Validation of Fluid Flow and Solidification Simulation of a Continuous Thin-Slab Caster

Brian G. Thomas[1], Ron O'Malley[2],

Tiebiao Shi[1], Ya Meng[1], David Creech[1], and David Stone[1]

[1] *University of Illinois at Urbana-Champaign,*

Department of Mechanical and Industrial Engineering,

1206 West Green Street, Urbana, IL USA, 61801

[2] *AK Steel Research*

703 Curtis Street

Middletown, Ohio 45043

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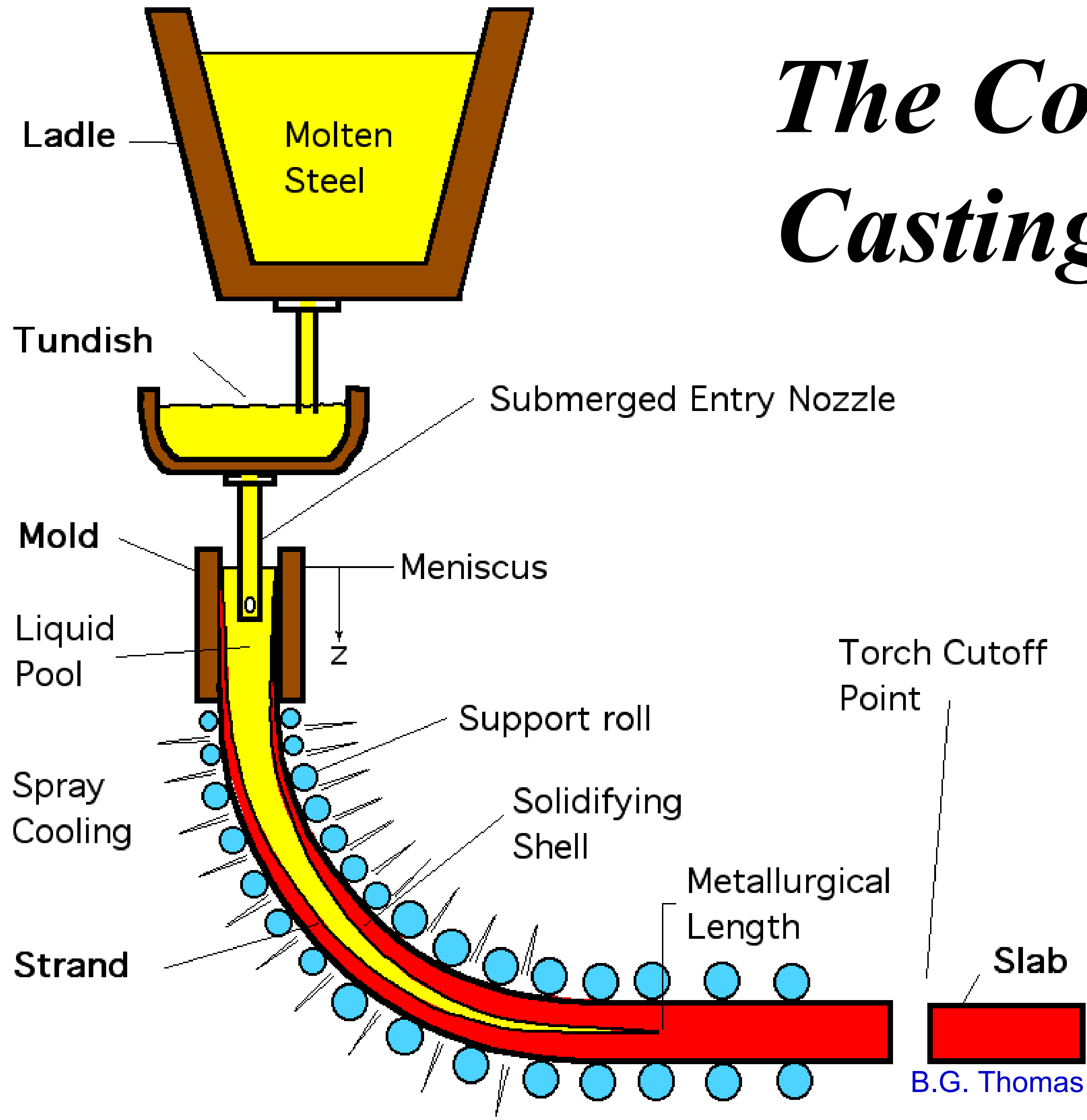
- AK Steel
  (water model and plant measurements)
- M. Langeneckert and G. Webster
  (finite element analysis of the mold)

Objective

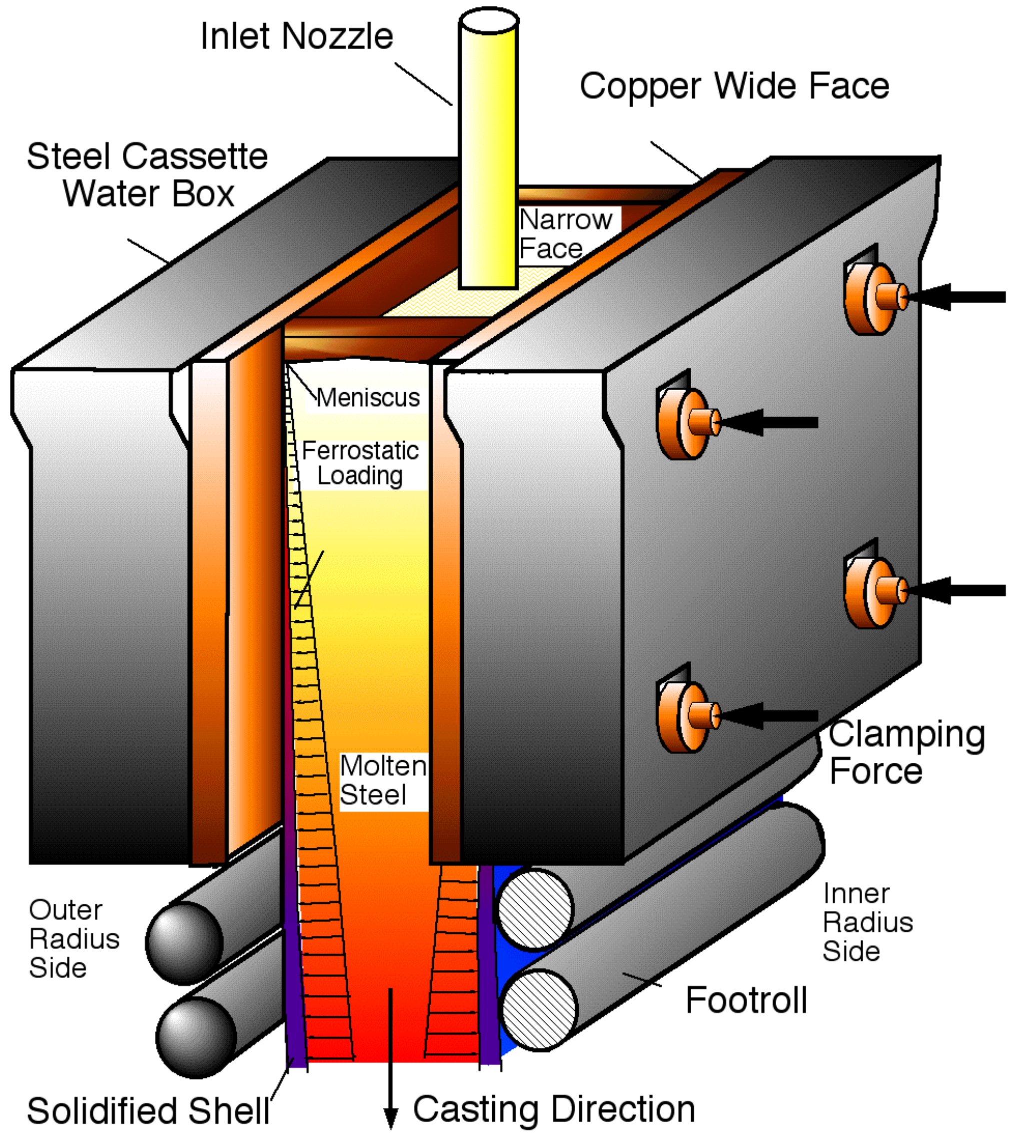
Validate fluid flow and solidification models with extensive measurements:

