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

EFFECT OF THERMAL PROPERTIES OF MOLD FLUX ON SURFACE QUALITY OF CONTINUOUSLY CAST SLAB

Hiroyuki Yasunaka*, Hiromu Matsuda and Katsuyoshi Matsuo****
***Iron and Steel Research Laboratories, Kobe Steel, Ltd. Japan**
****Kakogawa Works, Kobe Steel, Ltd. Japan**

Synopsis : To prevent surface cracks, which often appear in the continuously cast middle carbon steels, reducing and unifying the heat extraction of the mold is reported to be effective. Therefore, the apparent thermal conductivity of the mold flux was measured, which influences the heat transfer to a large extent. The apparent thermal conductivity in the liquid state was about five times larger than that of the solid state, because it is expected that the heat extraction of the mold is reduced by using the mold flux of high solidification temperature.

Surface quality of continuously cast middle carbon steels was much improved by using the mold flux of high solidification temperature.

Key words : continuous casting, middle carbon steel, thermal conductivity, mold flux, heat extraction, longitudinal crack

1. Introduction

In the continuously cast middle carbon steels, the carbon content of which is between 0.08~0.16%, surface cracks often appear because uneven solidification easily occurs.[1)]

To prevent these cracks, reducing and unifying the heat extraction of the mold is reported to be effective.[2)] Therefore, the heat transfer phenomenon between the mold and solidified shell was investigated,[3)] and the apparent thermal conductivity of the mold fluxes was measured, which influences the heat transfer to a large extent. Based on these results, the effect of the mold fluxes on the heat extraction of the mold and surface cracks formation was investigated. Here, the apparent thermal conductivity consists of thermal (phonon), radiative and convectional conduction.

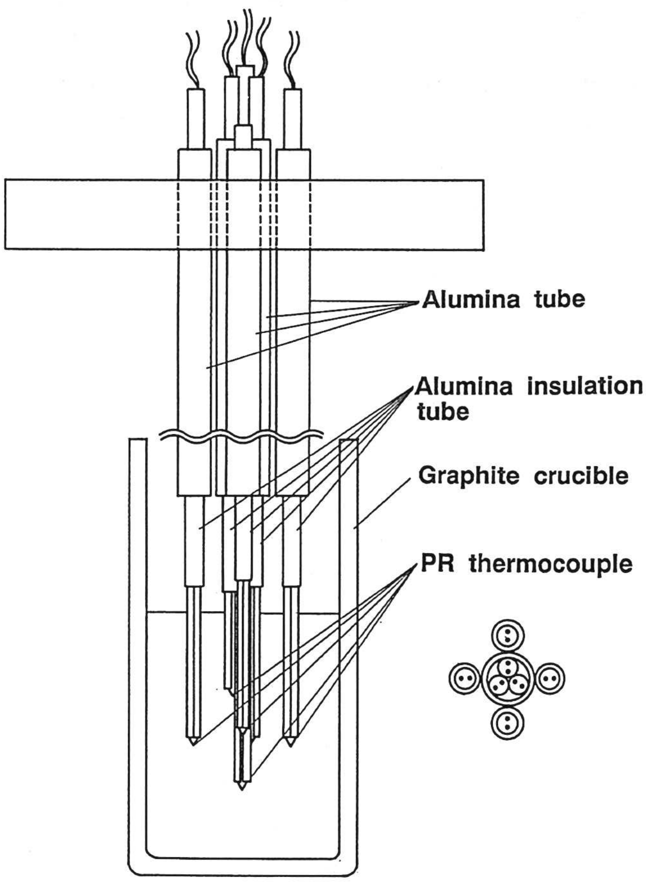

Fig.1 Experimental apparatus

2. Apparent thermal conductivity of mold flux

The heat extraction near the meniscus in the mold was much influenced by the heat transfer through the flux film between the mold and the solidified shell, because the apparent thermal conductivity of the mold flux was measured.

