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

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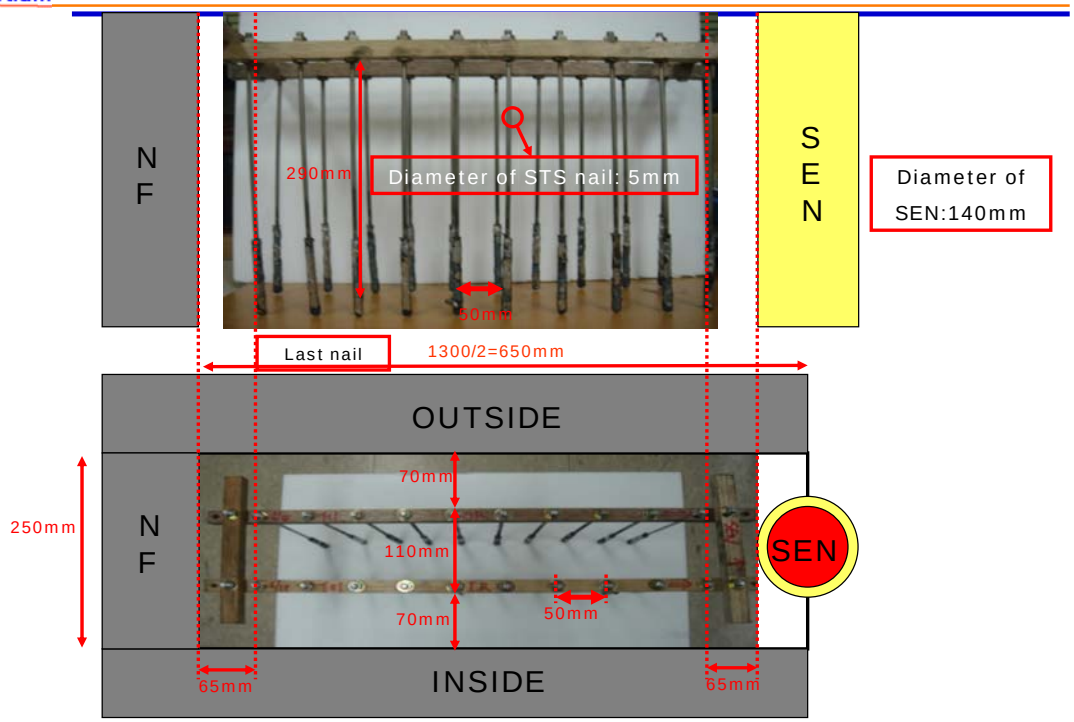
