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Preparation of casting alloy ZL101 with coarse aluminum-silicon alloy

YOU Jing(尤 晶)[1], WANG Yao-wu(王耀武)[1], FENG Nai-xiang(冯乃祥)[1], YANG Ming-sheng(杨明生)[2]

1. School of Materials Science and Metallurgy, Northeastern University, Shenyang 110004, China;
2. Dengfeng Electric Group Aluminum Alloy Corporation, Dengfeng 450013, China

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Abstract: The coarse Al-Si alloy produced by carbothermal reduction of aluminous ore contains 55% Al, 25% Si and some impurities. The main impurities are slag and iron. The process of manufacturing casting Al-Si alloy ZL101 with the coarse Al-Si alloy was studied. The phase constitution and microstructure of the coarse Al-Si alloy, slag and ZL101 were examined by X-ray diffractometry and scanning electron microscopy. The results show that the content of silicon and iron in the casting alloy reduces with the increase of the dosage of purificant and manganese, but increases with the rise of filtering temperature. It is found that casting Al-Si alloy conforming to industrial standard can be produced after refining by using purificant, and removing iron by using manganese and added magnesium.

Key words: coarse Al-Si alloy; casting Al-Si alloy; flux refining; removing iron

1 Introduction

Because of their excellent mechanical properties and casting properties, aluminum-silicon alloys are widely used to engine piston and apparatus crust[1]. At present, most of aluminum-silicon casting grade alloys are produced by melting pure aluminum and silicon. Making casting grade Al-Si alloy using coarse aluminum-silicon alloy produced by carbothermal reduction of aluminous ore can reduce energy consumption significantly. It also can use inferiority ores[2]. Because of the high level of impurities, the coarse Al-Si alloy is often used as deoxidant in steel-making process[3]. Using it to produce casting grade aluminum alloy has not been reported. In this paper the study of making casting Al-Si alloy ZL101 with the coarse aluminum-silicon alloy is described.

2 Experimental

2.1 Composition and phases of coarse Al-Si alloy

Since the raw materials used to produce coarse Al-Si alloy are low grade bauxite or other kinds of aluminum ores, the coarse Al-Si alloy contains a lot of metallic impurities, metallic oxides and metallic carbides. Table 1 lists the main ingredients of the coarse Al-Si alloy.

Table 1 indicates that the content of slag is too much. Iron, calcium and titanium are the main metallic impurities. Figs.1 and 2 show that the coarse Al-Si alloy takes on honeycomb structure and it mainly contains seven phases. The types of metallic impurities are mostly $FeAl_3Si_2$, $FeAl_3$, $CaAl_2Si_2$ and $TiSi_2$. The slag is mainly $Al_2O_3{\cdot}SiO_2$. Since the mechanical property and ductility are poor, the alloy cannot be used for making casting alloy directly.

2.2 Experimental method

Fig.1 Photograph of coarse Al-Si alloy

Corresponding author: YOU Jing; Tel: +86-24-83686463; E-mail: wangyw113@163.com

Table 1 Composition of coarse aluminum-silicon alloy (mass fraction, %)

Al	Si	Fe	Ca	Ti	Mg	Zn	Cu	Ni	As	Slag
>55	25.48	4.36	2.06	0.718	0.010	0.008	0.005	<0.005	<0.005	<12.354

