Experimental Study on Mixing Time under Different Operation Parameters in CAS Process

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Abstract. In view of the problems existing in bath mixing, a water model has been established to study the mixing time of CAS process on the basis of similarity principle. In this paper, the influences of the bottom blowing position, bottom blowing rate, the immersion depth, the position and the size of the impregnation cover on bath mixing time have been investigated in detail. To ensure the amount of slag in the impregnation cover as little as possible, it would be better that the slag area is equal to the diameter of impregnation cover. The optimum bottom blowing position is located at 0.5r, the bottom blowing rate is between 0.18 m\textsuperscript{3}/h and 0.22 m\textsuperscript{3}/h, and the immersion depth of impregnation cover is about 60 mm.

1. Introduction

CAS is an effective refining process. It has the advantages of low equipment cost, convenient operation and high alloy yield, and so on. The process can be divided into two key stages that the first stage is to blow open the slag layer using bottom blowing argon and to lower the impregnation cover and the second stage is alloy adjustment. The former requires a large enough slag elimination area to ensure that there is no slag or less slag in the impregnation cover to reduce the alloy loss, while the latter requires optimization of the position of the porous plug, the bottom blowing rate, the bottom blowing position, the immersion depth and size of the impregnation cover to reduce the mixing time of molten steel.

It is one of the metallurgical features of CAS process to promote the homogenization of molten steel temperature and alloy composition by gas stirring. Jin Youlin \textit{et al.} \cite{1} studied the influence of bottom blowing position, bottom blowing rate and immersion depth of impregnation cover on the mixing of molten steel in ladle during CAS process using water model experiments, and the optimal operation parameters were obtained. In order to optimize the 230 t CAS process, Shu Zhihao \textit{et al.} \cite{2} studied the mixing time using a physical model and optimized the bottom blowing position, bottom blowing rate and immersion depth of impregnation cover. The mixing time and flow field of molten steel at large ladle height to diameter ratio were also studied by Pan Yuhua \textit{et al.} \cite{3} using a water model, and some suggestions were proposed for the design and operation of CAS. Aiming at problem
of the overflow of a large number of bubbles in CAS process and on the basis of similarity principle, a water model of CAS ladle was established by Ma Wen-jun et al. [4]. Then the influence of the bottom blowing rate, immersion depth and bottom blowing position on the mixing time was studied in detail. Le Kexiang et al. [5] used physical simulation method to study the relationship between the mixing time and the bottom blowing rate, the bottom blowing position and the immersion depth of the impregnation cover during the CAS process.

In this paper, the flow field in the CAS process is studied by using the water model. The parameters including the bottom blowing position, bottom blowing rate, immersion depth of impregnation cover and so on are considered to study the influence on mixing time and inclusions floating. That it has practical application significance to quantificationally optimize the related parameters of CAS process.

2. Physical Experiment

2.1. Experimental apparatus and materials
A three-dimensional 1/5 scale water model of certain steel mill with 250 t CAS ladle has been established on the basis of similarity principle. In the experiment, the water and oil mixture are employed to simulate molten steel and slag, respectively. The bottled argon is employed to simulate the bottom blowing gas. The properties of water and molten steel are listed in Table 1. Fig. 1 shows a schematic diagram of the experimental apparatus, including the main apparatus, conductivity acquisition system, bottom blowing system and digital image acquisition system. The main apparatus is made of organic glass.

| Type  | Ladle top diameter | Ladle bottom diameter | Ladle height | Bath depth | Impregnation cover inner diameter | Impregnation cover outer diameter | Porous diameter |
|-------|-------------------|----------------------|--------------|------------|-------------------------------|---------------------------------|----------------|
| Prototype | 3934 | 3263 | 4112 | 3342 | 1340 | 1760 | 120 |
| Model    | 786.8 | 652.6 | 822.4 | 668.4 | 268 | 352 | 24 |

Figure 1. Experimental apparatus

2.2. Experimental methods
According to the stimulation-response principle, the mixing time was measured by the electrolyte solution tracer method. The tracer NaCl solution with a certain amount and concentration was injected into the ladle from the top. The moment of the solution injected into the ladle is denoted as the starting point. Then the data of concentration are collected by three conductivity electrodes which are fixed in the ladle. These data are directly recorded on the computer by data processing system. When the data tend to constant, this moment is denoted as the ending point. The time between the starting point and
the ending point is defined as the mixing time. In order to eliminate the influence of external factors and system error, the experiment will be repeated three times to calculate the average as the final mixing time [6].

