Proceedings of the 9th International Conference on Aluminium Alloys (2004)
Edited by J.F. Nie, A.J. Morton and B.C. Muddle

Modification of Fe-containing Intermetallic Compounds in an Al-Si-Cu-Fe Cast Alloy Using Sr, Li and Mn Additions

P. Ashtari[1], H. Tezuka[2], T. Sato[2]

[1] Graduate student, Department of Metallurgy & Ceramics Science, Tokyo institute of Technology, 2-12-1 O-okayama, Meguro-ku, Tokyo 152-8552, Japan
[2] Department of Metallurgy & Ceramics Science, Tokyo institute of Technology, 2-12-1 O-okayama, Meguro-ku, Tokyo 152-8552, Japan

Keywords: Aluminum-silicon alloys, Sr, Li, Mn, Intermetallic compounds, Modification.

Abstract

The influence of Sr, Mn, Sr/Mn and Sr/Li combined additions on the Fe-containing intermetallic compounds in an Al-Si-Cu-Fe cast alloy has been investigated. The results show that Sr and Sr/Mn combined additions successfully modify the branched β platelet phase (β: Al_5FeSi) into Chinese script or spherical morphologies, however, Sr/Li combined addition partly modifies the β platelets and Mn addition causes various intermetallic compound morphologies to form. Thermal analysis results show that the temperatures of the liquidus, intermatallic compound crystallization and eutectic reaction are influenced by the above additions.

1. Introduction

Aluminum-Silicon cast alloys usually contain impurities such as Fe that form high melting point and hard intermetallics with different morphologies including platelet (β), Chinese script (α) and polyhedral (sludge). The platelet Fe containing phase is the most harmful one for the mechanical properties. Mn is widely used as an alloying addition to neutralize the effect of iron and modify the platelet β-phase to less harmful morphologies. However, Mn is not always the best solution because in order to obtain the crystallization of the α-phase and to avoid the other morphologies, a certain critical ratio of Fe:Mn is required. This ratio depends on the cooling rate [1] and improper control of Mn may result in sludge formation which has a detrimental effect on the mechanical properties of the alloys. The goal of this study is to find effective elements to modify the β-phase. Some limited work has been done on this subject. Sigworth [2] reported that the formation of Fe containing brittle phases were retarded in the Sr modified 319 aluminum alloy. Paray et al. [3] demonstrated that Sr addition to the wrought 6061 aluminum alloy causes the α–phase to be the dominant intermetallic phase during the solidification of the billets. The influence of Sr, Mn, Li, and Sr/Mn combined additions with a high Fe amount (1wt%Fe) had been studied in the previous works [4,5]. In the present study, the effect of Sr, Mn, Sr/Mn and Sr/Li additions with a lower Fe amount (0.5%Fe) has been studied.

2. Experimental Procedure

Chemical compositions of the alloys used in this study are shown in Table 1. In order to obtain different cooling rates the alloys were cast into cast iron and graphite molds where the alloys were solidified at average cooling rates of 4.2 and 1.4 °C/s respectively. The microstructures of the alloys were studied by an optical microscope and SEM. An image analysis method was utilized to measure the volume fraction and number density of the intermetallic compounds. Differential thermal analysis (DTA) was performed to reveal the influence of the additions of several elements on the solidification phenomena.

Table 1: Chemical composition of the alloys (wt%).

Alloy	Si	Cu	Fe	Sr	Mn	Li	Al
No addition	7.32	3.48	0.57	0.000	0.00	-	Bal.
Sr	7.34	3.46	0.56	0.014	0.00	-	Bal.
Mn	7.13	3.39	0.54	0.000	0.32	-	Bal.
Sr/Mn	7.13	3.40	0.54	0.013	0.31	-	Bal.
Sr/Li	7.00*	3.50*	0.50*	0.015*	0.00*	0.12*	Bal.

*Nominal value.