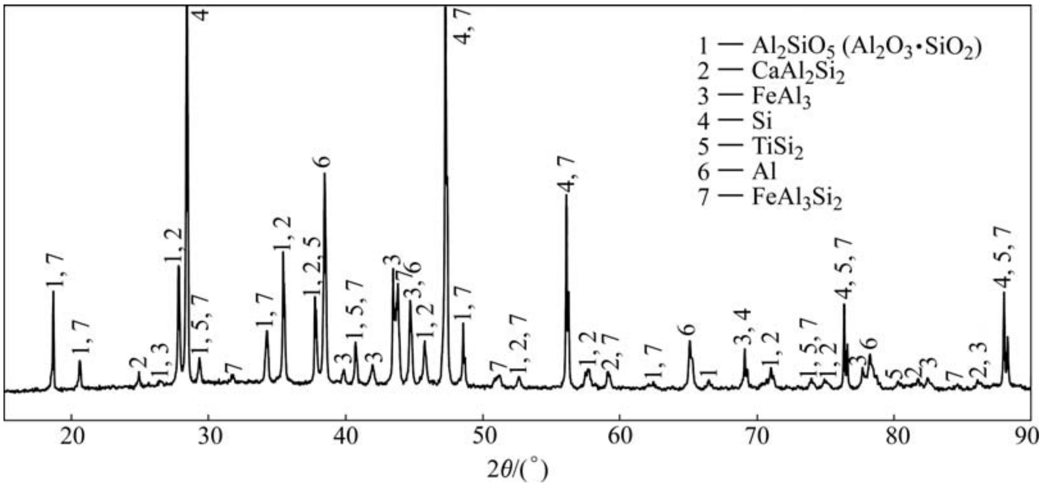

Fig.2 XDR pattern of coarse Al-Si alloy

Firstly pure aluminum was used to dilute the coarse Al-Si alloy. After the processes of purifying, removing iron and adding magnesium, the casting alloy ZL101 was made. Fig.3 gives the flow of experiment.

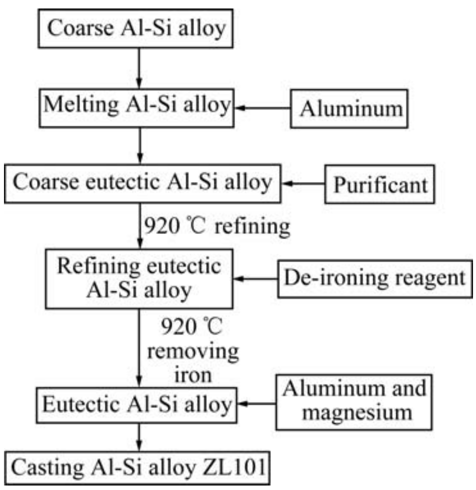

Fig.3 Experiment flowchart

Purificant Na_3AlF_6 (industrially pure) and NaCl (analytically pure) in all experiments were used. Manganese (industrially pure) was used as de-ironing additive[4].

3 Results and discussion

3.1 Refining of Al-Si alloy

Since the coarse alloy contains a mass of slag, it must be refined before removing iron. In the present experiment a flux refining method was used. The alloy was treated with a molten mixture of chloride and fluoride. On one hand, it makes the oxide inclusions float on the fusant surface to enter into the slag[5]. On the other hand, the floating flux on the surface can prevent aluminum and silicon in the alloy from being oxidized.

The effect of purificant addition on the net quantity of slag (the net quantity of slag was the difference between the filtering slag and the purificant addition) is shown in Fig.4. The effect of purificant addition on the composition of Al-Si alloy is shown in Fig.5.

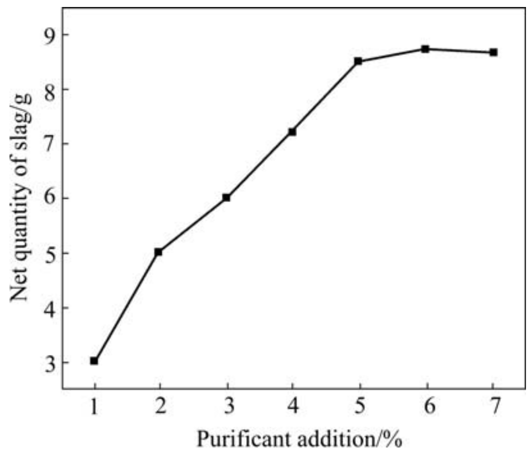

Fig.4 Effect of purificant addition on net quantity of slag

Fig.4 shows that the net quantity of slag initially increases with the increase of purificant addition, but keeps unchanged after the purificant addition reaches a certain value.