- velocities within the liquid pool
  (from water models)
- temperatures measured in the molten steel pool
  (plant trial)
- temperatures measured in the copper mold walls
  (mold thermocouples)
- heat flow rate
  (heat balance on the mold cooling water)
- thickness of the solidified steel shell
  (from breakout shell measurements)

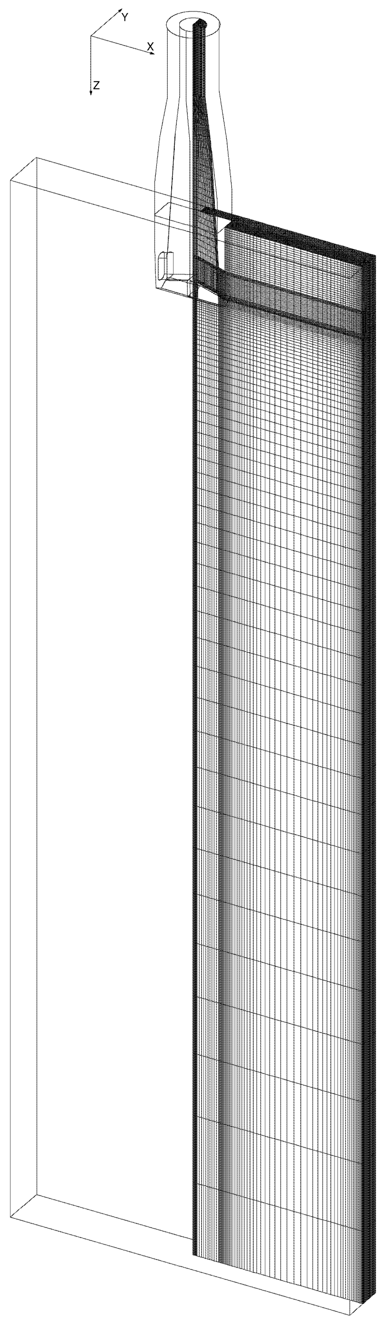
The Continuous Casting Process



Thin Slab Casting Mold



Fluid Flow Model

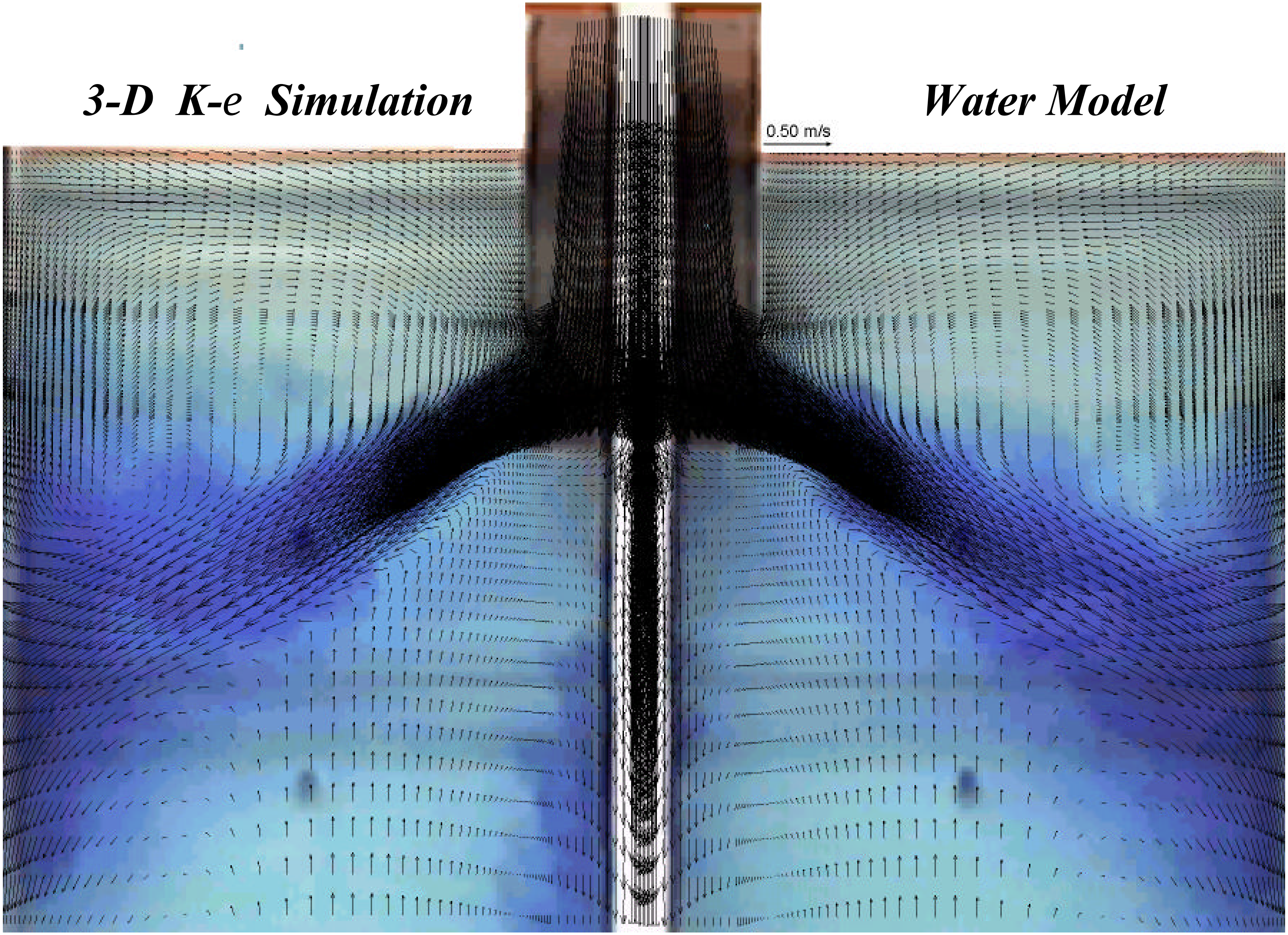


3D Domain and Mesh of

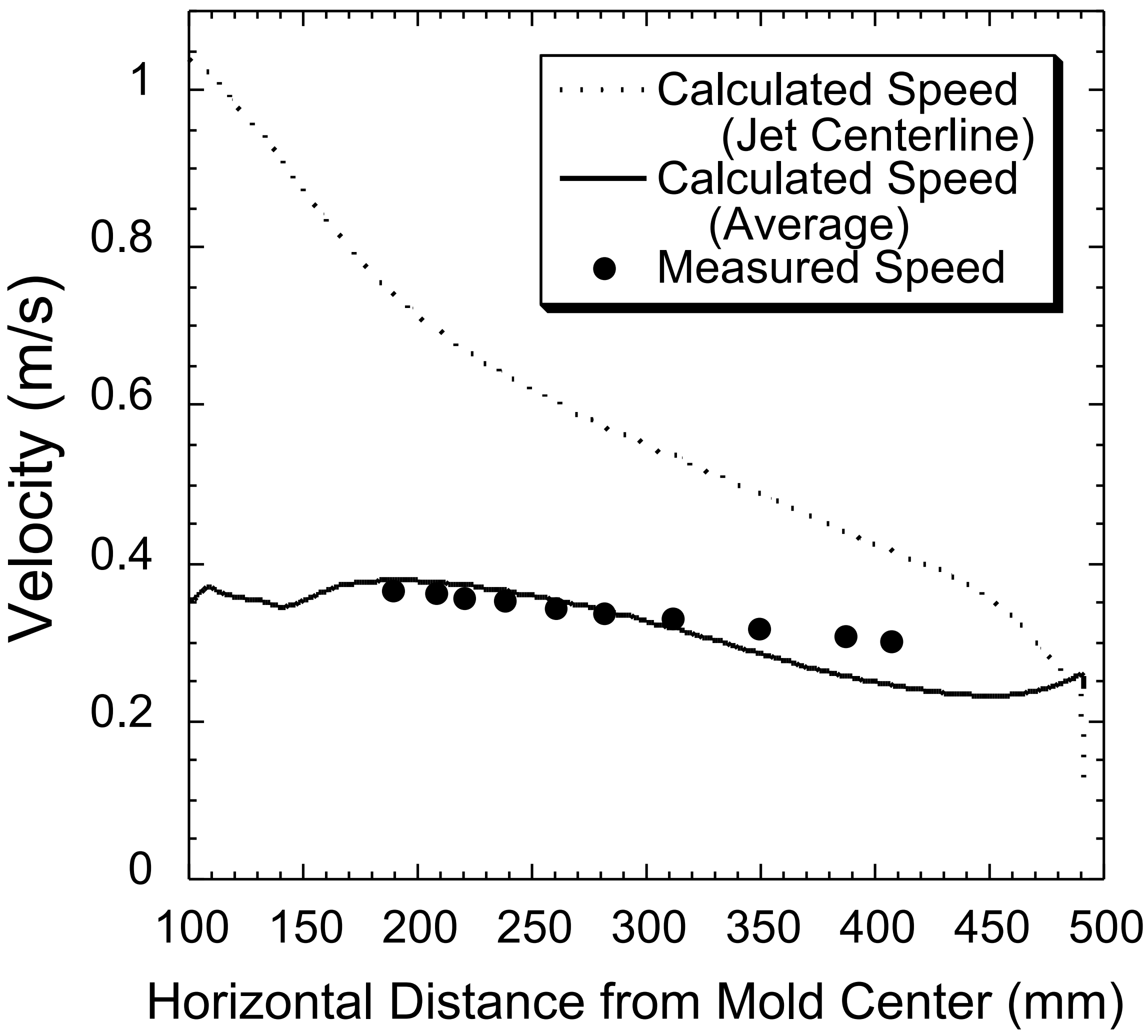
¼ of Liquid Pool:

