4th International Conference on Molten Slags and Fluxes, 1992, Sendai, ISIJ

INVESTIGATION OF OPTIMUM SLAG FOR REMOVAL OF Al_2O_3 INCLUSION IN STEEL[1)]

Kaoru SHINME and Tohru MATSUO

Research & Development Div. Sumitomo Metal Ind. Ltd., Japan

Synopsis: The investigations of molten slags were carried out for making clean steel. To determine an optimum slag system and composition for removal of fine Al_2O_3 inclusion in Al-killed steel, a wettability of molten slag with Al_2O_3 and dissolution rate of Al_2O_3 to slag were measured experimentally. From those results, $CaO-CaF_2-Al_2O_3$ system slag could be estimated to eliminate Al_2O_3 inclusion effectively. To confirm this estimation, Al-killed steel were made with the flux by a 2.5t vacuum furnace experimentally. This slag could decrease total oxygen content to about 6 ppm in Al-killed steel. Futhermore it was found that basicity of the slag and composition of CaF_2 were also affected to absorption of Al_2O_3 inclusion in an application process.

Key words : Inclusion, Clean steel, Wetting angle, Dissolution rate, Slag, Refining, Al_2O_3 inclusion, Basicity, Secondary Refining,

1. Introduction

In recent years there has been an increased demand for steels containing extreamely low levels of nonmetalic inclusion. By reducing the number and decreasing the size of the non-metalic inclusion to extremely low levels, the characteristics of steels, such as tough -ness, fatigue-resistance and flexible bending, were improved. The bearing industry and its steel supliers have given a lot of attention to lowering the non-metalic inclusion content of bearing steels.

The purpose of this study is to find the optimum slag composition, in order to remove the inclusion containing Al_2O_3 by absorving the inclusions into the molten slag. It is considered that the optimum slag has to possess properties, as follows; shown in Fig.1. 1) Small wettingangle between molten slag and solid Al_2O_3, so that it is easy for the non-metalic inclusion such as Al_2O_3 particles, to adhere to molten slag. 2) High dissolution rate of adhered Al_2O_3 particles in the molten slag.

In this report, the slag system and its composition met above-mentioned demands have been decided by using $CaO-CaF_2-Al_2O_3$ and $CaO-CaF_2-SiO_2$ slag systems.

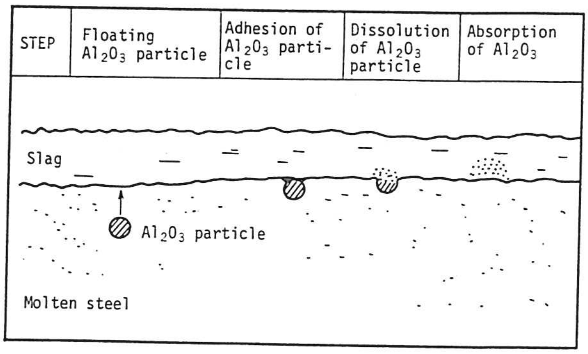

Fig.1 Schematic profile of absorption mechanism of Al_2O_3 particle into molten slag

2. Wettability between molten slag and solid Al_2O_3

In order to clarify the adhesion level of Al_2O_3 particle to the molten slag, the wetting angle between the molten slag and the solid Al_2O_3 has been measured by using a high temperature microscope.

2-1 Experimental method

A schematic profile of the high temperature microscope is shown in Fig. 2. The graphite plate and Al_2O_3 plate were set side by side, as shown in Fig. 3, on the support table which was made of graphite. After melting the mixed flux on the graphite plate, the molten slag was moved to the Al_2O_3 plate. The wetting angle between the molten slag and Al_2O_3 plate were measured by recording photographicaly the change of molten slag image. Temperatures of slag sample and Al_2O_3 plate were kept at 1600℃. The mixed flux systems were 1) $CaO-CaF_2-Al_2O_3$ and 2) $CaO-CaF_2-SiO_2$.

