COMPOSITION CONTROL OF REOXIDATION PRODUCTS IN SILICON KILLED STEEL

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ABSTRACT

Billet casting is a more energy saving process than bloom casting. From the viewpoint of energy saving, it is important to increase variety of steel grades that can be produced by the billet caster. One of the problems to overcome in the billet casting is to suppress the generation of high melting point SiO_2 rich scum that is harmful to surface quality of billet in continuous casting of low Mn/Si steel without shrouding. Composition change in the scum due to reoxidation of steel has been investigated with cold crucible experiments to clarify condition which can avoid high melting point scum. A mathematical model for prediction of reoxidation product in steel has been newly developed to estimate composition change in scum and to design an optimum composition of steel and operating condition. Comparison of calculated composition change with data obtained in the cold crucible experiments showed that the mathematical model is powerful for estimation of the composition of the scum and for the design of the steel to avoid high melting point scum. It has been found that addition of titanium in steel is very effective to prevent from generation of high melting point scum even in the case of large input of oxygen in continuous casting.

INTRODUCTION

Billet casting is a more energy saving process than bloom casting. From the viewpoint of energy saving, it is important to increase variety of steel grades that can be produced by the billet caster. One of the problems to overcome in the billet casting is to suppress the generation of high melting point SiO_2 rich scum that is harmful to surface quality of billet in continuous casting of low Mn/Si steel without shrouding [1]. Composition change in the scum due to reoxidation of steel has been investigated with cold crucible experiments to clarify condition which can avoid high melting point scum. A mathematical model for prediction of reoxidation product in steel has been newly developed to estimate composition change in scum and to design an optimum composition of steel and operating condition.

METHODOLOGY

Experimental

Reoxidation experiments were carried out with cold crucible melting facility shown in Figure 1. The advantages of the cold crucible are no contamination from refractory and ejection of oxidation products to the surface of specimen. Steel specimen was melted in vacuum chamber and kept at 1823 K. Ar + O_2 gas mixture was blown onto the surface of the specimen. Reoxidation product was ejected to the surface of the steel by electromagnetic force and quenched by He gas blowing. The quenched reoxidation product was submitted to observation of morphology and analysis of chemical composition. Main experimental conditions are shown in Table 1. In the experiments, contents of [Si], [Mn] and [Ti] in steel were varied. Ratios of content of [Mn] to that of [Si] are 1.9 and 2.8. Other conditions are also listed in Table 1.

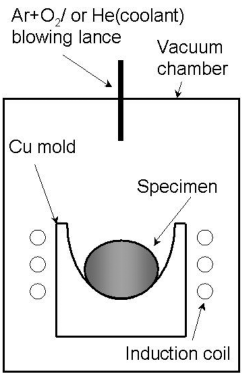


Figure 1: Experimental apparatus for reoxidation of steels

Table 1: Experimental conditions

	Steel Compositions (mass%)					
	No.	C	Si	Mn	Ti	Mn/Si
	a	0.06	0.25	0.48	tr.	1.9
	b	0.06	0.18	0.53	tr.	2.8
	c	0.06	0.25	0.48	0.007	1.9
Weight of Specimen	70 g					
Temperature	1823 K					

$Ar+O_2$ Gas Blowing		
	Oxygen content	20 vol%
	Flow Rate	5 x 10^{-5} m^3/s
	Blowing Time	10, 30, 60, 120 s

Mathematical Modelling

A mathematical model for prediction of composition of the reoxidation product in steel has been newly developed to estimate composition change in scum and to design an optimum composition of steel and operating condition of continuous casting. The model was based on the calculation model for slag-metal reaction developed by one of authors and co-workers [2, 3] using cell model. The cell model is one of prominent thermodynamic models for slags and fluxes developed by H. Gaye *et al*. [4] In this model the number of each cell in liquid oxide solutions, which consists of cation pair and an oxygen atom in between, is calculated so that the free energy of the solutions is minimized under a condition of the set values of the energy parameters, formation energy of the cells with heterogeneous cation pair and interaction energy between the cells with consideration of the entropy of mixing of the cells.

To clarify appropriate content of titanium in steel, change in chemical composition of reoxidation product during $Ar+O_2$ gas blowing was calculated with the model.