- Includes 3-port nozzle
- Standard high-Re K-ε turbulence model and wall laws
- Solidification front (boundary): liquidus temperature
- Predicts velocities and superheat distribution

3-D K-e Simulation **Water Model**

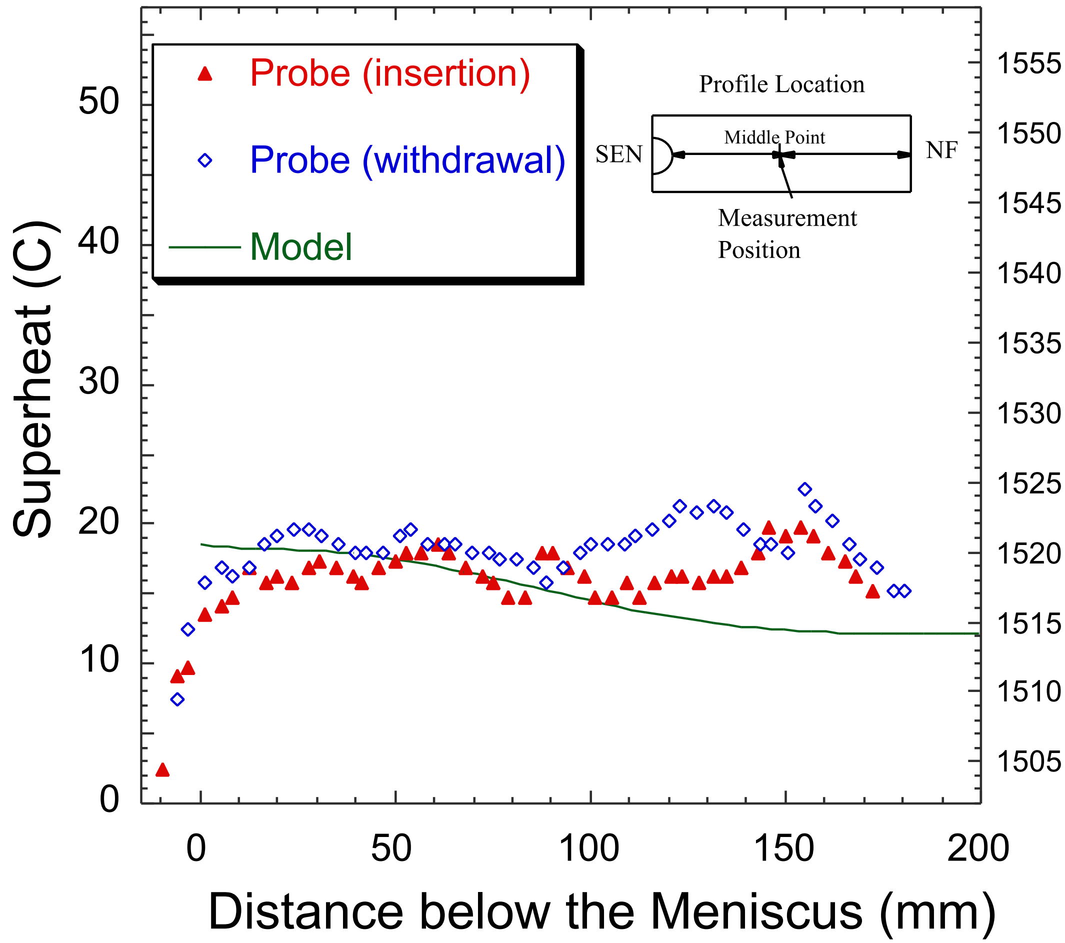


Water Model Flow



Velocity Along Flowing Jet (Calculated and Water Model Measurements)

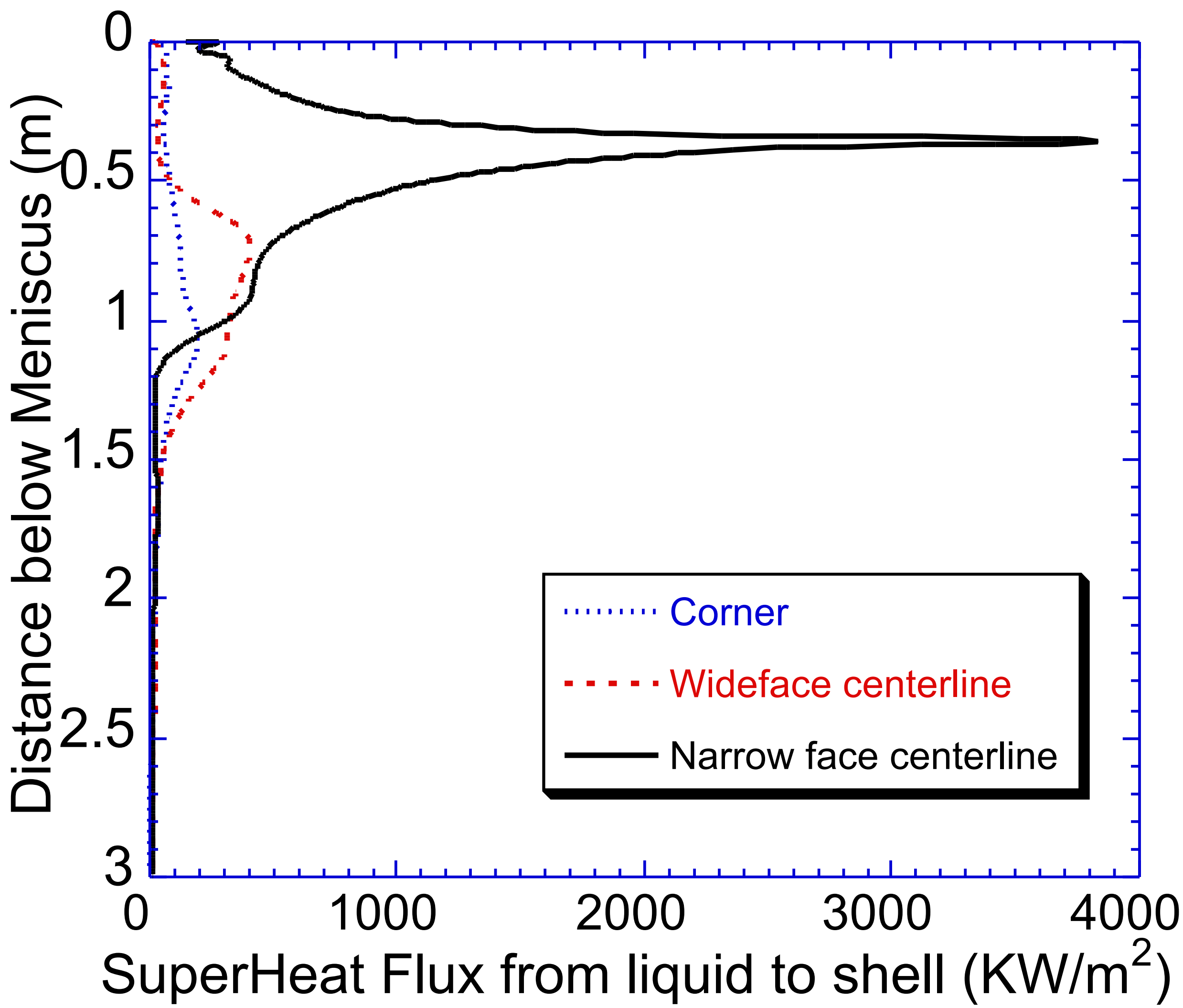
Molten Steel Temperature
(Model Validation)