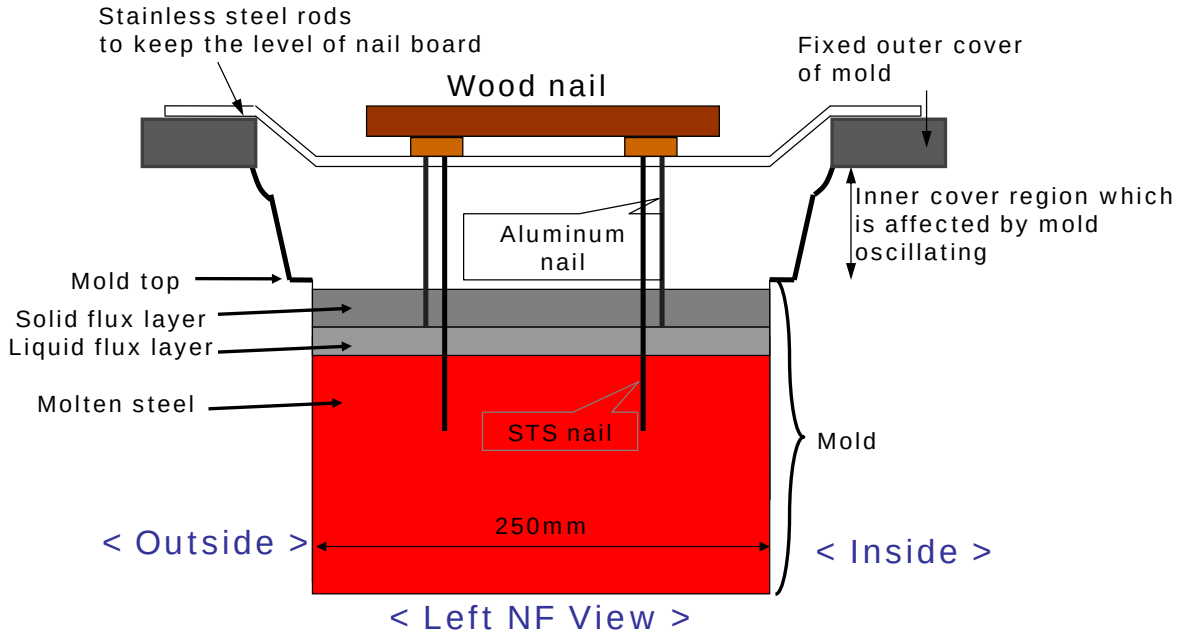
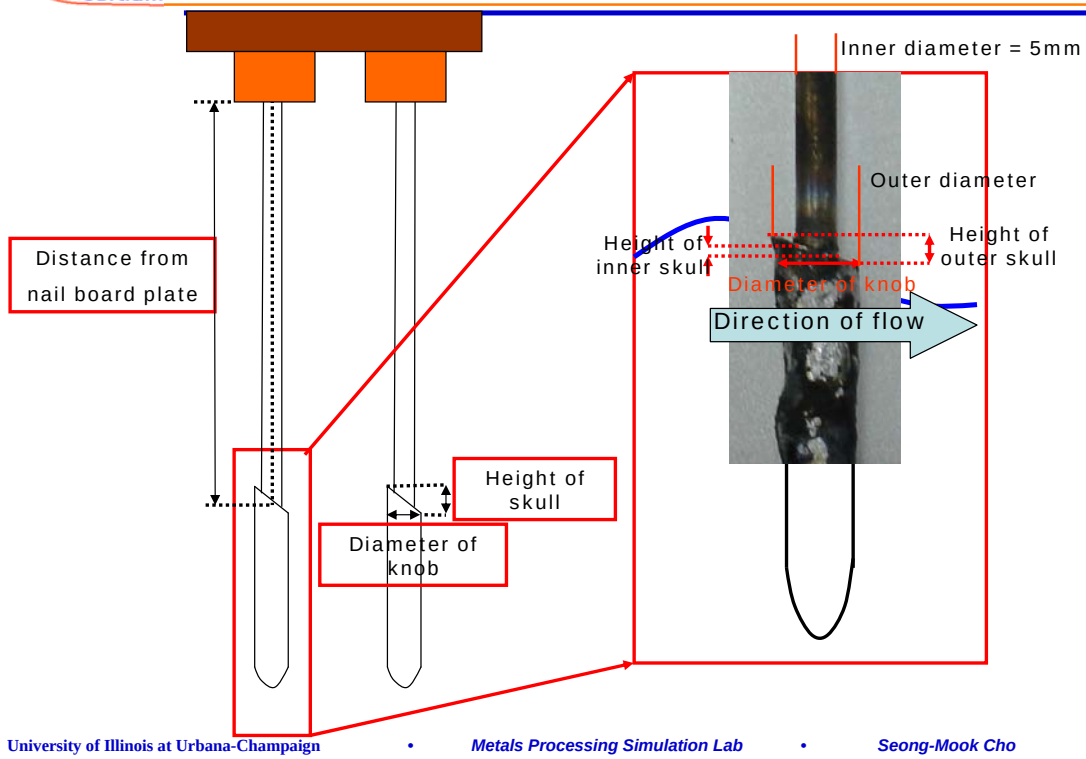
Schematic of Nail Board Set



