EFFICIENCY of Sr MODIFICATION in HYPEREUTECTIC Al-Si ALLOYS

Muhammet ULUDAĞ[1], Lokman GEMİ[2], Derya DIŞPINAR[3]

[1]*Selcuk University, Faculty of Engineering–Metallurgical and Materials Eng. Dept., Konya-Turkey, dr.uludagm@gmail.com*

[2] *NecmettinErbakan University, Seydisehir Technical Science College, Konya-Turkey, lgemi@konya.edu.tr*

[3] *Istanbul University, Faculty of Engineering, Metallurgical and Materials Eng. Dept., Istanbul-Turkey, deryad@istanbul.edu.tr*

ABSTRACT :*Melt treatment of aluminum alloys are typically carried out in transfer furnaces prior to casting. Depending on the size of the crucible and the volume of the castings, the melt may be led to remain in the liquid state up to two hours. It is well known that as the holding period is increased, the effect of modifiers fade away. In this work, the mechanism of this fading effect has been investigated for the first time by means of melt cleanliness. Reduced pressure test was used to measure bifilm index of the melt. Al-19Si was used and two temperatures were selected: 725^{o}C and 800^{o}C. Hydrogen content of the melt was measured by AlSPEK and excess amount of Al-15Sr modifier was added once the desired temperature was reached. Samples were collected every 20 minutes up to two hours and the microstructural results (i.e. efficiency of modification) was correlated with bifilm index (melt quality).*

KEYWORDS -*Hypereutectic Al-Si alloy, Modification, Morphology of Si, Hydrogen content, Bifilm index*

I. INTRODUCTION

Hypoeutectic Al-Si alloys are typically used in applications where high wear resistance is required. In addition, these alloys exhibit good corrosion resistance (Matsuura, Kudoh et al. 2003, Xu and Jiang 2006). The microstructure of such alloys consists of nucleation of primary Si, followed by the eutectic (α-Al dendrites and secondary Si) phase formation. The size, shape and distribution of primary Si plays a significant role on the mechanical properties (Li, Xia et al. 2013).

The primary Si usually had coarse pentagonal shape compare to the Si in hypereutectic Al-Si alloys. This geometry gives a huge advantage for improved wear resistance and thus these alloys can be found in pistons and etc (Chien, Lee et al. 2002). However, although high wear resistance is obtained by primary Si, the ductility is significantly reduced (Shi, Gao et al. 2010). Therefore, there are several studies in literature on the modification of Si (Zhao, Zhao et al. 2014).

The methods to modify primary Si can be listed as addition of alloying elements, heat treatment, ultrasonic vibration and rapid cooling (Ward, Atkinson et al. 1996, Shi, Gao et al. 2010, Hu, Jiang et al. 2012, Zhao, Zhao et al. 2014). Modification of primary Si also results in modification of the remaining eutectic.

Many of the modification studied earlier have been found to be unstable and non-environmental friendly. The loss of additives, burning and pollution made phosphorus not a good choice of modifier (Shi, Gao et al. 2010, Hu, Jiang et al. 2012, Zhao, Zhao et al. 2014). Therefore, Sr has been studied in the last decade as the primary Si modifier (Kang, Yoon et al. 2005).

In this work, the effect of pouring temperature, holding time, cooling rate and Sr modification on the morphology of primary Si have been investigated.

II. EXPERIMENTAL WORK

Primary Al-17Si alloy was used in the experiments which was provided form Eti Aluminum, Turkey. The chemical composition is given in Table 1. The charge was melted in 20 kg capacity resistance furnace. The castings were made at 725°C and 800°C in the following order: as melted, 1 hour and 2 hours later. In the final casting, at 800°C, Sr was added.

Table 1. Chemical composition of the alloy used in the experiments

Si	Fe	Cu	Mn	Mg	Zn	Ti	Ni	Al
17,0-19,0	0,60	0,80	0,20	0,80	0,20	0,10	0,80-1,3	rem

In order to investigate the effect of cooling rate, a step mould geometry was used (10, 15, 20 and 30 mm). A picture representing a casting has been given in Figure 1.

Figure 1. Top and side view of a cast part

Each thickness of the cast part was sectioned and subjected to metallographical examination. Image analysis was used to evaluate primary Si size, shape and dimension.

Reduced pressure test (RPT) samples were collected from each melt in order to check the melt quality by measuring bifilm index and the results were correlated with bifilm content.

