ANNUAL REPORT 2010

UIUC, August 12, 2010

Thermo-Mechanical Behavior of Continuous Casting Funnel Molds

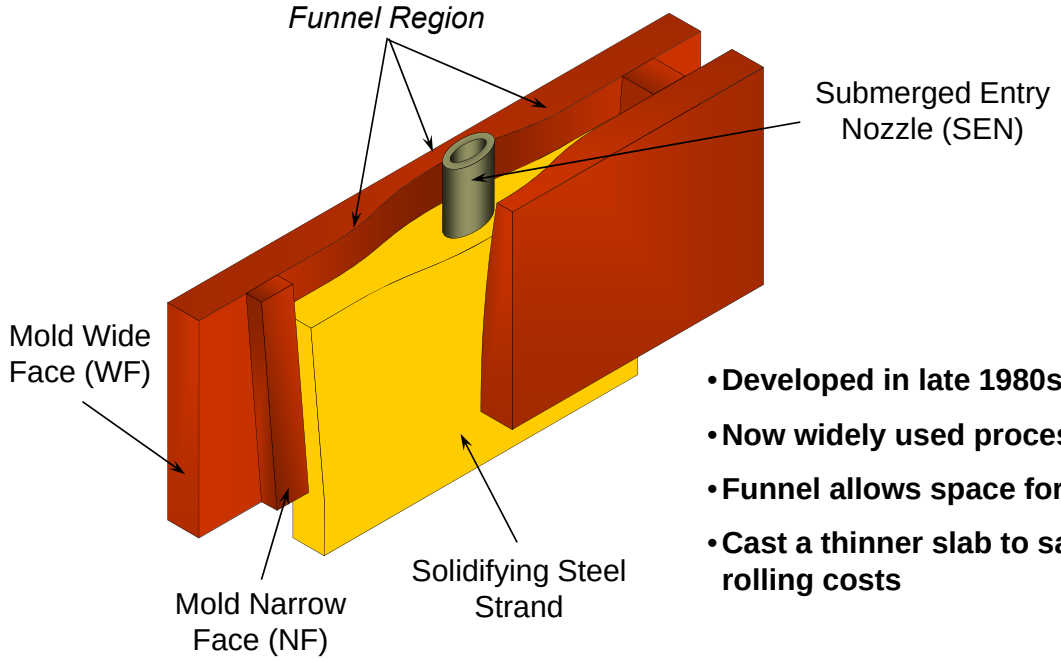
Lance C. Hibbeler
(Ph.D. Student)

Department of Mechanical Science and Engineering
University of Illinois at Urbana-Champaign

Objectives

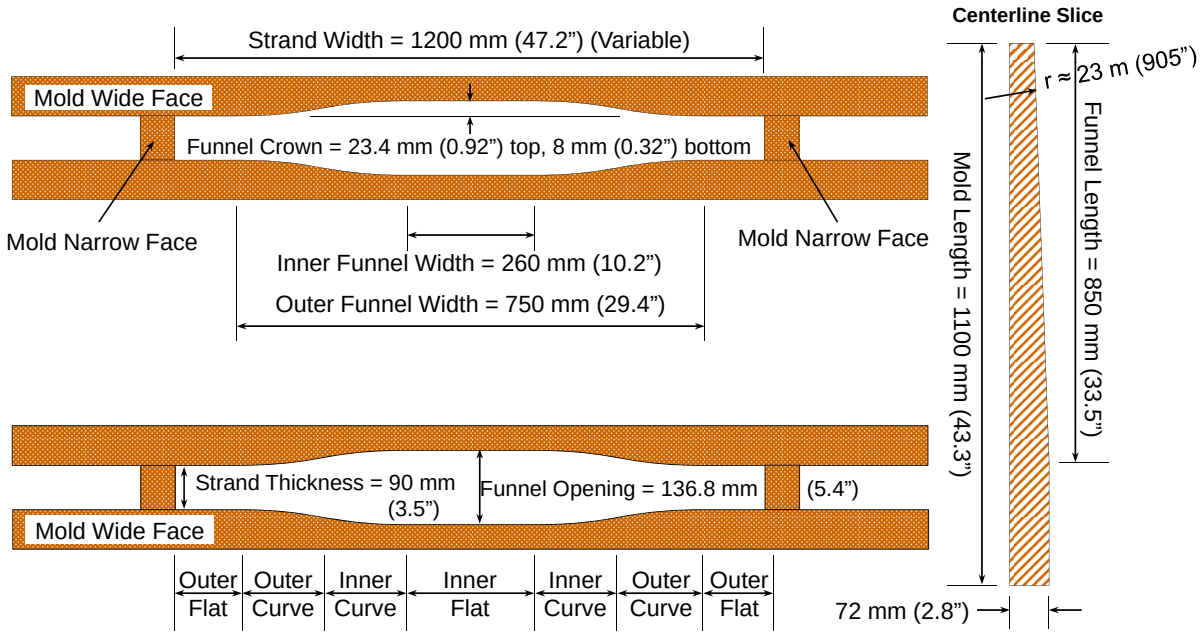
- Explore the thermal and mechanical response of the mold plates to the heat load experienced during regular casting, using a steady-state elastic finite-element model
- Recommend adjustment to taper to account for mold thermal distortion
- Recommend improvements to water box design
- Develop post-processing tool for exporting mold shape and temperatures into slice/chunk models of the solidifying shell

Continuous Casting Funnel Mold

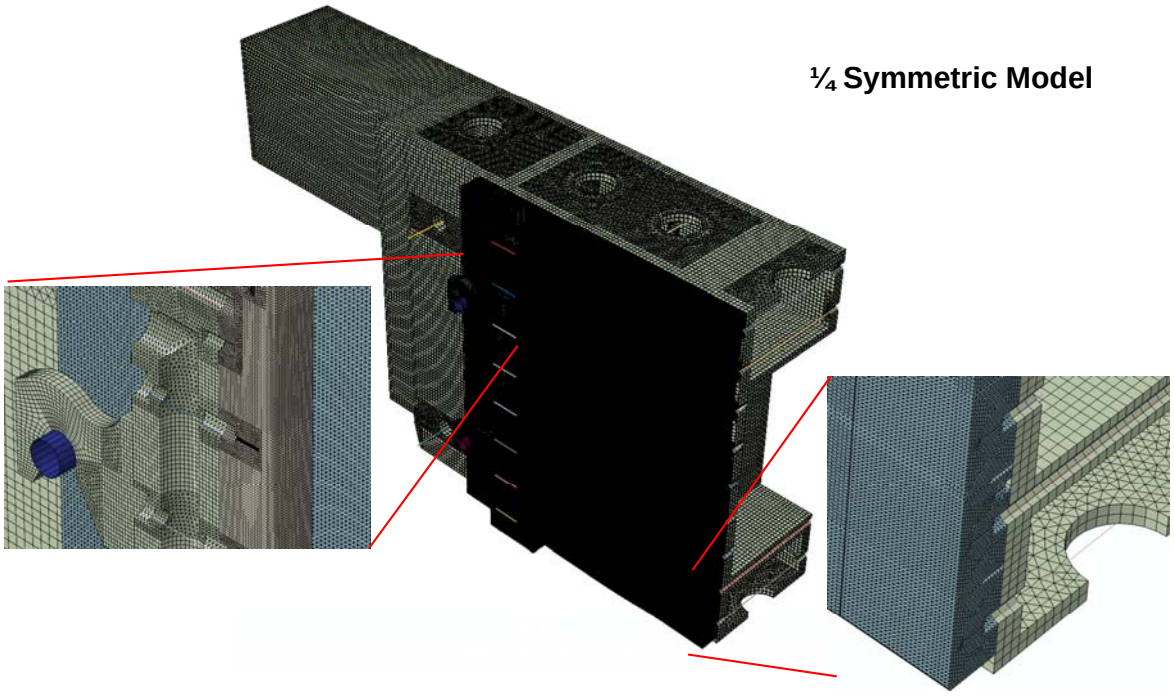


- **Developed in late 1980s**
- **Now widely used process**
- **Funnel allows space for SEN**
- **Cast a thinner slab to save on rolling costs**