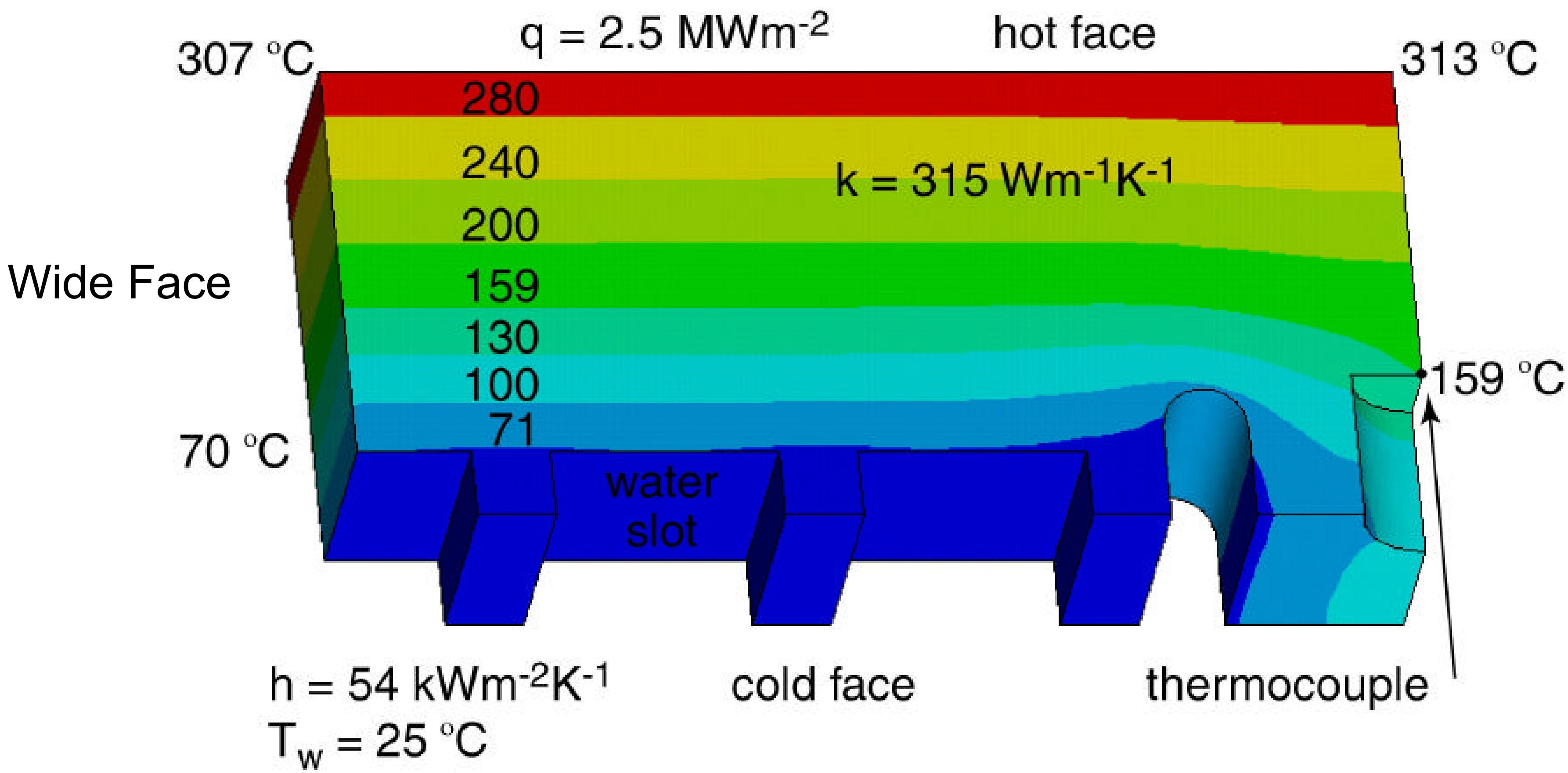
56℃ superheat

Superheat Flux Profiles

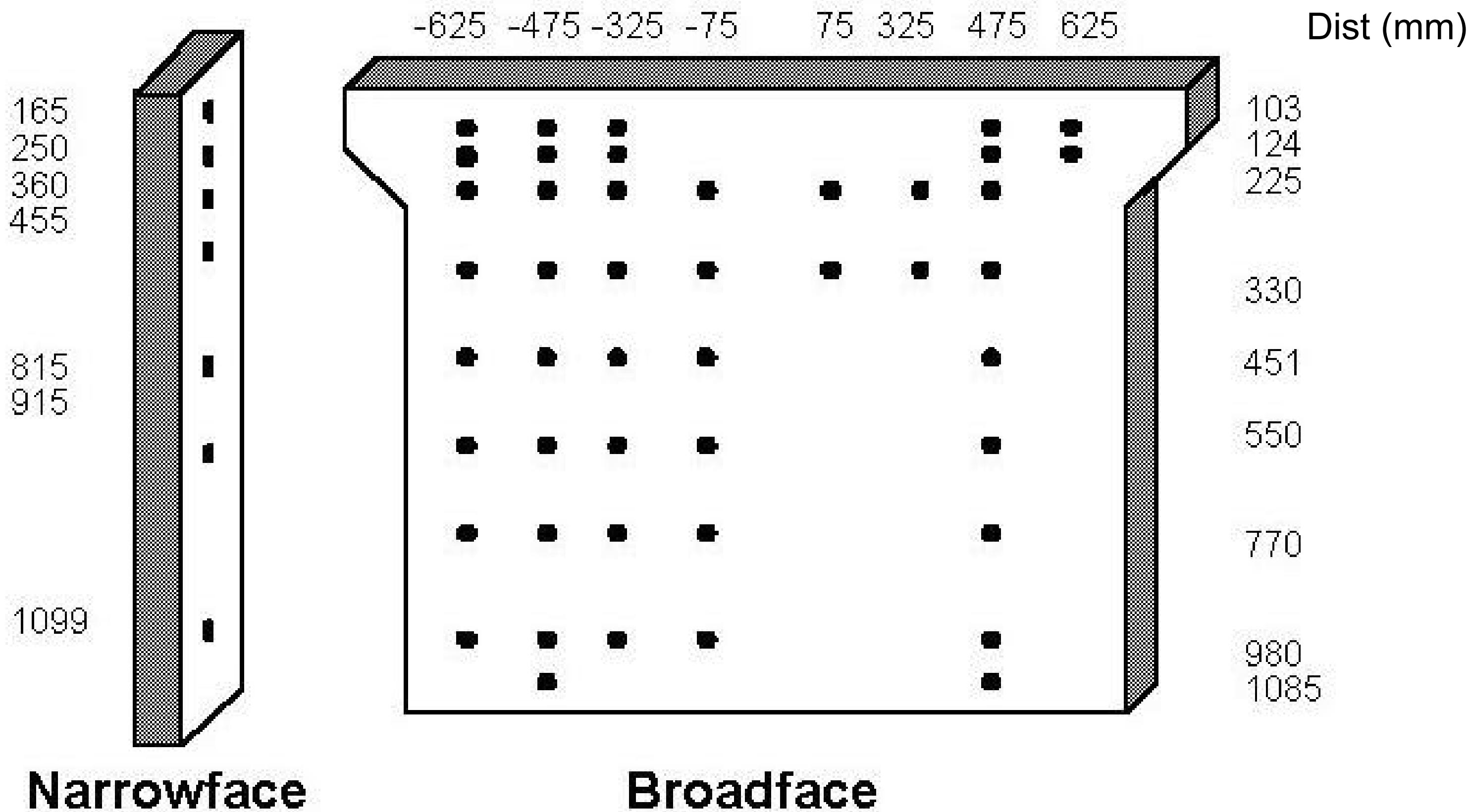
(Calculated Around the Exterior of the Strand Surface)



