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The DISSOLUTION RATE OF Al_2O_3 INTO MOLTEN SLAG

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Synopsis: The dissolution rate of Al_2O_3 into $CaO-Al_2O_3-CaF_2$, $CaO-Al_2O_3-SiO_2$ and $CaO-CaF_2-Al_2O_3-SiO_2$ systems was measured. The dissolution rate in the system of $CaO-Al_2O_3-CaF_2$ was faster than in the other systems, and increased according to the decrease of Al_2O_3 content. In the case that the CaO/CaF_2 ratio was constant in the $CaO-Al_2O_3-CaF_2$ system, the dissolution rate was fast in high CaO content slag. From these results, it was cleared that $CaO-CaF_2$ system was the optimum for the dissolution of Al_2O_3 inclusions into molten slag during the ladle refining. This slag was adopted to the production of special low oxygen steel in actual plant.

Key Words: high carbon steel, bearing steel, slag, inclusion, dissolution rate, diffusion coefficient

1. Introduction

The improvement of fatigue strength of high carbon bearing steel is important subject. The fatigue of the bearing steel is influenced by oxide inclusions in steel, especially Al_2O_3 inclusions. In order to improve the fatigue strength of the steel, the inclusions in the steel should be decreased as low as possible.

At ladle refining processes, removal of the Al_2O_3 inclusions is available for the improvement of the fatigue life. For the removal of the inclusions, it is necessary to optimize the ladle slag composition and the stirring intensity of molten steel, and also to prevent from reoxidation of the molten steel in the ladle and tundish.

In this study, the dissolution rate of Al_2O_3 into slags was measured, and the optimum slag composition for the ladle refining was decided. The present results were applied to the production of the high carbon bearing steel in the full plant scale, and the oxygen content less than 8 ppm could be obtained in the steel billet.

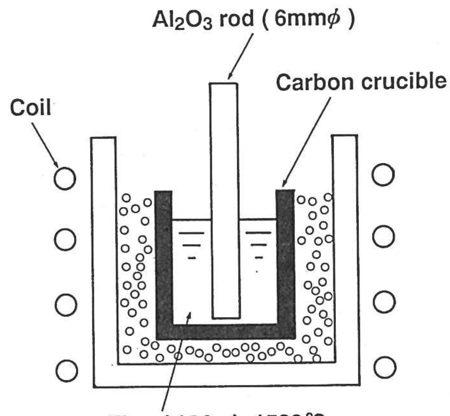

Figure 1 Experimental apparatus

2. Experimental apparatus and methods

The experimental apparatus is shown in figure 1. In the present study, three slag systems were studied, which are $CaO-Al_2O_3-CaF_2$, $CaO-Al_2O_3-SiO_2$, and $CaO-Al_2O_3-CaF_2-SiO_2$ systems.

One hundred gram of a slag was charged in a carbon crucible, whose inner diameter was 50mm.

The carbon crucible was placed in a high frequency induction furnace, and the slag was heated up to 1853K.

An Al_2O_3 rod, whose outer diameter was 6mm, was immersed into the slag for one minute, and the weight change of the rod was measured before and after the immersion. This procedure was repeated five times. The dissolution rate of Al_2O_3 into slags, *Rd*, was determined by the average value of the five procedures.

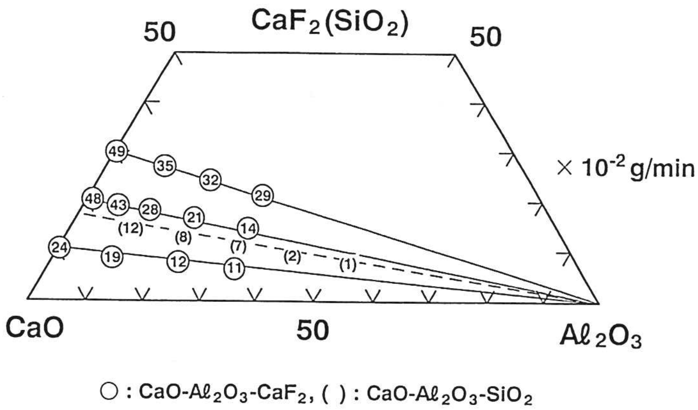

Figure 2 Dissolution rate of Al_2O_3 into CaO-Al_2O_3-CaF_2, CaO-Al_2O_3-SiO2 systems

