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Transformation of microstructure after modification of A390 alloy

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Abstract: A hypereutectic aluminum-silicon alloy with content of 17%Si, designed as A390, was modified. The change of microstructure was identified by optical microscopy. The results show that phosphorus can change the morphology and size of the primary silicon and control the length of needle-like eutectic silicon or dendrite. After modified by phosphorus, the primary silicon of star-like and coarse platelet is changed to polygonal with less cute angles and decreasing average size. The eutectic silicon is also changed because it grows from the tip of angles on the primary silicon and is influenced by the morphology and size of primary silicon. The eutectic silicon changes from needle-like or dendrite shape to short bars and dots with less average length.

Key words: aluminum-silicon alloys; modification; phosphorus; primary silicon; eutectic silicon

1 Introduction

Because of the interesting properties such as high wear resistance, low thermal expansion coefficient, good corrosion resistance and castability, hypereutectic Al-Si alloys have become a candidate material for the potential applications including aeronautical and missile field[1]. There are primary silicon looked like polygonal, star, coarser platelet and eutectic silicon looked like needle, dendrite in normal cast hypereutectic Al-Si alloy with no modification. The mechanical properties are worse due to the presence of big coarse primary silicon. The ways to minimize the size of silicon phases were studied, including modification[2], quick cooling[3], electro-magnetic stirring[4−5], complex modification[6] and spray forming[7]. Modification was normally used in commercial hypereutectic Al-Si alloys by adding single P[8], S[9], Na, Sr[10], rare earths[11], or their mixture[12−13] into melt. The modification of phosphorus is most commonly used.

It was well known that phosphorus modified primary silicon while it had little effect on eutectic silicon[14]. In this paper, a kind of hypereutectic Al-Si alloy designed as A390 was studied to show the transformation of silicon phases after P modification.

2 Experimental

2.1 Materials

The ingots of A390 with main contents(mass fraction) of 17% Si, 4.5% Mg, 0.55% Cu were chosen as the based material. The modifier was the mixture of 20%P (powder), 70% KCl and 10% $KTiF_6$. The mixture was pressed into blocks under 0.3 MPa and kept in dry bottle.

2.2 Experimental process

The ingots of A390 were put into a graphite-clay crucible and heated to about 850 ℃. Then modifier of different mass was added into the melt at about 800 ℃. The phosphorus mixture must be pressed into melt instead float on the liquid surface. After manual stirring, slag removing and holding for certain minutes, the melt was cast into preheated graphite mold.

3 Results and discussion

3.1 Effect of modification on primary silicon

3.1.1 Effect of modification on morphology of primary silicon

After slag removing, the melt was modified at about 800 ℃, and then stirred, held and poured into preheated

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graphite mold. A contrast sample was made before modification. With the more modifier addition, the modification temperature should be increased. The two samples were observed by optical microscopy and the typical microstructures are shown in Fig.1.

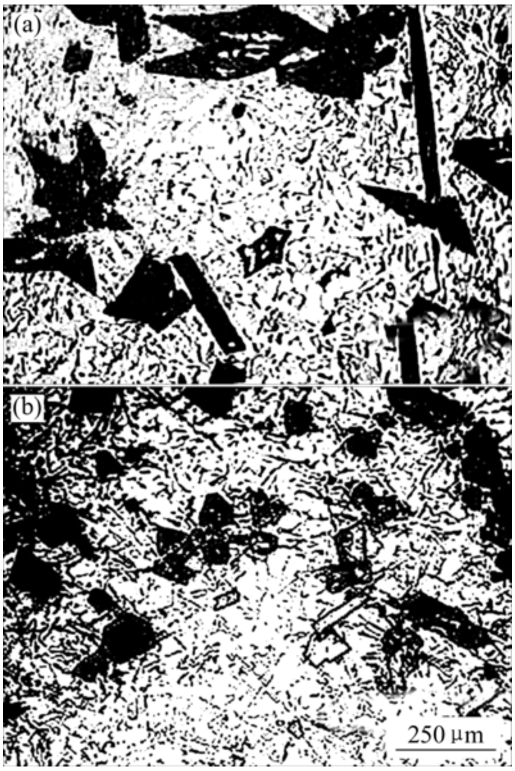

Fig.1 Morphologies of primary silicon in A390 alloy: (a) Un-modified; (b) Modified by 0.1% P for 150 min

Fig.1 (a) shows that primary silicon in unmodified A390 alloy presents a variety of shapes including large polygonal, star-like, coarse platelet, which lower is the mechanical properties and are not desired. Fig.1(b) shows that the addition of phosphorus changes the primary silicon to blocky and facetted shape.

