CCC Annual Report

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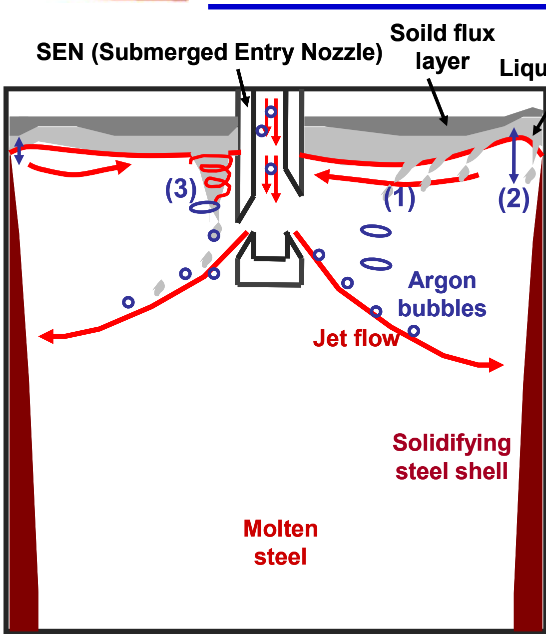
EMBr Effect on Mold Level Fluctuations

POSTECH: Seong-Mook Cho, Seon-Hyo Kim
UIUC: Brian G. Thomas
POSCO: Yong-Jin Kim

Research Background: Transient Surface Flow Problems



< Flow phenomena in the mold of steel continuous caster >

"Transient surface flow problems"

(1) High surface flow velocity

→ Mold flux entrainment by increasing the instability between mold flux layer and molten steel layer

(2) Level fluctuation

→ Mold flux entrapment by time-variations in the interface level between mold flux layer and molten steel layer

(3) Vortex formation

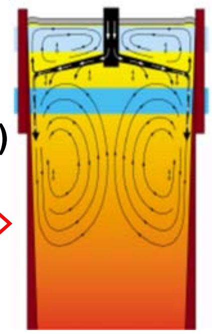
→ Mold flux entrainment by pulling a funnel of mold flux into the mold

⇒ **Slab surface defects**

Research Background: Electromagnetic Systems

❑ Braking

- Local Electro-Magnetic Brake(EMBr):
  Locally braking using Direct Current (DC)
- Double-ruler EMBr FC (Flow Control):
  Linear braking using DC
- EMLS (Electro-Magnetic Level Stabilizer):
  Moving braking using Alternating Current (AC)



❑ Accelerating

- EMLA (Electro-Magnetic Level Accelerater):
  Moving accelerating using AC

❑ Rotating

- EMRS (Electro-Magnetic Rotate Stirrier):
  Moving rolating using AC

Research Scope

❑ Objectives:

- To gain insight of double-ruler EMBr (FC) effect on transient surface flow pattern and surface level fluctuation

❑ Methodologies:

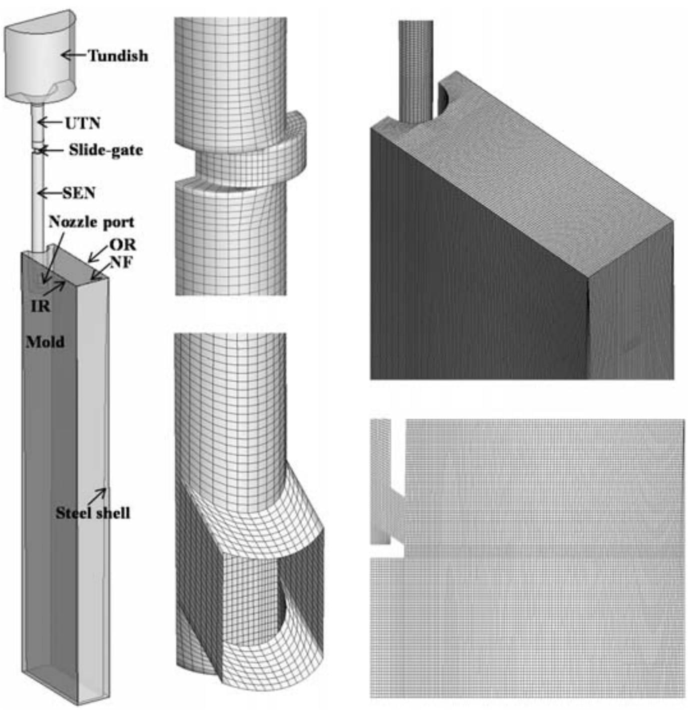
- Computational modeling for understanding nozzle and mold flow pattern without and with EMBr

- Nail board dipping tests & eddy current sensor measurements for visualizing surface flow pattern, level and quantifying surface velocity, level fluctuation