Fig.5 shows that the contents of iron and silicon in the alloy initially reduce with the increase of purificant addition, but when the purificant addition exceeds a certain value, the contents of iron and silicon do not

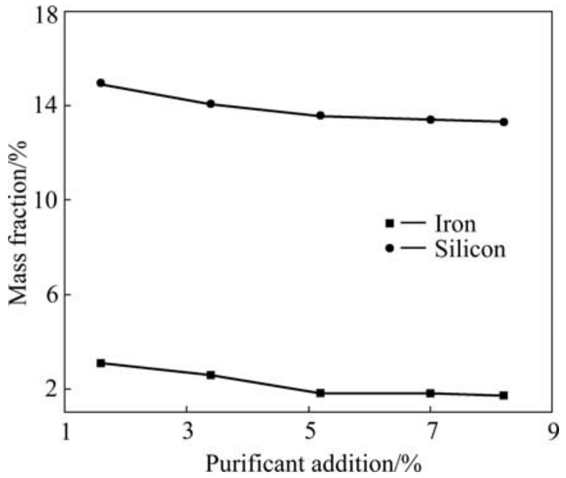

Fig.5 Effect of purificant addition on composition of Al-Si alloy

change any more. Since the slag that is mostly ferrous oxides and silicon oxide is taken out, the slag quantity increases and the contents of iron and silicon in alloy decrease with the increase of purificant addition. When the slag has been nearly all taken out, the slag would no longer increase and the contents of iron and silicon would no longer decrease.

Fig.6 shows the XRD pattern of the first residue (the first residue is the residue after refining).

The first residue mainly contains six phases. NaCl and NaF come from the purificant. Al_2O_3, SiO_2 and Fe_3O_4 are the constituent of the slag of coarse Al-Si alloy. CaF_2 is the production of Ca in the coarse alloy reacting with F^- from Na_3AlF_6. The composition of refined Al-Si alloy is listed in Table 2. The result proves that the process of refining can remove most of slag and Ca.

3.2 Removing iron

After refining, the main impurities are iron, copper and titanium. The copper and titanium content in the casting alloy is not very stringent. Low content of copper can enhance the alloy strength at high and room temperature[6]. Low content of titanium can refine crystal grain size and reinforce microstructure[7]. Iron is the most harmful impurity of casting Al-Si alloy. The form of iron in casting Al-Si alloy is generally β ferrite[8−9]. The β ferrite is hard and brittle and it always goes through the α(Al) crystal grain in the form of bulky spicula, weaken the matrix significantly and lower the mechanical properties of alloy[10−13]. So iron is the impurity that must be removed. Manganese was added at 920−960 ℃ and reacted for 30 min. Then the alloy was cooled slowly and filtered between 580 ℃ and 700 ℃.

At the filtering temperature of 580 ℃, the effect of manganese addition on the content of silicon, manganese and iron in alloy is shown in Fig.7.

The result shows that the contents of silicon and iron in Al-Si alloy first decrease, then reach a constant value with the increasing of the manganese addition. The addition of manganese can remove iron but import a new impurity of manganese. The manganese in the alloy increases with the increase of the manganese addition. The optimal addition is 3% of Al-Si alloy.

Fig.8 shows the effect of filtering temperature on the content of iron and silicon in the alloy. The result shows that the contents of silicon and iron in Al-Si alloy increase with the increase of filtering temperature.

