Effect of Sr Additive Amount and Holding Time on Microstructure of A390 Aluminum Alloy

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Abstract. The microstructure of A390 alloy under different Sr additive amounts and holding times was studied by means of direct reading spectrum analysis, energy spectrum analysis, optical microscope and electron microscope. The results show that Sr has a good modification to eutectic Si, while it has a negative effect on primary silicon. The Sr addition will increase the size of primary silicon. When the addition amount of Al-10Sr alloy is 0.6%, the modification of eutectic silicon is the optimum. The Sr has a short incubation period and a fine modification at 10min, but it is more serious burning rate in small furnace smelting, and the modification effect disappears basically after 100min.

1. Introduction
A390 hypereutectic Al-Si alloy has many advantages, such as small density, high temperature strength, good wear resistance, low thermal expansion coefficient and good thermal conductivity [1, 2]. It is an ideal wear-resistant and heat-resistant material which is widely used in engine piston and swash plate of automobile air conditioning compressor. In the conventional casting process, the microstructure of A390 is mainly composed of coarse primary silicon bulk phase, long needle eutectic silicon phase and dendritic primary α phase composition, in which the size and distribution of hard silicon phase points directly affect the mechanical properties, wear resistance and machinability of the alloy. Adding modifier can effectively refine the microstructure of alloy, which has been widely used in industrial production because of its simple process and easy operation [3].

Sr is usually used as metamorphic eutectic silicon, which can transform long acicular eutectic silicon into granular or fibrous form. Because of its stable modification effect and long effective time, it has become an effective eutectic silicon modifier [4, 5]. In the existing studies, Sr is usually added to hypoeutectic Al Si alloy, but its effect on hypereutectic Al Si alloy is seldom studied. In this paper, Sr was added to A390 hypereutectic Al alloy in the form of Al-10Sr master alloy, and the effects of Sr addition and holding time on the residual content and microstructure of Sr in A390 aluminum alloy were investigated.

2. Experimental materials and methods
The experimental material is A390 aluminum alloy, and its chemical composition is shown in table 1. Al-10Sr master alloy is used as a modifier.
Table 1. The chemical composition of A390 aluminum alloy (wt.%, the same below).

| Element | Si  | Cu  | Mg  | Zn  | Fe  | P   | Sr  | Ca  | Al  |
|---------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Content | 16.5| 4.8 | 0.52| 0.035| 0.016| 0.0035| 0.0025| 0.0010| Bal.|

The test equipment is a well type graphite crucible resistance furnace which is equipped with KSW-5-12A regulating temperature measuring controller. The A390 aluminium alloy crucible furnace was heated and melted at 760°C for refining and slag skimming. The experiment was divided into two groups. The first set of experiments as follows: adding 0.2%, 0.4%, 0.6%, 0.8% and 1.0% Al-10Sr master alloy respectively, mixing and holding 10min, then pouring into cylindrical steel mould in casting preheating 100°C, which size is φ50×40mm. The second set of experiments as follows: adding 0.6% Al-10Sr master alloy, stirring fully and holding 10min, 40min, 70min, 100min and 130min respectively, then pouring into cylindrical steel mould in casting preheating 100°C, which size is φ50×40mm. The 10mm location from the bottom of the casting was taken for component inspection and organization analysis. The samples were ground, polished and corroded in the mixed acid solution (2.5ml HNO3+1.5ml HCl+1.0ml HF+95ml H2O). The tissue characteristics were observed by DM2000 type metallographic microscope and S-4800 scanning electron microscope.

3. Results and discussion

3.1. Cast microstructure of A390 aluminum alloy

In this experiment, the composition of A390 alloy is Al-16.5Si-4.8Cu-0.5Mg, and the two element phase diagram of Al-Si alloy under this component is shown in figure 1. The dashed line in figure 1 is A390 alloy. From the dotted line, it is found that in the equilibrium solidification of A390 aluminum alloy, the precipitated phases are mainly composed of primary silicon phase, α-Al matrix phase, (α-Al+Si) eutectic phase and the second phase precipitated at the grain boundary [6].

![Figure 1. Al-Si binary alloy phase diagram.](image)

The microstructure of the untreated A390 aluminum alloy is shown in figure 2. The microstructure of A390 is composed of dark gray block facies A, pale grey needle-lamellar phase B, white bright near globular phase C, white bright irregular phase D and matrix E. In order to further confirm the phases in A390 aluminum alloy, EDS analysis is carried out. A point components 98.7%Si and 1.3%Al, which can be identified as the primary silicon phase. B point components 53.1%Al, 45.8%Si, 0.9%Cu and 0.2%Mg, which can determine the eutectic silicon phase. C point components 64.8%Al, 31.3%Cu, 2.3%Si, 1.4%Mg and 0.2%Fe, which can be identified as CuAl2 intermetallic compounds, also known as θ phase. D point components 76.7%Al, 15.4%Cu, 4.1%Si and 3.8%Mg, which can be identified as
Al₃Mg₆Cu₃Si₆ intermetallic compounds, also known as the Q phase. E point components 97.7%Al, 1.4%Si, 0.7%Cu and 0.2%Mg, which can be identified as α-Al phase.