Process Conditions

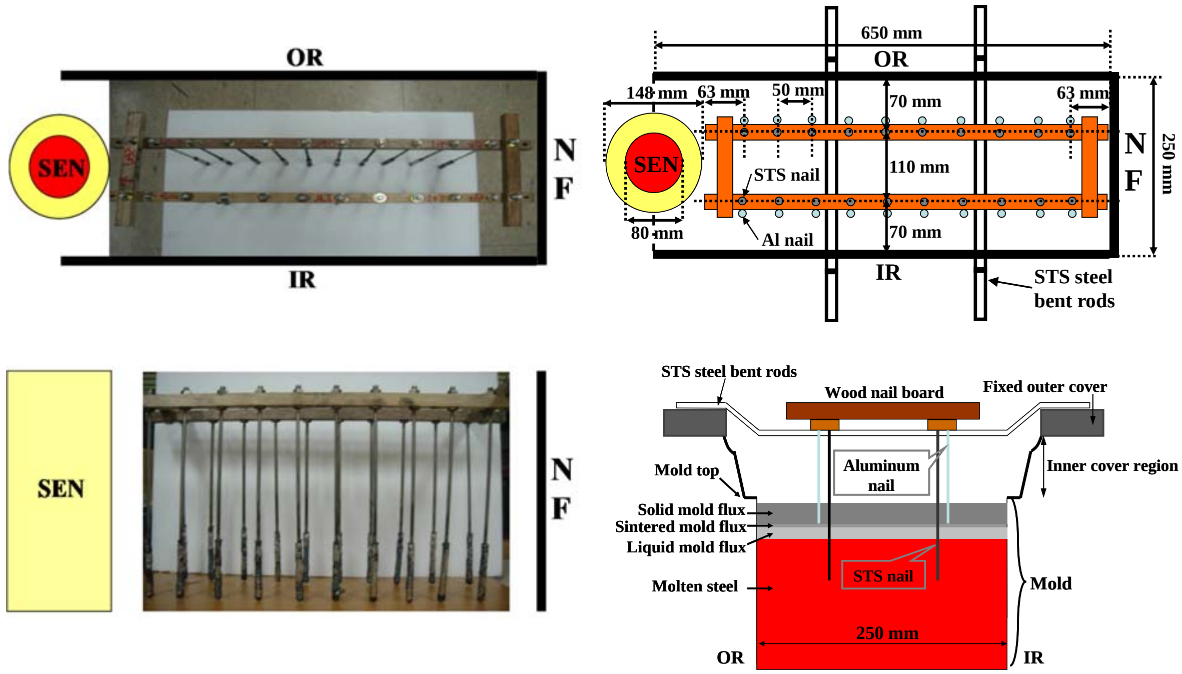
Steel flow rate		552.5 LPM (3.9 ton/min)
Casting speed		1.70 m/min
Argon gas injection rate		9.2 SLPM (1atm and 273K); 33.0 LPM (1.87 atm, 1827 K) & 5.6 % (hot)
Flow control system		Slide-gate
Nozzle	Bottom type	Well bottom (depth: 19 mm)
	Port angle	35 degree angle at both top and bottom
	Port area	80mm (width) x 85mm (height)
	Bore diameter (inner/outer)	90 mm (at UTN top) to 80 mm (at bottom well) / 160 mm (at UTN top) to 140 mm (at SEN bottom)
Mold	Width	1300 mm
	Thickness	250 mm
EMBr Current		Upper: 300A, Lower: 300A

Computational Modeling



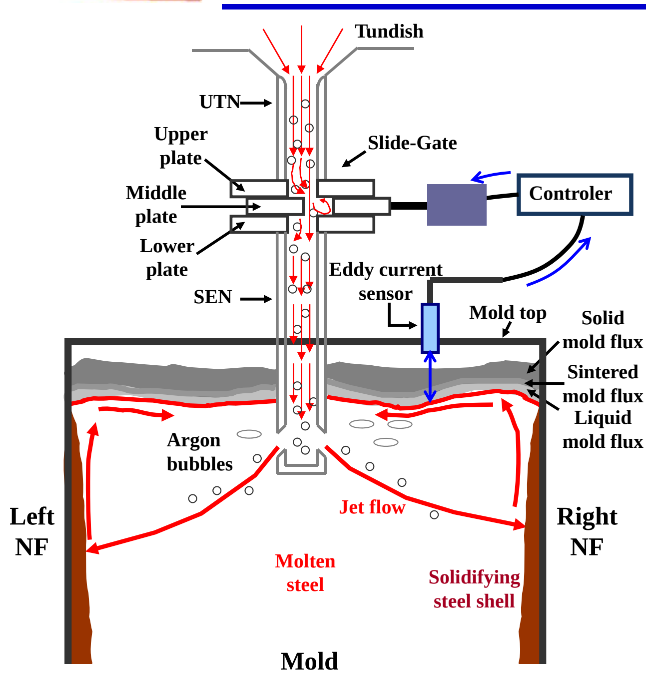
- LES coupled with Lagrangian DPM
- Standard $k-\varepsilon$ model coupled with MHD
- ~1.8 million cells

Nail Board Dipping Test



<Photos & schematics of nail board in the mold>

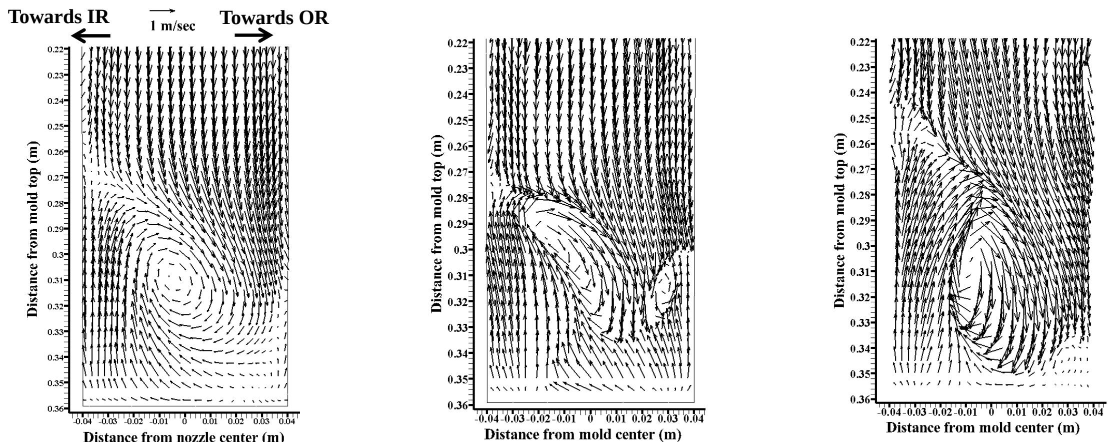
Eddy Current Sensor Measurements



< Position of eddy current sensor >

- **Position: "Quarter point" located midway between the SEN and the NF**
- **1 sec time-averaging for controlling the surface level**
- **700 sec recording**