Various kinds of the mold fluxes were melted in a graphite crucible by using a high frequency induction heater. A temperature measurement probe composed of seven thermocouples was immersed into the melt at about 1600K as shown in Fig.1, and the temperature changes during cooling were measured.[4)]

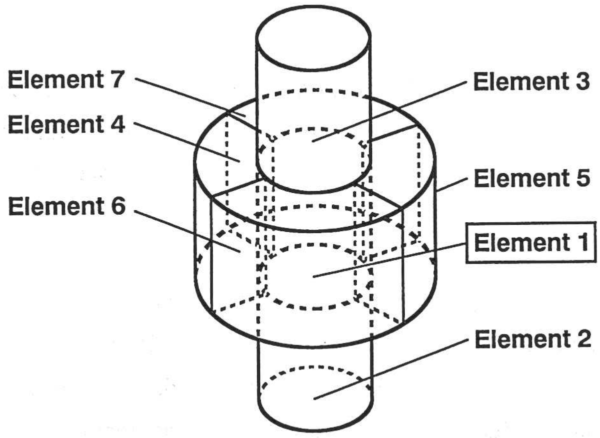

Fig.2 Schematic representation of volume element

The apparent thermal conductivity was calculated by using the finite differential method. A volume around the probe was assumed and was divided into seven volume element, as shown in Fig.2. The thermocouples were located at the center of each volume element. Fourier's thermal conduction equation (1) could be applied for volume. If the temperature in each volume element was constant, heat flow from element 1 to element i was given by equation (2), and accumulated heat in element 1 was expressed by equation (3). The apparent thermal conductivity λ was calculated by using equation (4), which was obtained from equation (2) and (3) by considering the heat balance for element 1 at the center of the volume.

• Fourier's differential equation

$$\frac{\partial T}{\partial t} = a \cdot \nabla^2 \cdot T \qquad (1)$$

• Heat flow from element 1 to element i

$$q_i = \lambda \cdot S_i \cdot (T_I - T_1) / \Delta X_i \qquad (2)$$

• Accumulated heat in element 1

$$Q = \rho \cdot Cp \cdot V_1 \cdot (T_1' - T_1) / \Delta t \qquad (3)$$

• From heat balance

$$\lambda = \rho \cdot Cp \cdot V_1 \cdot (T_1' - T_1) / \Delta t \quad \Sigma S_i \cdot (T_i - T_1) / \Delta X_i \qquad (4)$$

T : Temperature
t : Time
a :Temperature conductivity
λ :Apparent thermal conductivity
S_i :Surface area of element i
V_i :Volume of element i
ΔX_i : Distance between thermocouple 1 and i
ρ :Density
Cp : Specific heat

Physical properties of the mold fluxes used for experiments were shown in Table 1. Basicity and solidification temperature of the mold fluxes changed in the range of 0.99~1.57 and 1253~1433K, respectively.

Fig. 3 shows a typical experimental result. The solidification temperature of this mold flux was about 1410K. The apparent thermal conductivity of the mold fluxes decreased sharply near the solidification

Table.1 Physical properties of mold fluxes

mold flux	wt. % CaO	wt.% SiO_2	CaO/SiO_2	Solidification temperature (K)	viscosity at 1573K (Pa·s)
A	39.0	31.8	1.23	1253	0.06
B	38.1	38.5	0.99	1353	0.14
C	46.5	29.7	1.57	1353	0.04
D	43.8	32.6	1.34	1413	0.06
E	37.6	31.6	1.19	1433	0.11

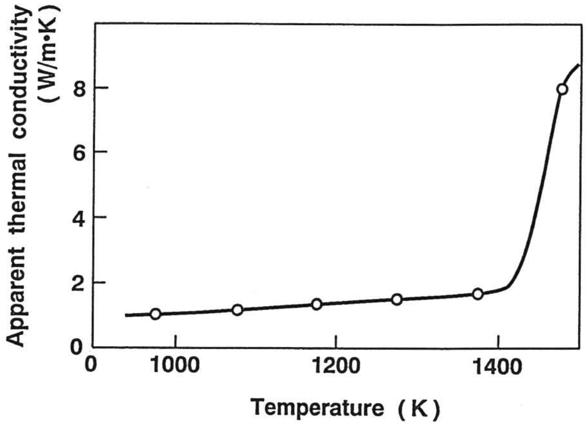

Fig.3 Effect of temperature on apparent thermal conductivity of urold flux

temperature, though it decreased slightly in the solid state. It was confirmed that the apparent thermal conductivity of the liquid mold flux is about five times larger than that of the solid mold flux.