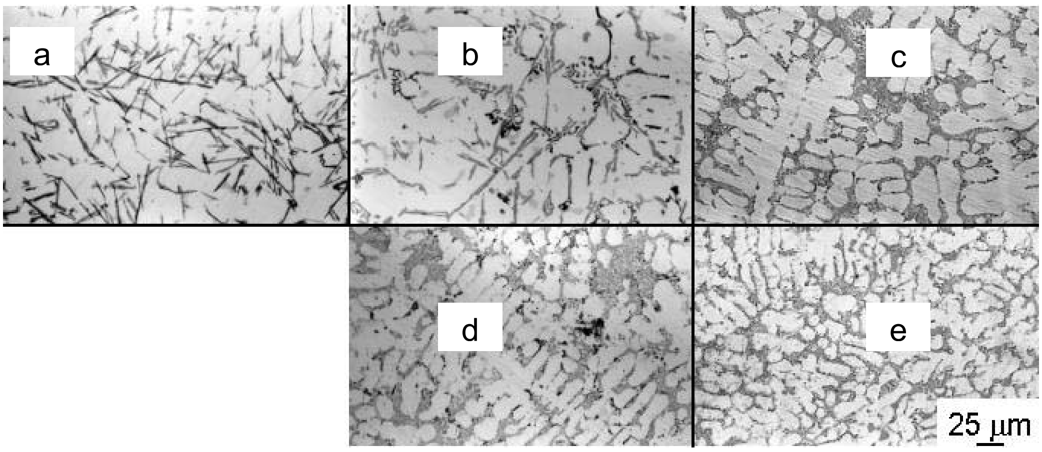

Figure 1: Microstructures of iron mold cast alloys for (a) no-addition, (b) Mn added, (c) Sr added, (d) Sr/Mn added and (e) Sr/Li added.

3. Results and Discussion

The microstructures of the alloys cast into an iron mold, as shown in Figure 1, indicate that the non-added alloy contains intermetallics in the form of the β–platelet phase. The Sr, Sr/Mn and Sr/Li added alloys contain a large number of fine particles and the β-phase almost disappears. The fine particles can clearly be seen in the SEM images (Figure 2), which shows that the Sr and Sr/Mn added alloys contain Chinese script and spherical type compounds (α-phase) and the Sr/Li alloy contains the α phase and some fine β particles. Figure 3 shows that the volume fraction of the β–phase decreases by the addition of various elements. The number density of the compounds is shown in Figure 4. It can be seen that the non-added alloy contains the β–phase, the Mn added alloy contains α, β and sludge type compounds, a large number of the α-phase is formed in the Sr added and Sr/Mn combined added alloys, and the Sr/Li combined added alloy contains α and β phases. Thus, Sr and Sr/Mn additions are very effective in modification of the platelet β intermetallic compound.