![Figure 2. SEM image of A390 aluminum alloy.](image)

The above analysis results show that the microstructure of A390 aluminum alloy consists of α-Al phase, primary silicon phase, eutectic silicon phase, intergranular binary phase θ and quaternary element phase Q. As Al-Si alloy belongs to a small plane-non small plane alloy, high melting point of silicon phase is easy to generate a small plane, while the low aluminum low melting point phase is easy to generate non small plane, so the primary silicon phase appears polygonal massive, eutectic silicon phase appears flaky, silicon phase distribution inside α-Al matrix phase, also θ phase and Q phase present in the interdendritic of α-Al phase.

### 3.2. Effect of Sr additive amount on A390 alloy

![Figure 3. Microstructure of A390 aluminum alloy without and with Al-10Sr master alloy addition](image)

Figure 3 shows the microstructural photographs of the Al-10Sr intermediate alloy A390 with different additions of Al-10Sr master alloy. It can be seen from figure 3(a) that the primary silicon is polygonal and the eutectic silicon is long acicular, and the α-Al phase exhibits dendritic morphology in the unmodified A390 alloy. Because the magnification is not high enough, the phase of θ and Q is not observed in the metallographic picture. After adding 0.2% and 0.4% Al-10Sr master alloy to A390 alloy (figure 3b, 3c), primary silicon is still polygonal massive, which size increases obviously. While eutectic silicon starts to change into fiber shape, and α-Al phase has no obvious change. When the Al-10Sr intermediate alloy content reaches 0.6% (figure 3d), eutectic silicon presents fibrous, small size
and uniform distribution. The morphology of eutectic silicon is optimum. At the same time, the size of the primary silicon no further increases, α-Al phase is still no significant change. When the amount of Al-10Sr master alloy is more than 0.8%, as shown in figure 3(e, f), the eutectic silicon is large in size, its boundary is not clear and the distribution is uneven. The eutectic silicon begins to appear modification. The above analysis shows that the addition of Al-10Sr master alloy can significantly change the morphology of eutectic silicon, but will cause coarsening of primary silicon, which may be due to the melt trace P and Al reaction of AlP as heterogeneous nucleation of primary silicon, and the addition of Sr generates Al$_2$Si$_2$Sr which has the poison effect on AlP particles, resulting in nucleation rate decreases and the size of primary silicon phase increases [7].

3.3. Effect of holding time on A390 alloy

As shown in figure 4, the Sr residual content varies with the holding time after the A390 alloy adding with the 0.6%Al-10Sr master alloy. As can be seen from figure 4, in the case of 720°C preserve heat, with the increasing of holding time, the Sr residual content in A390 decreases gradually and declines obviously. When the holding time is 10min, the residual Sr content is 0.0235% and the Sr loss rate is 60.8% which is much higher than the 30% Sr the burning rate in industrial applications, this may be due to stirring the melt in order to ensure the sufficient dissolution of Sr causes to the acceleration of Sr oxidation. When the melting time is 100min, the Sr residual content is 0.0025%, which has dropped to the original Sr content of A390 alloy, and the external Sr has been completely burnt out. Under the experimental conditions, the effective metamorphic time of Sr is less than 100min.

![Figure 4](image)

**Figure 4.** Effect of holding time on Sr residual content of A390 alloy with 0.6%Al-10Sr addition.

Figure 5 shows the micrographs of A390 alloy with 0.6% Al-10Sr master alloy under different holding times. As can be seen from figure 5, the holding time has a significant influence on the modification effect. When the holding time is 10min (figure 5b) compared with unmodified A390 alloy (figure 5a), the eutectic silicon appeared typical metamorphic organization, which morphological changes obviously. Most of the coarse acicular eutectic silicon phases translate into fine micro morphology, the particle size is relatively uniform, and the phenomenon of agglomeration occurs. But the primary silicon is still polyhedron. The size of primary silicon increases obviously, which average grain size is 50μm, meanwhile, the phase of α-Al is dendritic. When the holding time increases, as shown in figure 5(c, d), the primary silicon size decreases, and the eutectic silicon gradually changes from fiber to needle like, the eutectic silicon cluster phenomenon disappears gradually, and the phase of α-Al has no obvious change. When the holding time increases to more than 130min (figure 5e, 5f), the eutectic silicon appears long acicular, and the modification effect of Sr is almost disappeared. The change rule of microstructure is corresponding to the change rule of Sr residual content in the melt. When the holding time is 10~100min, the residual content of Sr decreases gradually and the modification effect decreases in response. When the holding time is more than 100min, the deterioration effect of Sr is almost disappeared because the content of Sr is completely burnt out.
4. Conclusion
(1) The addition of Sr has a good modification effect on eutectic Si, but it is detrimental to primary silicon and will increase the size of primary silicon. When the addition amount of Al-10Sr alloy is 0.6%, the modification of eutectic silicon is the optimum.

(2) With the increase of holding time, the residual content of Sr in melt decreases gradually, and the modification effect gradually decreases. The metamorphic incubation period of Sr is relatively short, and it has well modification at 10min. However, the burning is more serious in small furnace smelting, and the modification effect disappears basically after 100min.

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