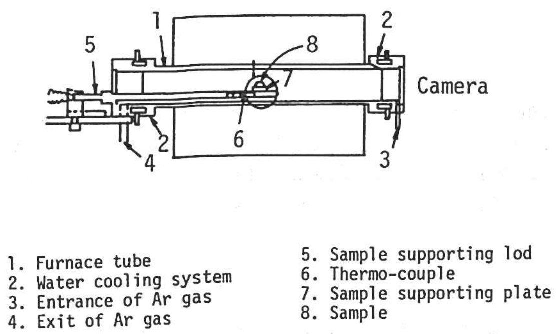

Fig. 2 Schematic profile of high temperature microscope

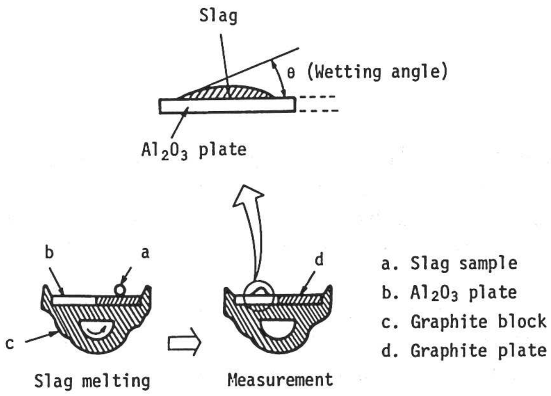

Fig. 3 Experimental method of measuring a wetting angle between molten slag and solid Al_2O_3 at 1600℃

2-2 Results and discussion

1) $CaO-CaF_2-Al_2O_3$ system

a) Influence of CaF_2 content in molten slag on the wetting angle(θ)

When the basicity of the mixed flux was kept at constant, ($CaO/Al_2O_3=1.0$), the behaviours of wetting angle was shown in Fig. 4. The wetting angles decreased with time, and the final values reached 15 degree in $CaF_2=5\%$, and 10 degree in $CaF_2=20\%$. The wetting angle θ decreased with the increase of the CaF_2 composition in the molten slag.

b) Influence of the basicity of the molten slag on the wetting angle(θ)

When the CaF_2 content in molten slag was kept at constant, ($CaF_2=20\%$), the final value of wetting angle reached 10 degree, independent of the slag basicity.

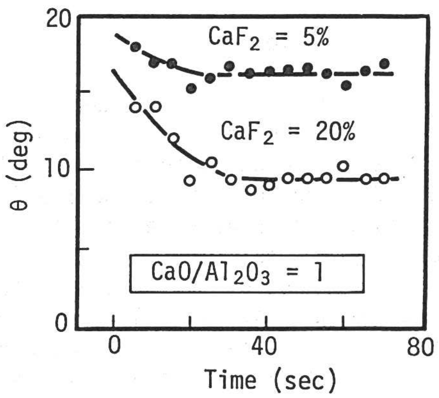

Fig. 4 Behaviours of wetting angle (θ) between molten slag and solid Al_2O_3 (Infuluence of CaF_2 content in $CaO-CaF_2-Al_2O_3$ slag system on θ)

2) $CaO-CaF_2-SiO_2$ system

a) Influence of CaF_2 content in molten slag on the wetting angle(θ)

When the basicity of the mixed flux was kept at constant, ($CaO/SiO_2=1.0$), the behaviours of wetting angle was shown in Fig. 5. The wetting angles decreased with time, and the final values reached 10 degree, independent of the CaF_2 content in molten slag.

b) Influence of the basicity of the molten slag on the wetting angle(θ)

When the CaF_2 content in molten slag was kept at constant, ($CaF_2=20\%$), the final value of wetting angle reached 10 degree in $CaO/SiO_2=1.0$, and 13 degree in $CaO/SiO_2=2.0$. The wetting angle increased with the increase of the basicity of the molten slag. And it was found out that the wetting angle of high basicity slag was quite low level at the very beginning of the contact between the molten slag and Al_2O_3 plate.

3) Comparison of two slag systems on the wetting angle between the molten slag and Al_2O_3 plate.