Funnel Mold Terminology and Nominal Dimensions



Finite Element Mesh

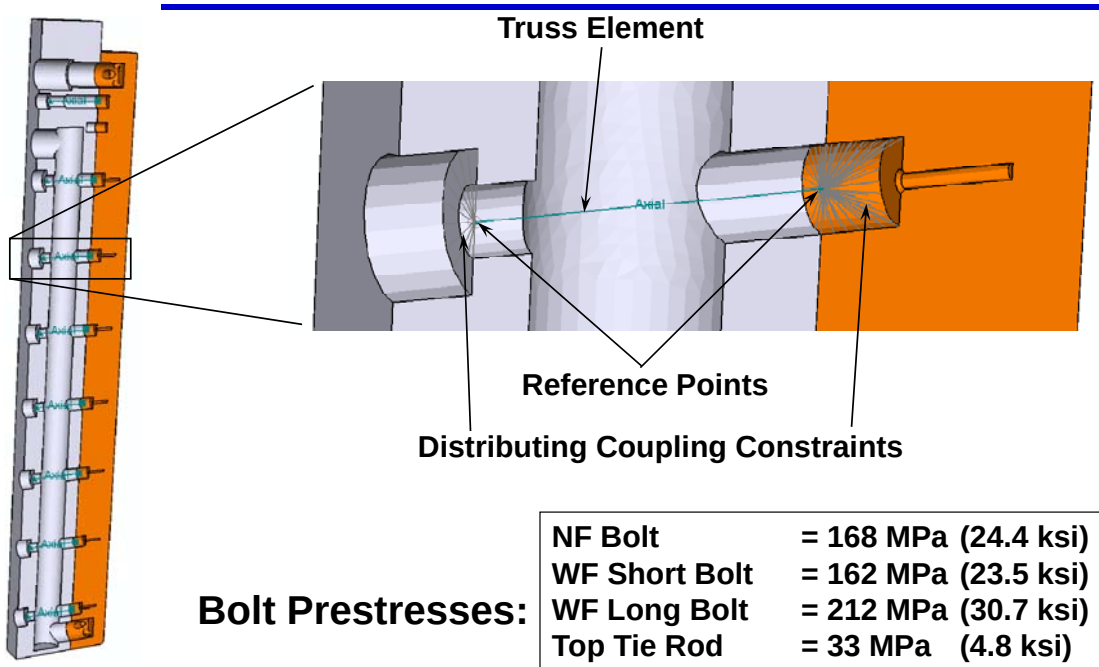


Finite Element Mesh

Part	Nodes	Elements	
Wide Face Mold Plate	855,235	(Tet)	4,223,072
Wide Face Water Box	185,534	(Tet, Wedge, Hex)	190,457
Wide Face Bolts	90	(Truss)	45
Tie Rods	4	(Truss)	2
Narrow Face Mold Plate	233,931	(Tet, Wedge, Hex)	495,566
Narrow Face Water Box	83,269	(Tet, Wedge, Hex)	239,604
Narrow Face Bolts	16	(Truss)	8
Narrow Face Hangers	2	(Analytical Surf.)	0
Total	1,358,081		5,148,754

Thermal DOF = *1,089,166* **Mechanical DOF = *4,830,081***

Mold Bolts



Bolt Prestresses:

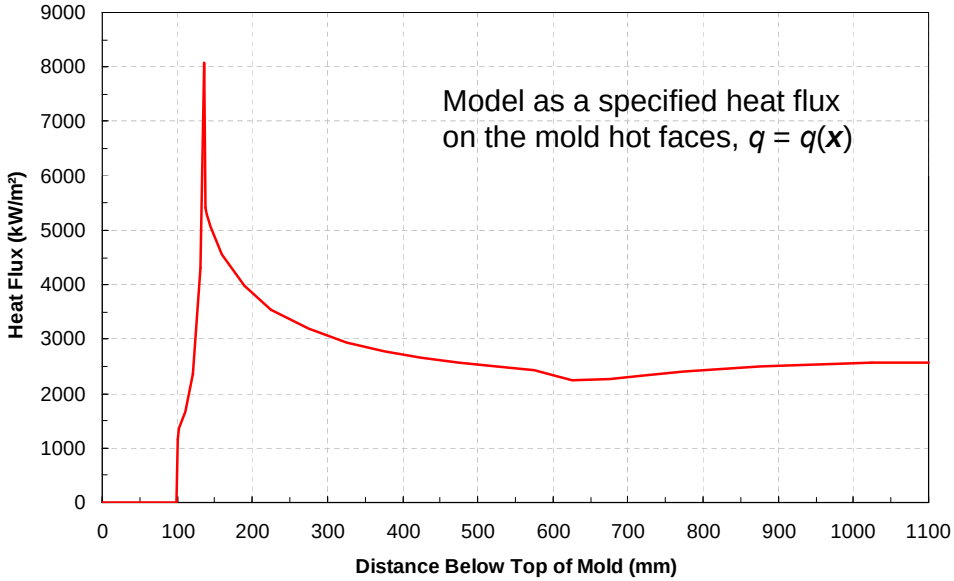
NF Bolt	= 168 MPa	(24.4 ksi)
WF Short Bolt	= 162 MPa	(23.5 ksi)
WF Long Bolt	= 212 MPa	(30.7 ksi)
Top Tie Rod	= 33 MPa	(4.8 ksi)
Bottom Tie Rod	= 58 MPa	(8.4 ksi)

Material Properties

- Mold: Cu-Zr-Cr alloy
  - Thermal conductivity = 350 W/(m·K)
  - Density = 8900 kg/m³ (0.322 lb/in³)
  - Elastic modulus = 117 GPa ($17 \cdot 10^3$ ksi)
  - Poisson's ratio = 0.181
  - Coefficient of thermal expansion = $18.0 \cdot 10^{-6}$ 1/ºC
- Water box: AISI 316Ti stainless steel
  - Elastic modulus = 200 GPa ($30 \cdot 10^3$ ksi)
  - Poisson's ratio = 0.299
- Copper/steel coefficient of friction = 0.5

