Mold Flux for High Speed Continuous Casting

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Abstract

The initial stage of solidification for continuous casting is very important in optimising the surface quality of steel, and it is well known that hypo-peritectic steel has problems with longitudinal cracking due to shrinkage resulting from the $\delta \rightarrow \gamma$ transformation. High speed continuous casting, with a speed range of 4-5m/min, suffers from the same problem, and in this study, the physical properties of a mold flux are discussed. In addition to this study, the mold fluxes for high speed continuous casting were developed in order to improve the surface quality of high speed casting. Thus, the results can be summarized as follows:

1)Viscosity, solidification temperature and surface tension of the mold flux can be calculated.

2) A high CaO/SiO_2 ratio mold flux with a low viscosity and a high solidification temperature is the most suitable for a slab caster.

key words:hypo-peritectic steel, continuous casting, high speed casting, mold flux, slab CC, longitudinal cracking

1.Introduction

The initial stage of solidification in continuous casting with regard to the surface quality of the steel and operation is very important. However, for high speed continuous casting, with a speed range of 4-5m/min, preventing break out and longitudinal cracking is very important. The character of the mold flux is affected significantly, and in this study, the physical properties of mold flux are discussed. In addition to this study, the mold fluxes for high speed continuous casting were developed.

2. Physical Properties of Mold Flux

The functions of the mold flux are 1)lubrication between solidified shell and mold surface, 2)medium for heat transfer, 3)thermal insulation and preventing re-oxidation and 4)absorption inclusion. In these functions, 1) and 2) are important for high speed casting because these two factors are related to casting operations. The effective physical properties for these functions are viscosity, surface tension and solidification temperature.

2·1 Viscosity

The viscosity of the mold flux is important for the flux in the gap between a solidified shell and a mold wall. In addition to this importance, the viscosity of the mold flux is a controllable property. Because the siliceous mold flux containing fluoride melts, its viscosity depends on a network structure. Iida et al proposed a network parameter [1], and several equations for viscosity using the network parameter [2) 3) 4)]. Therefore, it is possible to estimate viscosity with an arbitrary component by using these equations. However , these equations are not very useful, because they cannot give the necessary accuracy for estimating mold flux viscosity which should be $\pm$ 5% in a region that is under 0.1Pa·s. Estimating viscosity from an observed value is very beneficial, because these equations are based on experimental data of different composition. Equation (1) was obtained from Iida's equation, when μ_m was defined as an observed viscosity, and μ_n was defined as a new flux viscosity.

$$\log \mu_n = a_0 \{1/(a_1 - I_n) - 1/(a_1 - I_m)\} - \log \mu_{0n} - \log \mu_{0m} + \log \mu_m \quad \text{-----(1)}$$

I_m and I_n are anion cation interaction parameters, μ_{0n} and μ_{0m} are viscosities of hypothetical single molecular melt and μ_n and μ_m are viscosities of melt for each composition. Equation (1) consists of parameters which are determined by Equation (2) for arbitrary composition, so that the viscosity of the new flux is:

$$\mu_0 = 1.8 \times 10^{-7} \frac{(MT_m)^{1/2}}{V_m^{2/3}} \cdot \frac{\exp(H_\mu/RT)}{\exp(H_\mu/RT_m)} \quad \text{-----(2)}$$

$$H_\mu \equiv 5.06 \times T_m^{1.2}$$

M is molecular weight (kg), T_m is melting point (K), V_m is molar volume at melting point (m^3/mol) and R is gas constant (J/mol·K)

Fig.1, calculated from equation(1), shows the effect of additive content on the viscosity of mold flux.

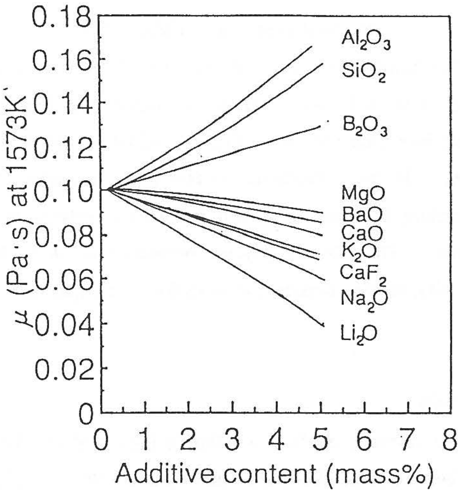


Fig.1 Effect of additive content on viscosity of mold flux.
(Base:SiO_2 37.7,CaO35.7,Al_2O_3 6.3,Na_2O 11.2,F9.1(mass%))