Therefore, it is expected that thickness of the solidified mold flux film between the mold and solidified shell is increased, and heat extraction is reduced by using the mold flux of high solidification temperature.

3. Thickness of mold flux film during casting

To analyze the heat transfer phenomenon through the mold flux film, it is necessary to know the thickness of mold flux film during casting. Then, tracer mold flux, which contains BaO, was added into the mold during casting, as shown in Fig. 4. The mold flux films were collected from the mold wall surface, and EPMA line analysis was carried out along the cross section of the mold flux films. A sharp Ba intensity change was found in the mold flux film, and a high Ba intensity range was considered to be liquid state during casting.

Fig. 5 shows the thickness of the solid and liquid layer of the mold flux film obtained by EPMA line

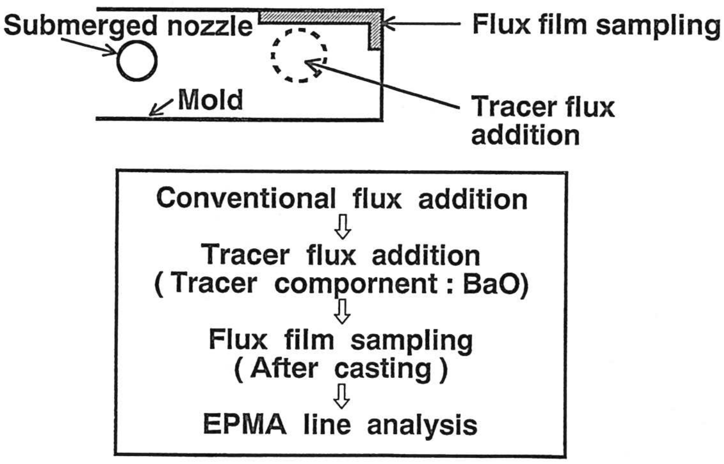

Fig.4 Procedure of tracer flux test

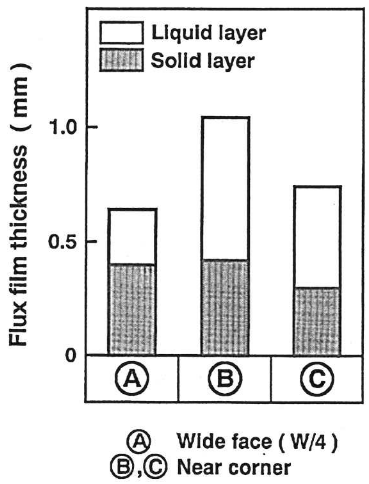

Fig.5 Liquid and solid layer thickness of mold flux film

analysis. Total flux film thickness was about 0.7mm, and solid flux film thickness was 60~70% of total thickness at the position of 1/4W of the mold.

4. Heat transfer analysis through the mold flux film

The effect of solidification temperature of mold fluxes on heat flux at the meniscus was calculated by using a two dimensional finite element method based on the model shown in Fig.6. The main boundary conditions used for calculation were as follows. Molten steel temperature : 1793 K. Total flux film thckness : 0.7 mm. Thermal conductivity of liquid mold flux : 8.4 W/m•K. Thermal conductivity of solid mold flux : 1.4 W/m•K. Copper plate thickness : 10 mm. Cooling water temperature : 303 K.

The effect of the solidification temperature of the mold flux on the calculated heat flux and the ratio of the solid layer in the mold flux film is shown in Fig.7. The ratio of the solid layer in the mold flux film increased, and then heat flux decreased with an increase of solidification temperature of the mold flux.