III. RESULTS AND DISCUSSION

Figure 2 shows a selected microstructural representation of 30 mm thickness obtained from 725 °C, 800 °C and 800 °C+Sr additions. As seen in this figure, there are group of blocky primary Si phases grown in various directions. There is a quite homogeneous distribution of eutectic phase around the primary Si. As the section thickness was lowered from 30 to 20, 15 and 10 mm, the primary Si size was getting smaller and finer and evenly distributed along the sectioned surface. Furthermore, the eutectic phase was also getting finer and α-Al size was getting larger in terms of fraction of area. What was interesting was the ratio of primary Si getting lower around the α-Al dendritic structure. In general, it can be concluded that when the alloy is cast at 725°C, the primary Si size decreases with decreased section thickness and the shape becomes more smoother.

When the casting was carried out at 800°C, the microstructural evaluation was almost similar to the ones cast at 725°C. The main difference was the size of primary Si was slightly higher.

When Sr was added to the melt, it was observed that the size and ratio of primary Si was significantly reduced and the eutectic phase ratio was increased. More regular α-Al phase formation was observed and secondary Si was segregated along the microstructure.

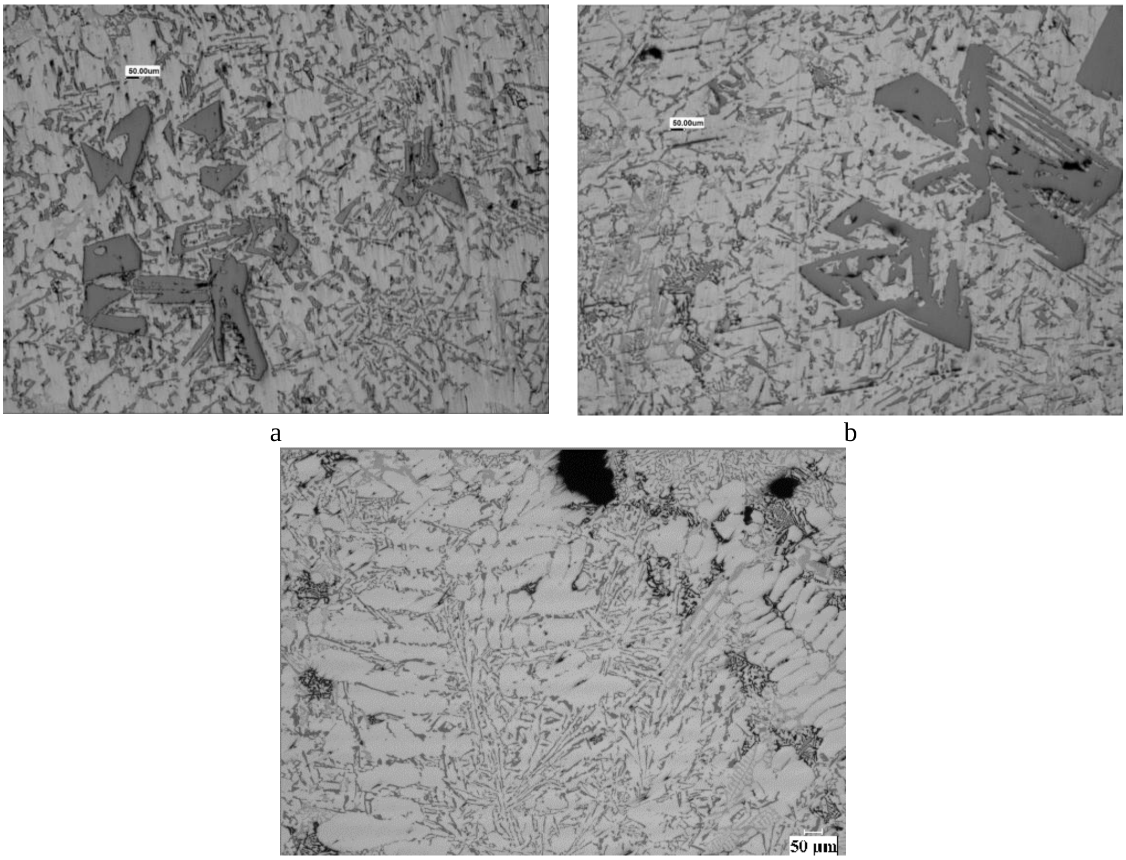


Figure 2. Microstructural change with casting parameters
a) 725 °C, b) 800 °C, c) 800 °C+Sr

Bifilm index measurement were made from RPT samples' cross section and the results are reported in Figure 3.