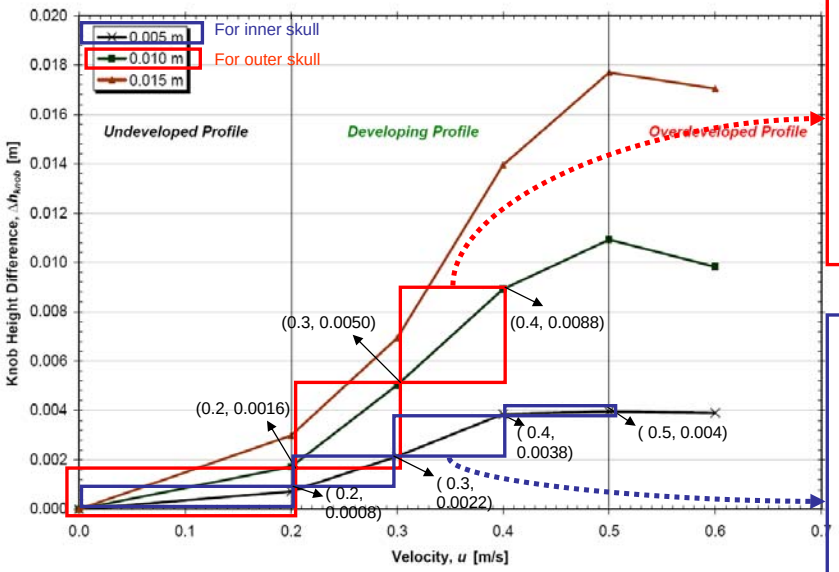
Position of Nail Board in a Mold



Definition of Measurement



Calculation Surface Horizontal Velocity Magnitude from Height of Skull



< Bret Rietow, June 2007 University of Illinois >

$x: Height\ \ of\ \ skull(mm)$

$y: Horizontal\ \ velocity(m/\sec)$

1) $0 \le x < 1.6:\ y = \frac{1}{8}x$

2) $1.6 \le x < 5:\ y = \frac{x+5.2}{34}$

3) $5 \le x < 8.8:\ y = \frac{x+6.4}{38}$

$x: Height\ \ of\ \ skull(mm)$

$y: Horizontal\ \ velocity(m/\sec)$

1) $0 \le x < 0.8:\ y = \frac{1}{4}x$

2) $0.8 \le x < 2.2:\ y = \frac{x+2}{14}$

3) $2.2 \le x < 3.8:\ y = \frac{x+2.6}{16}$

4) $3.8 \le x \le 4.0:\ y = \frac{x-3}{2}$

Conditions of Nail Board Tests

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

	FC off	FC on
2008-1 test	1.64m/min	1.70m/min
2008-2 test	1.64m/min	1.64m/min
2008-3 test	1.70m/min	1.70m/min

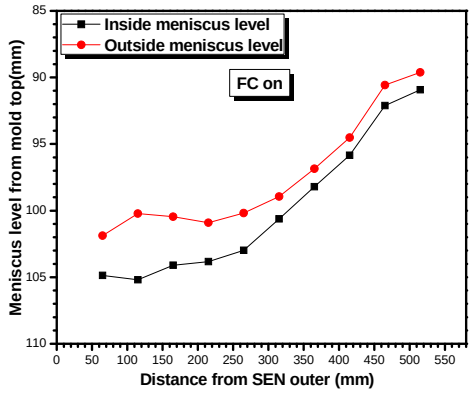
5. Flow rate of Argon gas:9.2L/min(Injection is done in gas channel of UTN)
6. Condition of FC:

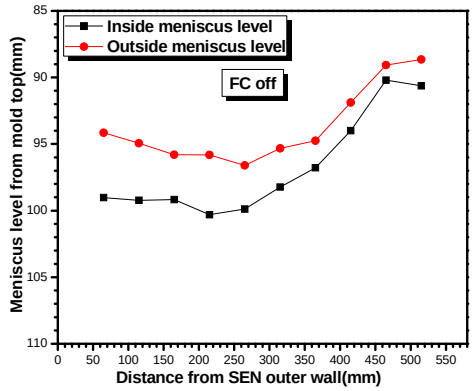
	FC OFF	FC ON
Upper	0 A	300 A (DC)
Lower	0 A	300 A (DC)

7. Time of measurement:

Dipping	Interval of each test	Interval between FC off and on
3 sec	1min	5~10min

Comparison of Meniscus Level between FC off and FC on





FC off	Average	Meniscus Level (mm)	Stdev by distance (mm)
	Outside	97.4	4.4
	Inside	99.9	5.3

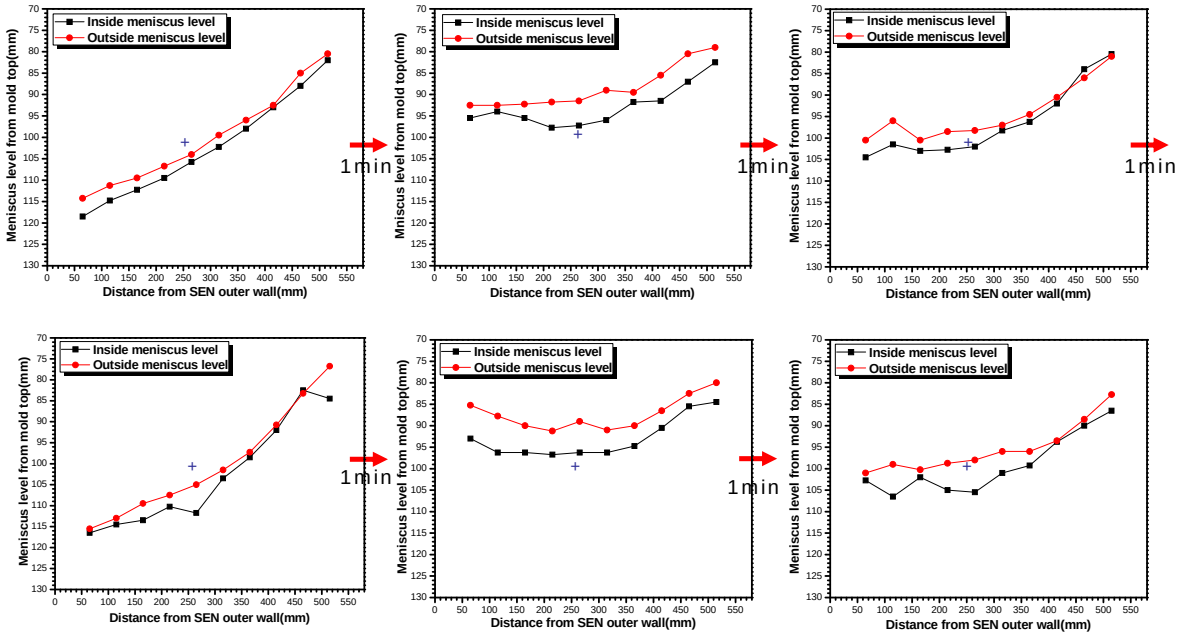
FC on	Average	Meniscus Level (mm)	Stdev by distance (mm)
	Outside	93.7	2.9
	Inside	96.7	3.8