When the basicity of the slag and the CaF_2 content were the same conditions, 2.0 and 20% respectivety, the final value of the wetting angle in the CaO-CaF_2-Al_2O_3 system was lower than that of the CaO-CaF_2-SiO_2 system in Fig.6.

Table 1 shows the experimental results of measuring the wetting angle between molten slag and solid Al_2O_3. As for the adhesion of Al_2O_3 particle to the molten slag, CaO-CaF_2-Al_2O_3 system was selected at the conditions of high basicity and high CaF_2 content.

Table 1 Experimental results of measuring wetting angle (θ) between molten slag and solid Al_2O_3

Slag system / Condition	CaO-CaF_2-Al_2O_3	CaO-CaF_2-SiO_2
Increase of basicity	No significant effect on decrease of θ	Not so good for decrease of θ
Increase of CaF_2 content	Good for decrease of θ	No significant effect on decrease of θ

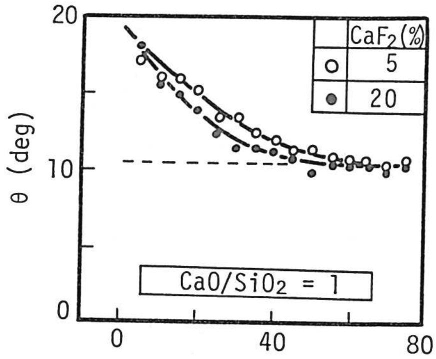

Fig.5 Behaviours of wetting angle (θ) between molten slag and solid Al_2O_3 (Infuluence of CaF_2 content in CaO-CaF_2-SiO_2 slag system on θ)

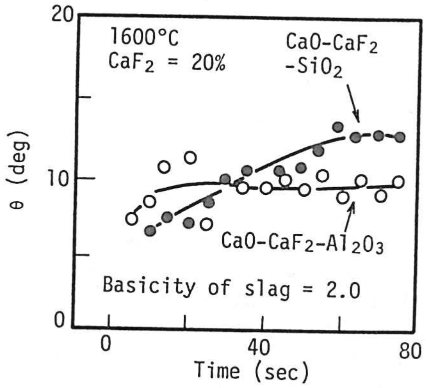

Fig.6 Infulence of slag system on wetting angle (θ) between molten slag and solid Al_2O_3

3. Dissolution rate of Al_2O_3 to molten slag

3-1 Experimental method

A schematic profile of Tammann furnace is shown in Fig.7. Al_2O_3 disk was rotated at a desired speed, 100 rpm in the molten slag which was mixed to 200g and was melted at 1600℃. the dissolution rate was calculated by the change of the Al_2O_3 disk weight.

1) Al_2O_3 disk

The shape of the Al_2O_3 disk was $50.85\phi \times 5^t$, the density was 3.94g/cm^3, the weight was 38.77g and the porosity was 0.0. Photograph 1 shows the cross section of the Al_2O_3 disk after an experiment.

2) Calculation of dissolution rate

The dissolution rate was calculated by the following equation which was contained with the weight of Al_2O_3 disk, the thickness of the disk and the dissolution time.

$$j=(1/2)\{(W_o-W_1)/\pi r_2 \rho t\}$$
$$=(1/2)(h/t)(1-W_1/W_o)$$

j : Dissolution rate (cm/sec),
W_o : Initial weight of disk (g),
W_1 : Final weight of disk (g),
r : Radius of disk (cm),
ρ : Density of disk (g/cm$_3$),
t : Dissolution time (sec)
h : Initial thickness of disk (cm)

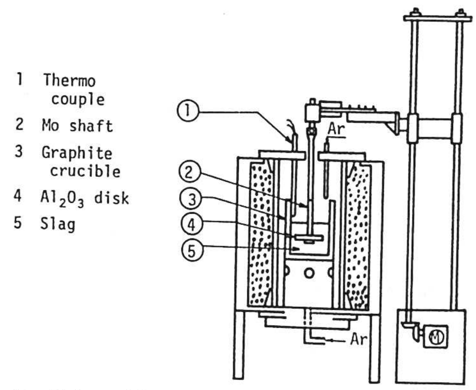

Fig.7 Schematic profile of tammann furnace for measuring a dissolution rate of Al_2O_3 into molten slag at 1600℃