2·2 Solidification temperature

Solidification temperature of a mold flux is important for both lubrication and heat conductivity between a mold wall and a solidified shell. Generally, the solidification temperature of a mold flux is a break point determined by the viscosity measurement. These values are not liquidus and solidus temperatures but are the maximum temperature of fluid flow. The solid fraction at the maximum temperature of fluid flow is 0.49, and was determined by Mori and Ototake's equation [5]. It is possible to calculate the temperature with 0.49 solid fraction by using thermodynamics calculation [6]. Fig.2 shows the comparison of the temperature with 0.49 solid fraction calculated by ChemSage [6] and the observed solidification temperature measured by oscillating-plate viscometer. The calculated values agree with the observed values.

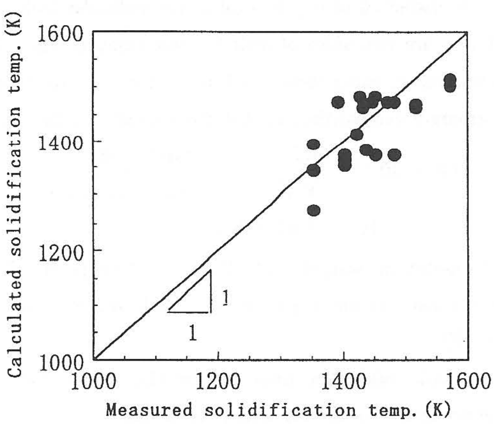


Fig.2 Comparison of temperature with 0.49 solid fraction calculated by ChemSage and an observed solidification temperature measured by oscillating-plate viscometer.

2·3 Surface tension

Surface tension is an important physical property for interface phenomenon between molten steel and molten flux in the mold. However, surface tension measurement of mold flux is very difficult. From a hard sphere model, the surface tension of simple liquid at its melting point depends on T_m and V_m [7], where T_m is melting point and V_m is molar volume at its melting point. Fig.3 shows the surface tension of molten oxides and fluorides as a function of $T_m \cdot R/V_m^{2/3}$. In the case of molten oxides and fluorides, they are in good relation, and it is possible to estimate surface tension by this relation.

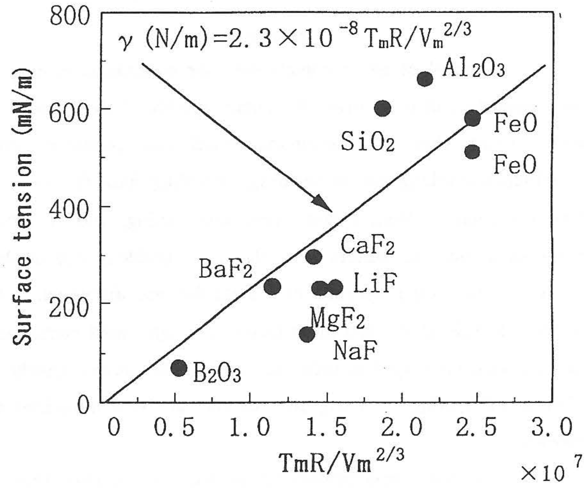


Fig.3 Surface tension of oxides and fluorides as a function of $T_m \cdot R/V_m^{2/3}$

3. Flux consumption

Flux consumption is an important factor of lubrication between the mold wall and solidified shell for preventing sticker break out. Fig.4 shows flux consumption as a function of casting speed. Generally, flux consumption decreases with increasing casting speed. The control factors of flux consumption are flux properties and casting conditions including mold oscillation. The flux consumption of developed mold fluxes, flux C and D, is higher than other fluxes, and the viscosity of these developed fluxes are lower. The viscosity of flux D for 5m/min casting speed is 0.02Pa·s at 1573K, and this flux has achieved 5m/min casting speed without sticker break out.