Surface Heat Flux

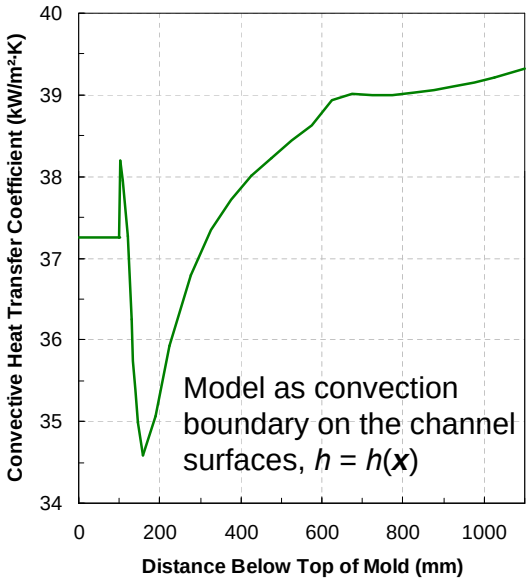
Calculated with CON1D, calibrated with plant measurements

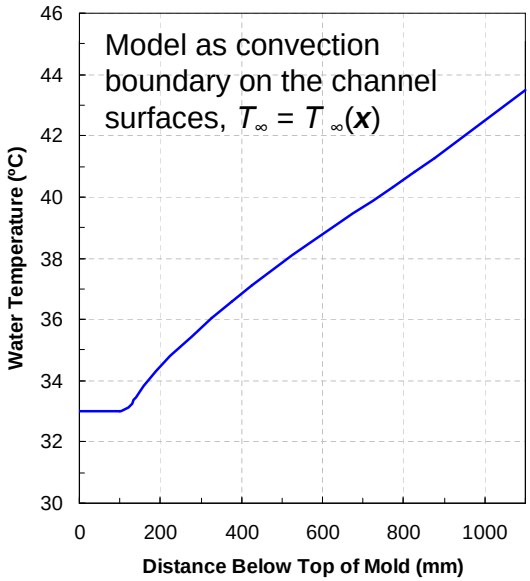


Santillana *et al.*, *ISIJ Int.* **48**:10 (2008), pg. 1380

Water Channel Conditions

Calculated with CON1D, calibrated with plant measurements





Santillana *et al.*, *ISIJ Int.* **48**:10 (2008), pg. 1380

Modeling Approach

- Heat transfer in mold
  - Initial temperature of 30 ºC (86 ºF)
  - Calibrated surface heat flux, water temperature
  - Water box has little effect on thermal results
  - 12 minutes*
- Stress model in mold and water box
  - Ferrostatic pressure, bolts, contact with friction
  - 44.6 days*

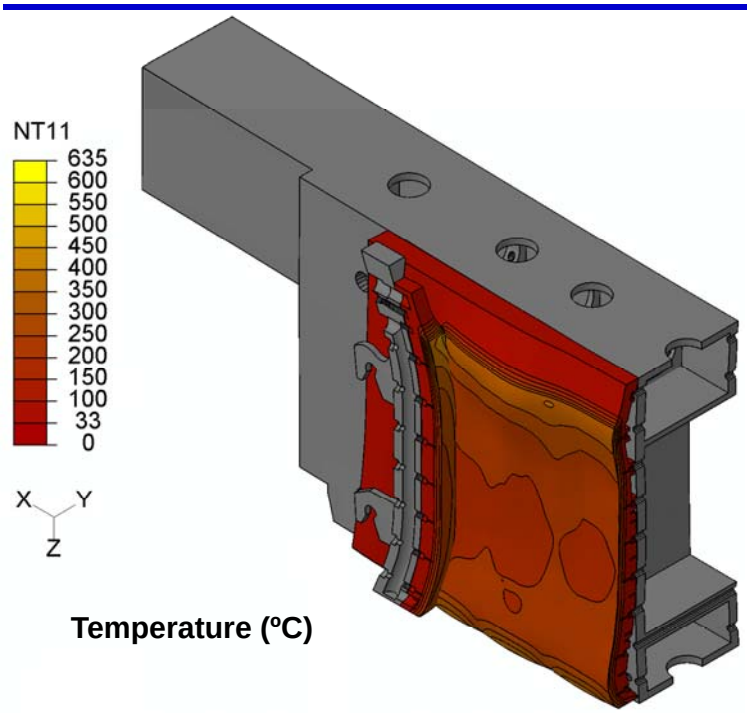
*** 2x 2.66 GHz Quad-core Intel Xeon, 8 GB RAM**