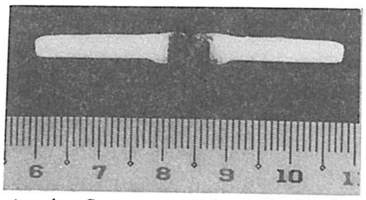

Photo.1 Cross section of Al_2O_3 disk after experiment

3-2 Results and discussion

The increased value of Al_2O_3 content in the molten slag during rotating the Al_2O_3 disk was just equal to the calculated value by the amount of Al_2O_3 disk dissolution.

1) Infuluence of rotating speed on the Al_2O_3 disk dissolution

It was found out that the dissolution rate of Al_2O_3 disk increased in proportion to the square root of rotation speed of the disk[2)-4)] when the rotation speed was less than 100 rpm. And the shape of this disk was not maintained uniformly after experiment at over 120 rpm rotating speed. The experiments were proceeded at the rotation speed of 100 rpm.

2) Influence of slag basicity on the Al_2O_3 dissolution rate(j)

Figure 8 shows the influence of slag basicity on the dissolution rate of the Al_2O_3 disk into the molten slag, $CaO-CaF_2-Al_2O_3$ system and $CaO-CaF_2-SiO_2$ system respectively.
In each slag system, the dissolution rate of Al_2O_3 disk increased with the increase of slag basicity. And that value in the $CaO-CaF_2-Al_2O_3$ system was about twice as much as that in $CaO-CaF_2-SiO_2$ system.

3) Influence of the CaF_2 content in the slag on the Al_2O_3 dissolution rate(j)

Figure 9 shows the influence of the CaF_2 content in the slag on the dissolution rate of the Al_2O_3 disk into the molten slag, $CaO-CaF_2-Al_2O_3$ system and $CaO-CaF_2-SiO_2$ system respectively.
In each slag system, the dissolution rate of Al_2O_3 disk increased with the increase of the CaF_2 content. And that value in the $CaO-CaF_2-Al_2O_3$ system was about twice as much as that in $CaO-CaF_2-SiO_2$ system.

4) Comparison of two slag systems on the dissolution rate of solid Al_2O_3 into the molten slag

When the basicity of the slag and the CaF_2 content were the same conditions, the dissolution rate of solid Al_2O_3 in the $CaO-CaF_2-Al_2O_3$ system was much higher than that in $CaO-CaF_2-SiO_2$ system.
Table 2 shows the experimental results of measuring the dissolution rate of Al_2O_3 disk into the molten slag. As for the dissolution of Al_2O_3 particle into the molten slag, $CaO-CaF_2-Al_2O_3$ system was selected at the conditions of high basicity and high CaF_2 content.

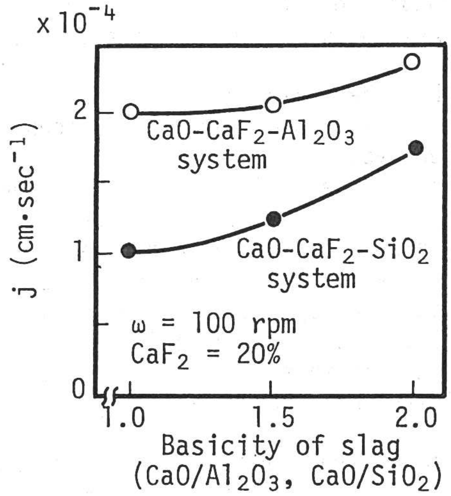

Fig. 8 Infuluence of slag basicity on the dissolution rate (j) of Al_2O_3 disk into the molten slag at 1600℃

