Electromagnetic sensor just below CC mold by using magnetic transformation of steel

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Abstract
Electromagnetic sensor to detect the unbalanced flow in CC strand by using the magnetic transformation just below CC mold has been proposed, noticing that the narrow face of slab has been cooled below Curie temperature at the beneath of mold. As preliminary experiments, laboratory experiments have been performed to clarify the relationship between the temperature and induced electric voltage, when AC magnetic field has been imposed on the slab surface. Moreover, plant tests have been conducted by installing the sensor just below the narrow face of mold to show that the proposed sensor could measure surface temperature under severe conditions and detect the unbalanced flow in CC strand.

Key words : magnetic transformation, Curie point, continuous casting, unbalanced flow, solidification

Introduction

Molten steel flow in CC mold largely affects the cast slab quality and the productivity of CC. As shown in Fig.1, unsymmetrical discharged flow from submerged entry nozzle causes unbalanced flow in CC strand and local remelting of solidified shell at the impinging points of the discharged flow. Additionally, the unbalanced flow leads to the entrapment of mold powder at meniscus and the inner defects due to deeply transported Ar bubbles. Therefore, suitable control of the discharged flow and the entire flow pattern in CC strand are necessary. At the same time, the detection of the unbalanced flow becomes important in order to escape from serious casting troubles and slab defects. Several detection methods of the unbalanced flow in CC mold have been reported [1] [2]. However, it is impossible to directly detect the unbalanced flow in CC strand. In this study, noticing that the unbalanced flow forms the large differences of surface temperature of slab just below the mold, and that strong cooling beneath the mold causes magnetic transformation of steel, the electromagnetically detecting methods of unbalanced flow in CC strand have been developed.

The principle of electromagnetic sensor and laboratory experiment for verification

In the continuous casting of slab, wide face of slab is supported with many rolls at CC strand. On the contrary, narrow face of slab is only supported with some rolls at the beneath of mold and is cooled with a large amount of water to suppress the bulging. Therefore, slab surface temperature of narrow face rapidly drops and then increases at the beneath of CC mold as shown in Fig.2. At that time, slab surface temperature passes through Curie point (Tc), which is magnetic transformation temperature. Fig.3 shows the principle of the proposed electromagnetic sensor. When AC magnetic field is applied normal to the slab surface, the distribution of magnetic field in the slab is dependent of magnetism of slab surface. When surface temperature (Ts) is higher than Tc, the distribution of magnetic field line is the same as the one in vacuum. On the contrary, when Ts is lower than Tc, the applied magnetic field is concentrated on the surface, this causes the big distortion of magnetic field. This change of magnetic field line is governed by the magnetism of slab surface, in other words, slab surface temperature. By measuring the induced electric voltage due to the change of imposed magnetic field line, surface temperature is presumed in this sensor.

The sensor is composed of primary coil and secondary coil. A set of coils is mounted into the cylinder made of stainless steel. AC electric current of 1.5 Hz is supplied to primary coil by using a constant current power amplifier, AC magnetic field is imposed normal to the slab surface. The noise in secondary coils is minimized with low pass filter of 5Hz. Moreover, only the signal with 1.5Hz component is elucidated by using Lock in amplifier.

First of all, laboratory experiment has been performed to clarify the relationship between sensor signals and surface temperature of slab. Slab samples are inserted into a heating furnace and heated into 1350 degree. A thermocouple is inserted into the slab, in which the position is 1mm from the surface of slab. After extraction of the heated slab, aforementioned sensor is set on the heated samples and the relationship between induced electric voltage of secondary coils and surface temperature of slab has been investigated. Fig.4 shows the typical example of the obtained results. It can be found that the induced electric voltage is almost constant in high temperature and low temperature region. On the contrary, the electric voltage changes with temperature around Curie temperature. This relationship between the electric

voltage and temperature can be expressed by using polynomial approximation. By using this relationship, surface temperature at the beneath of CC mold can be presumed.

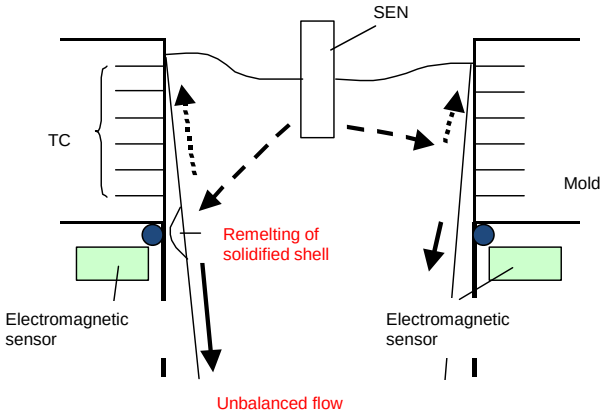


Fig.1: Schematic view of unbalanced flow in CC strand.

