## Steel Flow Control in Continuous Slab Caster Mold by Traveling Magnetic Field

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Steel flow control in a continuous slab caster mold is effective for preventing mold powder entrapment and maintaining high slab quality. NKK has developed steel flow control technology that utilizes a traveling magnetic field to optimize the flow of steel in the mold from the start to the end of casting. This paper describes the features of this technology.

## 1. Introduction

Continuous casting is a liquid to solid phase transformation process. Fundamental characteristics of the final steel products are established during this process. Cleanliness of the steel is one of the critical variables that is determined in this process. In recent years, the casting speed has been continuously increased to raise production efficiency, but this has also increased the density of kinetic energy of the molten steel in the continuous caster mold. The increase in kinetic energy tends to cause non-uniform growth of the solidified shell in the mold and promotes entrapment of non-metallic inclusions into the molten steel. Accordingly, control of the molten steel flow in the mold has become an important technology to prevent operational problems such as breakout and to stabilize the continuous caster operation. Steel flow control is also important for reducing quality defects and improving the quality and yield of the final products.

Two types of technology are combined to control the molten steel flow in the mold<sup>1),2)</sup>: the first is technology for estimating or detecting the state of molten steel flow in the mold, while the second is

## 2. Objective of controlling molten steel flow in mold

Mold powder that is trapped in molten steel during continuous casting becomes non-metallic inclusions in the steel. The main objective of the study was to find a way to prevent mold powder from being entrapped in the molten steel and caught in the solidified shell.

Mold powder tends to be trapped in the molten steel when the flow speed of the molten steel in the mold is increased. Many papers have been published with regard to this phenomenon<sup>6)-9)</sup>. Model experiments indicate that the

netic force on the molten steel innthe isouts of the interimentation of the molten possibility for flexibly controlling mubilel produter stand that the vortexes generated at the mewithout being subjected to these limitationsnay cause entrapment. The critical molten steel This paper describes the effect offlorom/melbinity theorem them meniscus (meniscus flow velocity) steel flow in the mold of a continueus/sliath casturaphyeousistents has been reported to be 0.13 to a traveling magnetic field generator. and the results of a study where this technology was applied to a commercial facility. \_1\_

thickness direction, as shown in the figure. In the EMLS mode, the magnetic flux travels from the narrow side of the mold toward the submerged entry nozzle, while the flux trav.6(e narrdmo1Tlt)12.8(t)3.8(h)-oppoow s12.8(e)3.8(cdw)5(srec.8(gnet)3.8(on(e narrdmo1Tlt)12.8(t)3.8(h)-1.5(e3(LA Tw[n

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Fig.8° Change of time-averaged meni

EMLS is applied. This is probably because the molten steel in the mold is driven by the traveling magnetic field of the EMLS to converge in the vicinity of the submerged entry nozzle, head upward to The velocity change  $u_2$  from  $u_0$  to  $u_2$ , which results from the compounding of  $Q_1$  and  $Q_2$ , is proportional to the impulse of the collision between  $Q_1$  and  $Q_2$ . The collision time of  $Q_1$  and  $Q_2$  is assumed to be inversely proportional to the relative velocity ( $u_0 + u_R$ ), and the force is assumed to be a drag acting between  $Q_1$  and  $Q_2$  and proportional to ( $u_0 + u_R$ )<sup>2</sup>. The impulse is then proportional to ( $u_0 + u_R$ ). Therefore, if  $u_0$  is constant, the value of t is proportional to  $u_R$ . As a result, the velocity change rate  $r_2$  resulting from the second braking effect is expressed by Eq.(6).

$$r_{2} = u_{2}/u_{0}$$
  
 $u_{R}/u_{0}$   
 $r_{R}$   
 $L_{e}/w) B^{2}$  (6)

 $\ddot{}$  Consequently, considering that both the first and second braking effects are simultaneously imposed by the application of EMLS, the combined braking effect R by EMLS is expressed by Eq.(7), where u<sub>e</sub> is the meniscus flow velocity while EMLS is applied.

 $\sim$  The coefficient (  $^{2}$  L L<sub>e</sub>)/w of the term B<sup>4</sup> has a value that is inherent to each continuous caster and magnetic field generator and is expressed by . Then, Eq.(7) can be rewritten as Eq.(8).

$$\tilde{R} = 1 - B^4 / v_0$$
 (8)

<sup>•</sup> Using the result obtained from the measurements at the commercial facility as shown in **Fig.9**, the value R was plotted against the values of  $B^2/v_0$  and  $B^4/v_0$  on the horizontal axis, as shown in **Figs.13**(a) and (b). The value of v used here was obtained from the measurements of the 1/3-scale water model of the commercial facility that has Fluid number similarity. **Fig.13**(a) has the value of  $B^2/v_0$  on the horizontal axis and assumes only the braking effect by  $r_1$  derived from Eq.(4). The graph shows no proportional relation. It is easily foreseen that the relation will not be proportional even when the value on the horizontal axis is changed from  $B^2/v_0$  to  $B^2/w$ . Therefore, the braking effect of EMLS on the meniscus flow velocity does not appear to be governed solely by either the first or the second braking effect. The braking effect is also not described

by the simple sum of these two braking effects. On the other hand, plotting R against  $B^4/v_0$  in accordance with Eq.(8) provides a good linear relation, as shown in **Fig.13**(b). Therefore, the braking effect of EMLS on the meniscus flow velocity can be expressed by the product of the first and second braking effects. Thus, measurements at the commercial facility confirmed that the EMLS meniscus flow braking effect is described by the product of the first and second braking effects and is proportional to the fourth power of the magnetic flux density of the applied magnetic field.

## Fig.13<sup>\*</sup> Relationship between EMLS braking ratio and two parameters for analyzing EMLS effect

**Fig.14** shows values of the EMLS braking effect coefficient <sup>°</sup> derived from the measurements at the commercial facility where molds of various widths were used with different submerged entry nozzle spouting angles. The value of <sup>°</sup> is proportional to the mold width for a downward spouting angle of 25 degrees. This presumably comes from the fact that the length in the mold width direction (where the magnetic field generator faces the molten steel) increases with increasing mold width, thus enhancing the contributions of both  $r_1$  and  $r_2$ . The value of

can be obtained for specific mold width and other casting conditions by using this proportional relation. The value of *is* smaller when the spouting angle is 45 degrees than when it is 25 degrees for the same mold width. The likely reason is that, when the spouting angle is Steel Flow Control in Continuous Slab Caster Mold by Traveling Magnetic Field

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