Funnel Mold Distortion

$u_x = u_x \cdot 50$

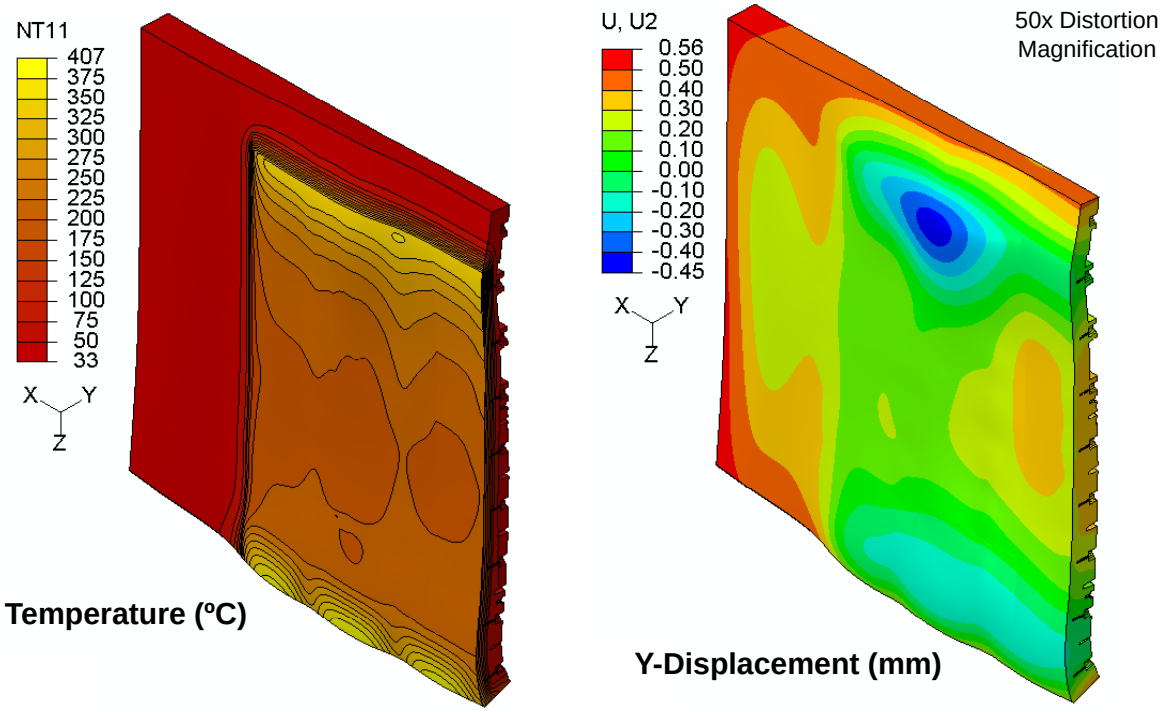
$u_y = u_y \cdot 50$

$u_z = u_z$

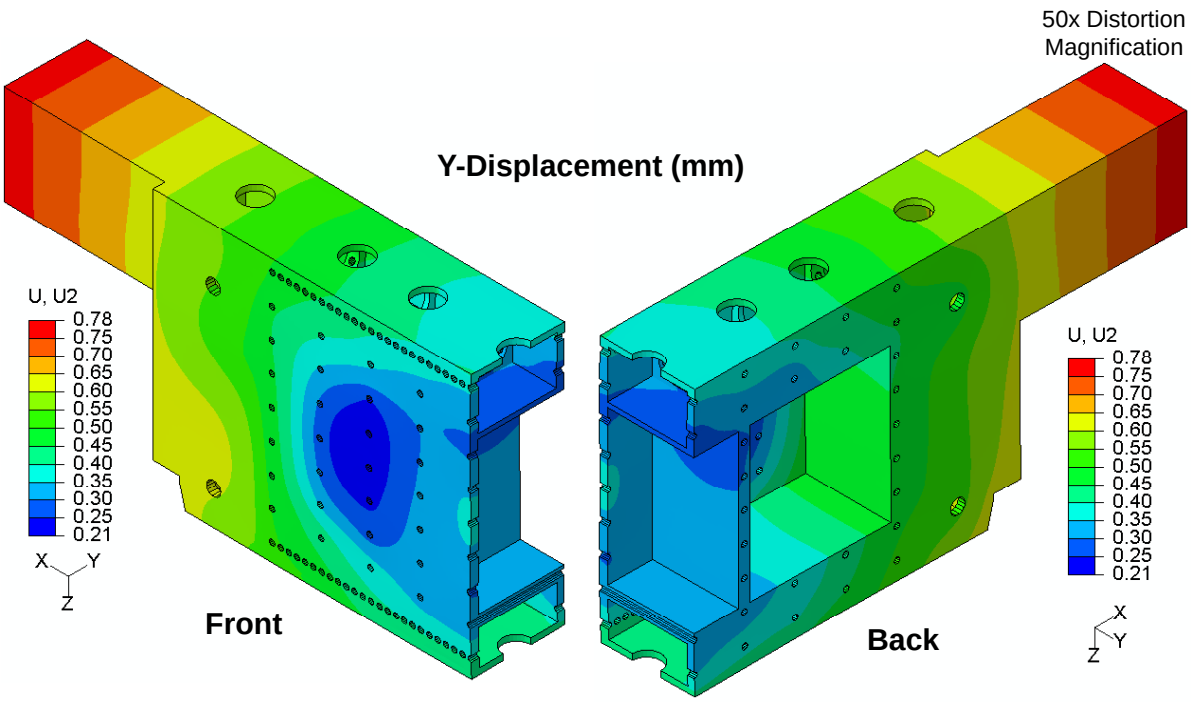


Temperature (ºC)

Wide Face Mold

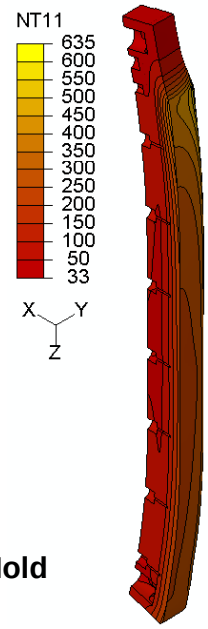


Wide Face Water Box



Narrow Face

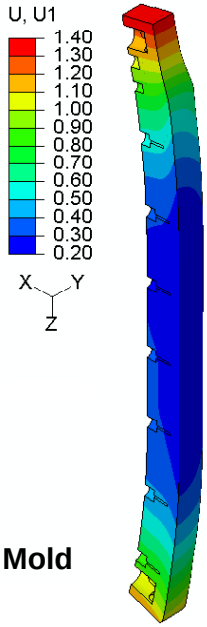
Temperature (ºC)



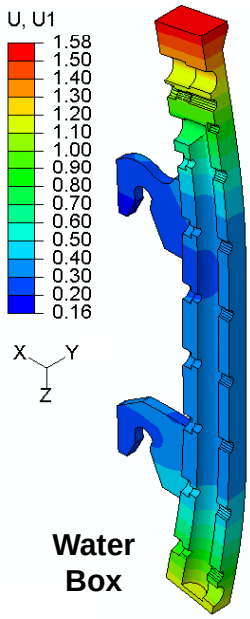
Mold

X-Displacement (mm)