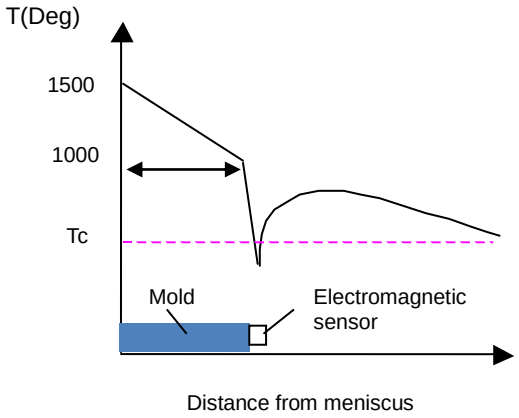


Fig.2: Schematic view of the surface temperature profile at the narrow face of slab.

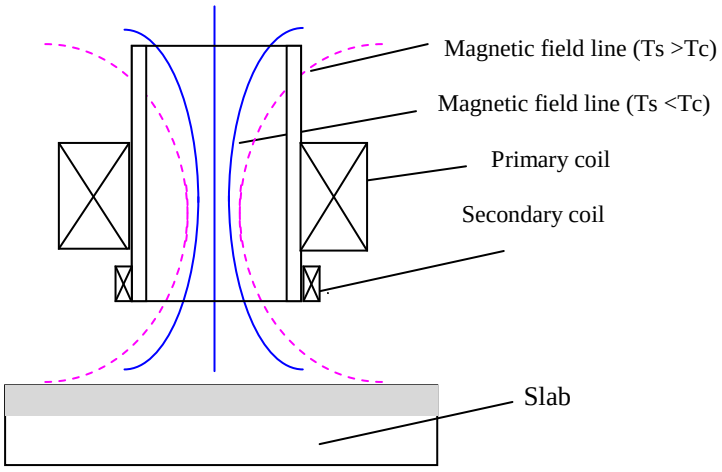


Fig.3: Schematic view of electromagnetic sensor and the change of magnetic field line due to magnetism of slab surface.

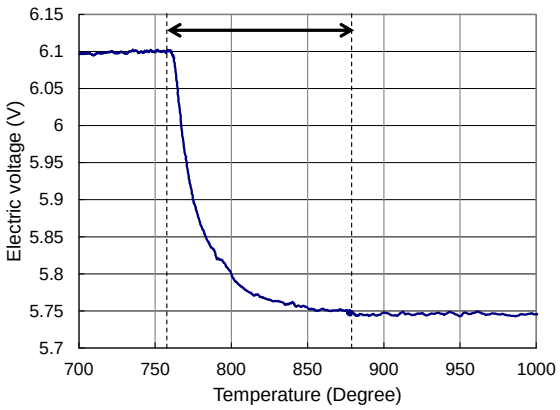


Fig. 4: Relationship between slab surface temperature and induced electric voltage of secondary coil.

Plant test for verification of the proposed sensor

A pair of sensor was installed under the respective narrow face of mold at bending type of continuous casting machine and plant tests have been performed to investigate the effects of casting conditions on the sensor signals. Table 1 shows the casting conditions. Fig.5 shows the time-change of sensor signals, when flow rate of water spray changes. In Fig.5, high electric voltage is equivalent to low surface temperature and low electric voltage is equivalent to high surface temperature. It can be seen that the electric voltage rapidly changes with correspondence of water flow rate. This results shows that the proposed sensor can be utilized to measure surface temperature of slab just below CC mold. Fig.6 shows the successive change of surface temperature at both narrow faces in sequential casting. In **Fig.6 (a)**, which 1st ladle and 2nd ladle data are plotted, most plots are concentrating at the lower left corner of a chart. It can be confirmed that stable casting has proceeded. On the contrary, it can be seen that temperature fluctuation and unsymmetrical distribution becomes marked with progress of cast as shown in Fig.6 (b). In this condition, nozzle clogging gradually proceeds and surface level fluctuation becomes marked in the latter part of cast. This means that nozzle clogging unstabilizes the discharged flow and forms the unbalanced flow in CC strand. Moreover, it is confirmed that the proposed sensor can directly measure surface temperature of cast slab to detect the unbalanced flow in CC strand.