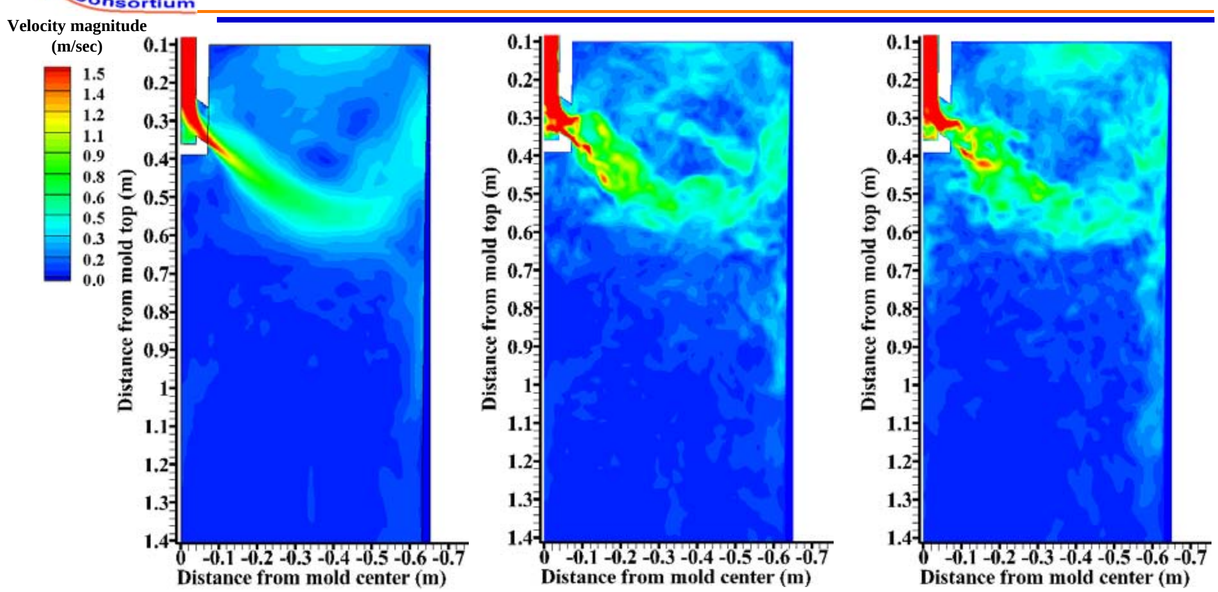
Transient Nozzle Flow



Time-averaged 4.8 sec | 13.8 sec | 15.0 sec

- Clockwise rotating flow pattern in the nozzle well
- When clockwise rotating flow becomes weak, small counter-clockwise rotating flow is also induced in the nozzle well

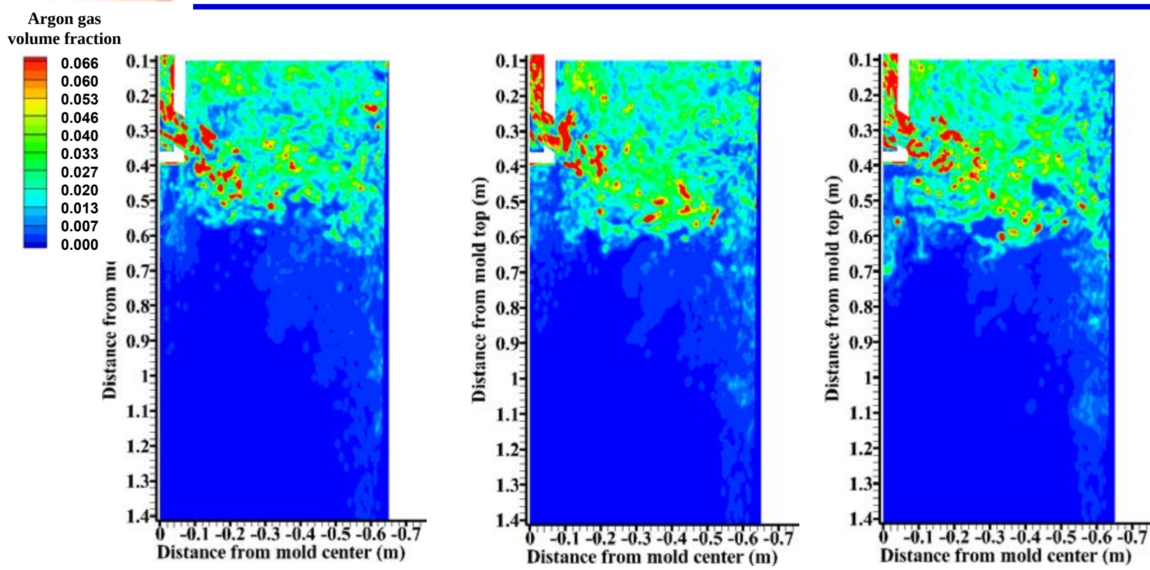
Transient Mold Flow



Time-averaged 4.8 sec | 18.6 sec | 19.8 sec

- Up-and-down wobbling of the jet flow induces variations of velocity magnitude and direction at the surface and changes the jet flow impingement point on the NF