50x Distortion Magnification



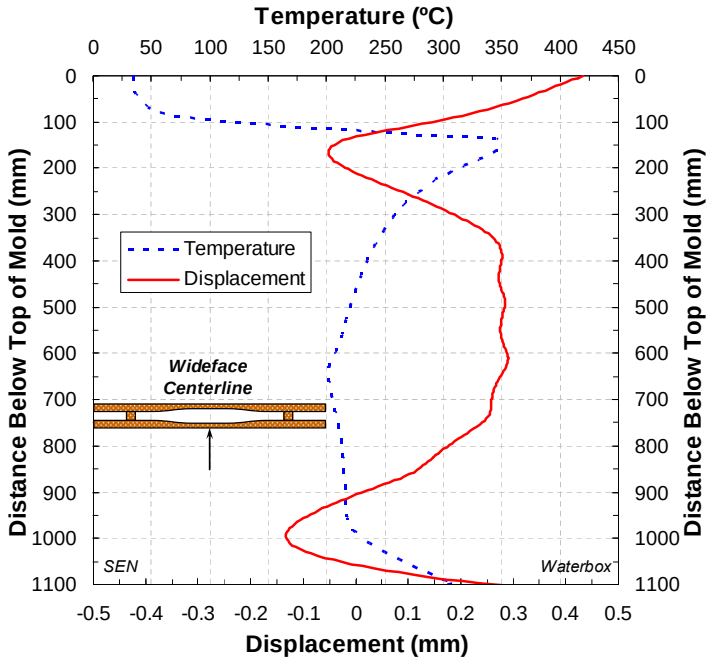
Mold

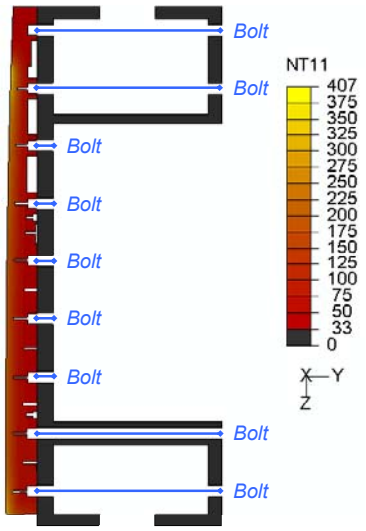


Water Box

Hot Face Thermo-Mechanical Behavior: Wide Face Centerline

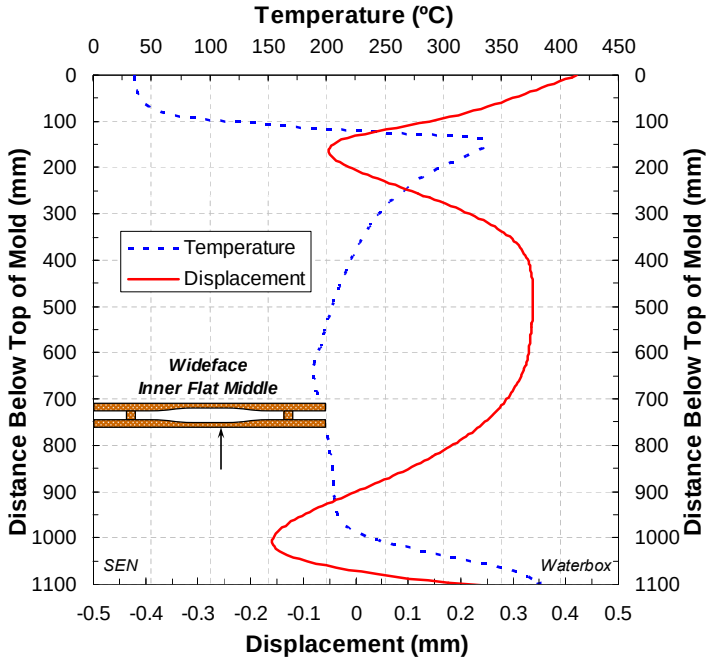
1x Distortion Magnification



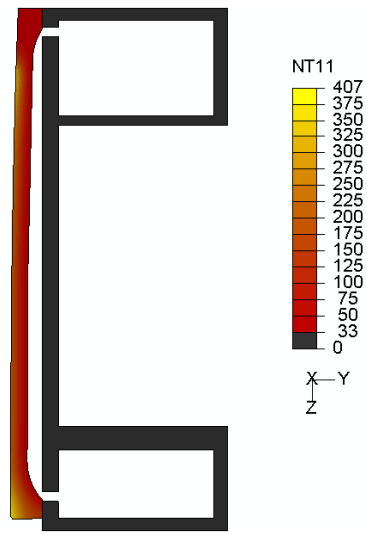


0 mm from WF centerline

Hot Face Thermo-Mechanical Behavior: Wide Face Inner Flat Middle

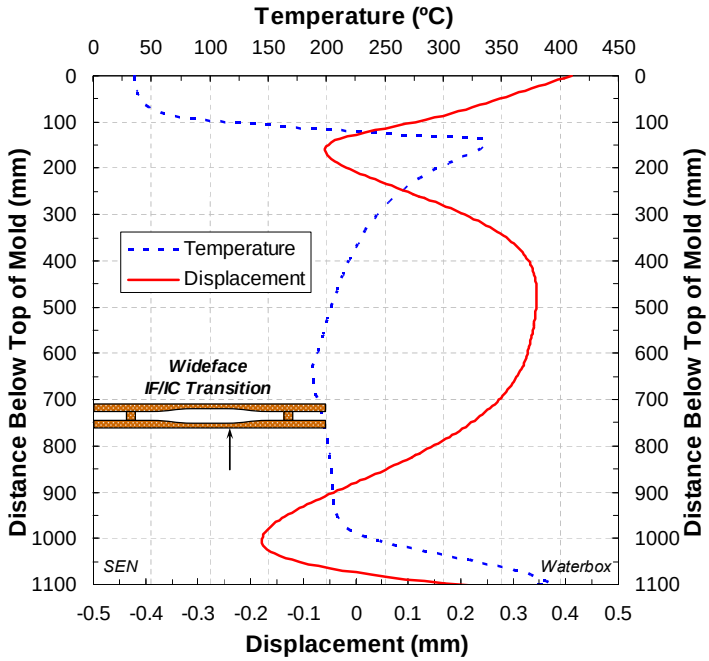


1x Distortion Magnification

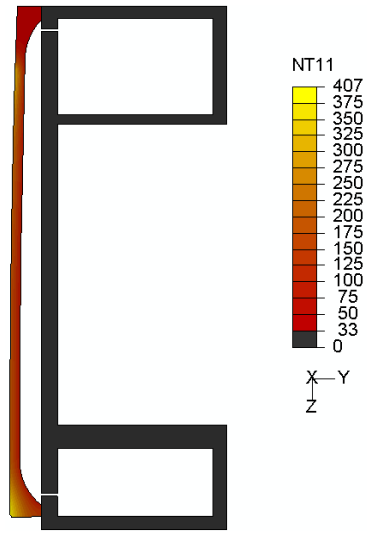


65 mm from WF centerline

Hot Face Thermo-Mechanical Behavior: Wide Face IF/IC Transition

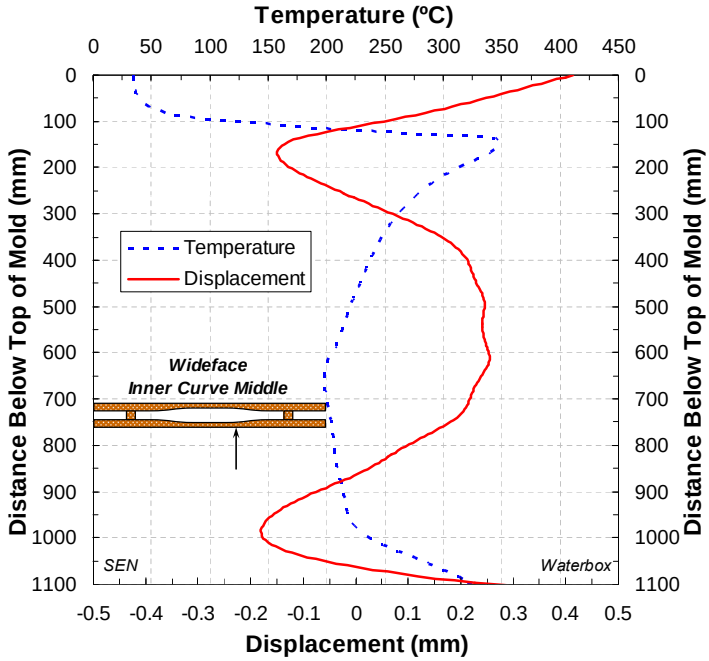