- Averaged meniscus level is higher with FC.

(inside: 3.2mm, outside: 3.7mm)

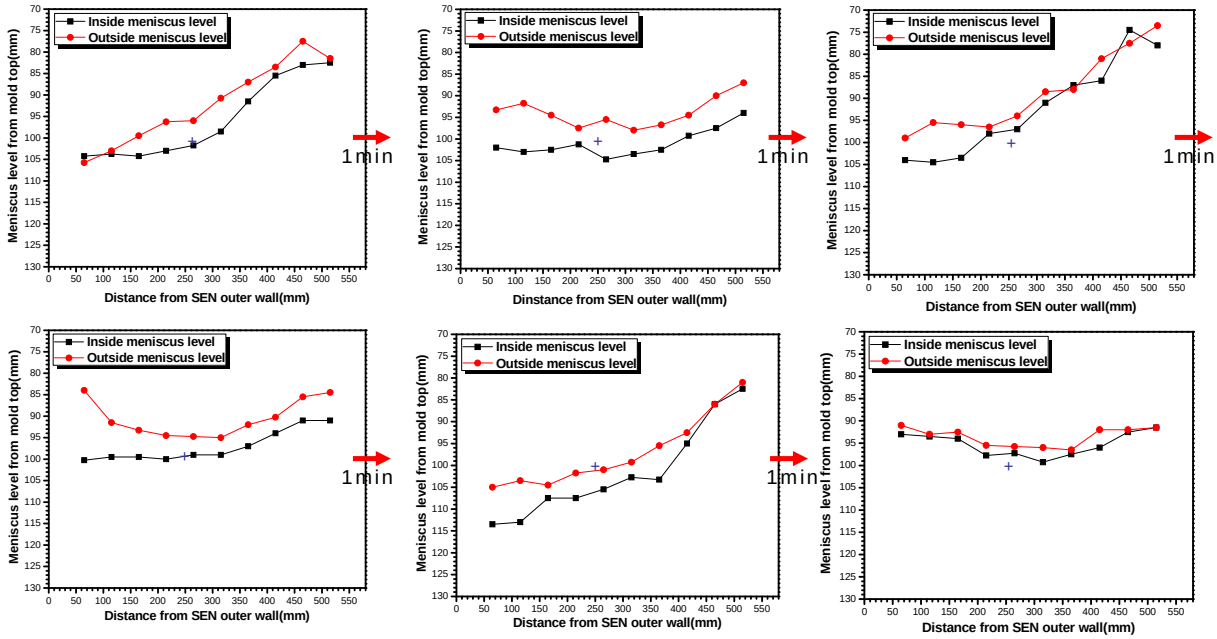
- FC induce the surface level flatter.

Level Variation with FC OFF(2008-3)



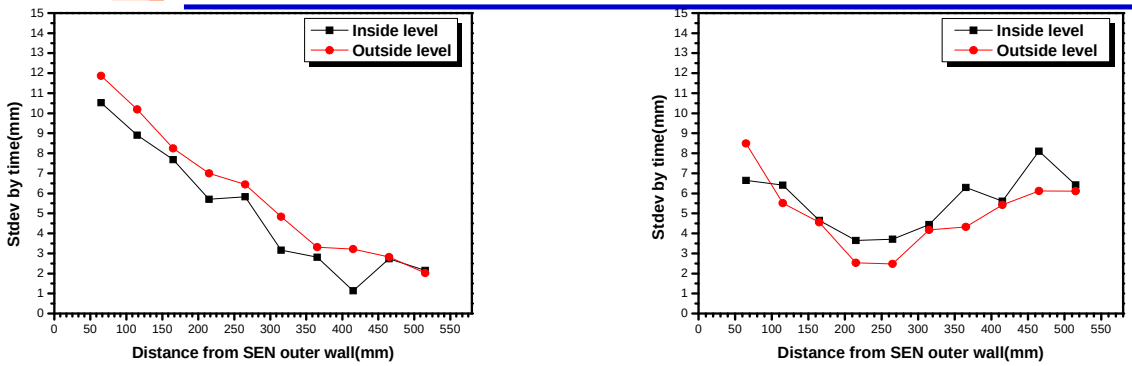
- Meniscus level fluctuation with time(sloshing)
- Cycle: at least 3 time intervals(3min)