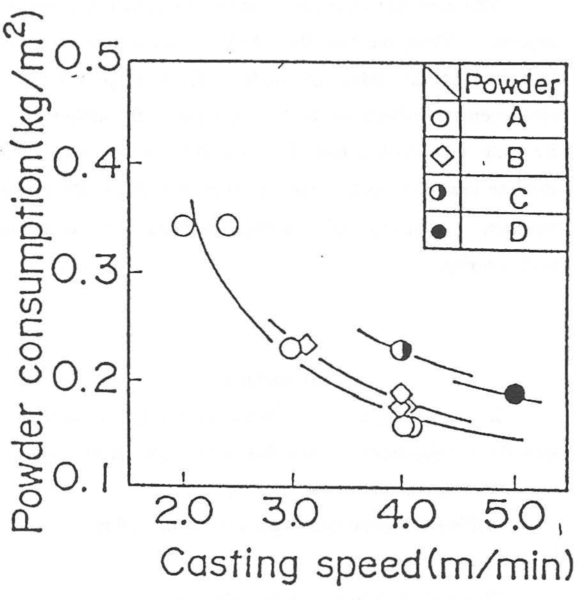


Fig.4 Flux consumption as a function of casting speed.

● (D):Improved flux for low carbon steel.

4. Preventing of longitudinal cracking

In high speed casting, longitudinal cracking occured in the steel surface. In order to prevent longitudinal cracking, it is customary to use a mold flux with a high solidification temperature where crystallization of cuspidine ($Ca_4F_2Si_2O_7$) has occurred [8]. Fig.5 shows the longitudinal cracking index as a function of heat flux in the mold [8]. It can be seen from this figure that longitudinal cracking occurred only when absolute values of heat flux exceeded certain critical values. However, these critical values are different for different steel grades.

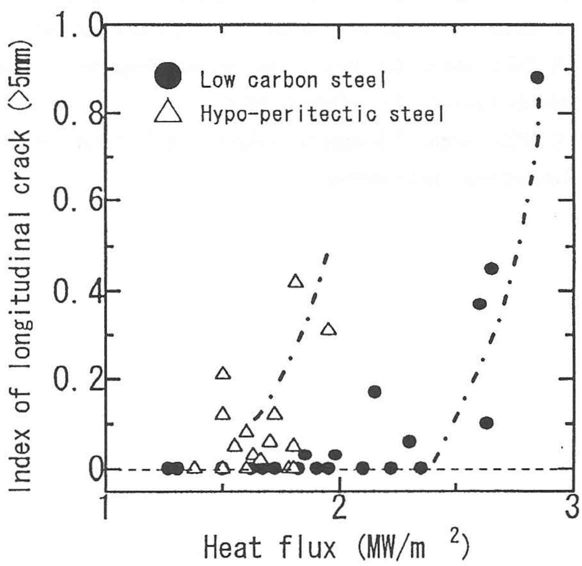


Fig.5 Longitudinal cracking index as a function of heat flux.

Fig.6 shows the longitudinal cracking index using a flux with a low solidification temperature. Longitudinal cracking occurred with a carbon range over 0.07mass%. This region agrees with the hypo-peritectic region. Fig.7 shows heat flux in the mold and the longitudinal cracking index as a function of solidification temperature. Heat flux decreases with increasing solidification temperature. The longitudinal cracking occurred using a mold flux with low solidification temperature.

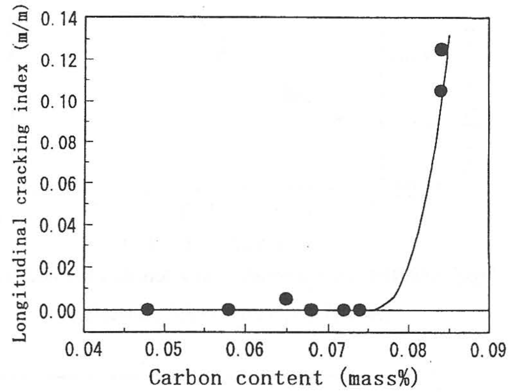
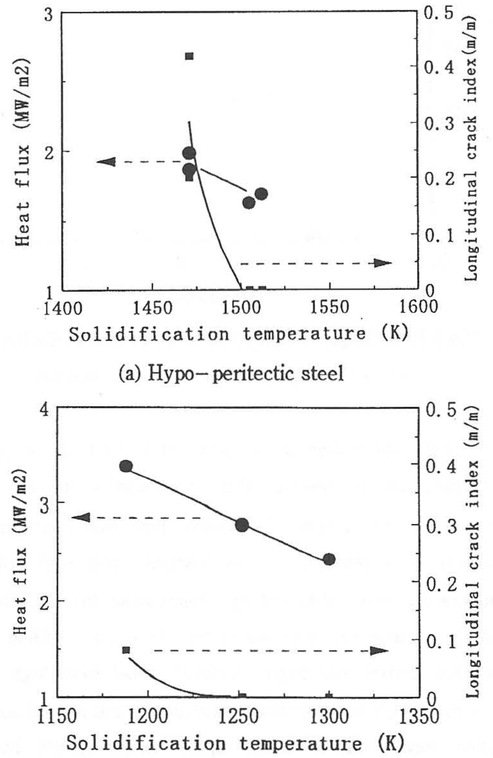