1x Distortion Magnification

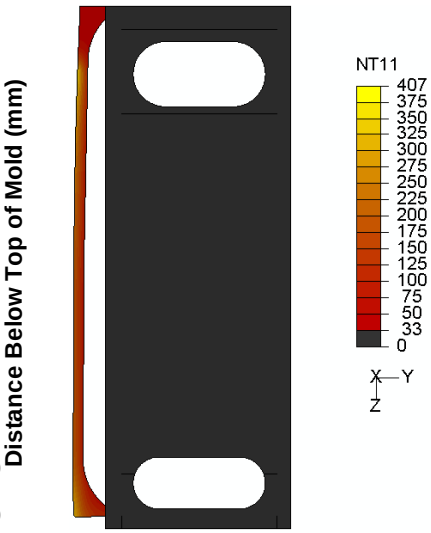


130 mm from WF centerline

Hot Face Thermo-Mechanical Behavior: Wide Face Inner Curve Middle

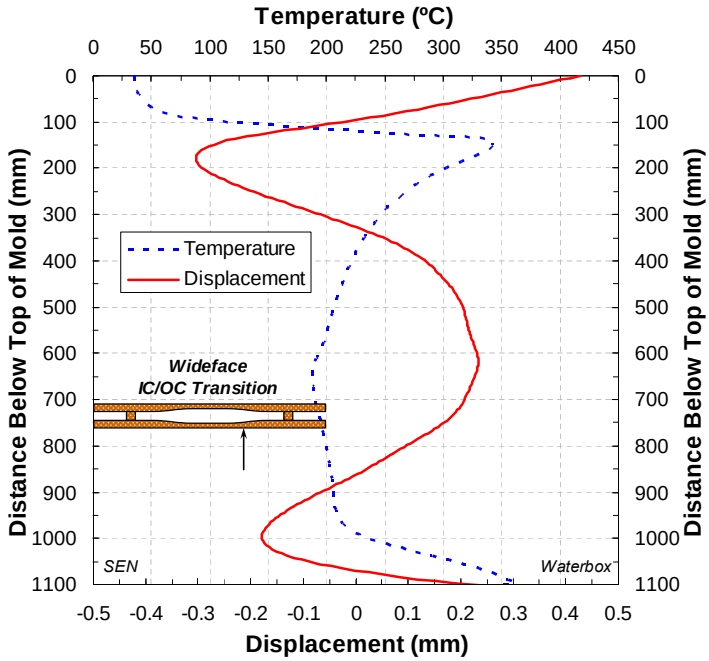


1x Distortion Magnification

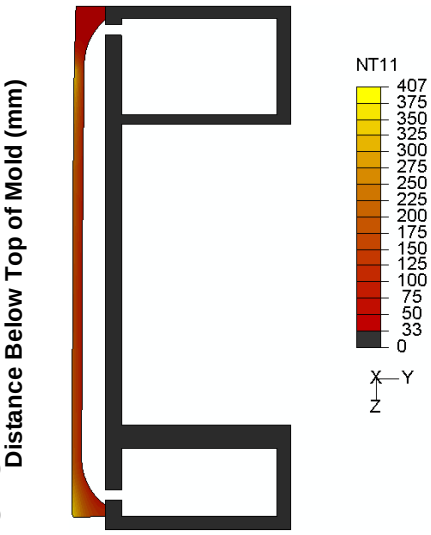


191.25 mm from WF centerline

Hot Face Thermo-Mechanical Behavior: Wide Face IC/OC Transition

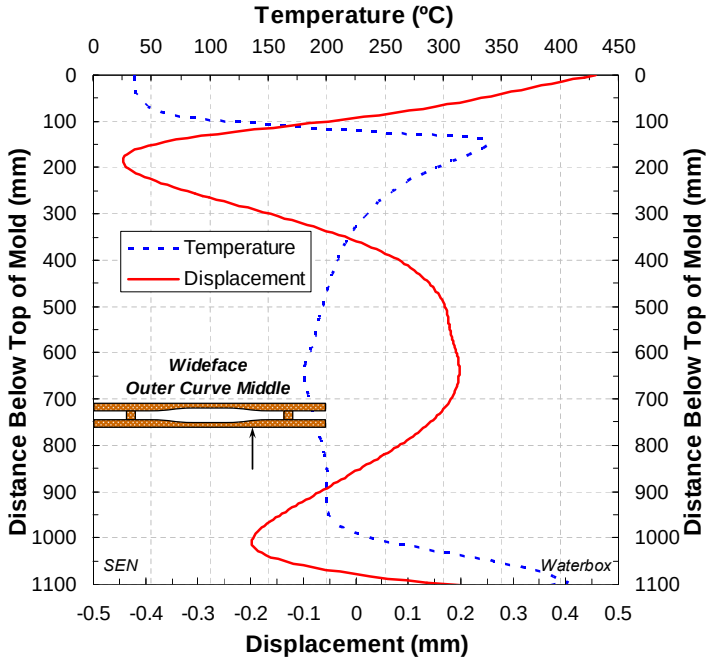


1x Distortion Magnification

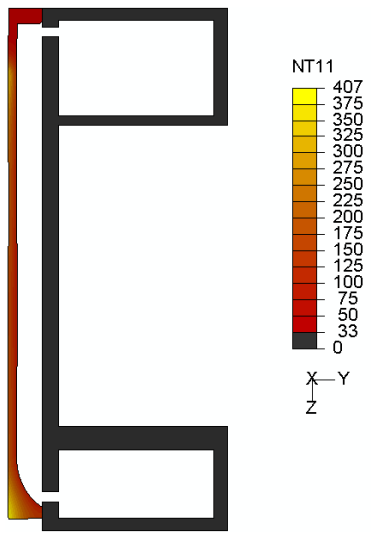


252.5 mm from WF centerline

Hot Face Thermo-Mechanical Behavior: Wide Face Outer Curve Middle

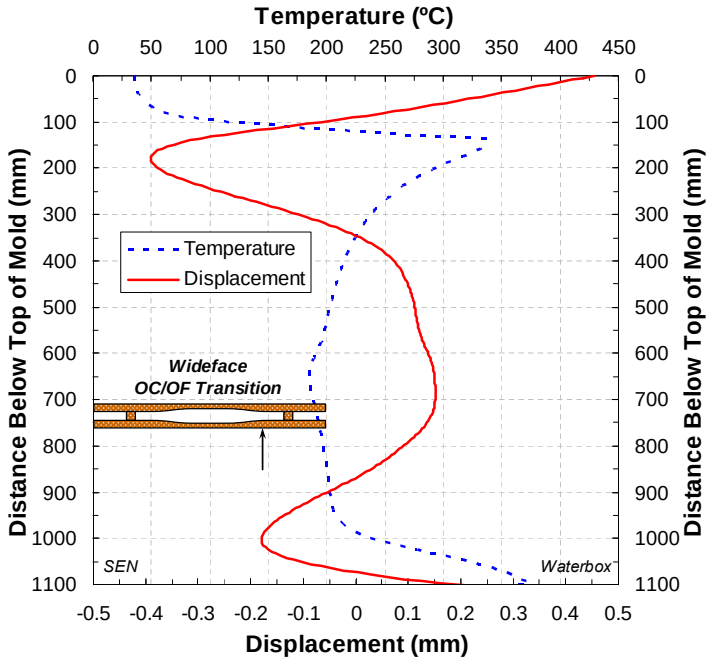