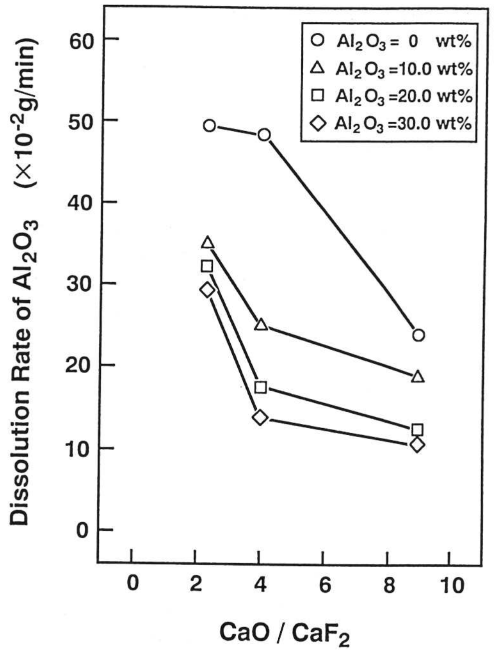

Figure 3 Influence of the CaO/CaF_2 ratio on dissolution rate into CaO-Al_2O_3-CaF_2 system

3. Experimental results and discussion

(1) Dissolution rate of Al_2O_3

The measurement results of CaO-Al_2O_3-CaF_2 and CaO-Al_2O_3-SiO_2 systems, are shown in figure 2. *Rd* into the CaO-Al_2O_3-CaF_2 system is higher than that into the other system. As the Al_2O_3 contents increased in the systems, *Rd* decreased.

The relation between the CaO/CaF_2 ratio and *Rd* in CaO-Al_2O_3-CaF_2 system is shown in figure 3. *Rd* was decreasing with the increase of CaO/CaF_2. The maximum value of *Rd* was 0.5 g/min. when the slag composition was 70%CaO-30%CaF_2.

The measurement results of *Rd* in CaO-Al_2O_3-CaF_2-SiO_2 is shown in figure 4. *Rd* was decreased by addition of SiO_2 to the CaO-Al_2O_3-CaF_2 system.

Accordingly, the CaO-CaF_2 slag system is available for obtaining the fast dissolution rate of Al_2O_3 and removing inclusions in molten steel.

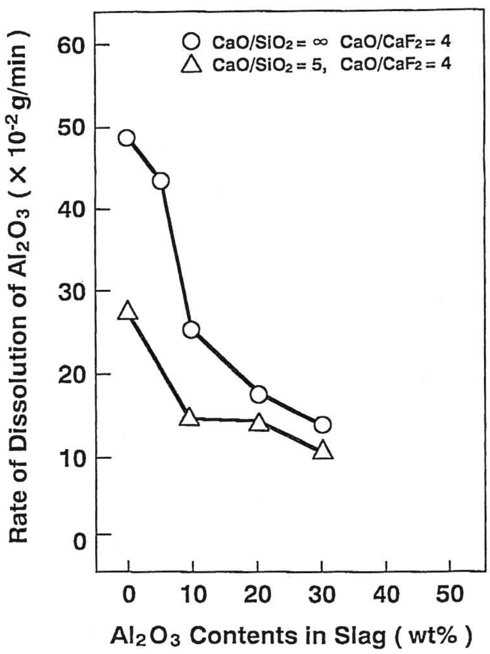

Figure 4 Dissolution rate into CaO-Al_2O_3 -CaF_2-SiO_2 system

(2) Change of the slag composition during Al_2O_3 dissolution into slag

The change in slag composition during Al_2O_3 dissolution into slag was analyzed with EPMA analyzer. Figure 5 shows the composition change in the case of 80%CaO-20%CaF_2 slag system. As the Al_2O_3 dissolved into the slag, the composition changed along the liquidus of 1853K to the line of CaO/CaF_2=80/20. After then, the slag composition moved along the line CaO/CaF_2= 80%/20%.