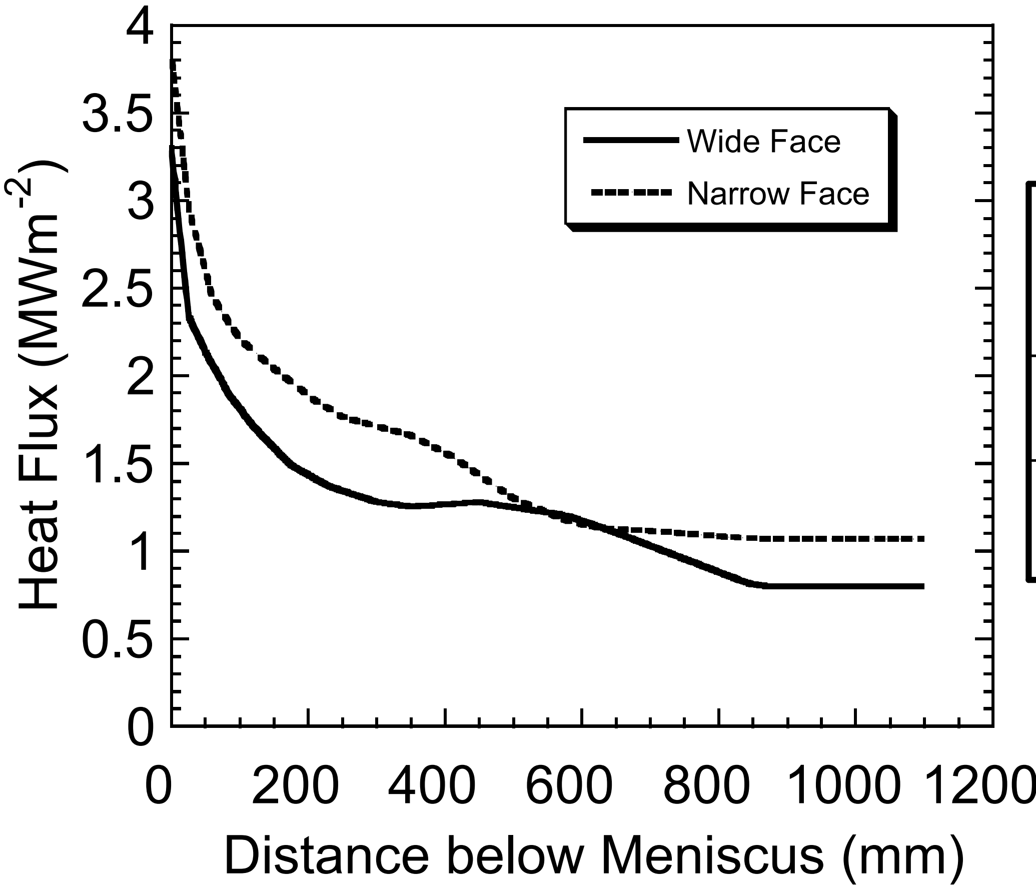
Temperature Contours in 3-D Portion of Mold Wall



Instrumented Mold (106 Thermocouples)



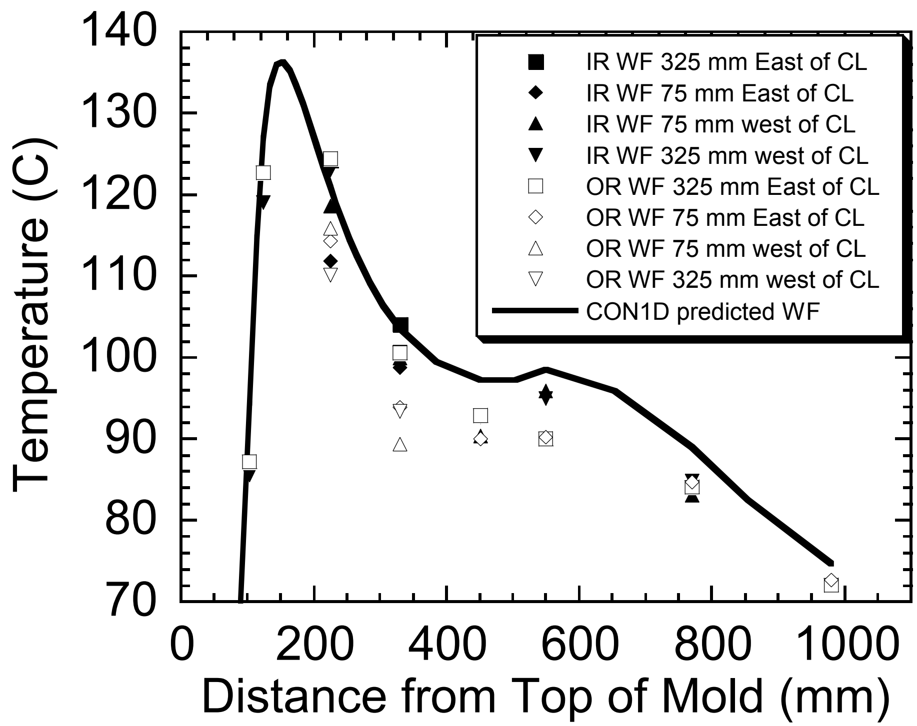
Heat Flux and Cooling Water Heat Balance



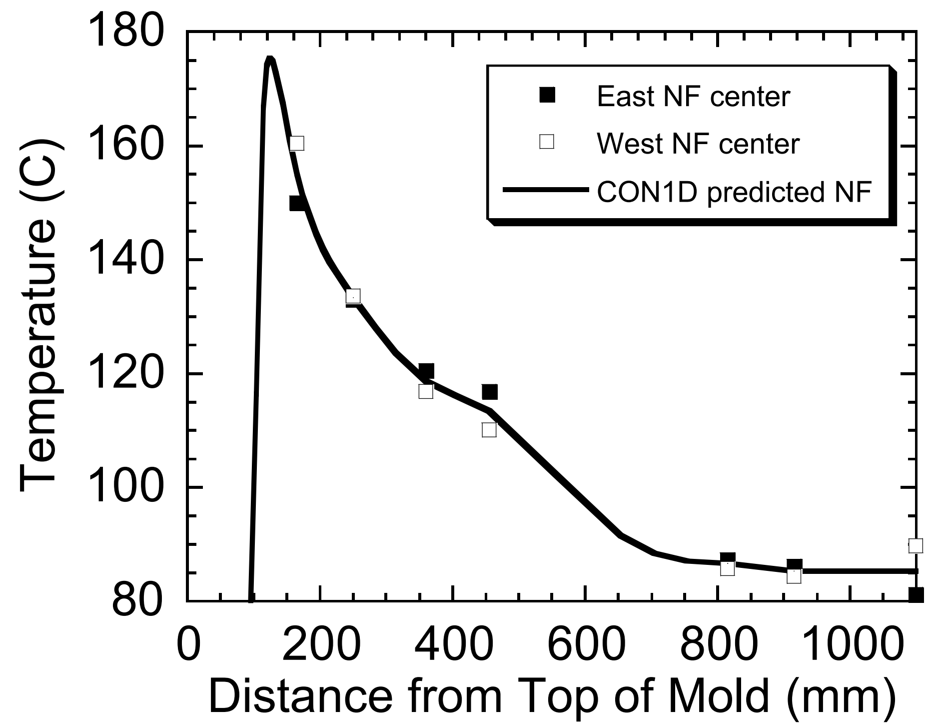
Unit : °C	measurements		CON1D predicted
	Steady state	Breakout shell	
Wide Face	6.12	6.28	5.61
Narrow Face	7.98	8.28	8.22

Temperatures Down Mold Walls (Calculated and Measured at Thermocouple Locations)