Level Variation with FC ON (2008-3)



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

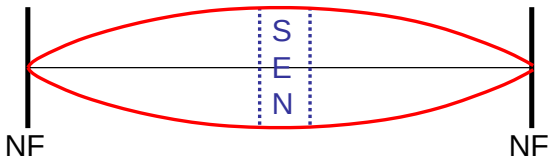
Comparison of Level Variation between FC off and FC on

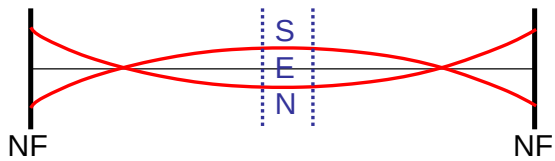


	Stdev by time	
	FC OFF	FC ON
INSIDE	5.1	5.6
OUTSIDE	6.0	5.0

- **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**

Characteristic of level variation with FC



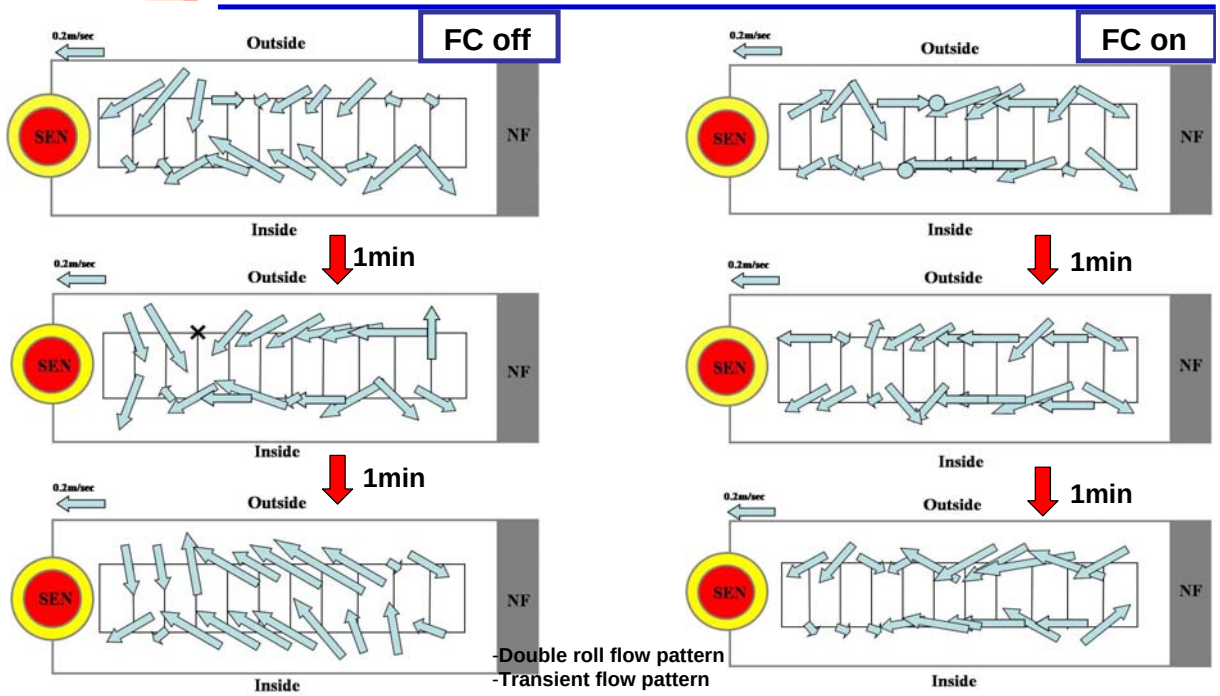


Cycle: at least 3 time intervals(3min)
Stdev by distance(mm):7.7
Stdev by time(mm): 5.5

