Electromagnetic effects on multi-phase flow in the slab casting mold- plant measurements

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Schematic of Nail Board Set

Diameter of STS nail: 5mm

Diameter of SEN: 140mm
Position of Nail Board in a Mold

Stainless steel rods to keep the level of nail board

Fixed outer cover of mold

Inner cover region which is affected by mold oscillating

Mold top

Solid flux layer

Liquid flux layer

Molten steel

Wood nail

Aluminum nail

STS nail

Mold

Wood nail board

Stainless steel rods to keep the level of nail board

250mm

Distance from nail board plate

Height of skull

Diameter of knob

Direction of flow

Definition of Measurement

Inner diameter = 5mm

Outer diameter

Height of inner skull

Height of outer skull

Diameter of knob

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Calculation Surface Horizontal Velocity Magnitude from Height of Skull

\[ x : \text{Height of skull (mm)} \]
\[ y : \text{Horizontal velocity (m/ sec)} \]

1) \[ 0 \leq x < 1.6 : y = \frac{1}{8} x \]
2) \[ 1.6 \leq x < 5 : y = \frac{x + 5.2}{34} \]
3) \[ 5 \leq x < 8.8 : y = \frac{x + 6.4}{38} \]

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Conditions of Nail Board Tests

1. Steel grade: Ultra low carbon steel \(( [C] < 0.01 \%)\)
2. Slab size: 250mm(Thickness) \( \times \) 1300mm(Width)
3. System of controlling flow: Slide gate
4. Casting speed:

<table>
<thead>
<tr>
<th></th>
<th>FC off</th>
<th>FC on</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008-1 test</td>
<td>1.64m/min</td>
<td>1.70m/min</td>
</tr>
<tr>
<td>2008-2 test</td>
<td>1.64m/min</td>
<td>1.64m/min</td>
</tr>
<tr>
<td>2008-3 test</td>
<td>1.70m/min</td>
<td>1.70m/min</td>
</tr>
</tbody>
</table>

5. Flow rate of Argon gas: 9.2L/min (Injection is done in gas channel of UTN)
6. Condition of FC:

<table>
<thead>
<tr>
<th></th>
<th>FC OFF</th>
<th>FC ON</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper</td>
<td>0 A</td>
<td>300 A (DC)</td>
</tr>
<tr>
<td>Lower</td>
<td>0 A</td>
<td>300 A (DC)</td>
</tr>
</tbody>
</table>

7. Time of measurement:

<table>
<thead>
<tr>
<th></th>
<th>Dipping</th>
<th>Interval of each test</th>
<th>Interval between FC off and on</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3 sec</td>
<td>1 min</td>
<td>5~10 min</td>
</tr>
</tbody>
</table>
Comparison of Meniscus Level between FC off and FC on

- Averaged meniscus level is higher with FC.
  (inside: 3.2mm, outside: 3.7mm)
- FC induce the surface level flatter.

<table>
<thead>
<tr>
<th>Meniscus Level (mm)</th>
<th>Average</th>
<th>Stdev by distance (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outside</td>
<td>97.4</td>
<td>4.4</td>
</tr>
<tr>
<td>Inside</td>
<td>99.9</td>
<td>5.3</td>
</tr>
</tbody>
</table>

- Meniscus level fluctuation with time (sloshing)
- Cycle: at least 3 time intervals (3min)
Level Variation with FC ON (2008-3)

- Meniscus level fluctuation with time (sloshing)
- Cycle: at least 2 time intervals (2 min)

Comparison of Level Variation between FC off and FC on

- With FC off, level variation is towards SEN.
- With FC on, level variation is severe at the region near NF and SEN compared with center of mold
- With FC on, outside level is stable

<table>
<thead>
<tr>
<th>Stdev by time</th>
<th>FC OFF</th>
<th>FC ON</th>
</tr>
</thead>
<tbody>
<tr>
<td>INSIDE</td>
<td>5.1</td>
<td>5.6</td>
</tr>
<tr>
<td>OUTSIDE</td>
<td>6.0</td>
<td>5.0</td>
</tr>
</tbody>
</table>

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Characteristic of level variation with FC

Cycle: at least 3 time intervals (3min)
Stdev by distance (mm): 7.7
Stdev by time (mm): 5.5

Cycle: at least 2 time intervals (2min)
Stdev by distance (mm): 5.7
Stdev by time (mm): 5.3

<table>
<thead>
<tr>
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<th>High amplitude</th>
<th>Low frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>FC on</td>
<td>Low amplitude</td>
<td>High frequency</td>
</tr>
</tbody>
</table>

Flow pattern variation with FC off, on (2008-2)

- Double roll flow pattern
- Transient flow pattern
- Chaotic flow near SEN
- Generally towards SEN (double roll flow pattern)
- Transient flow pattern
- Diagonal cross-flow mainly towards inside radius
- Chaotic flow near SEN

- Surprisingly! similar flow trends, variations, and magnitudes as with FC off

Flow pattern variation with FC off (2008-3)
Quantification of Averaged Surface Velocity Vector

**Splitting velocity magnitude into x,y components**

**Averaging each velocity component in the same nail**

**Determining the flow direction from information of velocity components**

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Comparison of Flow Pattern Variation

**Comparison of Flow Pattern Variation**

- **< 2008-2 >**
- **< 2008-3 >**
- **< AVG >**
- Electromagnetic force affects the flow toward SEN and change the distribution of rising argon gas on surface.
- With FC on, more argon gas rising to region near SEN could make the surface flow symmetrical.
- With FC on, turbulent kinetic energy of argon gas rising to region near SEN make the flow near SEN faster.

### Influence of FC on Velocity Components

#### Horizontal Velocity Components

- Electromagnetic force affects the flow toward SEN (velocity x component).
- Argon gas rising to the surface near SEN affect the surface flow.
- The surface flow without FC is affected by rising argon gases and slower toward SEN.
- Distribution of argon gas at surface could be affected by FC.
- Flow is mainly from OR to IR (+), especially with EMBr.
Influence of FC on Slag Pool Depth

- With FC off, Slag pool thickness of outside is thicker than inside
- With FC off, Slag pool thickness is thicker than FC on
  (More bubbles surrounded by molten steel could enter the interfacial zone between steel and slag phases.)

Effect of FC on meniscus level:
- Meniscus level is transient by time (sloshing)
- Averaged meniscus level is higher with FC
- FC makes the surface level flatter
- FC make outside level more stable
- Level variation is more at the region near SEN with FC off
- Level variation at the region near narrow face and SEN is higher than center of surface with FC
- Characteristic of level variation with FC

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<tr>
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<td>High frequency</td>
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</tbody>
</table>

Summary
Summary

Effect of FC on surface flow velocity:

- Electromagnetic force affects the flow toward SEN and changes the distribution of rising argon gas on surface.
- More argon gas rising to the region near SEN could induce the symmetrical surface flow to WF

Effect of FC on slag pool:

- With FC off, Slag pool thickness of outside is thicker than inside
- With FC off, Slag pool thickness is thicker than FC on:
  (More bubbles surrounded by molten steel could enter into the interfacial zone between steel and slag phases)

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