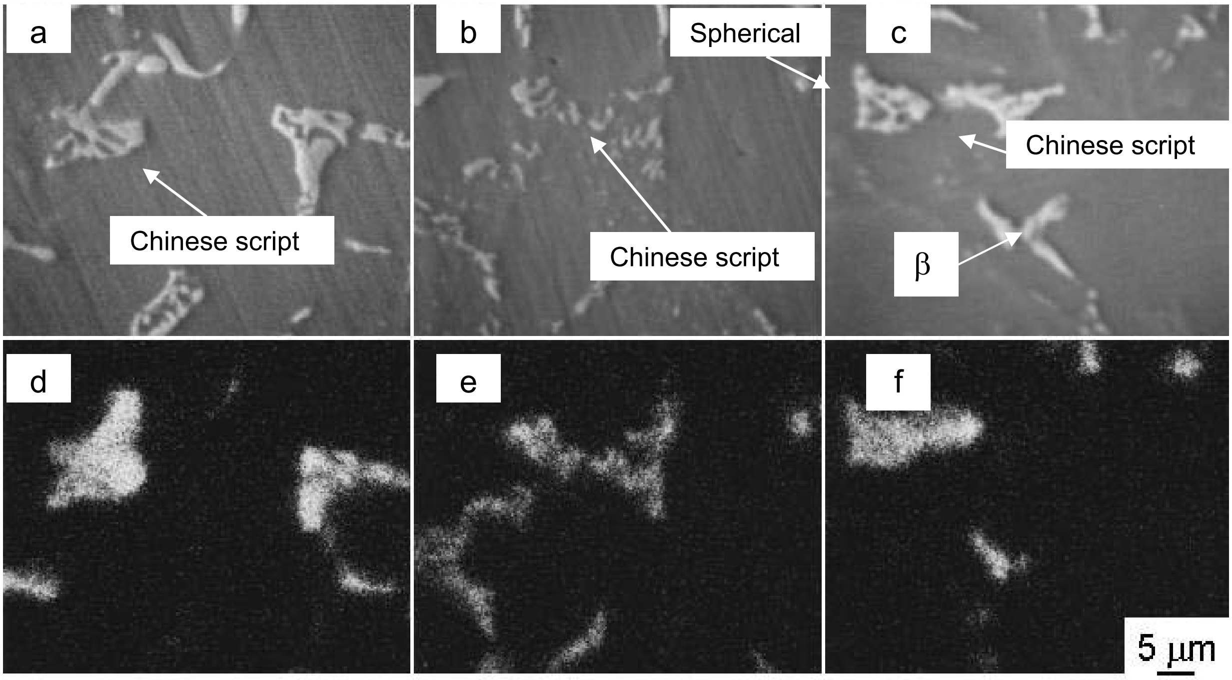

Figure 2: (a), (b) and (c): Back scattered electron images for Sr, Sr/Mn and Sr/Li added alloys respectively; (d), (e) and (f): X-ray mapping of Fe in the regions corresponding to the (a), (b) and (c) respectively.

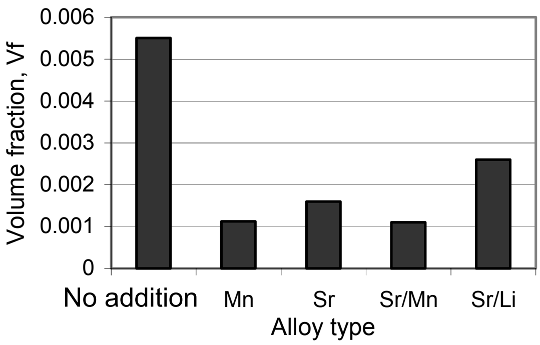

Figure 3: Effects of the additions on the volume fraction of the β–phase of iron mold cast alloys.

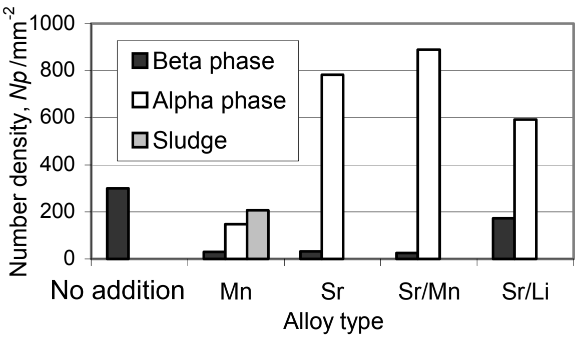

Figure 4: Effects of the additions on the number density of the intermetallics of iron mold cast alloys.

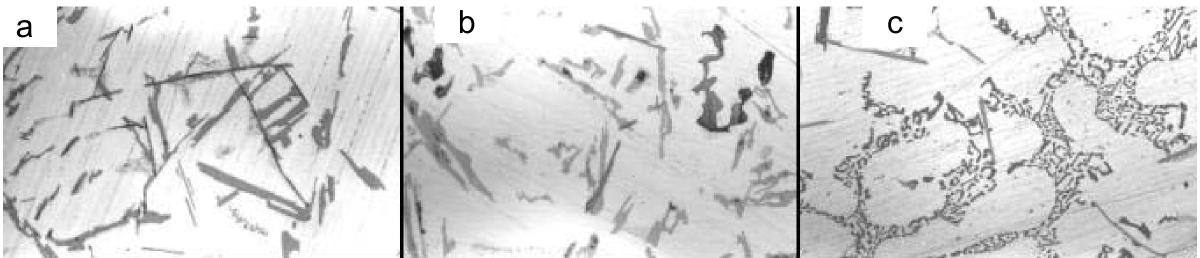

Figure 5: Microstructures of graphite mold cast alloys for (a) no-addition, (b) Mn added, (c) Sr added, (d) Sr/Mn added and (e) Sr/Li added.