3. Results and discussion

3.1. Influence of bottom blowing position on the mixing time

The installation position of the porous plug corresponds to the entry position of the gas, that is, the bottom blowing position, which has a great influence on the composition and temperature mixing of molten steel in the CAS ladle. Therefore, it is necessary to study the influence of the bottom blowing position on the mixing time. In the molten steel, gas appears in the form of bubbles, and the generation position of bubbles has obvious influence on the flow field of molten steel.

Fig. 2 shows the influences of bottom blowing position on the mixing time under different bottom blowing rate and different immersion depths of the impregnation cover. As can be seen from Fig. 2, the mixing time increases at first and then decreases and finally slows down as the porous plug moves away from the ladle center under different bottom blowing rate and different immersion depths of the impregnation cover. When the impregnation cover is immersed at a depth of 0, that is, when the impregnation cover is not used, the mixing time reaches a minimum when the porous plug is installed at a position of 0.6r. When the immersion depth of the impregnation cover is 60 mm, the ultimate installation position of the plug is 0.55r to ensure its center being coaxial to the center of the impregnation cover. If the installation position of the plug is more than 0.55r, these two centers begin to deviate. When the deviation position is larger, a large number of bubbles are observed to escape from the impregnation cover during the experiment. The escaping bubbles not only affect the utilization of the bottom blowing gas, but also lead to large fluctuation of the liquid level, and the removed inclusions are re-sucked into the water. Therefore, to achieve a better refining effect of CAS ladle, the installation position of the porous plug should be installed at 0.5r.

[Figure 2. Influence of bottom blowing position on the mixing time]

3.2. Influence of bottom blowing rate on the mixing time

Not only the bottom blowing position has an influence on the mixing of molten steel in the CAS ladle, but the bottom blowing rate has a more obvious influence on the mixing time. Fig. 3 and Fig. 5 shows the influences of bottom blowing rate on the mixing time under different immersion depths of the impregnation cover, respectively.
As can be seen from Fig. 3, the mixing time significantly decreases with the increase of bottom blowing rate under different immersion depths of the impregnation cover. When the bottom blowing rate exceeds 0.18 m$^3$/h, the variation of mixing time becomes flat. When the bottom blowing rate increases more than 0.22 m$^3$/h, the mixing time increases. The reason is that there are big bubbles emerging from the porous plug as the blowing rate is too large during the experiment process. Then the big bubbles burst when they rise to the liquid surface, causing the larger liquid level fluctuation. If this phenomenon occurs in the actual production, it not only causes the molten steel exposure and further the secondary oxidation but also causes severe spillage of molten steel and steel fluid loss. Thus the cost of smelting increases. Therefore, the bottom blowing rate should be strictly controlled to avoid this phenomenon. Therefore, the appropriate bottom blowing rate is between 0.18 m$^3$/h and 0.22 m$^3$/h in this experiment.

3.3. Influence of immersion depth of impregnation cover on the mixing time

In the CAS ladle, the introduction of the impregnation cover can not only improve the yield of the alloy, but also play a certain role in the stability of the molten steel. Therefore, it is necessary to study the influence of immersion depth on mixing time. The influence of different immersion depths of the impregnation cover on the mixing time is shown in Fig. 4.

It can be seen from Fig. 4 that with the increase of the immersion depth, the mixing time increases. The increase of mixing time means that the mixing time of composition and temperature in molten steel is prolonged, and the processing time of molten steel at CAS station is increased, which is not only unfavorable to the subsequent casting process of molten steel, but also greatly increases the thermal burden of refractories in the CAS ladle and reduces the life of refractories. Therefore, the immersion depth of the impregnation cover should be as small as possible under the condition of ensuring the mixing of molten steel. However, it was observed that if the immersion depth of the impregnating cover was too small in the water model experiment, the bubbles generated by the bottom blowing gas would easily escape from the impregnating cover, which would affect the utilization of the bottom blowing gas. Based on the consideration of the influence of the immersion depth on mixing time, the immersion depth of the impregnation cover should be 60 mm.
Figure 4. Influence of immersion depths of impregnation cover on the mixing time

4. Conclusions
In this paper, the influences of bottom blowing position, bottom blowing rate, immersion depth of impregnation cover on mixing time are studied in detail. The conclusions are as follows.

(1) The mixing time significantly decreases with the increase of bottom blowing rate under different immersion depths of the impregnation cover. With the increase of the immersion depth, the mixing time increases.

(2) According to the experimental results, the optimal operation parameters are as follows: bottom blowing position should be set at 0.5r, the bottom blowing rate should be set between 0.18 m³/h and 0.22 m³/h, and the immersion depth of impregnation cover should be controlled in about 60 mm.

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