1x Distortion Magnification

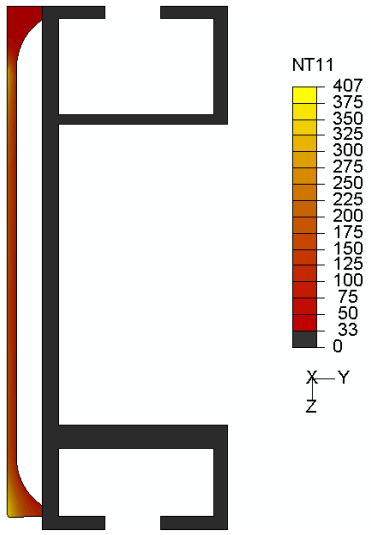


313.75 mm from WF centerline

Hot Face Thermo-Mechanical Behavior: Wide Face OC/OF Transition

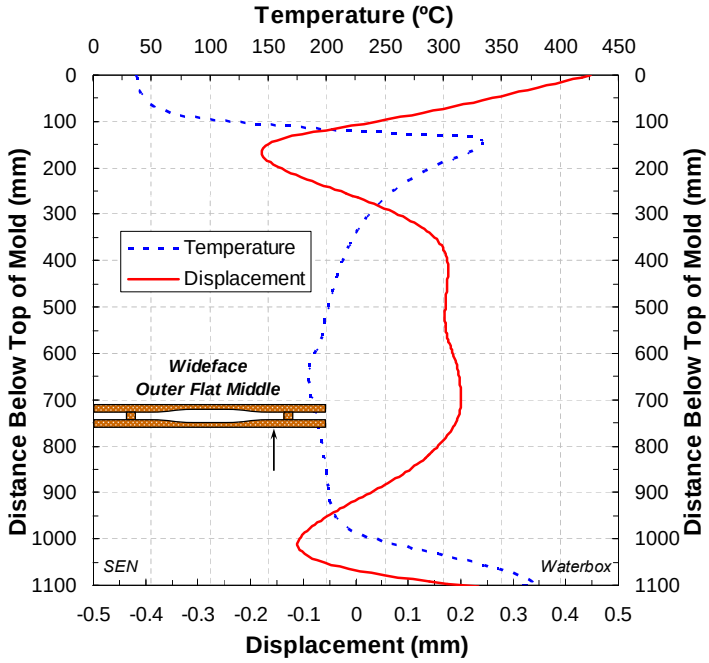


1x Distortion Magnification

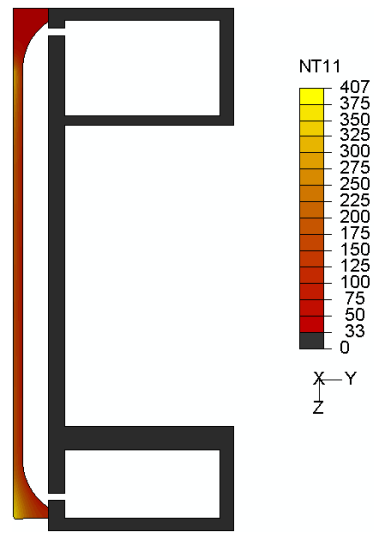


375 mm from WF centerline

Hot Face Thermo-Mechanical Behavior: Wide Face Outer Flat Middle

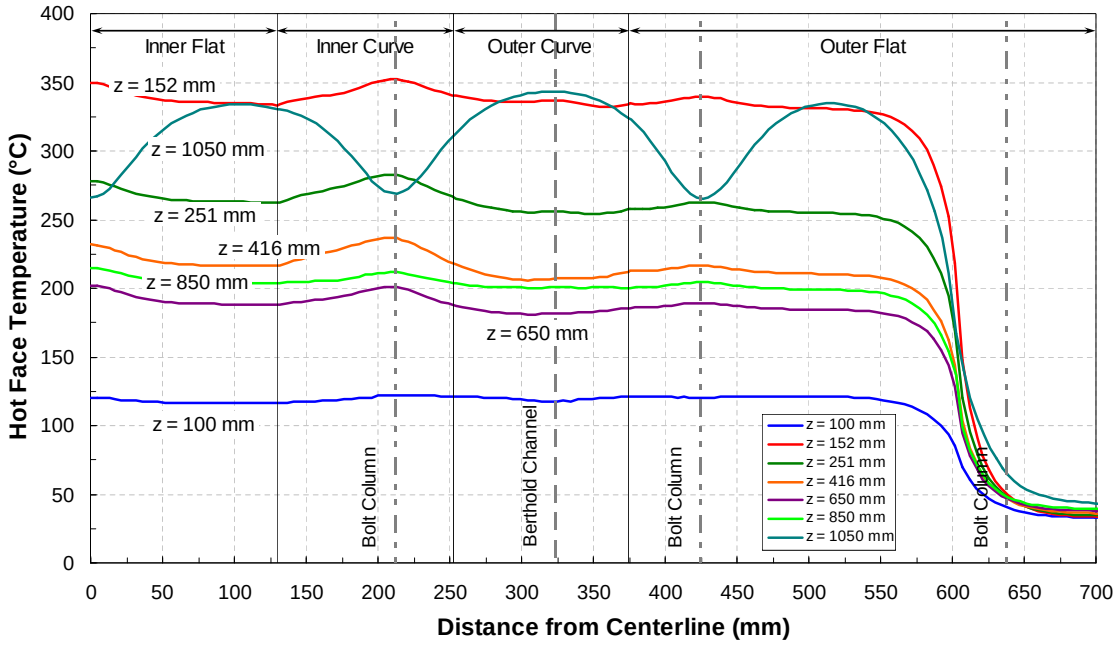


1x Distortion Magnification



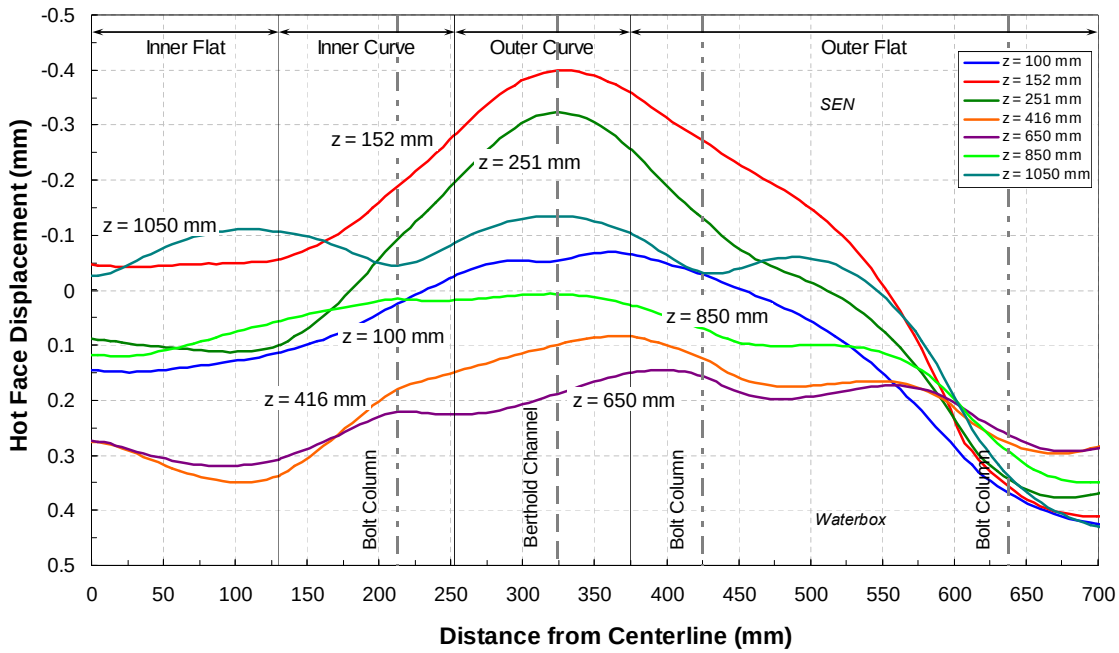
487.5 mm from WF centerline

WF Hot Face Temperature



Temperatures most affected by variations in cooling slot design

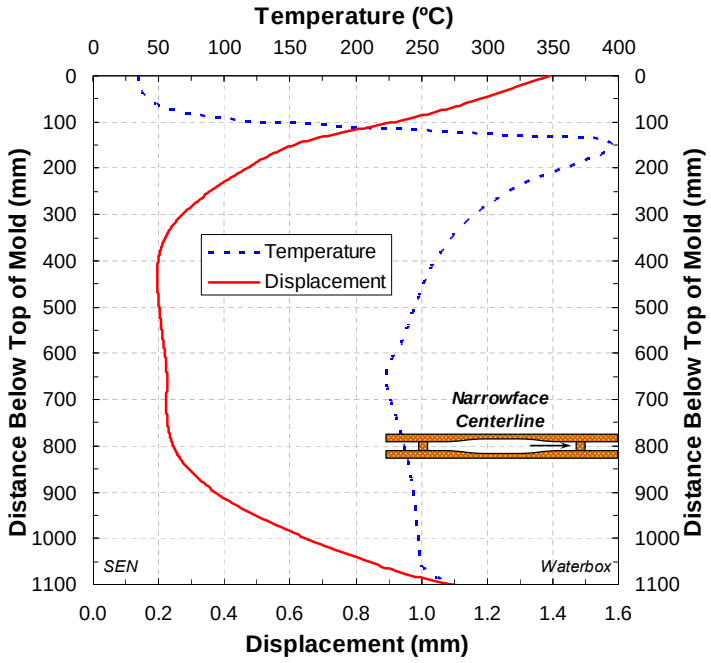