RESULTS AND DISCUSSION

Experimental Results

First of all, oxygen input to molten steel, Δ[O], was estimated as follow. Relationship between Δ[O] and $Ar+O_2$ gas blowing time in reoxidation experiments is shown in Figure 2. Oxygen input was calculated from changes in contents of Si, Mn and Ti in steel assuming following reactions.

$$[Si] + 2[O] = SiO_2 \quad (1)$$

$$[Mn] + [O] = MnO \quad (2)$$

$$[Ti] + 2[O] = TiO_2 \quad (3)$$

From Figure 2, the oxygen input is proportional to $Ar+O_2$ gas blowing time in the present experiment. The oxygen input can be controlled by changing blowing time.

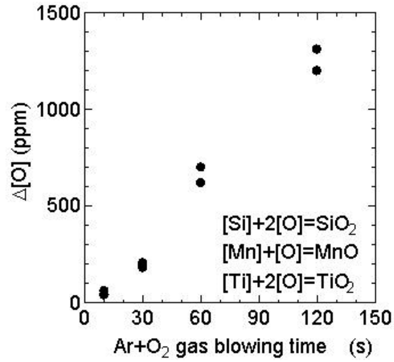


Figure 2: Relationship between Δ[0] and Ar+0_2 gas blowing time

A typical morphology of reoxidation product is shown in Figure 3. SiO_2 which is dark grey (2 in the figure) is precipitated in Manganese silicate matrix which is light grey (1 in the figure).

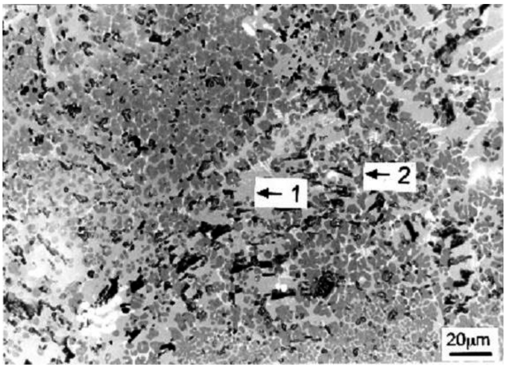
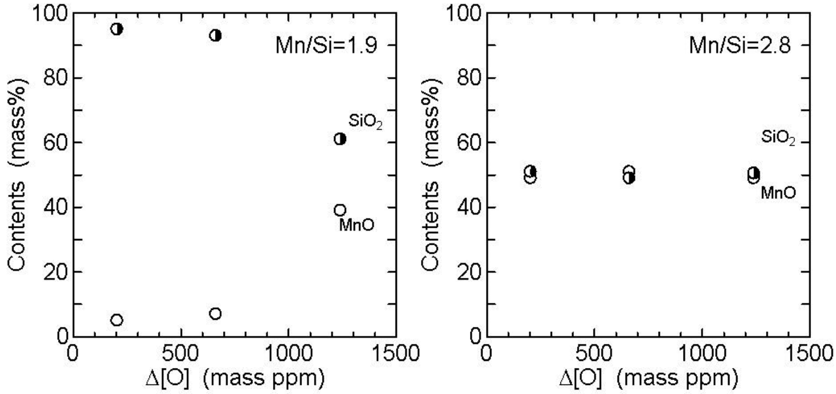


Figure 3: A typical morphology of reoxidation product

Figure 4 represents composition change in scum in the case of steel without titanium. When Mn/Si is low, high melting point SiO_2 rich scum was generated, while no SiO_2 rich scum was generated in low Mn/Si steel.



(a) Mn/Si = 1.9 (b) Mn/Si = 2.8

Figure 4: Composition changes in scum during Ar+0_2 gas blowing. (a) Mn/Si = 1.9 and (b) Mn/Si = 2.8

Figure 5 shows composition change in scum in the case of steel with titanium. No SiO_2rich scum was generated until oxygen input reached about 600 ppm even at low Mn/Si. It have been found that relatively small amount of titanium addition is very effective to suppress the generation of high melting point scum.