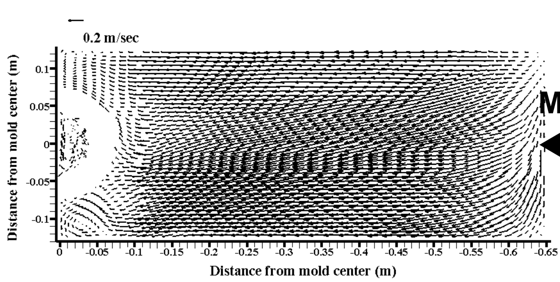
Argon Gas Distribution



18.6 sec | 19.2 sec | 19.8 sec

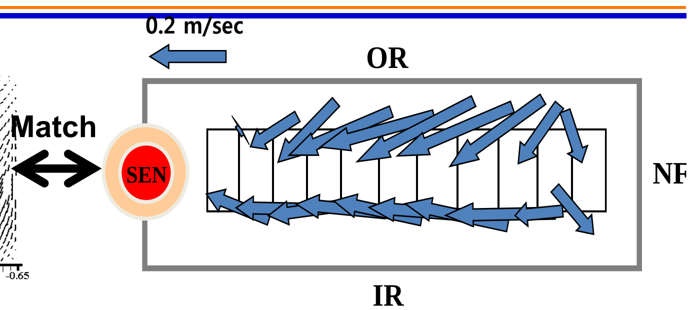
- The jet wobbling also influences argon gas distribution with time in the mold

Surface Flow Pattern

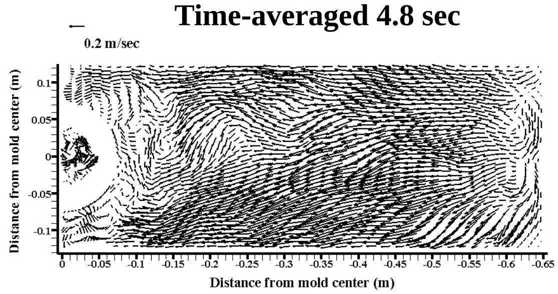


Time-averaged 4.8 sec

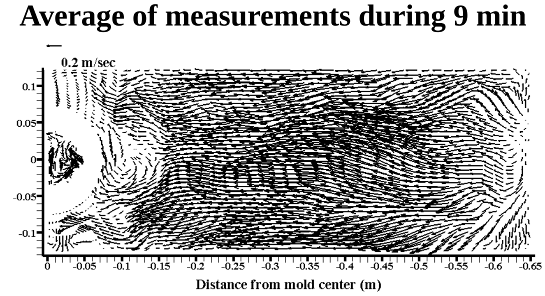
Match



Average of measurements during 9 min



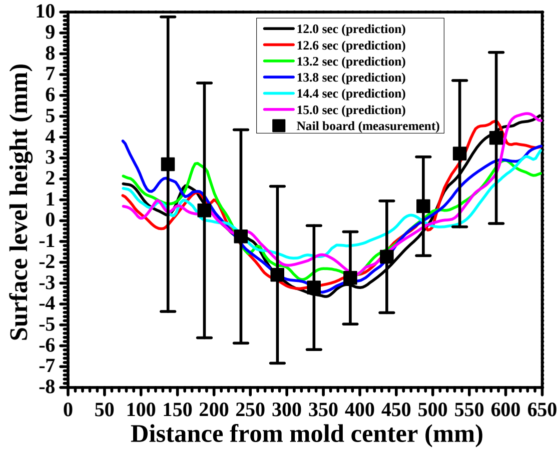
18.6 sec

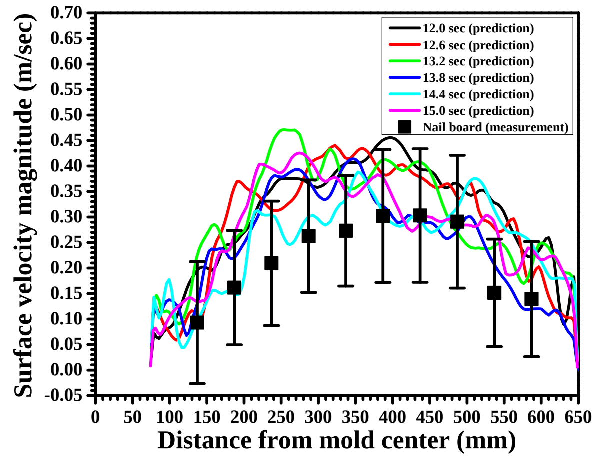


19.8 sec

- **Surface flow mostly goes towards to the SEN**
- **Transient asymmetric flow between the IR and the OR mainly goes towards to the IR at the region near the OR and shows random variation in the region near the IR**