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

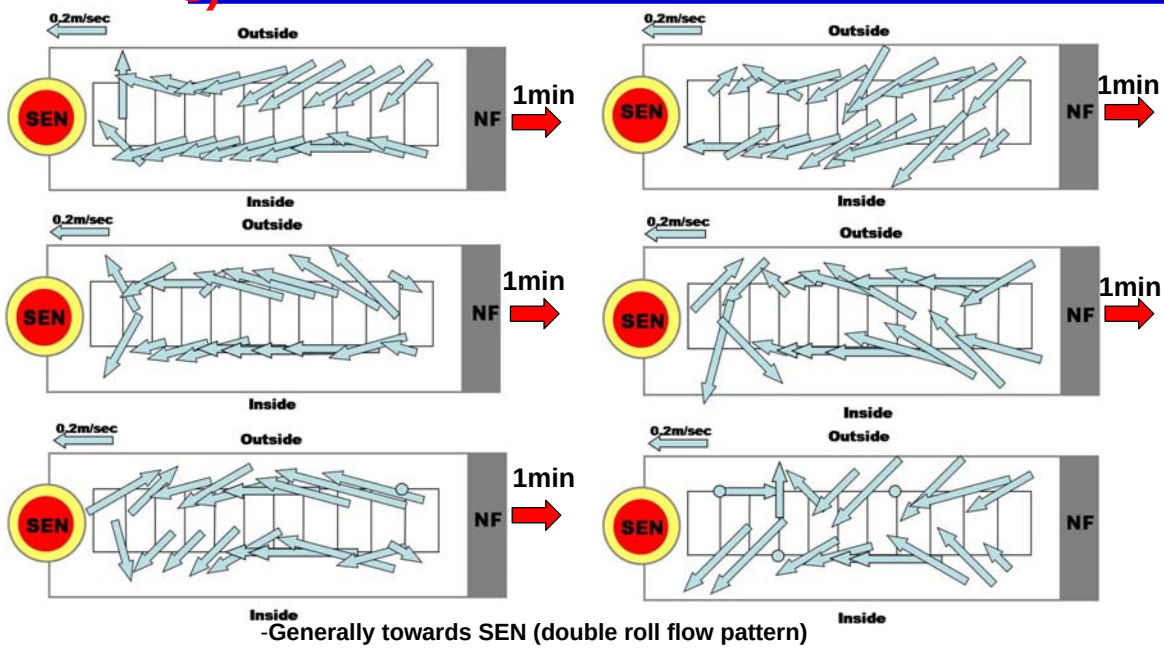
FC off	**High amplitude**	**Low frequency**
FC on	**Low amplitude**	**High frequency**

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



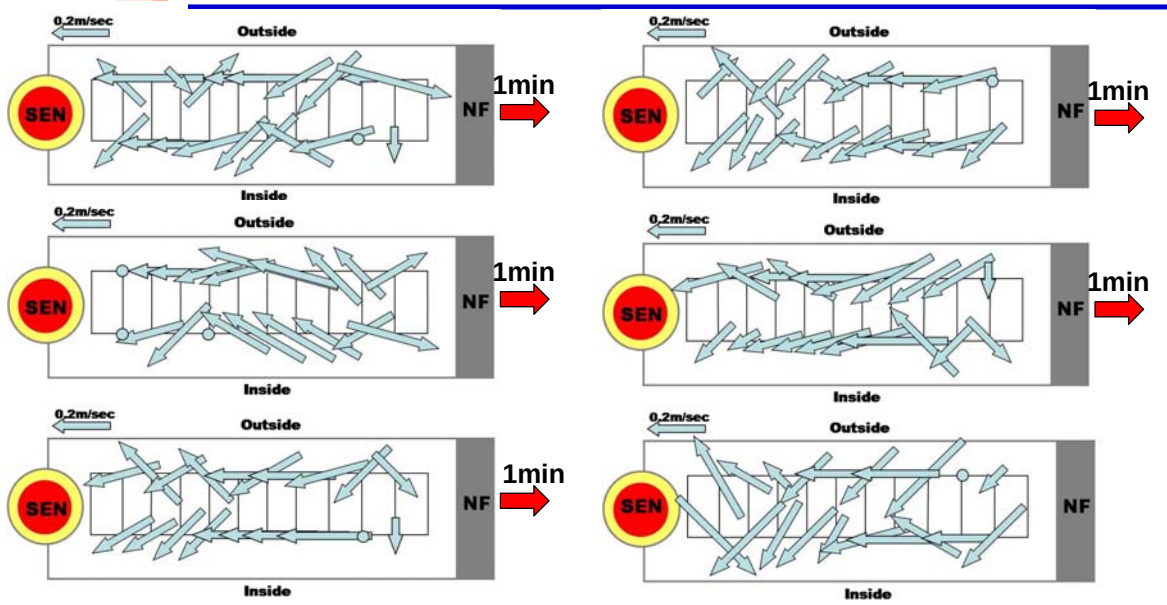
-Double roll flow pattern
-Transient flow pattern
-Chaotic flow near SEN

Flow pattern variation with FC off(2008-3)