The common modification mechanism of phosphorus is as follows. The addition of phosphorus gives birth to AlP as nucleus of primary silicon growth. According to Ref.[15], AlP(Al(1)+P(1)→AlP(s)) and Si are both cubic with very similar lattice parameters (Si 5.42 Å, AlP 5.45 Å). The primary silicon nucleates heterogeneously on the solid AlP particles with a cube-cube orientation relationship and solidifies, and thus promotes the refinement of primary silicon.

GUI et al[16] made a thermal analysis on the solidification process of hypereutectic Al-Si alloy[13]. The result shows that phosphorus can significantly increase the precipitation temperature of primary silicon. Primary silicon can precipitate at high temperature with no silicon agglomerates in melt, so its morphology changes to regular facetted shape.

3.1.2 Effect of modifying time and addition on size of primary silicon

Phosphorus mixture of different content (0.1%, 0.2%, 0.4%, 0.8% of based alloy, respectively) was added to A390 melt, and then the melt was held for 10, 20, 30, 60, 90, 120, 150, 180 min. The samples gained at every P content and time intersection were used to examine the average size of primary silicon and the results are shown in Fig.2. The average size is the statistic size of all the particles in three random pictures.

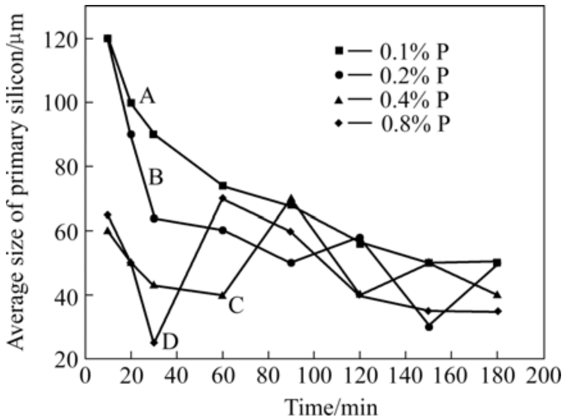

Fig.2 Average size of primary silicon with different modifier addition and different modifying time

In Fig.2, the curves A and B show that with prolonging modifying time the average size of primary silicon decreases. Time affects the nucleation and growth of AlP. Only the one whose diameter is bigger than the critical diameter can be used as nucleus for primary silicon. Fig.2 shows that from 30 min to 180 min the average size waves in ±16%. The modifier has stable and long-time effects.

When the modifier addition increases, the average size decreases because with the increased phosphorus addition the number of AlP increases and the size of primary silicon decreases. The minimum of 25 μm is achieved at 0.8% P and 30 min. When the addition gets to 0.4% P or more, the average size waves strangely, in curves C and D of Fig.2. There may be relationship between increased AlP and modifier addition that will be discussed in following text.

3.1.3 Effect of modifier addition on number of primary silicon

The four optimized samples chosen from different modifier addition were observed by optical microscope to detect the number of primary silicon. The result is shown in Fig.3.

Fig.3 shows that with increasing modifier addition the number of primary silicon increases and the size decreases. The reason is that more phosphorus addition creates more AlP and then Si grows from more nucleus, which makes the size of primary silicon smaller.