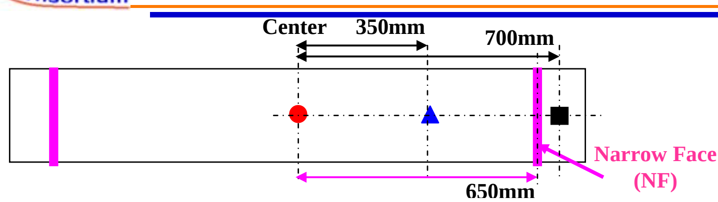
Model Validation

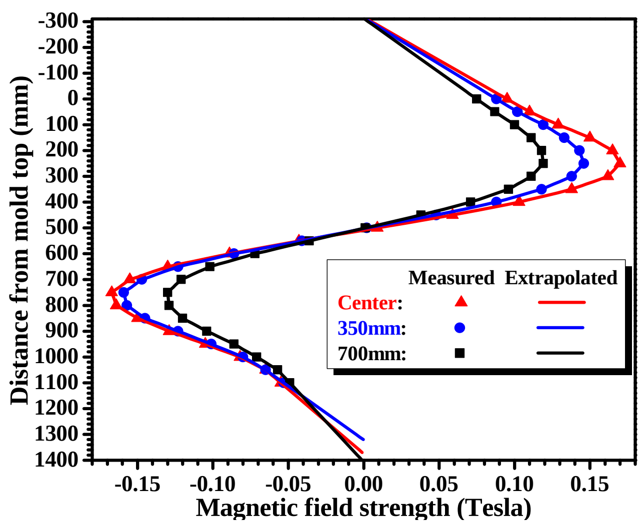


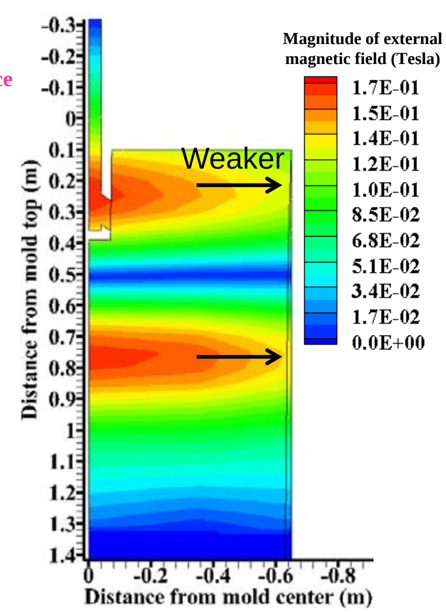


- LES coupled with Lagrangian DPM shows a very good quantitative match with the average surface profile and velocities
- The model under-predicts the magnitude of the measured variations of both level and velocity, likely due to the short modeling time, which is insufficient to capture the important low-frequency fluctuations

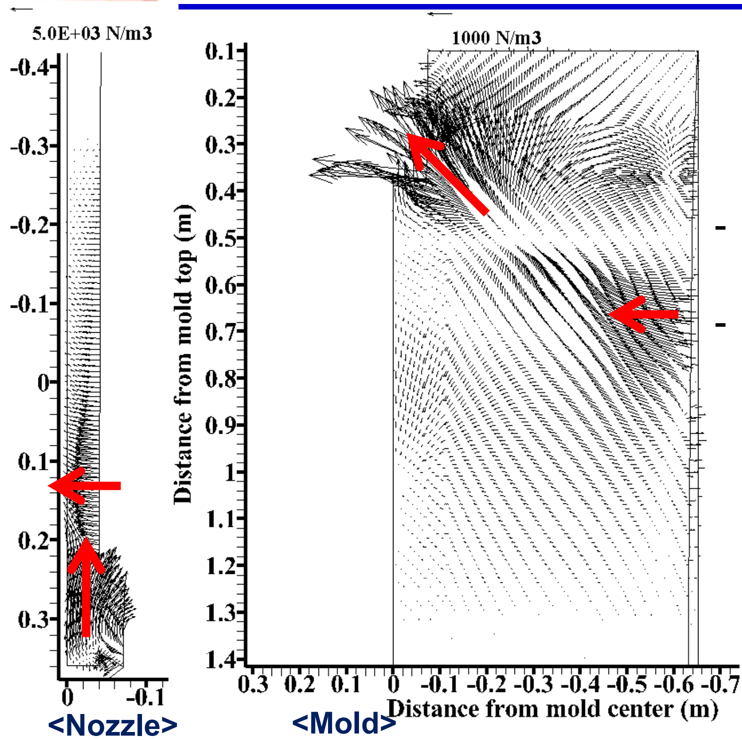
Applied Magnetic Field by Double-ruler EMBr