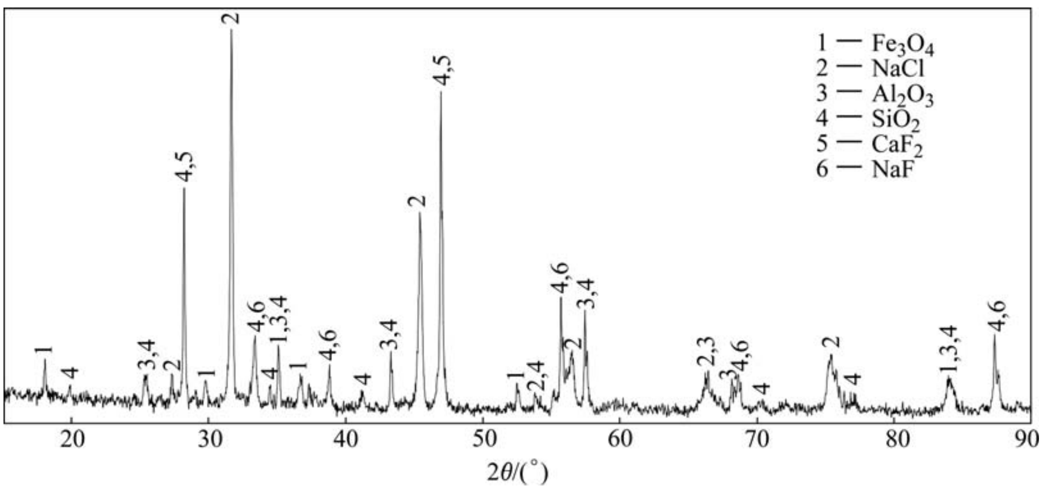

Fig.6 XDR pattern of first residue

Table 2 Composition of Al-Si alloy after refining (mass fraction, %)

Si	Fe	Cu	Mn	Mg	Ca	Ti	Al
14.0−14.5	2.0−2.7	0.06−0.10	<0.01	<0.01	0.10−0.50	0.50−0.70	Bal.

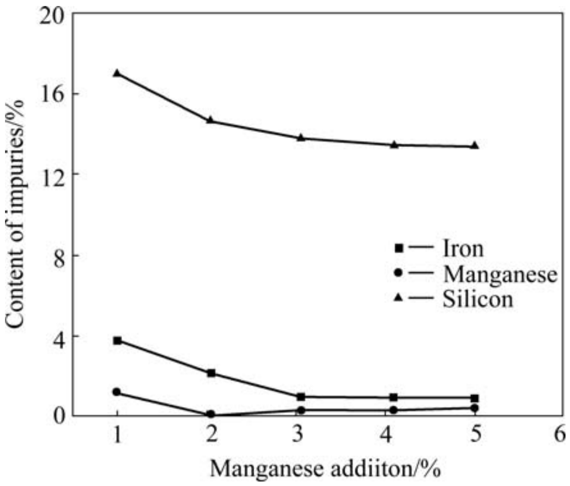

Fig.7 Effect of manganese addition on content of silicon, manganese and iron in alloy

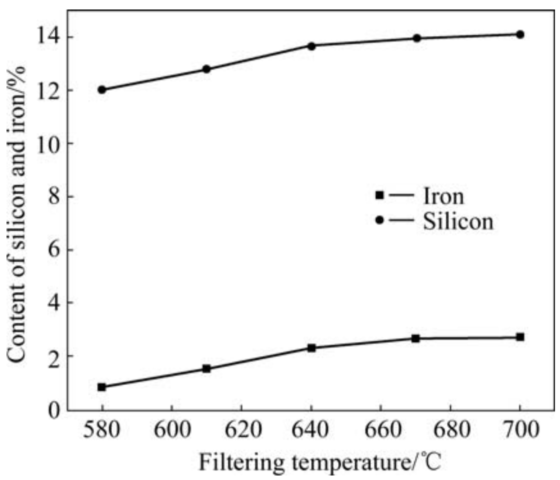

Fig.8 Effect of filtering temperature on content of iron and silicon in alloy

After filtering, the fusant was divided into two parts, Al-Si alloy and the second residue. The second residue comes from two parts. One was the filter residue and the other was the residue in the bottom of cell. The filter residue floats on the fusant surface. It mainly contains TiO_2, $FeMnO_3$, Mn_3O_4 and CaF_2. The bottom residue is the bottom coagulation. Its quantity is related to the filtering temperature. When the filtering temperature is 580 ℃ (the eutectic temperature is 577 ℃[14]), the quantity of residue is approximately 15% of the casting Al-Si alloy, but it is only 7%−10% at 640 ℃. And when being filtered at 640 ℃, the casting Al-Si can meet the requirement. So 640 ℃ is the optimal temperature for filtering.