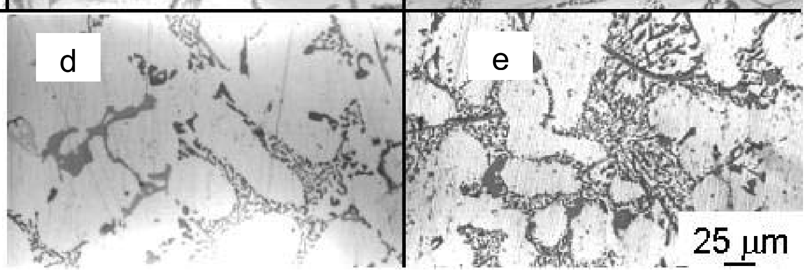

Figure 5 shows the microstructure of the alloys cast into a graphite mold. These microstructures are coarser than those of the alloys solidified at a higher cooling rate (compare Figs (5) and (1)). However the Si particles are modified by the addition of Sr, Sr/Mn and Sr/Li, the β-phase is not modified remarkably. A compound described as AlLiSi is also formed in the Sr/Li added alloy. The above trends can be clearly noticed in the image analysis results.

Figure 6 shows that the volume fraction of the β–phase only decreases in the Mn containing alloys, which is due to the formation of α and sludge type compounds, as shown in Figure 7. The above results indicate that the additions of the present elements are less effective when the cooling rate is low. Thus, the cooling rate is an important factor to control the size and morphology of the intermetallic compounds. It can be suggested that the modifier elements are rejected from the solid-liquid interface when the cooling rate is high. Therefore, during subsequent cooling and solidification, the liquid in front of the solid-liquid interface becomes enriched in the modifier element and as a result, effective modifier is increased. However the amount of modifier enrichment in front of the solid-liquid interface is lower when the cooling rate is low, because the rejected modifier has much more time to diffuse into the liquid.

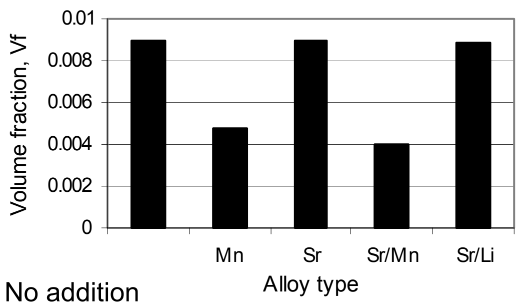

Figure 6: Effects of the additions on the volume fraction of the β-phase of graphite mold cast alloys.

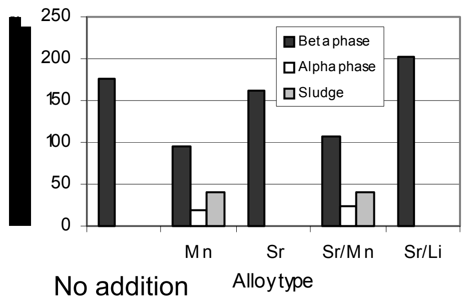

Figure 7: Effects of the additions on the number density of the intermetallics of graphite mold cast alloys.

The above morphological changes may be explained by a change in the phase diagram. The addition of the modifying elements may expand the α–phase region in the Al-Si-Fe phase diagram. The results of the thermal analysis are shown in Figure 8. The solidification sequence of the present alloy is the aluminum, β, ternary eutectic and Al_2Cu phases. It can be observed that all the additions increase the liquidus temperature and except the Mn addition, the other additions decrease the eutectic reaction temperature. The peak corresponding to the β-phase disappears by the addition of Mn and Sr/Mn. This can be attributed to an increase in the α–phase region in such a way that the amount of the β–phase is decreased and thereby the β-phase can not create a peak.