The dissolution process was considered as follows; A part of 80%CaO-20%CaF_2 slag mixture melted under 1853K. The composition of the molten slag was 20%CaO-80%CaF_2, the melting point of the slag was 1853K. Al_2O_3 dissolved into the molten slag, and also solid CaO and CaF_2 dissolved into the molten slag.

(3) Estimation of the diffusion coefficient of Al_2O_3 in the slag

It can be considered that the dissolution of Al_2O_3 into the slag is controlled by the diffusion of Al_2O_3 under this experimental condition. The decreasing rate of Al_2O_3 rod is expressed by equation (1), based on the mass balance.

$$-\frac{dr}{dt} = \frac{D \rho_b}{\pi \rho_s t}(C_s - C_b) \qquad (1)$$

Here,
- r : radius of Al_2O_3 rod
- t : time
- D : diffusion coefficient
- C_s : the saturated Al_2O_3 content at the interface between Al_2O_3 rod and molten slag
- C_b : Al_2O_3 content in a slag.
- ρ_b : density of slag
- ρ_s : density of Al_2O_3 rod

From equation (1), the diffusion coefficient of Al_2O_3 can be described by equation (2).

$$D = \pi \frac{\rho_s \, dr}{2\rho_b (C_s - C_b) dt} \qquad (2)$$

The diffusion coefficients of Al_2O_3 calculated by using equation (2) and the measurement value, are shown in Figure 6. The diffusion coefficient of Al_2O_3 in the CaO-Al_2O_3-CaF_2 system decreased with the increase of Al_2O_3 content and with the decrease of CaF_2 content in the slag.

Consequently, the measurement results of *Rd* can be explained by the diffusion coefficient of Al_2O_3 into slag.