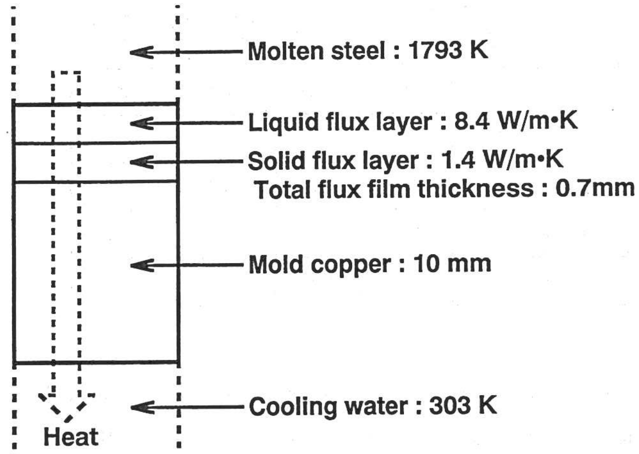

Fig.6 Boundary conditions for heat transfer analysis

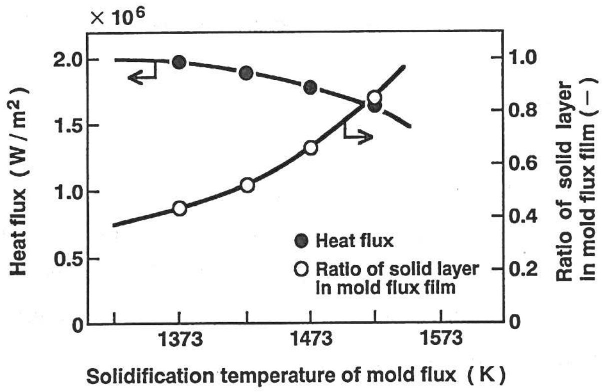

Fig.7 Effect of solidification temperature of mold flux on heat flux and ratio of solid layer

5. Continuous casting tests

Continuous casting tests were carried out to confirm the effect of the solidification temperature of the mold flux on heat extraction phenomenon of the mold and surface quality of cast slab. Fig.8 shows the position of installed thermocouples in the mold copper plate. 18 and 3 thermocouples were installed in the wide face and narrow face of the mold, respectively, and the distance from the copper plates surface to the thermocouple tips was 15 mm. Physical properties of the mold fluxes used for the

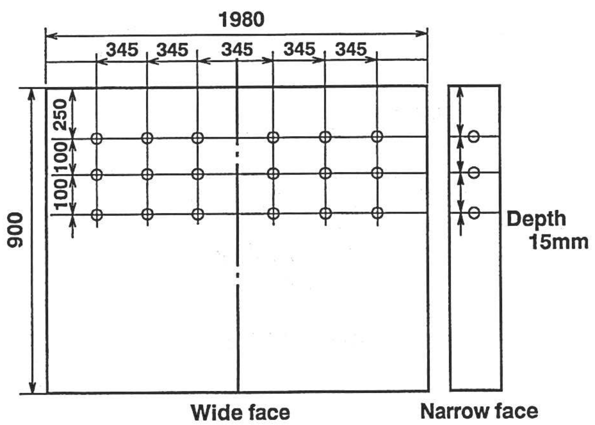

Fig.8 Positions of installed thermocouples in mold copper plate

continuous casting tests were shown in Table 2. The viscosity of the mold fluxes was equal, and the solidification temperature was changed from 1381 K to 1473 K.

Table.2 Physical properties of mold fluxes

mold flux	CaO/SiO_2	Viscosity at 1573 K (Pa•s)	Solidification Temperature (K)
F	1.15	0.05	1381
G	1.24	0.05	1420
H	1.32	0.05	1473

Fig.9 shows the influence of the solidification temperature of the mold flux on the copper plates' temperature during casting. The three lines of the lower part in Fig.9 show temperatures of the wide face copper plate at 150 mm below the meniscus, and the line of the upper part is