Wide Face

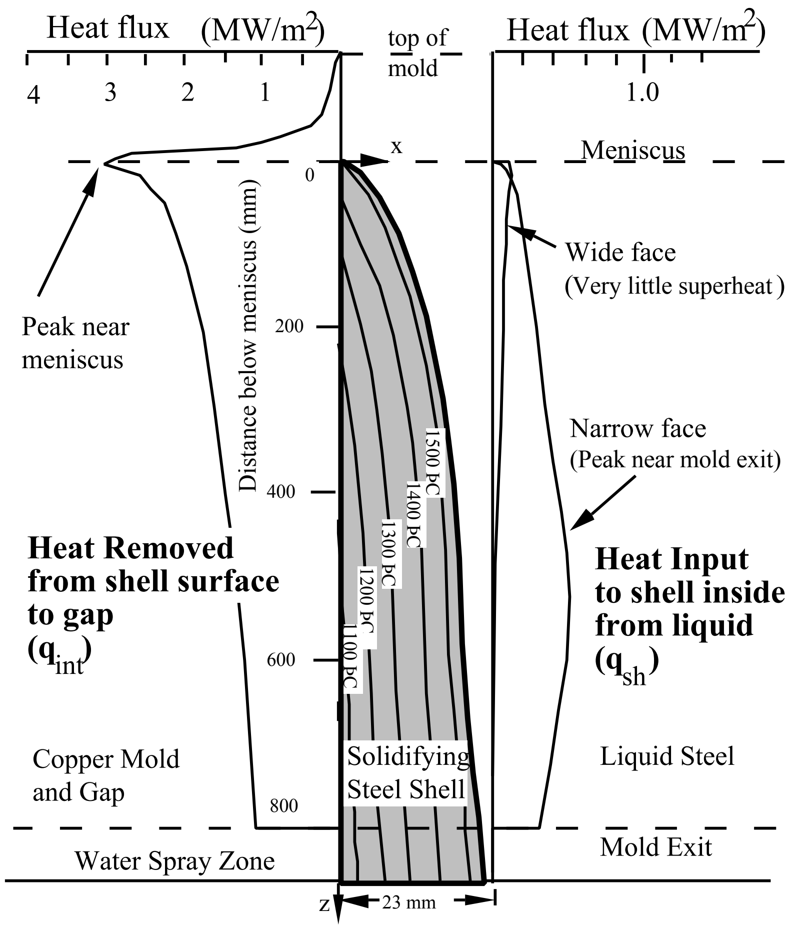


Narrow Face



CON1D calculation offset: 4.5mm 10.3mm

Solidification and Heat Transfer Model: CON1D



- 1-D transient finite-difference model of solidifying steel shell
- 2-D steady-state heat conduction within the mold wall
- detailed treatment of interfacial gap including mass and momentum balances on slag layers
- uses superheat flux from flow model
- predicts:

  -shell thickness down the mold

  -temperature in the mold and shell

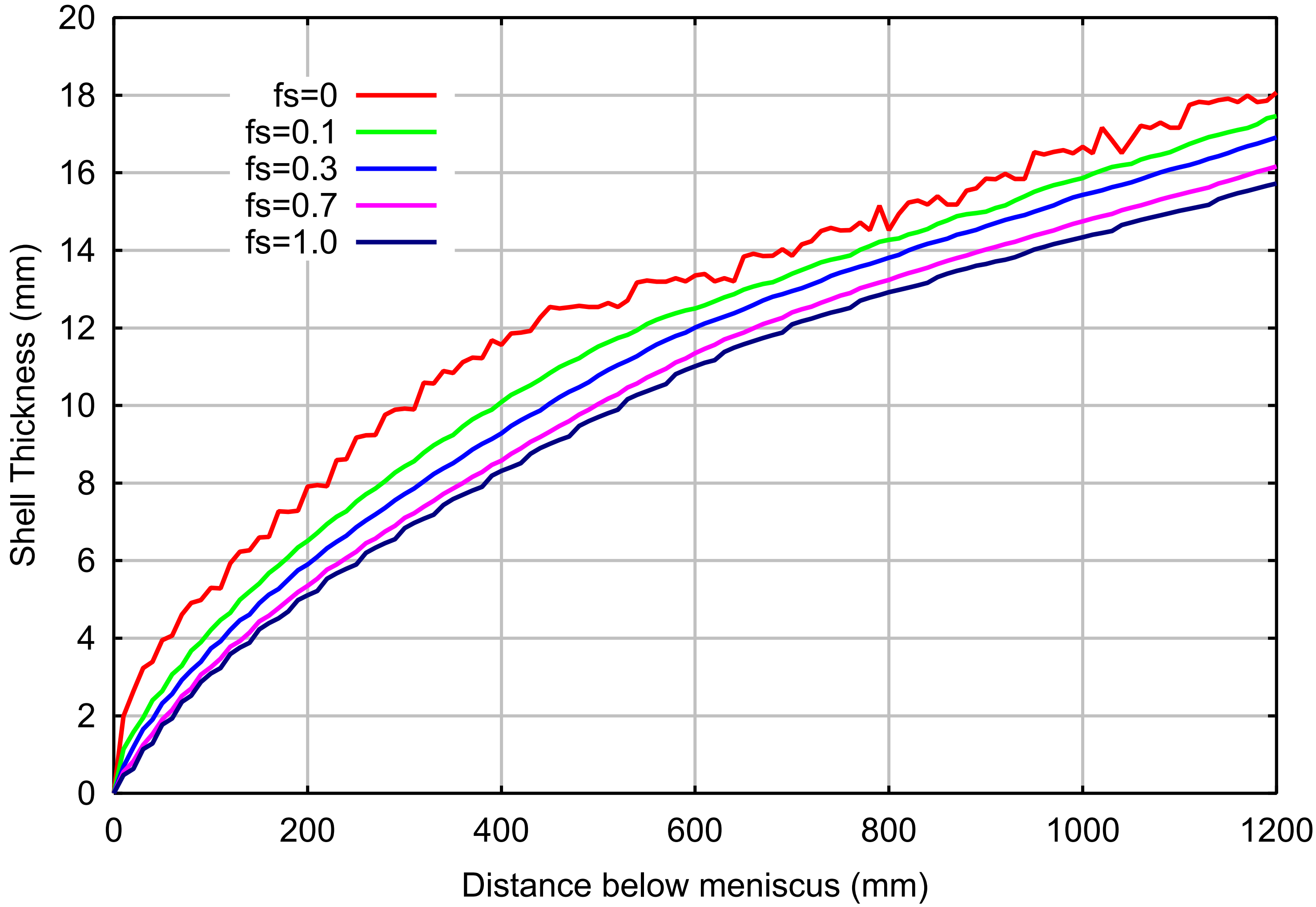
  -slag layer thicknesses (solid & liquid)