Table 3 gives the composition of the bottom residue. Table 4 gives the composition of the filtered alloy.

Table 3 and Table 4 show that compared with the filtered Al-Si alloy, the contents of iron, silicon, manganese and titanium in the bottom residue are too high. The reason is that when lowering the temperature slowly, the alloy segregates and the segregation makes iron, silicon, manganese and titanium move to the bottom to form another alloy (Al-Si-Mn alloy). The solidification point of the new alloy is higher than that of the casting eutectic Al-Si alloy. So it can be separated by filtering at low temperature.

3.3 Magnesium addition and form of iron in alloy ZL101

The filtered alloy was heated to 760 ℃, then some other aluminum (the mass was identical with the filtered alloy) and magnesium (0.8% of filtered alloy[15]) were added. When magnesium was put into the alloy, it must be drowned completely. After stirring for 10 min, the alloy was cast into a graphite crucible and the composition was measured. Table 5 lists the composition of ZL101. Fig.9 shows the microstructure of ZL101.

It is found that the casting Al-Si alloy ZL101 conforms to industrial standard. The form of iron in the alloy ZL101 is not β ferrite, but mostly skeleton structure and block like structure. Its composition is Al 65.29%, Si 9.10%, Fe 21.38% and Mn 4.23%.

Table 3 Composition of bottom residue (mass fraction, %)

Si	Fe	Cu	Mn	Mg	Zn	Ti	Cr	Al
16.5−18.0	4.0−5.0	0.05−0.10	3.0−4.0	<0.01	<0.03	0.50−0.60	<0.05	Bal.

Table 4 Composition of filtered Al-Si alloy (mass fraction, %)

Si	Fe	Cu	Mn	Mg	Zn	Ti	Cr	Al
13.0−14.0	0.7−0.9	0.06−0.08	0.10−0.40	<0.01	<0.02	0.05−0.15	<0.02	Bal.

Table 5 Composition of final casting Al-Si alloy ZL101 (mass fraction, %)

Si	Fe	Cu	Mn	Mg	Zn	Ti	Cr	Al
6.5−7.0	0.35−0.45	<0.05	0.10−0.20	0.35−0.40	<0.01	<0.10	<0.01	Bal.

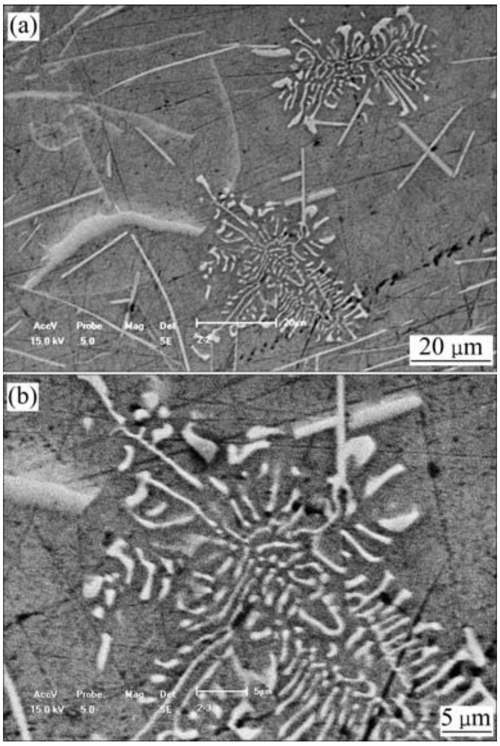

Fig.9 Microstructure of ZL101 alloy

4 Conclusions

1) The slag and Ca in coarse Al-Si alloy are removed by using sodium chloride and industrial cryolite as purificant.

2) The iron in the alloy is removed by two means. One is to form $FeMnO_3$ floating on the surface. The other is segregation and solidification at the bottom. The two parts can be separated from the casting Al-Si alloy by filtering.

3) Casting Al-Si alloy ZL101 conforming to international standards can be produced after refining by using purificant, removing iron by using manganese, diluting by aluminum and magnesium addition.

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