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# Furnace bottom rise mechanism in preparation of Al-Si alloys by electrothermal process[①]

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**Abstract:** The experiments of preparation of Al-Si alloys by electrothermal process were carried out respectively in 20 kW, 100 kW and 1 800 kW DC arc furnaces. The mechanism of furnace bottom rise was studied. It was found that the bottom rise can be divided into three types, including the low bottom temperature, abnormal reducing reaction and carbide deposition. The furnace bottom rise is related to the carbon ratio of the briquet, the heating speed of the briquet and the parameters and operation of furnace.

**Key words:** aluminum-silicon alloy; electrothermal smelting; furnace bottoms; rise; direct current arc furnace

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## 1 INTRODUCTION

The preparation of Al-Si alloys by electrothermal process has been advancing more greatly than that by cryolite-alumina melting electrolysis. It has many advantages such as short circuit, small investment of equipments, high production and utilization rate of energy. Especially it can use minerals with low ratio of Si to Al. Some foreign countries, mainly former Soviet Union, have been conducting industrial production in a large scale[1~3]. Domestic researches began in the 1960's. The most difficult problem in experiments was that furnace bottom rise caused smelting not to be continual in the process of production[4]. In present work, the experiments were carried out in 20 kW, 100 kW and 1 800 kW DC arc furnaces and the mechanism of bottom rise in the preparation of Al-Si alloys by eletrothermal process was studied systematically. It was found that two types of furnace bottom rise were relative to the carbon ratio, the parameters and operation of furnace. The research established a fundation for further studies to solve furnace bottom rise. And it could promote the spreading of the preparation of Al-Si alloys by electrothermal process.

## 2 EXPERIMENTAL

### 2.1 Equipments and raw materials

The needed equipments include:

20 kW graphite carbon pipe furnace with graphite pipe $d$50 mm, output voltage 0 ~ 50 V, output current 0 ~ 400 A, is made in former East Germany;

100 kW DC arc furnace with electrode $d$100 mm, hearth $d$300 mm × 375 mm, controllable silicon rectifier, output voltage 0 ~ 45 V, current 0 ~ 1 700 A, is self-made.

1 800 kW DC arc furnace with electrode $d$500 mm, hearth $d$2.00 m × 1.70 m, large power combined tube rectifier, output voltage 45 ~ 75 V, current 0 ~ 28 kA, is self-made.

Briquetting machine, patternmakers machine and so on.

Kyanite, bauxite, waste paper pulp, bitumenite and petroleum coke, alumina and silica were all commercially pure. The influence of raw materials ingredients was studied in former papers[5,6].

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### 2.2 Procedure of experiments

All the raw materials were crushed to < 149 μm. Kyniate or bauxite, bitumenite, petroleum coke and aluminia were added into the intermix machine at a definite ratio. The waste paper pulp was used as adhesive. The mixed materials were briquetted at a pressure of 30 MPa and dried at the temperature of 150 ℃. The average density of briquets was 1.53 ~ 1.57 g/cm$^3$, the porosity was 44 ~ 46 percent.

The carbon pipe furnace with a crucible in it was heated to 1 400 ℃ in advance. Then the briquet was put into the crucible. And then the furnace temperature rose to 2100 ℃ at a definite raising rate. After keeping the temperature for a period, the crucible was taken out. Then the samples were analyzed.

Silica was smelted to form the smelting chamber of furnace in a DC arc furnace in advance. After the temperature rose to a definite value, the briquet was added and Al-Si alloys were smelted. The electric parameters of furnace and the carbon ratio of briquet were adjusted in the process of smelting.

Some flowing liquid or samples in the definite positions of furnace after stopping furnace were analyzed.

### 2.3 Analysis of sample

The samples of slag were crushed to < 74 μm and analyzed by semiquantitative analysis of X-ray diffraction. X-ray diffraction instrument is D/max-rB (Japan)

## 3 RESULTS AND DISCUSSION

### 3.1 Carbon ratio in briquet

The preparation of Al-Si alloys from kynites or bauxite can be shown as follows:

$$n\mathrm{SiO_2} \cdot m\mathrm{Al_2O_3} + (2n + 3m)\mathrm{C} = 2m\mathrm{Al} + n\mathrm{Si} + (2n + 3m)\mathrm{CO} \quad (1)$$

The consumption of carbon in the equation was assumed to be 100 %. The experiments of the carbon ratio of briquet were carried out individually at 90 %, 92 %, 94 %, 96 %, and 98 % in the 20 kW and 100 kW furnaces. The samples of slag were analyzed by semiquantitative analysis of X-ray diffraction and the results are shown in Table 1.