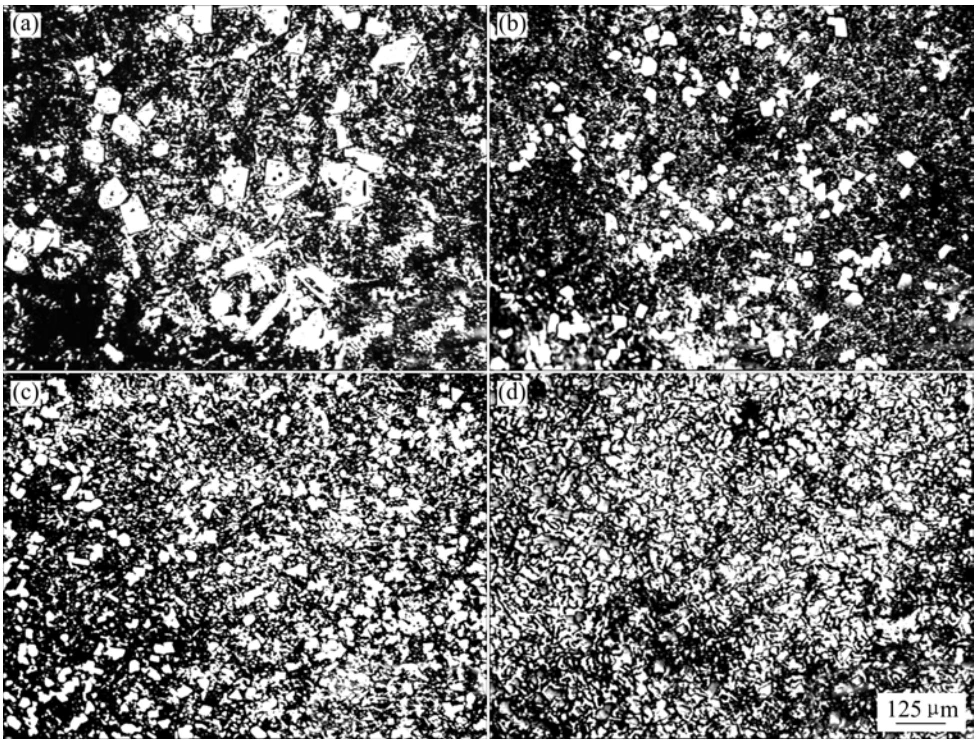

Fig.3 Morphologies of primary silicon in different hypereutectic Al-Si alloys: (a) Modified by 0.1% P for 120 min; (b) Modified by 0.2% P for 90 min; (c) Modified by 0.4% P for 60 min; (d) Modified by 0.8% P for 30 min

However, increased nucleus in melt at 760 ℃, about 100 ℃ higher than liquid line, may cause aggregation and then make primary silicon grow up against modification process. The concurrence of these two opposite processes may be the reason why the size waved(curves C and D in Fig.3).

3.2 Effect of modification on eutectic silicon

3.2.1 Effect of modification on morphology of eutectic silicon

The casts of A390 alloy unmodified and modified by phosphorus modifier were observed by optical microscopy. The results are shown in Fig.4.

In Fig.4 (a) the eutectic silicon exhibits large dendrite or needle-like shape. In Fig.4 (b) the eutectic silicon looks like short bars or dots.

From Fig.4, we can find that phosphorus modifier can control eutectic silicon besides modify primary silicon. The effect mechanism has not been reported. We suppose that the growth of eutectic silicon has a relationship with primary silicon.

3.2.2 Effect of modification on size of eutectic silicon

Fig.5 shows that the size of eutectic silicon in unmodified A390 alloy (Fig.5(a)) is obviously bigger than that in modified alloy (Fig.5(b)). When the primary silicon distributes in matrix alloy with long distance, the eutectic silicon will have grown into long needle. When the primary silicon distributes with short distance or phosphorus addition reaches a certain level, for example, 0.4% of matrix alloy, the average size of eutectic silicon will go down to 20 μm from 120 μm, some even to 1 μm.

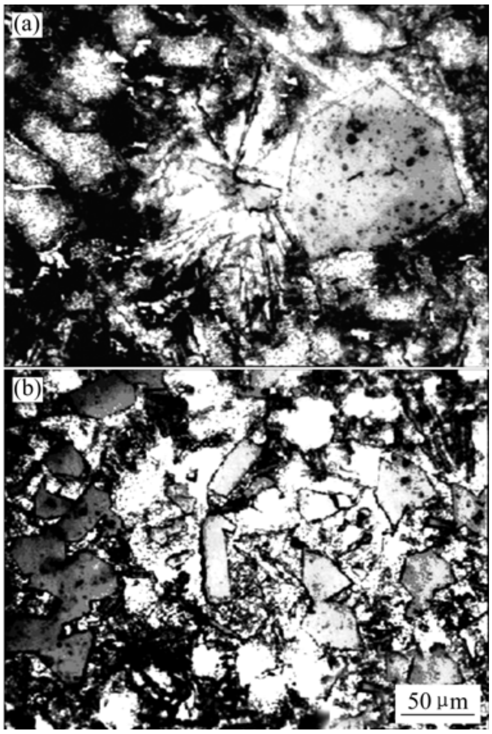

Fig.4 Morphologies of eutectic silicon in A390 alloy: (a) Unmodified; (b) Modified by 0.2% P for 90 min

This phenomenon indicates that eutectic silicon is affected by the size and distribution of primary silicon.

3.3 Relationship between primary silicon and eutectic silicon

Fig.6 (a) displays the primary silicon and eutectic silicon particles in A390 alloy unmodified. The extension lines of eutectic silicon needles converge to pits of primary silicon. In Fig.6 (b), we can see that a number of branches like sunlight center a primary silicon particle. From this phenomenon it can be deduced that the eutectic silicon has grown from the tip of angles on the primary silicon that pre-presents in melt in solidification process.