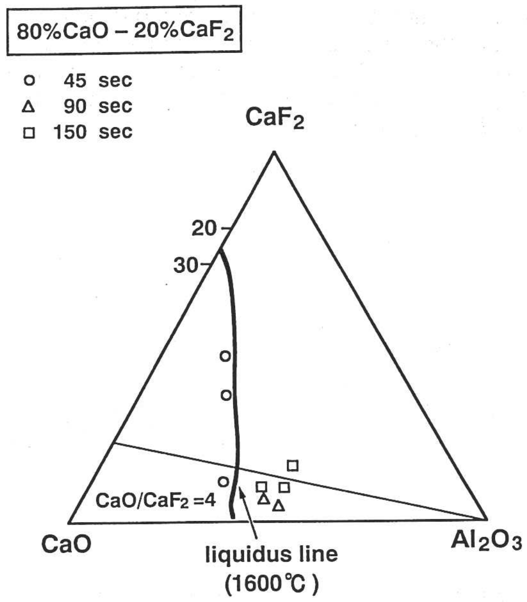

Figure 5 Change of slag composition

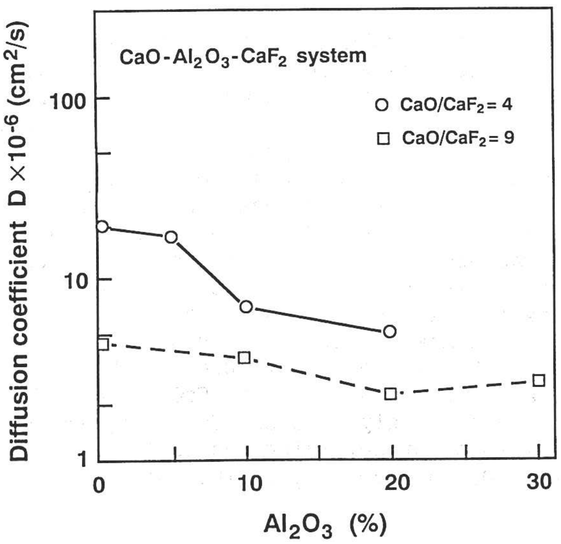

Figure 6 Diffusion coefficient of Al_2O_3 in CaO-Al_2O_3-CaF_2 system

4 Application to the full plant scale

The optimum slag composition determined by this study, was applied to the production of high carbon bearing steel in full plant scale.

The steelmaking process is shown in figure 7. After the dephosphorization and the desulfurization of hot metal, the oxygen steelmaking was carried out by converter with top and bottom blowing. The ladle refining process was ASEA-SKF type. After the refining, the molten steel was cast with bloom continuous casting machine.

The slag determined by the present study was applied to the ladle refining. The relation between oxygen content of the billet and Al_2O_3 content in the CaO-Al_2O_3-CaF_2 slag before the ladle treatment is shown in Figure 8. By reducing the Al_2O_3 content in the flux, the oxygen content in the billet could be less than 8 ppm.

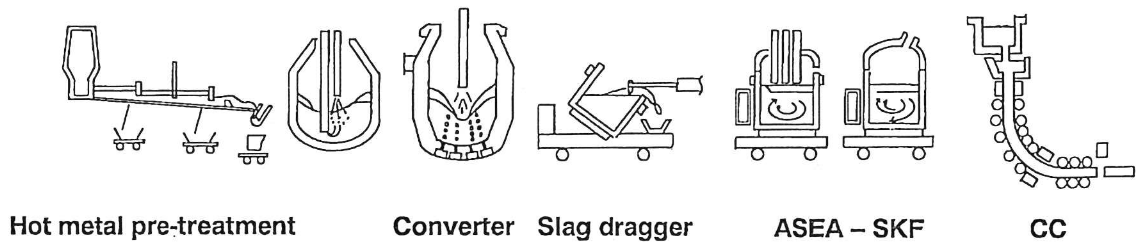

Figure 7 Schematic figure of steelmaking process

5. Summery

Al_2O_3 dissolution rate into CaO-Al_2O_3-CaF_2, CaO-Al_2O_3-SiO_2, and CaO-Al_2O_3-SiO_2-CaF_2 systems were measured. The dissolution rate into the CaO-Al_2O_3-CaF_2 system was the highest in the present study. The slag, which is available for the removal of Al_2O_3 inclusions, was put into the ladle refining of the actual plant. As a result, an oxygen content less than 8 ppm has been obtained in the high carbon bearing steel.

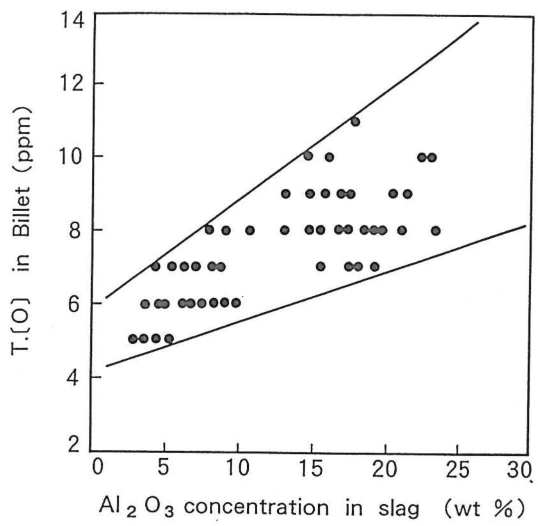

Figure 8 Relation between total oxygen content and Al_2O_3 content in ladle slag