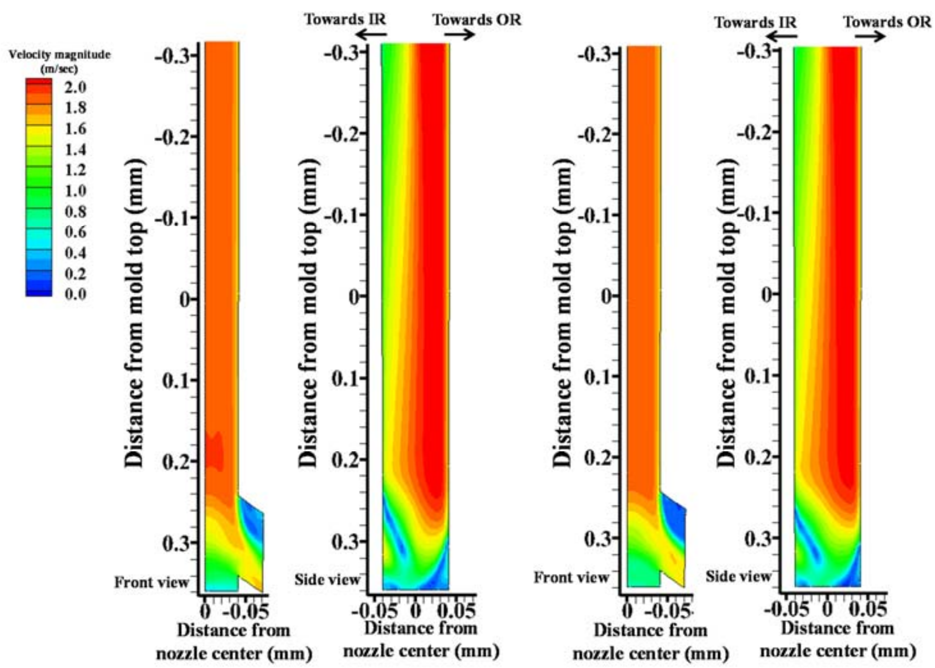


Electromagnetic Force



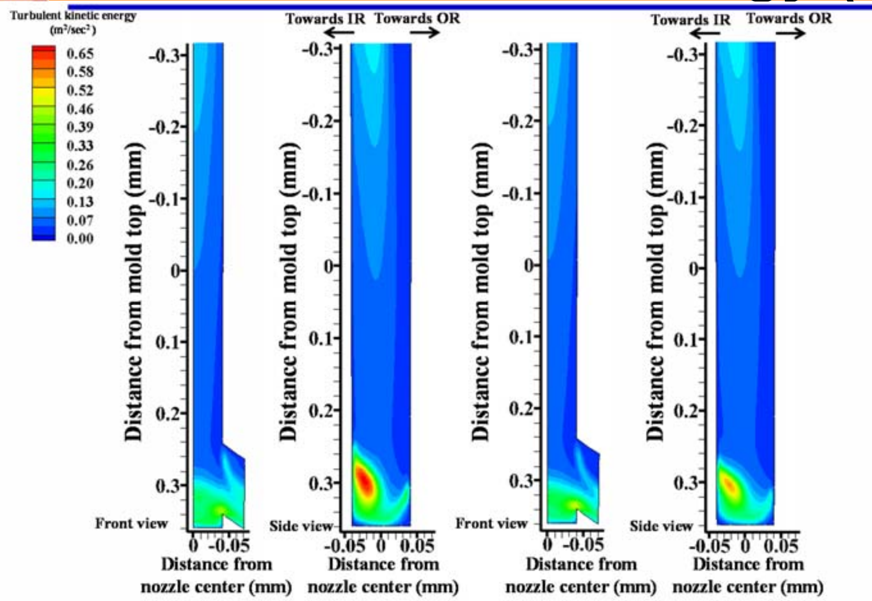
- Much bigger in the nozzle regions
- Two regions in the mold; smaller near the NF

EMBr Effect on Nozzle Flow: Velocity Magnitude



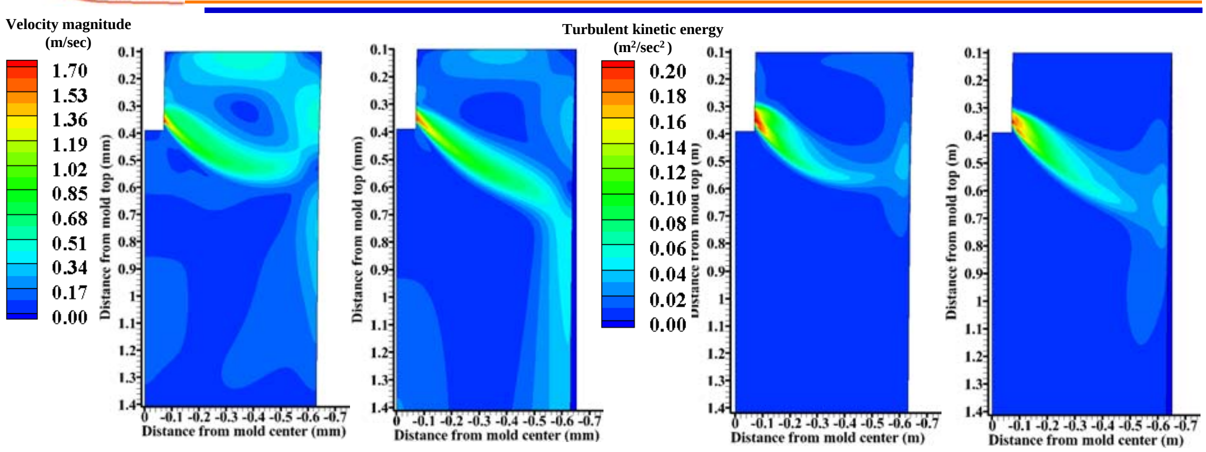
- Not effective to break the velocity in the nozzle

EMBr Effect on Nozzle Flow: Turbulent Kinetic Energy (TKE)



- With EMBr, TKE is decreased in the nozzle well region, where rotating swirl flow

EMBr Effect on Mold Flow

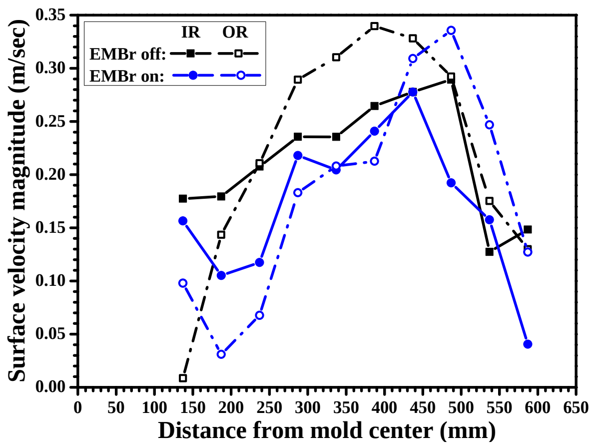


No EMBr **EMBr** **No EMBr** **EMBr**

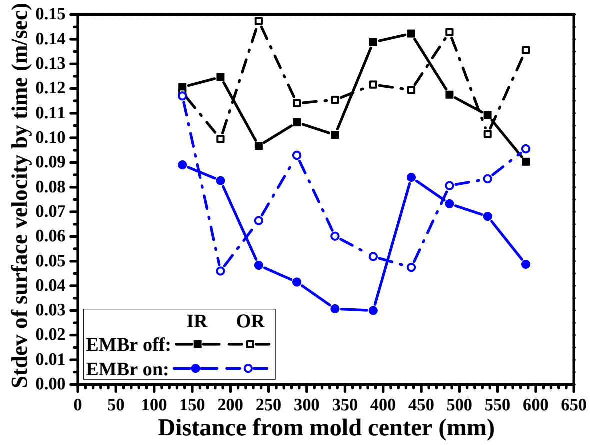
- **Jet flow is deflected downward, resulting in slower surface flow**
- **TKE is reduced at the surface, but increased deep into the mold**