Fig.6 (c) clearly shows the eutectic silicon growing from the tip of angles of primary silicon, but no complete eutectic silicon can be seen. Because eutectic silicon needles grow in three-dimension, we can see only parts of several branches. Fig.6 (c) shows the first part of eutectic silicon which grows up from tip of an angle and has no gap with primary silicon.

From mentioned above, it can be concluded that phosphorus modification does not change the relationship between eutectic silicon and primary silicon, but changes the morphology, size and distribution of primary silicon, thus changes the morphology and size of eutectic silicon.

4 Conclusions

1) Phosphorus as modifier can efficiently change both primary silicon and eutectic silicon; phosphorus

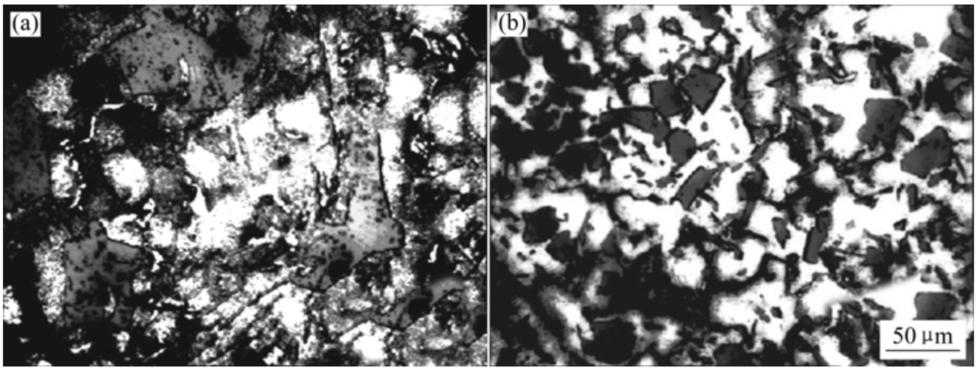

Fig.5 Morphologies of eutectic silicon in A390 alloy: (a) Unmodified; (b) Modified by 0.8% % P for 30 min

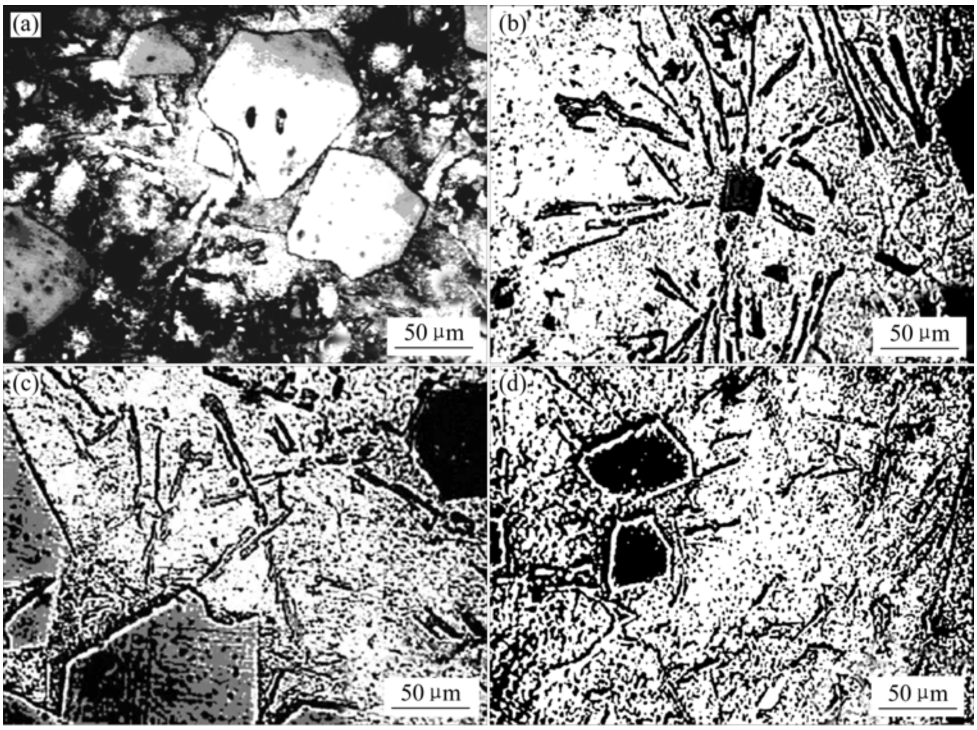

Fig.6 Morphologies of eutectic silicon and primary silicon in A390 alloy: (a) Unmodified; (b) Modified by 0.1% P for 120 min; (c) Modified by 0.1% P for 150 min; (d) Modified by 0.1% P for 180 min

modification changes the morphology and decreases the size of the two silicon phases. The optimized addition of phosphorus is 0.1%−0.4%.