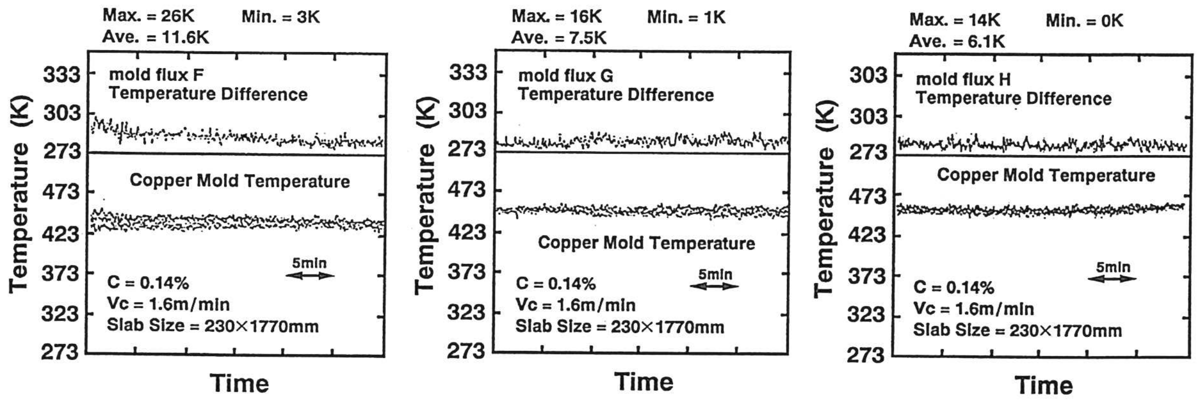

Fig.9 Influence of solidification temperature of mold flux on copper plate temperature measured at 150mm below meniscus.

the temperature differences among the three. The maximum temperature difference was 26 K when the mold flux of low solidification temperature (mold flux F) was used, but it decreased to 14 K by using the mold flux of high solidification temperature (mold flux H) . It is considered that soft cooling at near the meniscus was obtained by using the mold flux of high solidification temperature, and the contact between the mold and solidified shell was unified, because copper plates, temperatures along the wide direction could be unified.

Fig.10 shows the influence of the

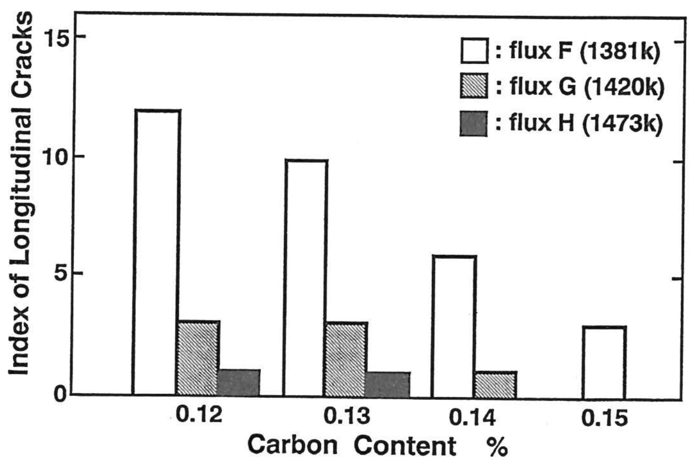

Fig.10 Influence of mold flux on longitudinal cracks formation

mold flux on the longitudinal cracks formation. The longitudinal cracks decreased and surface quality of cast slab was much improved by using the mold flux of high solidification temperature.

6. Conclusions

(1) The apparent thermal conductivity of the mold flux was measured, and it was confirmed that the apparent thermal conductivity in the liquid state was about five times larger than that of the solid state.
(2) The mold temperature fluctuations were decreased and surface quality of cast slab was much improved by using the mold flux of high solidification temperature.

References

(1) Y.Sugitani, and M.Nakamura : Tetsu to Hagane, 65, (1979), P1702
(2) T.Kobayashi, K.Matuo, J.Abu, S.Saruhashi : H.Matuda, and K.Ebina : CAMP–ISIJ, Vol.5, (1992), 208
(3) S.Ohmiya, K.Tacke, and K.Schwertfeger : Iron making and Steel making, 10 (1)(1983)P24
(4) K.Ogino, A.Nishiwaki, and T.Inoue : Proc. of 8th Japan Symp on Thermophys. Prop.