**Table 1** X-ray diffraction analysis results of bottom slag in different carbon ratio

| Carbon ratio / % | 20 kW furnace | | 100 kW furnace | |
|---|---|---|---|---|
| | $Al_2O_3$/ % | SiC/ % | $Al_2O_3$/ % | SiC/ % |
| 90 | 14.9 ±1.5 | 10.2 ±1.0 | — | — |
| 92 | 13.8 ±1.4 | 10.0 ±1.0 | 73.3 ±4.0 | < 1.0 |
| 94 | 14.4 ±1.4 | 10.0 ±1.0 | 52.9 ±3.0 | 1.8 ±0.9 |
| 96 | 16.1 ±1.6 | 18.4 ±1.8 | 49.5 ±3.0 | 7.7 ±1.1 |
| 98 | 16.2 ±1.6 | 26.2 ±2.6 | — | — |

The results listed in Table 1 show that the chemical reactions at high temperature are different with the changes of carbon ratio. The higher the ratio of carbon, the larger the production of SiC. When the ratio is more than 94 %, the production of SiC increases sharply.

### 3.2 Heating speed of briquet

In the smelting of Al-Si alloys by electrothermal process, the reaction will take place only when the briquet fall down from the preheating area on the furnace top into the reaction area on the furnace bottom and is heated to the reaction temperature (above 2 000 ℃). The briquet heating speed have great influence on the reducing reaction in the reaction area. So the chemical reactions were studied at different heating speed in the carbon pipe furnace (20 kW). The residue of alumina and the production of SiC in the briquet at different heating speed are shown in Table 2. The temperature range was from 1 400 ℃ to 2100 ℃.

**Table 2** Analysis results of bottom slag at different heating speeds

| | Heating speed /(℃·min$^{-1}$) | Residue of $Al_2O_3$/ % | Production of SiC per unit mass of briquet/ % |
|---|---|---|---|
| 1 | 140.0 | 5.1 ±1.8 | 5.0 ±0.8 |
| 2 | 87.5 | 8.2 ±1.2 | 7.7 ±1.1 |
| 3 | 50.0 | 10.3 ±1.0 | 10.1 ±1.0 |
| 4 | 25.0 | 12.9 ±1.0 | 13.3 ±1.3 |
| 5 | 12.5 | 17.8 ±1.8 | 18.3 ±1.8 |
| 6 | 9.3 | 21.5 ±2.1 | 23.8 ±2.4 |

The results indicate that the faster the heating speed is, the higher the reaction rate of alumina and the lower the production rate of SiC will be .

### 3.3 State of furnace at different voltage

The suitable parameters of furnace should be changed with the furnace models and metals smelted. The experiments were carried out by keeping current at 1 500 A and using different furnace voltage, in a 100 kW DC arc furnace for Al-Si alloys. The results are shown in Table 3.

From Table 3, it can be seen that the appropriate voltage is 30 ~ 35 V when current is about 1 500 A. If the voltage is too low, the temperature of furnace top will be low also, and the furnace throat be small and the casting speed be slow. On the contrary, the temperature of furnace bottom will be low, the unreacted burden be more, the burden layer be too thin, the furnace throat be too large and burden be easy to collapse.

**Table 3** State of furnace at different voltage

| Voltage/ V | State of furnace |
|---|---|
| 25 ~ 30 | Higher temperature of bottom, a little bottom slag, lower temperature of top, thicker burden layer, smaller furnace throat, slow feeding briquet speed |
| 30 ~ 35 | Suitable temperature of bottom, less bottom slag, suitable temperature of top, moderate burden layer, normal feeding speed |
| 35 ~ 40 | A little lower temperature of bottom, a bit more slag, a bit higher temperature of top, thinner burden layer, faster feeding speed |
| > 40 | Low temperature of bottom, slag coagurated easily, very high temperature of top, very thin burden layer, burden easy to collapse, too fast feeding speed |

### 3.4 Analysis of bottom deposit

The furnace bottom rise was studied in a 1 800 kW DC arc furnace. The results of the X-ray diffraction semiquanitative analysis of bottom deposit are shown in Table 4. It can be found that the deposit is composed of the unreacted oxides and the carbides.

### 3.5 Discussion

The experiments in different carbon ratios indicate that the carbon ratio in the briquet has a great influence on the production of carbide because the carbide is intermediate product in the preparation of Al-Si alloys.