The α–phase crystallizes shortly after the aluminum primary phase and constrains to interdendritic areas leading to Chinese script morphology. Expansion of the α–phase region by the addition of Mn is shown by Backerud et al. [6] The Sr and Sr/Li additions increase the β–phase crystallization temperature. As mentioned above, the Sr and Sr/Li additions are less effective when the cooling rate is low. Consequently, during the DTA test, performed at 0.08 °C/s, the β–phase is formed. When the cooling rate is high, it can be suggested that the Sr and Sr/Li additions may expand the α–phase region, in such a way that the Sr added alloy only contains the α-phase and the Sr/Li added alloy contains both of the α and β phases (see Figure 4).

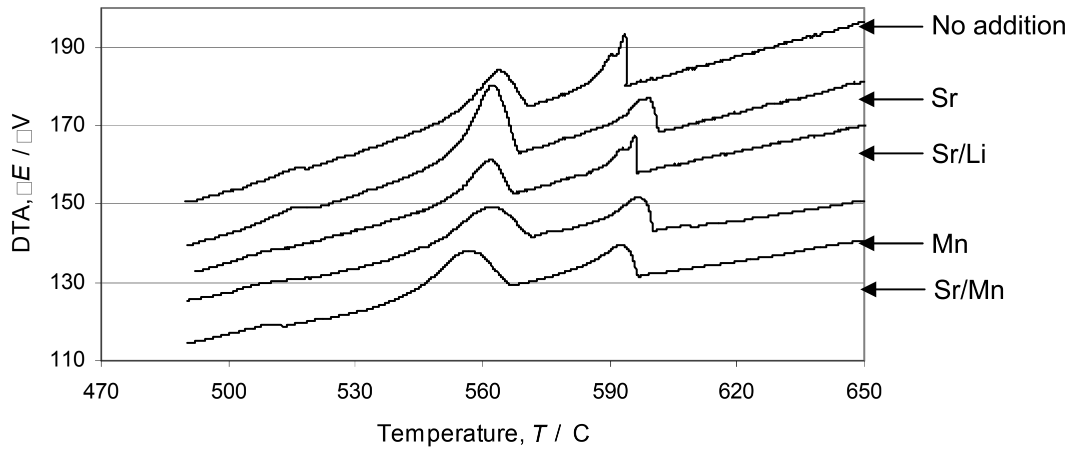

Figure 8: DTA analysis of different alloys cooled at 0.08 °C/s.

4. Conclusions

(1) The additions of Sr and Sr/Mn are very effective to modify the β–phase platelets to Chinese script or spherical morphologies and the Sr/Li addition partly modifies the β–phase in the case of high cooling rate solidification. The addition of Sr provides sufficient modification with no need to add the Mn which may induce a tendency to form sludge type compounds.

(2) The additions are less effective during the low cooling rate solidification and a tendency to form sludge type compound is observed in the presence of Mn.

(3) The additions of Sr, Mn, Sr/Mn and Sr/Li alter the Al-Si-Fe phase diagram by changing the temperatures of the liquidus, intermetallic crystallization and eutectic reaction. The change of the α and β regions of the phase diagram is suggested.

References

[1] L.A. Narayaman, F.H. Samuel, J.E. Gruzleski, Metall. Trans. A, 25A, 1761-1773, 1994.

[2] G.K. Sigworth, Mod. Cast., 77, 23-25, 1987.

[3] F. Paray, J.E. Gruzleski, B. Kulunk, M.H. Mulazimoglu, A. Zaluska, D.j. Zuliani, Metallurgical Effects of Strontuim on Wrought 6061 Alloys, Light Metals 1996, TMS, Warrendale, PA, USA, 707-711, 1996.

[4] P. Ashtari, H. Tezuka, T. Sato Metall. Trans. JIM, 44, 2611-2616, 2003.

[5] P. Ashtari, H. Tezuka, T. Sato, Influence of Li addition on Intermetallic Compound Morphologies in Al-Si-Cu-Fe Cast Alloys, Proceedings of the 143rd JFS Meeting, Toyama, Japan, 37, 2003.

[6] L. Backerud, G. Chai, and J. Tamminen, Solidification Characteristics of Aluminum Alloys, AFS/ SkanAluminum, Stockholm, Vol. 2, 72-73, 1990.