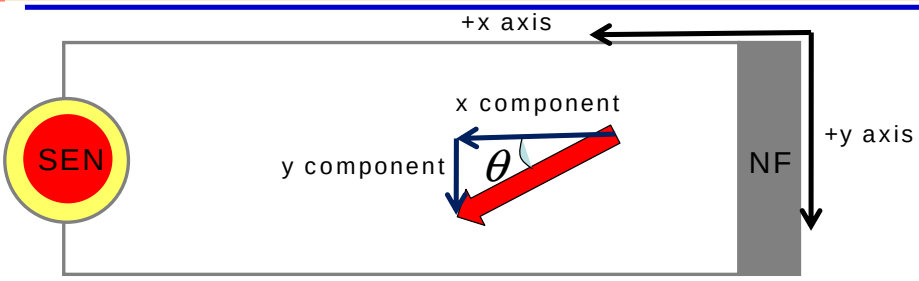
-Generally towards SEN (double roll flow pattern)
-Transient flow pattern
-Diagonal cross-flow mainly towards inside radius
-Chaotic flow near SEN

Flow pattern variation with FC on (2008-3)



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

Quantification of Averaged Surface Velocity Vector



Spliting velocity magnitude into x,y components

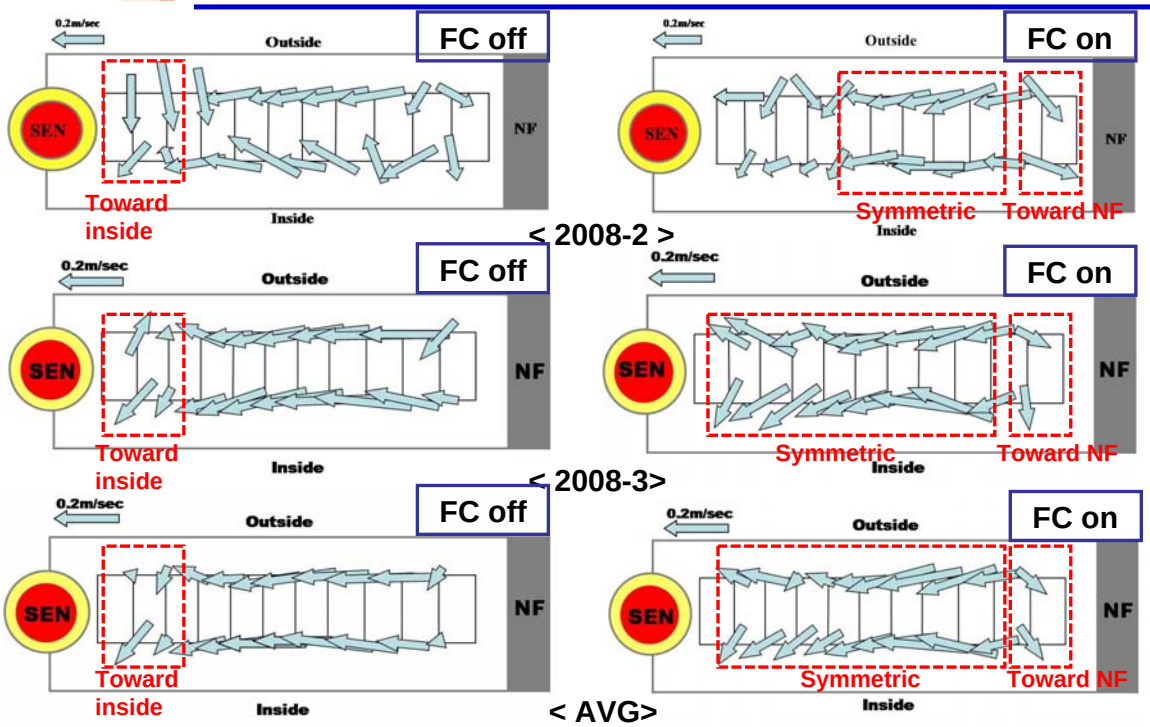
↓

Averaging each velocity component in the same nail

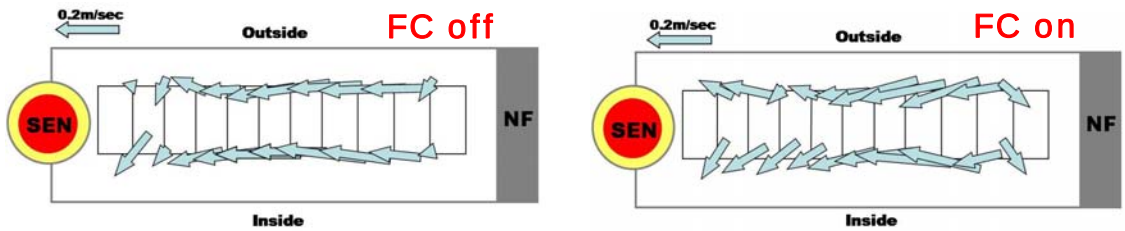
↓

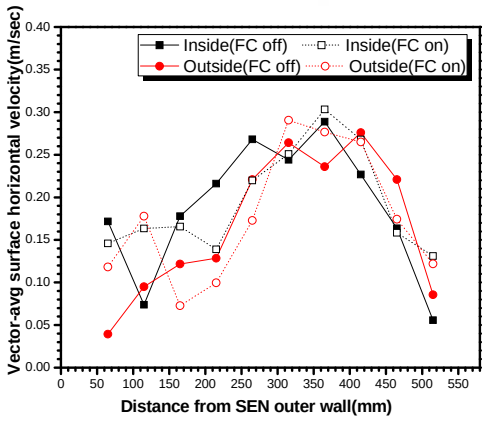
Determining the flow direction from information of velocity components

Comparison of Flow Pattern Variation



Influence of FC on Surface Flow Patterns and Velocity(average)

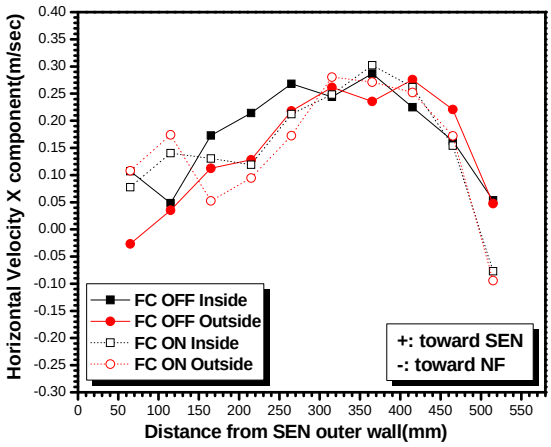


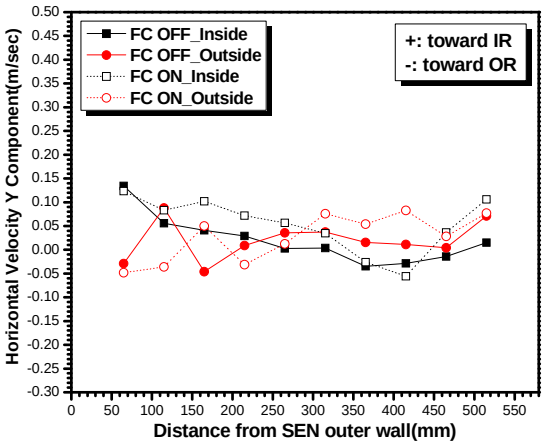


- Electromagnetic force affects the flow toward SEN and change the distribution of rising argon gas on surface.
- With FC on, more argon gas rising to region near SEN could make the surface flow symmetrical