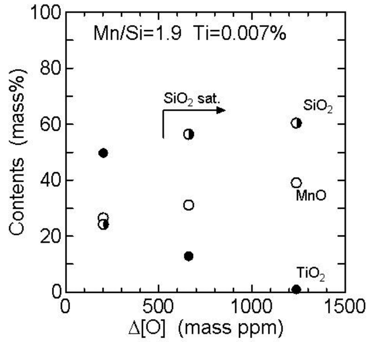
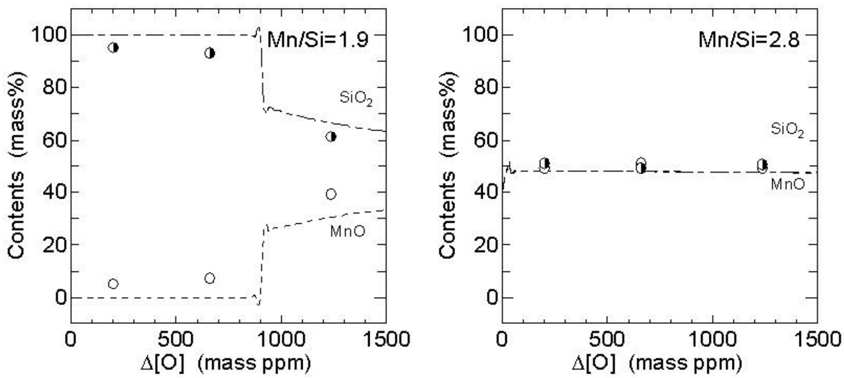


Figure 5: Composition Changes in Scum during $Ar+O_2$ Gas Blowing onto steel with 0.007%Ti

Calculated Results

Figure 6 and Figure 7 show comparison between calculated composition change of scum and experimental one. From these diagrams, calculated results were in fairly good agreement with experimental ones.



(a) Mn/Si = 1.9 (b) Mn/Si = 2.8

Figure 6: Comparison between calculated composition change of scum and experimental one in the case of steel without titanium. (a) Mn/Si = 1.9 and (b) Mn/Si = 2.8

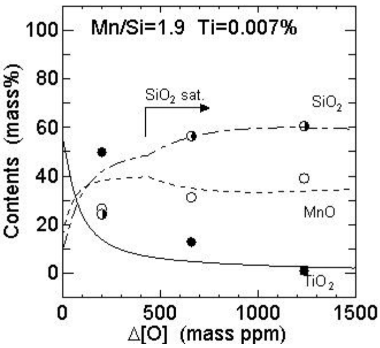


Figure 7: Comparison between calculated composition change of scum and experimental one in the case of steel with titanium

Figure 8 shows influence of titanium content on minimum oxygen input for solid SiO_2 precipitation. Oxygen input in practical casting was found to be about 300 or 400 ppm. So, we have to add titanium of 0.005 to 0.007%. In the plant experiments, generation of high melting point scum was avoided with 0.007% Ti addition to steel [5]. It has been found that the mathematical model is powerful for estimation of the composition of the scum and for the design of the steel composition to avoid high melting point scum.

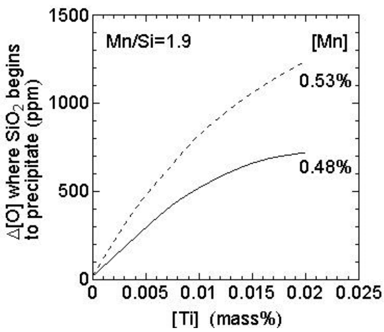


Figure 8: Influence of [Ti] content on minimum ΔO for solid SiO_2 precipitation in scum

CONCLUSIONS

In order to suppress the generation of high melting point SiO_2 rich scum (reoxidation product) that is harmful to surface quality of billet in continuous casting of low Mn/Si steel without shrouding, effect of addition of titanium in steel was investigated. From reoxidation experiment and mathematical modellng, following conclusions were drawn:

- Addition of small amount of titanium (<0.01%) in steel is very effective to prevent from generation of high melting point scum even in the case of large input of oxygen such as 200 ppm in non-shrouded casting.
- The mathematical model is powerful for estimation of the composition of the scum and for the design of the steel composition to avoid high melting point scum.

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