Experimental Study on Decarburization of Stainless Steel under Electromagnetic Levitation

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Abstract. The difficult in making stainless steel is decarburization and chromium conservation. Although the traditional AOD (Argon-Oxygen Decarburization) process was proved to be effective on decarburization and loss is minimized, the effect of the refractories on molten steel at high temperature still needs to be taken into account. However, application of CO2 in decarbonization during steel refining is a potential way to retain valuable alloy elements. Nevertheless, there are few reports about CO2 refining Fe-Cr-C alloy under vacuum levitation. In the present work, experimental data was collected for levitated stainless droplets exposed with Ar-CO2 mixture gas. The result shows that: (1) Stainless steel was refined by CO2 under electromagnetic levitation, the carbon content loss to 0.043 wt%; (2) Variation of gas flow rate and CO2 partial pressure has ignorable effect of chromium in the sample, and the effect of chromium conservation is obvious.

1. Introduction

In the production of smelting stainless steel, seventy-five percent of the stainless steel is deoxidized by AOD [1,2]. The traditional route is to introduce oxygen and argon during the decarburization process. The consumption of argon is large. During decarburization, the valuable metal elements are oxidized and lost. In this paper, the electromagnetic levitation method will be used. Electromagnetic levitation is a container less process that can reduce pollution effectively and produce ultra-pure metals and alloys. It is an ideal tool for studying gas-metal interactions and related kinetics [3-5]. When CO2 is used to replace oxygen under vacuum-suspension conditions, the oxidation potential for carbon dioxide, which is relative to oxygen, is low, it is available to avoid valuable metals losing during the decarburization process. Meanwhile, the effect of chromium conservation is remarkable. Making full use of carbon dioxide is beneficial to environmental protection, then realise the aim of clean metallurgy. The research of using carbon dioxide instead of oxygen-suspended and refined stainless steel, makes a great effect of decarbonization and chromium retention. Suspension refining technology can not only reduces the cost and emissions of stainless steel but also plays an important role in environmental protection.
2. Principle and test scheme

2.1 Principle of electromagnetic levitation
When a metal sample is placed in a coil of high-frequency currents, the sample will generate a Lorentz force, because the alternating electromagnetic field generates a high-frequency eddy current on the surface of the metal material and the high-frequency eddyed current interacts with the external magnetic field [6-8]. Under suitable space configuration, the direction of the electromagnetic force is opposite to the gravity. To change the power of the high frequency power supply, the electromagnetic force is equal to the gravity, and the electromagnetic levitation is realized. At the same time, the Joule heat produced by the eddy on the metal can melt the metal [9]. The conductor can be suspended, according to formula 1 which describes the balance between the gravity and the electromagnetic force (Lorentz force) [10].

\[ J \times B = \rho g \]  
(1)

Formula: J is induced eddy current induced by alternating magnetic field B; B is magnetic induction intensity; \( \rho \) is the density of suspended substance, and g is gravitational constant.

2.2 Test scheme

2.2.1 Test route
Compared with the traditional stainless steel refining method, this experiment has adjust the method and gas injection, using the Ar-CO$_2$ gas instead of the traditional Ar-O$_2$ gas, and take the electromagnetic levitation method to refine stainless steel. The main reactions are shown in the following formula (2)-(4) [1-4]:

\[ 2Cr + 3CO_2 (g) = Cr_2O_3 + 3CO (g) \]  
(2)

\[ C + CO_2 (g) = 2CO (g) \]  
(3)

\[ CO + \frac{1}{2} O_2 (g) \text{ in air} = CO_2 (g) \]  
(4)

2.2.2 Test conditions
The test temperature is 2023K (1750℃) and the time is 10 minutes. Three different chromium content of samples are selected to be studied. The content of the main components of each sample is shown in Table 1 [1]. The whole test is carried out in low velocity with a Reynolds number of 0.3~0.6, ensuring that the test process is controlled by natural convection.

| Sample | Cr (wt%) | C (wt%) |
|--------|----------|---------|
| 1      | 11       | 5.52    |
| 2      | 19       | 5.81    |
| 3      | 23       | 6.24    |

2.2.3 Test equipment
The schematic diagrams of the electromagnetic levitation equipment are shown in Figure 1. Illustrated by Figure 1, the device is mainly composed of gas inlet and outlet system, spiral induction coil and rotatable quartz disk. There is a quartz mouth in the suspension room, in order to measure the temperature by two colors infrared pyrometer. After the suspension is finished, the molten metal sample is quenched to the quartz tray.
3. Results and analysis

3.1 Effect and analysis of decarburization of samples

Figure 2[1] shows the change of carbon content in suspended stainless steel samples when the total gas partial pressure of CO\textsubscript{2} or O\textsubscript{2} is different. It is shown in Figure 2 that the carbon contents in stainless steel samples containing 11% (mass percent) of chromium, using 35% CO\textsubscript{2}-65%Ar decarbonization, is reduced from 5.81wt% to 0.043wt%, and the effect of decarbonization with 20%O\textsubscript{2}-80%Ar mixture is almost the same. After adjusting the gas partial pressure in CO\textsubscript{2}, the other samples can almost achieve the same decarbonization effect which used O\textsubscript{2}. In order to reflect the comparison of two gases decarbonization rate more directly, the ordinate is modified to -dC/dt, as shown in Figure 3.

Figure 4[1] shows the effect of gas composition and gas flow rate on decarburization behavior. It can be seen from Figure 4 that the higher the gas velocity is, the higher the partial pressure of CO\textsubscript{2} is, the faster the decarbonization rate is. When the gas velocity is small, but the partial pressure of CO\textsubscript{2} is larger, the decarbonization rate and the gas flow rate are large. When the pressure of CO\textsubscript{2} is less, then that of the two is close. It is found that the content of chromium has little effect on the degree of carbon removal and has no significant effect on the kinetics of decarburization.
In principle, the process of decarbonization with CO₂ suspension refining stainless steel is similar to that of AOD and VOD. However, the oxygen potential for CO₂ in the molten pool is lower than that of O₂, so the oxidation of carbon is preferable to the oxidation of chromium. Compared with O₂, chromium oxide is less likely to be oxidized by carbon dioxide, so CO₂ has certain advantages as a decarburizer.

### 3.2 The effect and analysis of specimen chromium protection

Table 2 is the change of the chromium content of the sample in different parameters, it indicating that the 15%CO₂-Ar velocity is 1.5L/min. The result of the test shows that when the velocity of 15%CO₂-Ar is 1.5L/min and the refining time is 120s, 220s, 320s, 420s, 520s, 620s, the chromium content is basically maintained at the 11wt%; When change the gas flow velocity, CO₂ partial pressure and the parameters of the sample, the chromium content of the sample is almost constant, and the use of CO₂ suspension refining stainless steel will not be accompanied by the loss of the important element chromium, and the effect of chromium conservation is obvious.

| Refining time/s | 120  | 220  | 320  | 420  | 520  | 620  |
|-----------------|------|------|------|------|------|------|
| [Cr]/wt%        | 11   | 10.97| 10.96| 10.95| 10.94| 10.94|

### 4. Conclusions

1. When using CO₂-Ar mixture gas, the carbon content can be removed to 0.043wt%, which can produce a good decarburization effect.
(2) When the parameters of gas flow rate and CO₂ partial pressure are changed, the chromium content of the sample is almost constant, it means that the chromium loss of the important element will not be accompanied by the use of CO₂ suspended refining stainless steel, and the effect of chromium conservation is obvious.

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