Surface Velocity

2010 Trial



Surface velocity

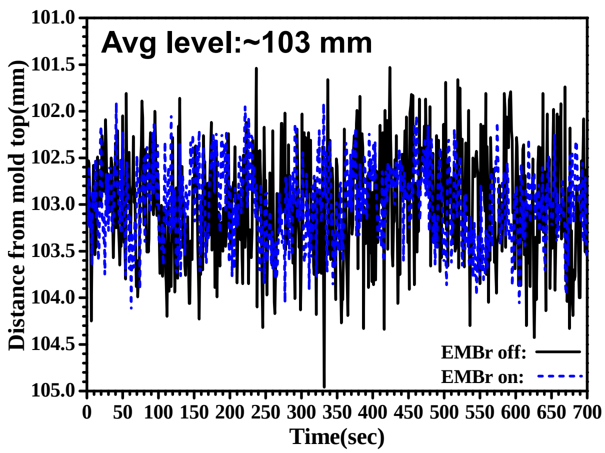


Surface velocity fluctuation

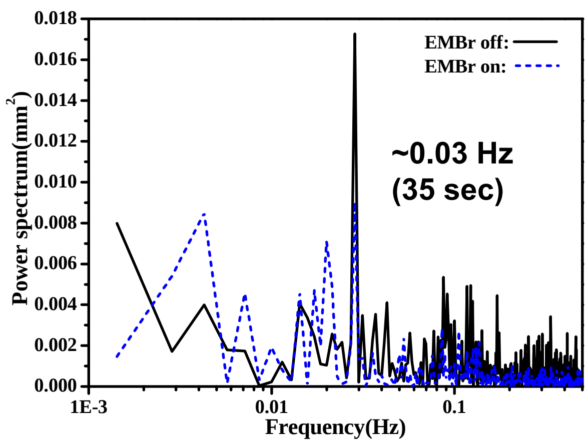
	No EMBr	EMBr	
Velocity	0.22 m/sec	0.18 m/sec	~20% ↓
Velocity fluctuation	0.12 m/sec	0.07 m/sec	~40% ↓

Surface Level Variation Measured by Eddy-Current Sensor

2010 Trial



Surface level variation by time

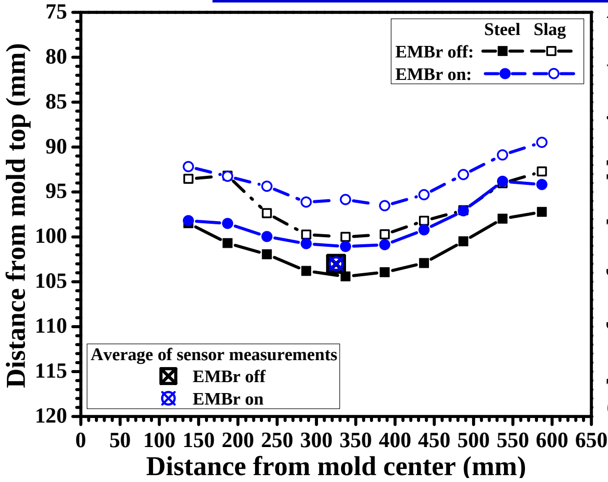


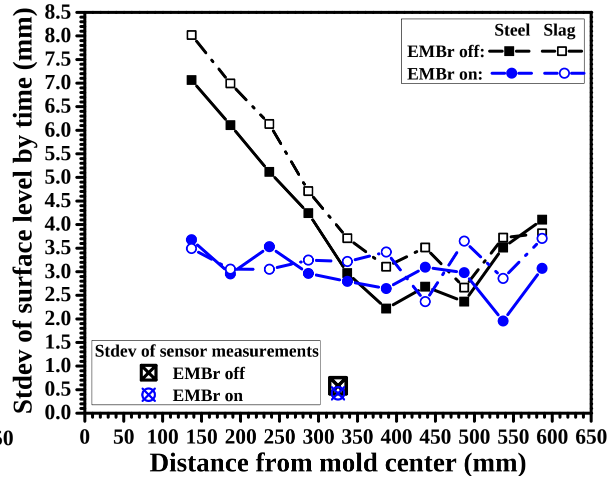
Power spectrum of level variation

	No EMBr	EMBr	
Surface level fluctuation	0.6 mm	0.4 mm	33 % ↓

Surface Level : Nail Board Tests

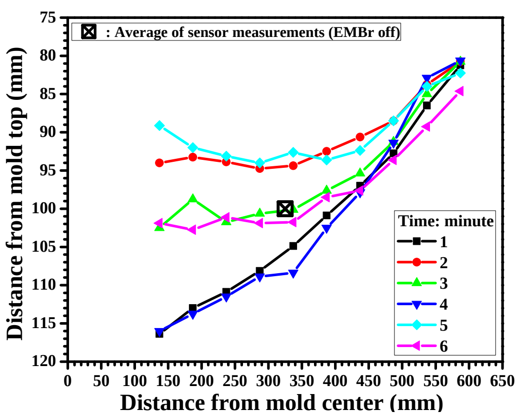
2010 Trial



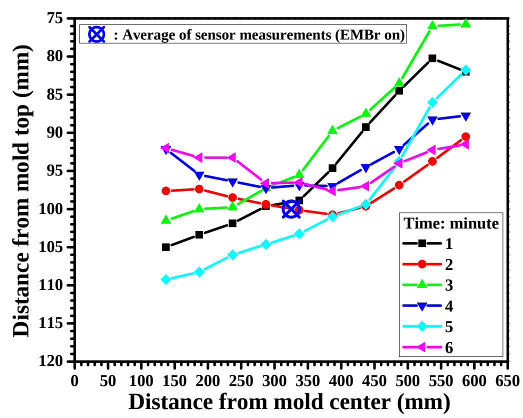


		No EMBr	EMBr	
Surface level fluctuation	Sensor	0.6 mm	0.4 mm	33 % ↓
	Nail board	4 mm	3 mm	25 % ↓