Table1 Casting conditions of plant test

Slab width	1000～1800mm
Casting speed	0.75～1.2m/min.
Steel grade	Middle Carbon Al-killed steel, Low Carbon Al-killed steel, IF steel
Sensor position	(i)Vertical position: just below the narrow face of mold (ii)Distance between sensor and narrow face of slab : 30mm

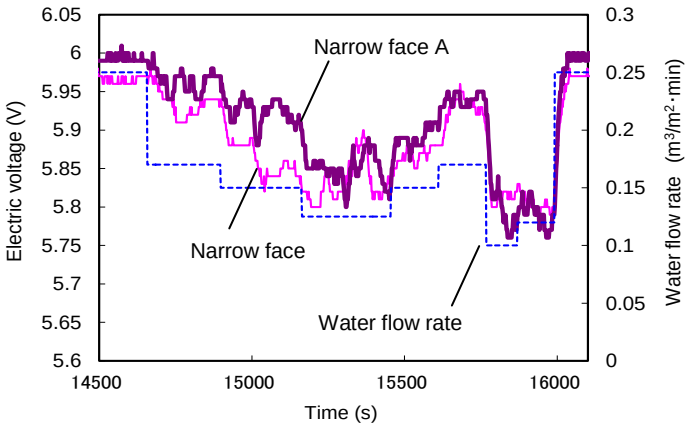
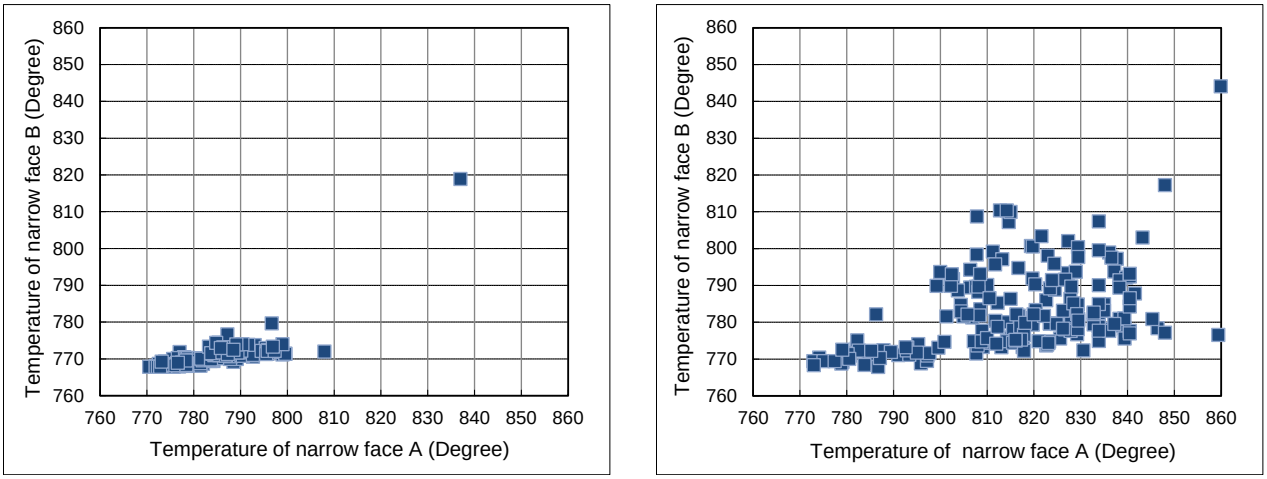


Fig.5: Successive change of sensor signals in the condition which water flow rate of spray at narrow face changes.



(a) (b)

Fig.6: Successive change of surface temperature at both narrow faces in the sequential casting. (a) Former part of cast data and (b) latter part of cast data are plotted.

Conclusions

Electromagnetic sensor to detect the unbalanced flow in CC strand by using the magnetic transformation just below CC mold has been proposed. The obtained results are summarized as follows:

(1) Noticing that the narrow face of slab has been cooled below Curie temperature at the beneath of mold, the sensing method to measure the change of imposed AC magnetic field due to slab surface temperature, has been constructed.

(2) After obtaining the relationship between the temperature and sensor signals at laboratory experiments, plant tests have been performed by installing the sensor under the respective narrow face mold to show that the proposed sensor could measure surface temperature under severe conditions and detect the unbalanced flow in CC strand.

References

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