen, X.; Geng, H.; Li, Y.: Study on the eutectic modification level of Al–7Si Alloy by computer aided recognition of thermal analysis cooling curves, Materials Science and Engineering A 419, (2006), p. 283-289.

[5] Shin, S-S.; Kim, E-S.; Yeom, G-Y; Lee, J-C.: Modification effect of Sr on the microstructures and mechanical properties of Al-10.5Si-2.0Cu recycled alloy for die casting, Materials Science and Engineering A 532, (2012), p. 151-157.

[6] Sun, Y.; Pang, S-P.; Liu, X-R.; Yang Z-R., Sun G-X.: Nucleation and growth of eutectic cell in hypoeutectic Al-Si alloys, Transactions of Nonferrous Metals Society of China 21, (2011), p. 2186-2191.

[7] Liu, L.; Samuel, A. M.; Samuel, F. H.; Doty, H. W.; Valtierra, S.: Characteristics of α-dendritic and eutectic structures in Sr-treated Al-Si casting alloys, Journal of Materials Science 39**,** (2004), p 215–224.

[8] Zafir, M.; Mckay, B.; Schumacher, P.: Study of Heterogeneous Nucleation of Eutectic Si in High-Purity Al-Si Alloys with Sr Addition, Metallurgical and Materials Transactions, (2011), p. 1684-1688.

[9] Gergely, G.; Gácsi, Z.: Characterization of the morphology of Si in the modified Al-Si alloys, Materials Science Forum, Vol. 649 (2010), p. 177-182.

[10] Garay-Tapia, A. M.; Romero, A. H.; Trapaga, G.; Arróyave, R.: First-principles investigation of the Al-Si-Sr ternary system: Ground state determination and mechanical properties, Intermetallics 21, (2012), p. 31-44.