**Table 4** Analysis results of bottom slag in the 1 800 kW furnace (%)

| No. | Al-Si alloy | SiC | $Al_2O_3 + SiO_2$ |
|---|---|---|---|
| 1 | 53.2 ±3.0 | 20.4 ±2.0 | 23.6 ±2.4 |
| 2 | 74.2 ±4.0 | 12.5 ±1.2 | 12.8 ±1.3 |
| 3 | 59.2 ±3.0 | 12.0 ±1.2 | 25.6 ±2.6 |

$$SiO_2(s) + 3C(s) = SiC(s) + 2CO(g) \quad (2)$$

When the carbon ratio is suitable, carborundum can react with alumina completely,

$$3SiC(s) + Al_2O_3(s) = 2Al(l) + 3Si(l) + 3CO(g) \quad (3)$$

If the carbon ratio is too high, alumina can not consume all the carborundum, and it will produce surplus carbide. The carbide will deposit on the bottom because its melting point is higher and its density is greater. The high carbon ratio of briquet is the considerable reason resulting in carbide depositing on bottom. The results show that the carbide will produce greatly when the carbon ratio is above 96 % of theoretical value. And it will cause furnace bottom rise. Here the carbon ratio is an insufficiency for theoretical value.

The different loss of carbon, silicon dioxide and alumina in furnace is the cause of insufficiency.

It is shown that the heating speed can greatly affect the reaction of smelting Al-Si alloys. If the energy density provided by furnace is not ample, or the temperature in the reaction area and on bottom is not enough high or concentrated, the heating speed will decrease. And it will lead to the decline of oxidation-reduction rate and the growing of carbide production rate. At the same time, the bottom slag will also increase. If these problems can not be solved, slag will deposit on the bottom and will cause bottom rise.

If the reducing reactions in furnace are not normal, it will also cause the production and coagulation of slag, and then bottom rise. When the working voltage of the furnace is low and the distance between the electrode and the bottom is short, the bottom temperature will be high, the energy density be great, the heating speed be fast, the reaction be normal and it be not easy to happen for furnace bottom rise. But if the working voltage is too low, the furnace throat will be small and it will affect the casting speed and reduce production and increase energy consumption. The suitable voltage not only makes the reducing reaction be able to go on normally, but also keeps production economical. If the working voltage is too high, the reduction will not be complete. Because the unreacted briquet falls on the bottom, the Al-Si alloy fusant is mixed with a large quantity of solid phase slag (oxides, carbides, carbon), and the fusant is so viscid that it is like gruel. So it is difficult to flow out of the furnace hole, and furnace bottom rise occurs.

The preparation of Al-Si alloys by discontinuous furnace causes the thermal equilibrium on the bottom to be changed periodically. After the product is out of furnace, the electrodes will be near the bottom, and the bottom gain more heat and the temperature be higher. As the amounts of Al-Si alloy fusant increase, the electrode will be far away from the bottom, and then the bottom gain less heat and the temperature is lower. The periodical change will not cause harmful cases in normal because the superheating temperature of Al-Si alloy is higher. When there are depositing infusible lumps on the bottom, however, the change of temperature will cause serious consequences. After the fusant being out of furnace, some deposit is not brought out by alloy fusant and it will sedimentate on bottom. Some lumps will protrude. The deposits are conductor at high temperature in the furnace. So the distance between the electrode and the bottom is replaced with that between the electrode and the deposit. And it will make electrode far away from the bottom. The periodicity of normal temperature change is destroyed. It makes the bottom cool. Then the slag further deposits, the electrode is more far away from the bottom and the bottom is cooler. If the vicious status is not changed, the results will be that the bottom temperature decreased and furnace bottom rise occurs.

## 4 CONCLUSION

It was found that the furnace bottom rise can be divided into three types during the process of smelting Al-Si alloys through laboratory experiments and industrial tests. The first is that heat supply isn't enough and the temperature on bottom and in furnace is lower. The second is that the reduction isn't complete, the Al-Si alloy fusant is mixed with a lot of solid phase slag because the burden does not react entirely and the fusant viscosity increases greatly. The third is that the high melting point deposits of carbide are produced. They gether, lump and make bottom covered. The furnace bottom rise is related to the carbon ratio of the briquet, the heating speed of the briquet and the parameters and operation of furnace.

## REFERENCES


1 Qiu Zhuxian. Light Metal, 1991, (1): 374 ~ 376.
2 Бюллетень. ОБТИ-ВАМИ, 1939, (65): 126 ~ 129.
3 Zhang Wanfu. Light Metal, (in Chinese), 1998, (8): 38 ~ 41.
4 Zhang Dingyong and Gao Haitao. Light Metal, (in Chinese), 1992, (12):
5 Yao Guangchun and Sun Ting. Nonferrous Metal, (in Chinese), 1997, (5): 11 ~ 13.
6 Yao Guangchun, Zhang Xiaoming and Sun Ting. Nonferrous Metal, (in Chinese), 1998, (1): 51 ~ 54.


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