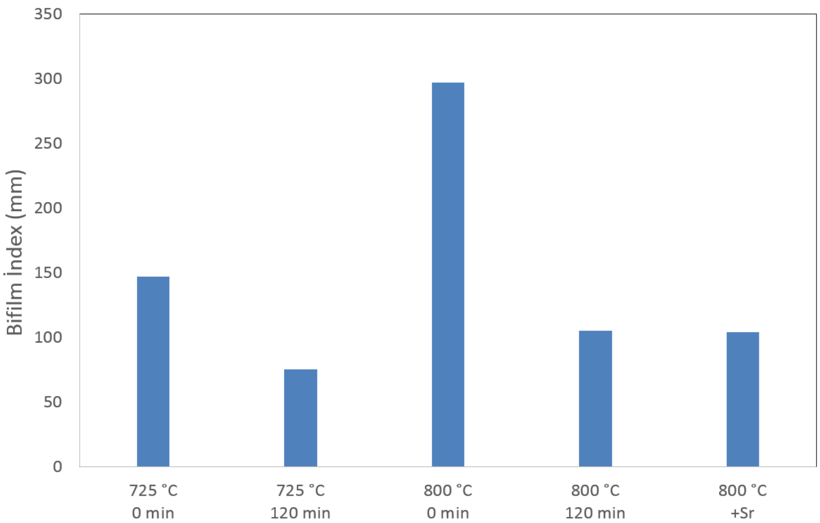
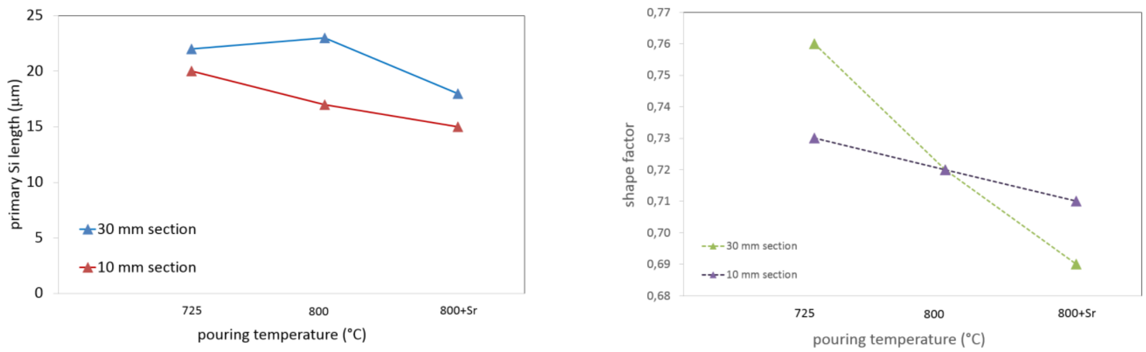


Figure 3. Bifilm index results of the casting experiments

One interesting observation in the melt quality measurements in Figure 3 was that was the melt was kept at the liquid state for 120 minutes, bifilm index was decreased almost three folds from 150 to 50 mm for 725°C, and

300 to 100 mm for 800°C castings. The change in the primary Si morphology was carried out by image analysis software and the results are given in Figures 4-7.

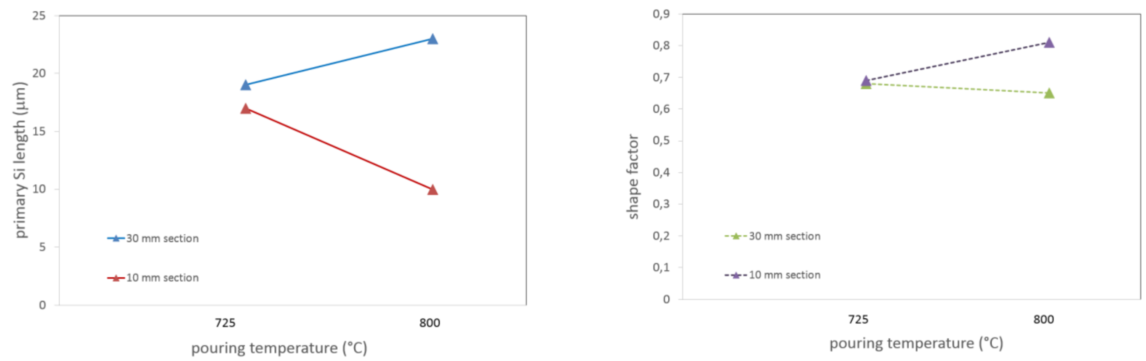
As seen in Figure 4, in the thinnest section of the mould (10 mm), the primary Si length was decreased from 10 to 15 μm when pouring temperature was increased from 725°C to 800°C. However, on 30 mm section, there is not much change in Si length. The significant change in primary Si was achieved by the addition Sr. On both cases, lowest primary Si length was obtained by Sr modification. Figure 4b shows the change in the shape factor of primary Si. Shape factor is given by the ratio of square of perimeter and area. Thus, 1 indicates a perfect sphere and 0 indicates a line. The more the shape factor is closer to zero, the more the complex the shape of the measured phase. Here, it can be seen that as the pouring temperature was increased, the more the complex primary Si was. This was more clear when the alloy was Sr modified.