- With FC on, turbulent kinetic energy of argon gas rising to region near SEN make the flow near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

	FC off	FC on
Outside	0.169	0.177
Inside	0.189	0.194
AVG	0.179	0.186

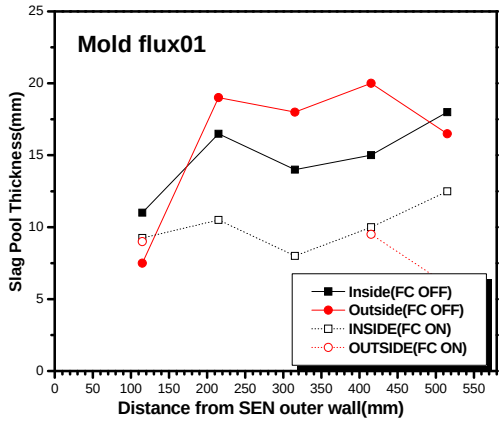
Influence of FC on Velocity Components

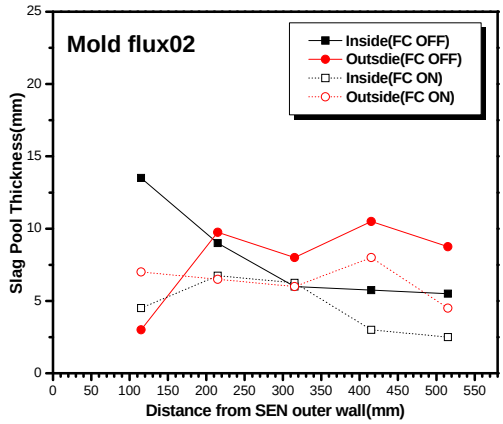




- Electromagnetic force affect the flow toward SEN (velocity x component)
- Argon gas rising to the surface near SEN affect the surface flow
- The surface flow without FC is affected by rising argon gases and slower toward SEN
- Distribution of argon gas at surface could be affected by FC
- Flow is mainly 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.)

Summary

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

FC off	High amplitude	Low frequency
FC on	Low amplitude	High frequency

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)

Acknowledgements

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