Fig.6 Longitudinal cracking index as a function of steel carbon content.



(a) Hypo-peritectic steel

(b) Low carbon steel

Fig.7 Longitudinal cracking index and heat flux as a function of solidification temperature of mold flux

These physical properties can be achieved by increasing the CaO/SiO_2 ratio. The relation between solidification temperature and CaO/SiO_2 ratio is shown in Fig.8. The relation between peak height of X-ray diffraction for cuspidine ($Ca_4F_2Si_2O_7$) and the CaO/SiO_2 ratio is shown in Fig.9.

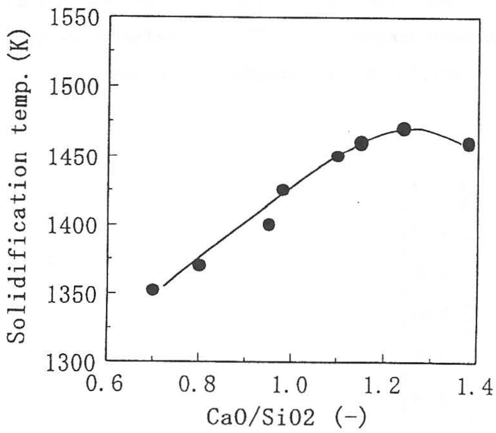


Fig.8 Solidification temperature as a function of CaO/SiO_2.
(Al_2O_3:6.3,Na_2O:8,F:8(mass%))

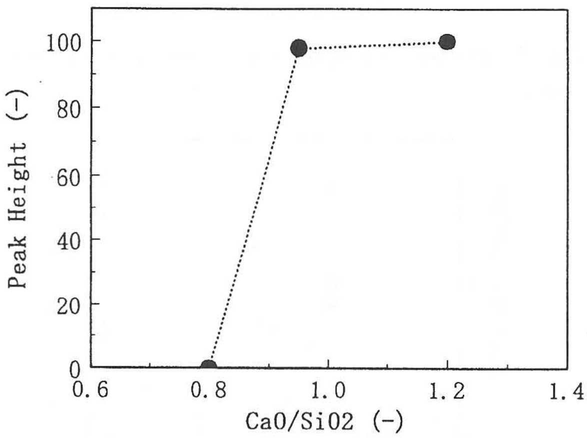


Fig.9 Peak height of cuspidine as a function of CaO/SiO_2
(Al_2O_3:4,MgO:8,Na_2O:8,F:8(mass%))

For mild cooling, a CaO/SiO2 ratio of 1.1-1.3 is adequate. For high speed casting, flux consumption is an important parameter, and in order to achieve high flux consumption, low viscosity is necessary. Low viscosity and high solidification temperature were obtained by 1)increasing the CaO/SiO_2 ratio and 2)increasing the contents of Na_2O and F. Mold fluxes for both low carbon and hypo-peritectic steel have high CaO/SiO2 ratio and a high solidification temperature, and mold fluxes for low carbon steel with a higher speed range should have lower viscosities and solidification temperatures.

The heat flux distribution of the horizontal direction is not uniform. Thus, the heat flux of the center is low, whereas the heat flux of the sides are high. It is suspected that this phenomenon results from the flow patterns of the molten steel. By using mild-cooling mold flux, it is possible to reduce both the absolute heat flux and the differences in heat flux of the horizontal direction. Longitudinal cracking decreases as a result of mild-cooling.

5.Conclusion

In this study, we have discussed principle factors involved with the development of mold fluxes for high speed casting. The results can be summarized as follows;

(1)Physical properties important for mold flux can be estimated.

(2)A high CaO/SiO_2 ratio mold flux with a high solidification temperature is the most suitable for slab casting.

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