a b

Figure 4. Pouring temperature vs (a) primary Si length and (b) shape factor at 0 min

The same parameters were used to plot the change of primary Si and shape factor with changing pouring temperature, but this time, the melts were kept at pouring temperature for 120 minutes; and the results are given in Figure 5. As seen in Fig 5a, the change of primary Si length with increasing pouring temperature from 725^{0}C to 800^{0}C is more significant when the melt was held for 120 minutes. In Fig 4a, this change was quite low. However, in Fig 5a, the length of primary Si is increased from 18 to 23 μm for 30 mm section thickness and it decreased from 16 to 9 μm at 10 mm section. On the other hand, the shape factor remained unchanged at 30 mm section when the pouring temperature increased to 800°C. Furthermore, it was increased at 10 mm section.

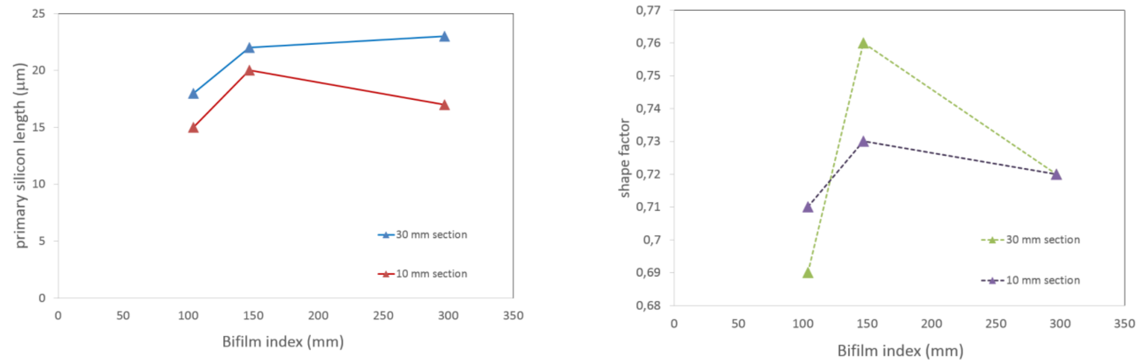


a b

Figure 5. Pouring temperature vs (a) primary Si length and (b) shape factor after 120 min

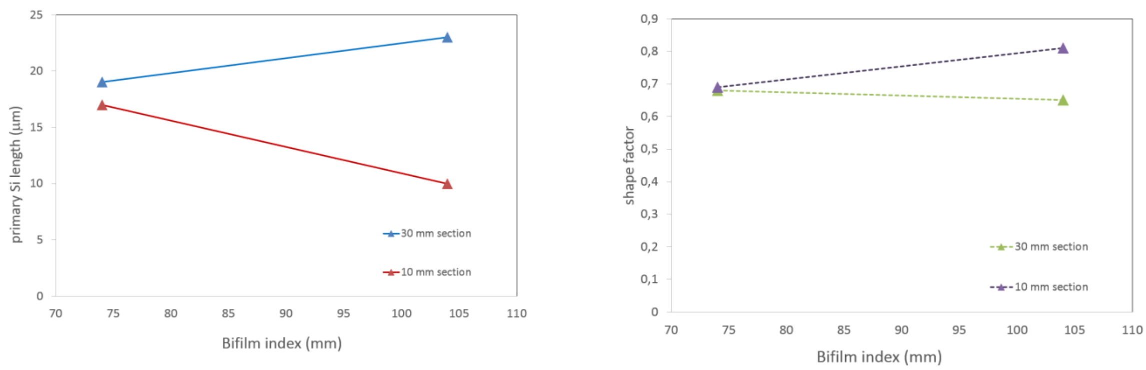
These findings indicate that when the casting of hypoeutectic Al-Si alloys are carried out at low temperatures such as 725°C, the shape and size and distribution of primary Si and secondary eutectic phase is not effect by the cooling rate. As seen in Figure 4 and 5, all the findings of 725°C casting lies almost on top of each other. However, when the pouring temperature is increased to 800°C, the effect of cooling rate, i.e. section thickness, was more dominant. At sections that were thicker than 30 mm, the size and shape of primary Si was increased and at 10 mm sections, these values were decreased significantly.