Surface Level Profiles
(2008 nailboard trial)



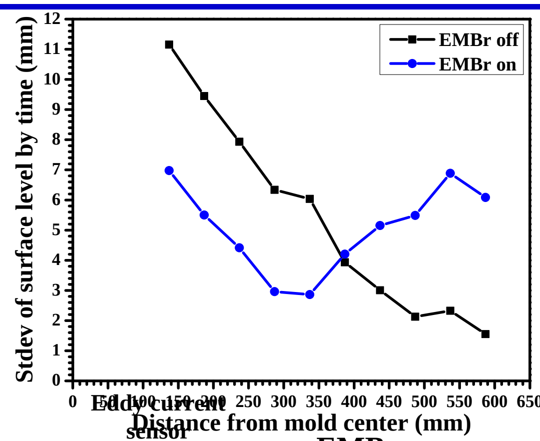
without EMBr

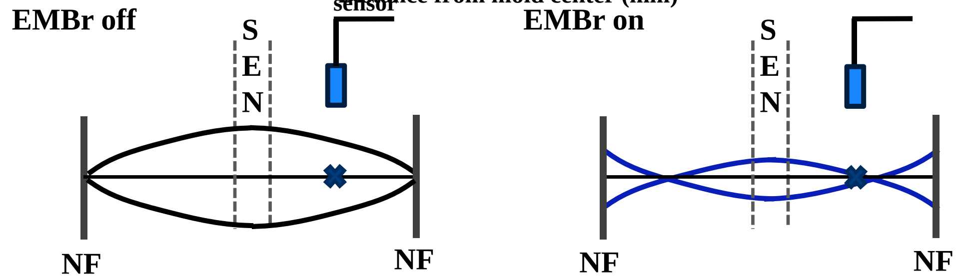


With EMBr

	No EMBr	EMBr	
Level Profile variation	12 mm	20 mm	
Level fluctuation	25 mm	15 mm	~40%

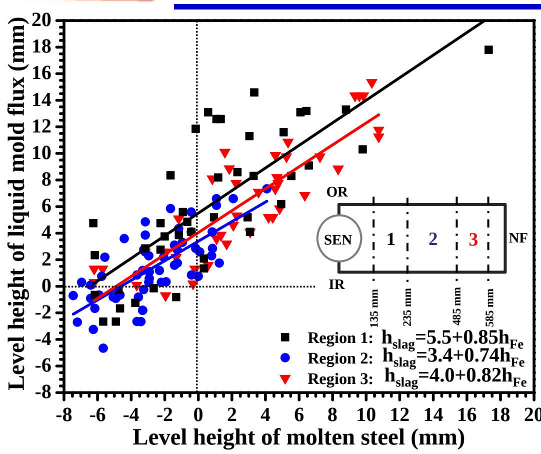
Surface Level Variations (2008 trial)



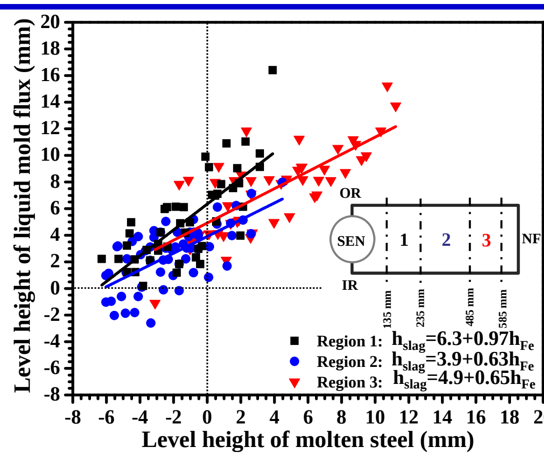


Slag Motion

2010 Trial



No EMBr



EMBr

- Motion of the steel-slag interface level mainly causes lifting of the slag layers near the SEN. Elsewhere, the slag layers are partially displaced by the steel near the NF, especially with EMBr
- Slag pool is slightly thicker with EMBr

Summary & Conclusions:
Transient Two-phase Flow

- Nail board dipping tests and eddy current sensor measurements together reveal level, velocity, & variations at the surface during nominally steady-state casting
- LES coupled with Lagrangian DPM agrees quantitatively with level & vel. measurements, and trends of fluctuations.
- Asymmetric slide-gate opening causes clockwise rotating swirl in the nozzle well leading to surface cross flow
- Both with and without EMBr, surface level has large (~8mm) sloshing waves with low frequency ~0.03 Hz (~35 sec)
- Surface level fluctuations measured by an eddy-current sensor are much smaller (<1mm) than those by nail board tests, (3-4mm), (due to sensor location and time filtering).
- Slag layer is mainly lifted (vs. displaced) by steel motion

Summary & Conclusions:
EMBr Effect on Flow

- Double-ruler "FC-Mold" EMBr creates two regions of equal-strength magnetic fields, that decrease greatly towards NF
- EMBr causes:
    - Lower turbulent kinetic energy in nozzle well
    - jet deflected downward
    - flatter surface level with less fluctuations near SEN
    - 20% slower surface velocity with 40% less variations
    - Slightly thicker slag pool
- EMBr may help to reduce defects caused by surface instability if used properly

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