  -heat flux down the mold

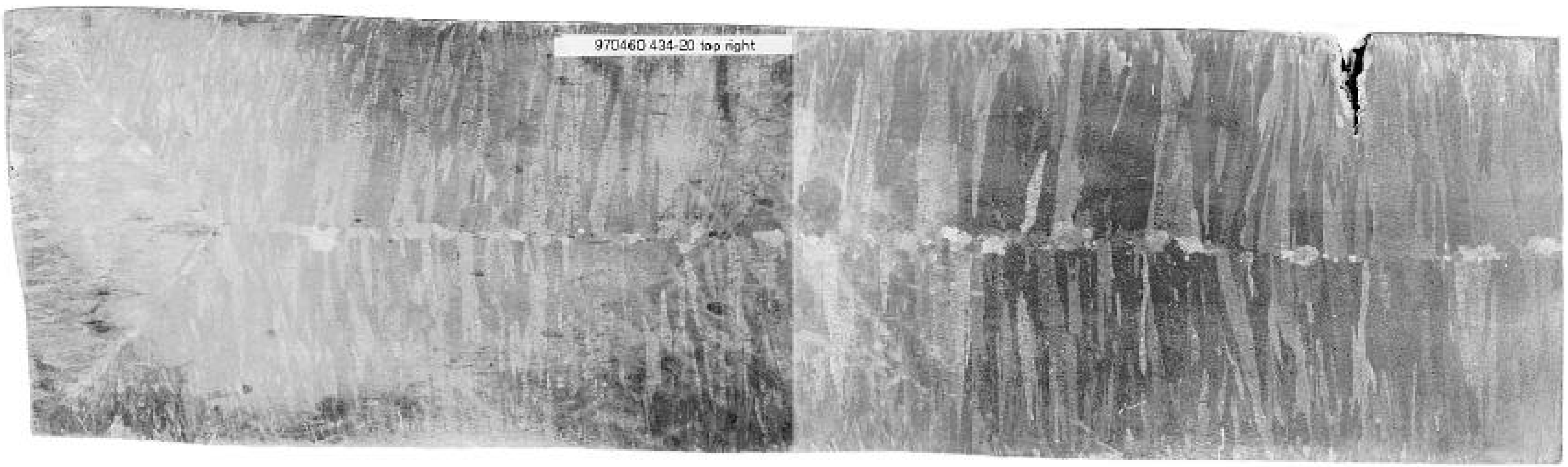
  -mold water temperature rise

  -ideal taper of mold walls

Solid Fraction Effect on Steady-state Shell Thickness



Section through slab showing longitudinal crack that started breakout



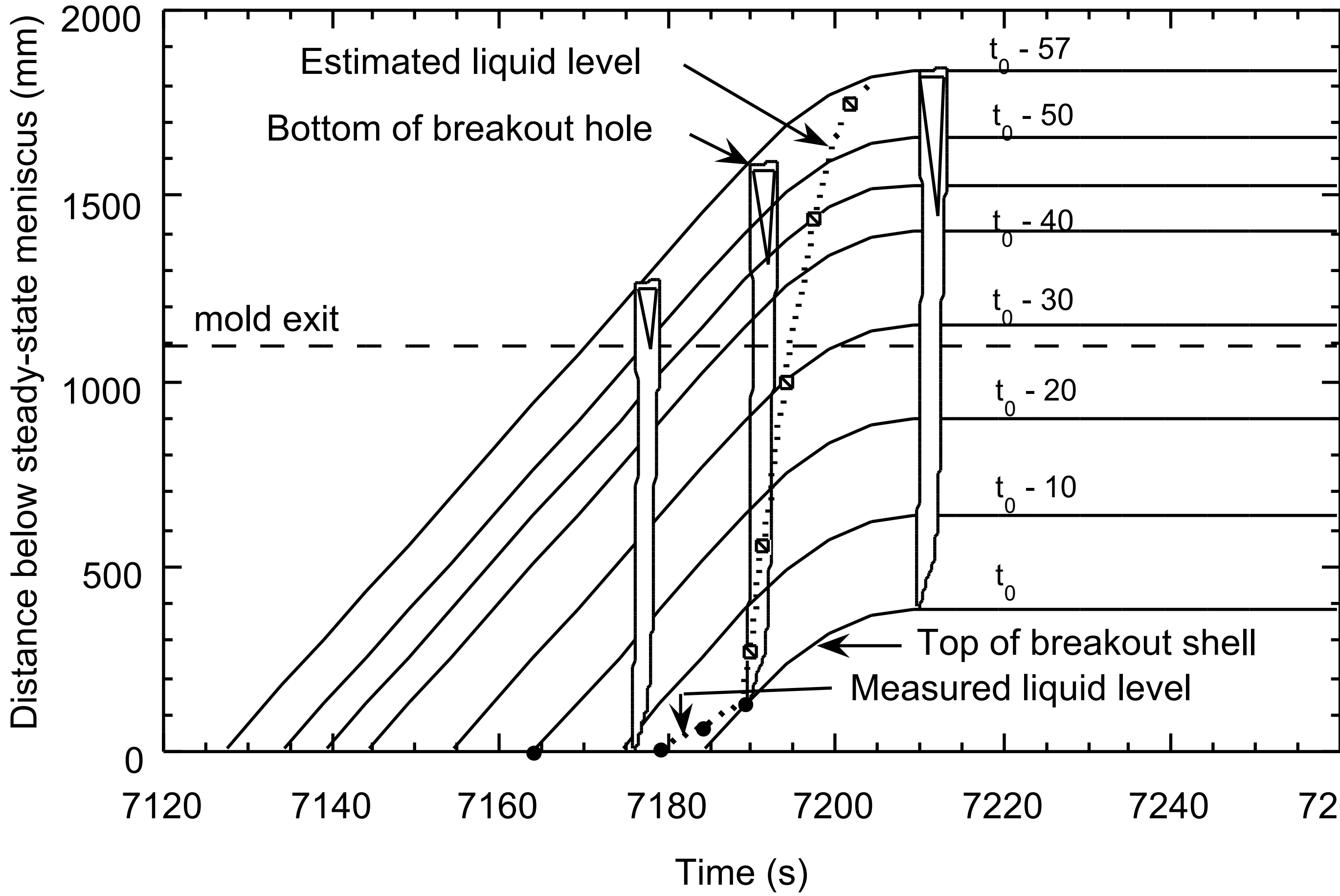
Narrow Face

Centerline

Casting Conditions & Simulation parameters

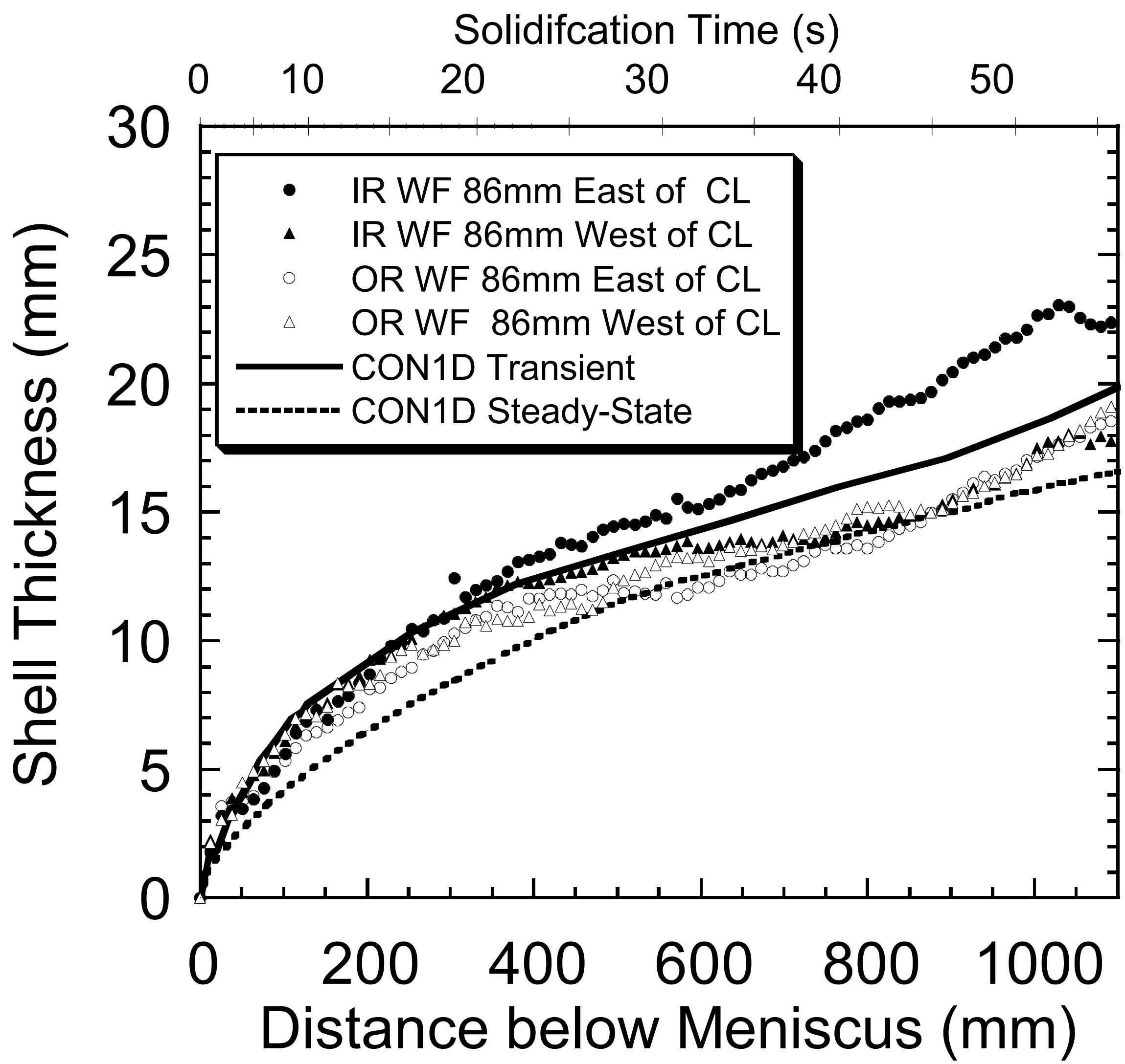
- Casting Speed: 1.524m/min
- Pour Temperature: 1563 ^{o}C (61 ^{o}C superheat)
- Slab Size: 984mm*132mm
- Mold Length: 1200mm
- Nozzle Submerge depth: 127mm
- Mold Powder Consumption Rate: 0.48kg/m^2
- Mold Thickness: wide face 35mm; narrow face 25mm
- Steel Grade: 434 Stainless Steel
- Inlet Cooling Water Temperature: 25 ^{o}C
- Fraction Solid for Shell Thickness Location: 0.1

Events during breakout



Shell Thickness Along Wide Face (WF)

(Calculated Compared with Breakout Shell Measurements)



Shell Thickness Along Wide Face (WF)