2) Increasing phosphorus addition can increase the number of nucleating center of silicon, change the growth of primary silicon and eutectic silicon, change the morphology and size of two silicon phases though aggregation occurs.

3) The eutectic silicon has phase relationship with primary silicon. The highly enlarged structure shows that the eutectic silicon grows from the tip of angles on primary silicon.

References

[1] PENG Jin-min, QIAN Han-cheng. Current application situation and development of as-cast Al-Si alloys[J]. Foundry Technology, 2000, 6: 32−34.(in Chinese)

[2] ZHANG Zhong-hua, ZHANG Jing-xiang, BIAN Xiu-fang. New PM phosphorous modifier[J]. Special Casting & Nonferrous Alloys, 2000(2): 13−15.(in Chinese)

[3] ZHAO Ai-min, MAO Wei-min, ZHEN Zi-sheng. Effects of cooling rate on solidification microstructures and wear resistance of hypereutectic Al-Si alloy[J]. The Chinese Journal of Nonferrous Metals, 2001, 11(5): 827−832. (in Chinese)

[4] MAO Wei-min, LI Shu-su, ZHAO Ai-min. Microstructures of hypereutectic Al-24% Si alloy stirred by electromagnetic field[J]. The Chinese Journal of Nonferrous Metals, 2001, 11(5): 819−823. (in Chinese)

[5] XU Zhen-hu. A study on solidified structures of Al-Si alloys under rotary magnetic field condition[J]. Foundry, 2000, 49(2): 115−119. (in Chinese)

[6] ZHANG Jin-shan, XU Chun-xiang, HAN Fu-gen. Effect of composite modifier on structures and properties of hypereutectic Al-Si alloy[J]. The Chinese Journal of Nonferrous Metals, 2002, 12(S1): 107−109. (in Chinese)

[7] ZHANG Yong-an, Xiong Bai-qing, WEI Qiang. Aluminum alloys with high properties produced by spray forming process[J]. Materials for Mechanical Engineering, 2001, 25(4): 22−25.

[8] WANG De-man, ZHENG Zi-qiao. Effect of phosphorous modifier made by melting and casting on microstructure and properties[J]. Light Alloy Fabrication Technology, 1995, 23(9): 9−12.(in Chinese)

[9] XIAN Z H, FEI X X. Refinement of Al-Si hypereutectic alloys[J]. Light Met, 1995: 995−998.

[10] GRIFFITHS W D, JOLLY M R, KAETTLITZ W, KENDRICK R, NIBLETT A M. Effect of simultaneous additions of sodium and strontium on the modification of aluminum silicon alloy[J]. Light Met, 1990: 1047−1049.

[11] XU C L, JIANG Q C, YANG Y F, WANG H Y, WANG J G. Effect of Nd on primary silicon and eutectic silicon in hypereutectic Al-Si alloy[J]. Journal of Alloys and Compounds, 2006, 422: L1−L4.

[12] WU S S, TU X L, FUKUDA Y, KANNO T, NAKAE H. Modification mechanism of hypereutectic Al-Si alloy with P-Na addition[J]. Trans Nonferrous Met Soc China, 2003, 13: 1285−1286.

[13] JIANGA Q C, XUA C L, LUB M, WANGA H Y. Effect of new Al-P-Ti-TiC-Y modifier on primary silicon in hypereutectic Al-Si alloys[J]. Materials Letters, 2005, 59: 624−628.

[14] YAO Shu-fang, MAO Wei-min, ZHAO Ai-min. Research on modifier for hypereutectic Al-Si alloys[J]. Special Casting & Nonferrous Alloys, 2000, 5: 1−3.(in Chinese)

[15] JIANG Q C, XU C L, LU M, WANG H Y. Effect of new Al-P-Ti-TiC-Y modifier on primary silicon in hypereutectic Al-Si alloys[J]. Materials Letters, 2005, 59: 624−628.

[16] GUI Man-chang, JIA Jun, LI Qing-chang. Effect of Na, Sr and P on nucleating and growth of star like primary silicon in hypereutectic Al-Si alloy[J]. Journal of Aeronautical Materials, 1997, 17(4): 1−7.(in Chinese)

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