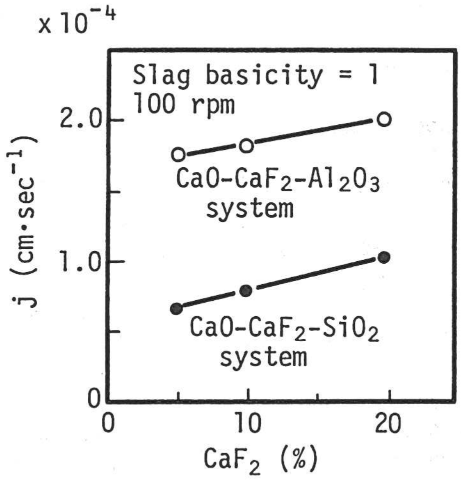

Fig. 9 Infuluence of CaF_2 content on the dissolution rate (j) of Al_2O_3 disk into the molten slag at 1600℃

Table 2 Experimental results of measuring the dissolution rate (j) of Al_2O_3 disk into the molten slag

Condition \ Slag system	$CaO-CaF_2-Al_2O_3$	$CaO-CaF_2-SiO_2$
Increase of basicity	Good for increase of j	Good for increase of j
Increase of CaF_2 content	Good for increase of j	Good for increase of j

4. Experiment of removal of Al_2O_3 inclusion from Al-killed steel containing 1%-Carbon

In order to confirm the above estimation, the experiment was proceeded by use of a 2.5t induction furnace.

4-1 Experimental method

After the decarburization by use of oxygen gas, deoxidation of molten steel was proceeded by metallic Al, and the mixed flux was put on the molten steel surface.

The flow rate of Argon gas was about 1 Nm^3/min.t and the temperature of the molten steel was controlled at 1600℃. The lining of this furnace was Al_2O_3 brick and MgO-Cr_2O_3 brick.

The amount of flux used was 40 kg/t . The basicity of the flux was 2.0 and the CaF_2 content was 20%.

4-2 Results and discussion

Figure 10 shows the behaviours of T.[O] content and Al_2O_3 inclusion number in 1%C steel which was covered by each slag system.

In the case of using the CaO-CaF_2-Al_2O_3 system, T.[O] and Al_2O_3 inclusion number were reduced to half of these in the case of the CaO-CaF_2-SiO_2 system.

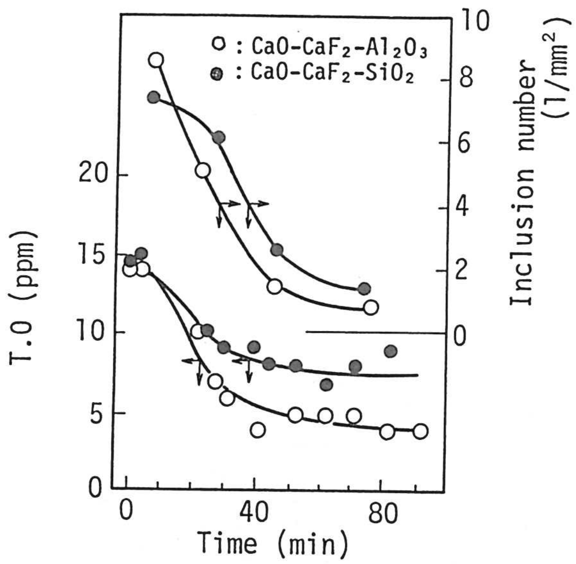

Fig.10 Infuluence of slag system on the behaviours of T.[O] and of inclusion number in 1%C-steel (2.5t induction furnace lined with Al_2O_3 brick)

5. Conclusion

Optimum slag system and composition was investigated in order to remove the Al_2O_3 inclusions by absorving the inclusions into the molten slag. The best slag system was CaO-CaF_2-Al_2O_3 system at the conditions of high basicity and high CaF_2 content. The recomended flux-composition was CaO=50～60%, CaF_2=15～20% and Al_2O_3=20～25%.

6. References

1) K.Shinme and T.Matsuo : Tetsu to Hagane,73,(1987) S1027
2) V.G.Levich : Physicochemical Hydrodynamics, Prentice-Hall Englewood Cliffs, N, J, 1962
3) V.G.Levich : Discussion Faraday Soc.,1,(1947) 37
4) D.P.Gregory and C.Riddiford : J.Chem.Soc.,(1956) 3756