The change of primary Si size and shape factor with bifilm index after 0 and 120 minutes of holding was given in Figure 6 and 7 respectively.



a b

Figure 6. Bifilm index and (a) primary Si size and (b) shape factor relationship, cast after 0 min of holding



a b

Figure 7. Bifilm index and (a) primary Si size and (b) shape factor relationship, cast after 120 min of holding

Bifilm are folded oxide skin defects that are introduced into the melt by turbulence. Therefore, they can act as nucleation sites for many of the defects as well as intermetallic phases. Here, in this work, such effect of bifilms can be clearly seen. As the bifilm index is increased, coarser primary Si phase is formed. On the other hand, when the cooling rate is increased (from 30 mm section thickness to 10 mm), the diffusion rate decreases and primary Si cannot find the time to nucleate on bifilms, and freeze on their own to form more finer and homogeneously distributed primary and secondary eutectic phases.

IV. CONCLUSIONS

Pouring temperature affects the primary Si morphology only when the section thickness is smaller than 30 mm.

As the pouring temperature is increased, coarser primary Si can be obtained. As the cooling rate is increased, finer primary Si can be produced.

By Sr modification of hypoeutectic Al-Si alloys, both primary and secondary Si size decreases and more ordered, regular growth can be achieved.

As the melt was held for longer times in the liquid state, bifilm index was decreased. There was not much clear correlation between bifilm index and morphology of primary Si.

REFERENCES

[1.] Chien, C. W., S. L. Lee, J. C. Lin and M. T. Jahn (2002). "Effects of Sip size and volume fraction on properties of Al/Sip composites." *Materials Letters***52**(4–5): 334-341.

[2.] Hu, X., F. Jiang, F. Ai and H. Yan (2012). "Effects of rare earth Er additions on microstructure development and mechanical properties of die-cast ADC12 aluminum alloy." *Journal of Alloys and Compounds***538**(0): 21-27.

[3.] Kang, H. S., W. Y. Yoon, K. H. Kim, M. H. Kim and Y. P. Yoon (2005). "Microstructure selections in the undercooled hypereutectic Al–Si alloys." *Materials Science and Engineering: A***404**(1–2): 117-123.

[4.] Li, Q., T. Xia, Y. Lan, W. Zhao, L. Fan and P. Li (2013). "Effect of rare earth cerium addition on the microstructure and tensile properties of hypereutectic Al–20%Si alloy." *Journal of Alloys and Compounds* **562**(0): 25-32.

[5.] Matsuura, K., M. Kudoh, H. Kinoshita and H. Takahashi (2003). "Precipitation of Si particles in a super-rapidly solidified Al–Si hypereutectic alloy." *Materials Chemistry and Physics***81**(2–3): 393-395.

[6.] Shi, W. X., B. Gao, G. F. Tu and S. W. Li (2010). "Effect of Nd on microstructure and wear resistance of hypereutectic Al–20%Si alloy." *Journal of Alloys and Compounds***508**(2): 480-485.

[7.] Ward, P. J., H. V. Atkinson, P. R. G. Anderson, L. G. Elias, B. Garcia, L. Kahlen and J. M. Rodriguez-ibabe (1996). "Semi-solid processing of novel MMCs based on hypereutectic aluminium-silicon alloys." *Acta Materialia***44**(5): 1717-1727.

[8.] Xu, C. L. and Q. C. Jiang (2006). "Morphologies of primary silicon in hypereutectic Al–Si alloys with melt overheating temperature and cooling rate." *Materials Science and Engineering A***437**: 451-455.

[9.] Zhao, L. Z., M. J. Zhao, L. J. Song and J. Mazumder (2014). "Ultra-fine Al–Si hypereutectic alloy fabricated by direct metal deposition." *Materials & Design***56**(0): 542-548.