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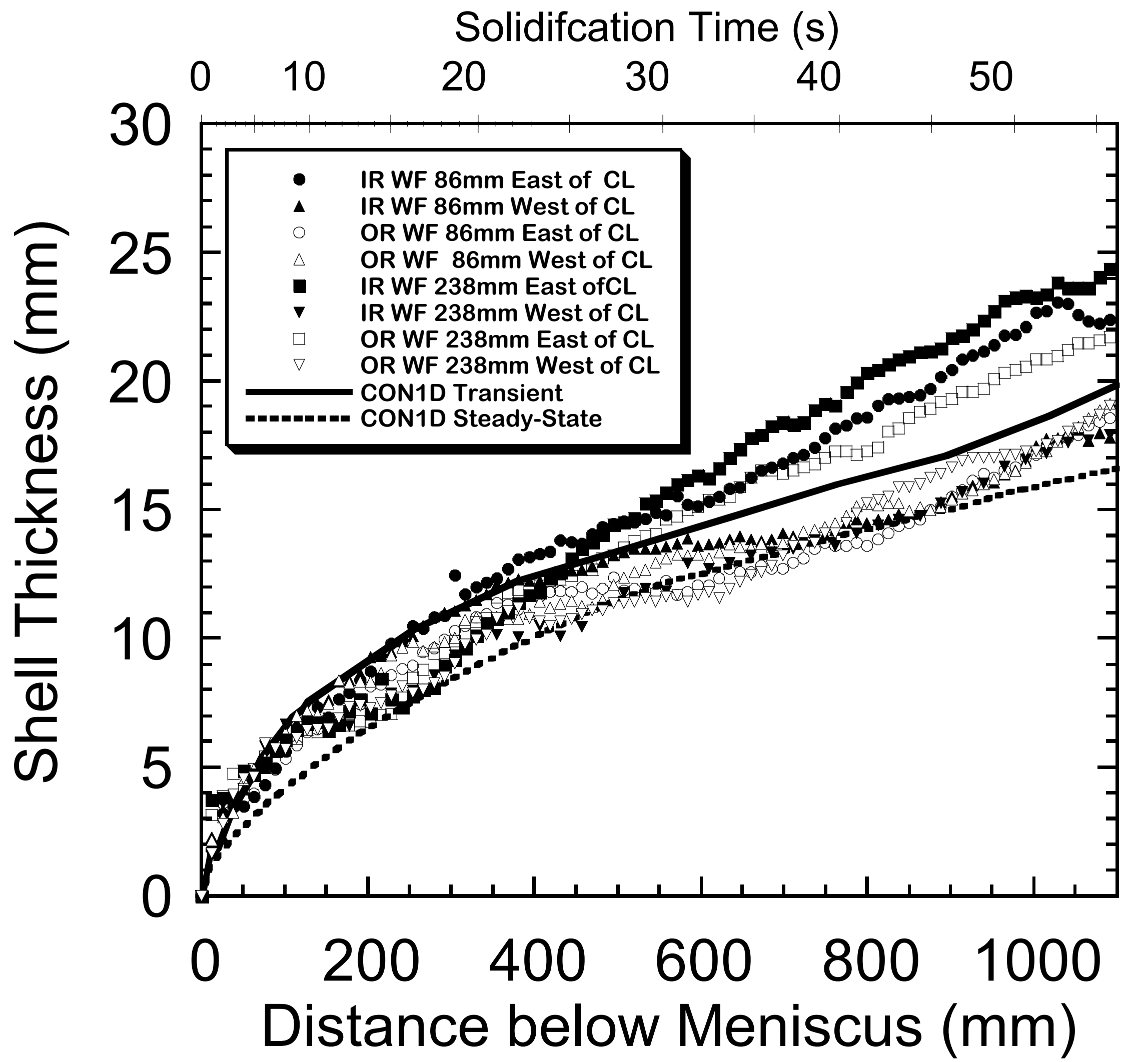
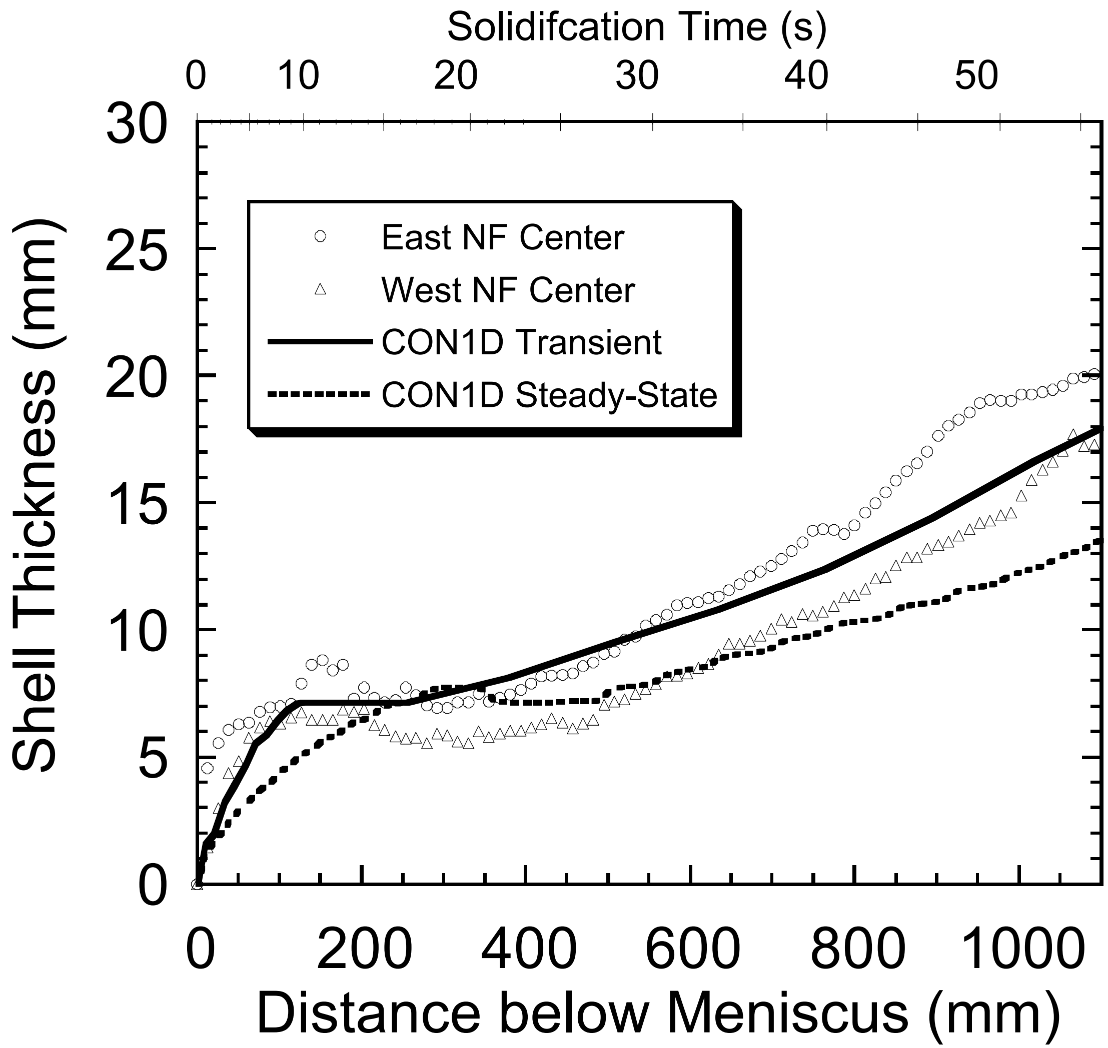


Shell Thickness Along Narrow Face (NF)

(Calculated Compared with Breakout Shell Measurements)



Model Applications

These validated modeling tools can now be applied to study related phenomena of practical significance in a quantitative manner, which include:

- ideal taper of the mold walls to match the shell shrinkage,
- critical shell thickness to avoid breakouts,
- behavior of flux layers in the interfacial gap,
- crack formation,
- relationships between mold wall temperatures and events in solidifying shell to enable online quality prediction.

Conclusion

- An efficient model of 3-D turbulent flow, heat transfer and solidification in a thin slab caster has been developed, featuring one-way coupling between
  - K-ε flow model (CFX) and
  - 1-D transient model of heat transfer in the mold, interface, and solidifying steel shell (CON1D).

- The accuracy of this modeling approach has been demonstrated by comparison with
  - experimental measurements of fluid flow in the liquid pool,
  - temperature in the molten steel,
  - temperature in the copper mold walls,
  - temperature increase of the cooling water, and
  - breakout shell thickness.