WF Hot Face Displacement

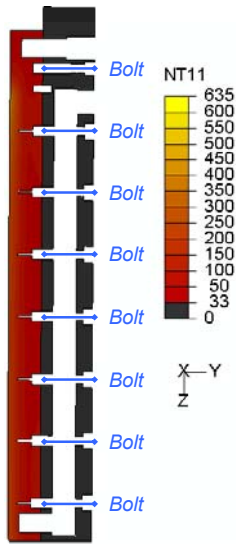


Distortion most affected by bolt design

Hot Face Thermo-Mechanical Behavior: Narrow Face Centerline

1x Distortion Magnification

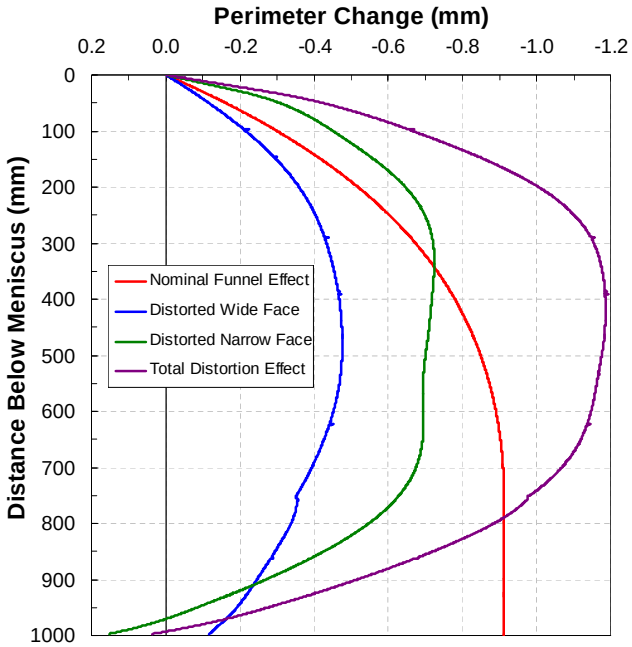




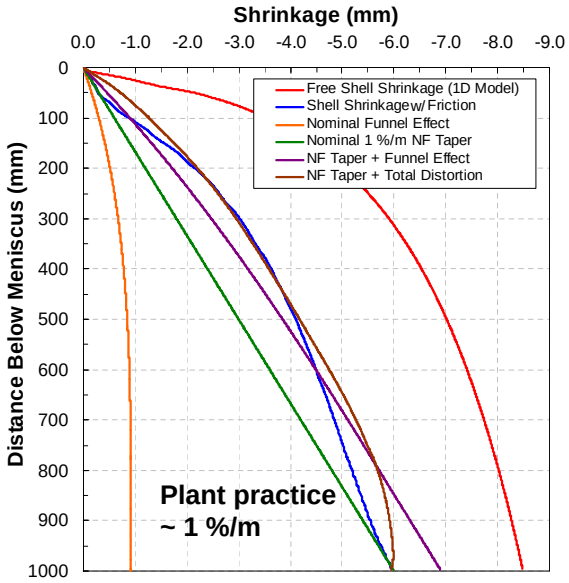
0 mm from NF centerline

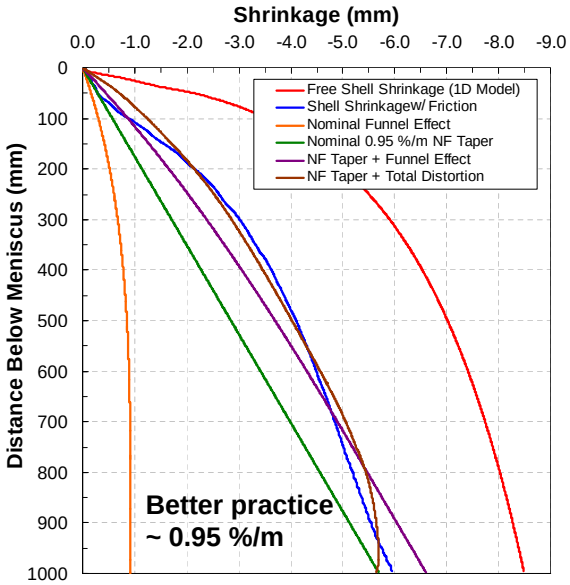
Taper Considerations

- Mold distortion creates extra perimeter change (~1.2 mm per ¼ mold)
- Funnel effect on taper is significantly reduced by mold distortion
- This must be accounted for when designing taper practices



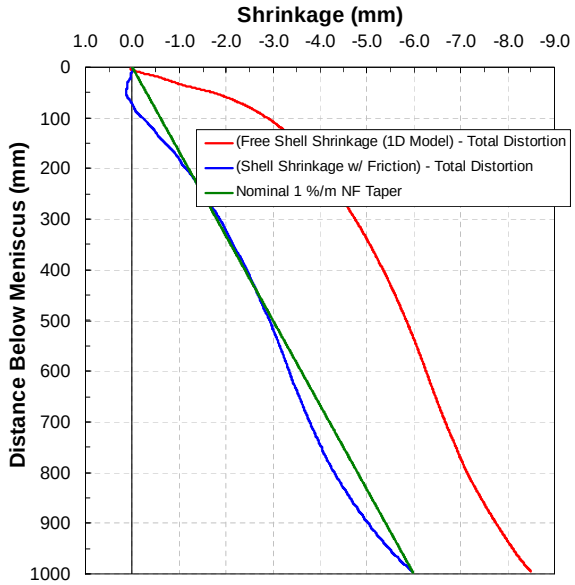
Taper Design

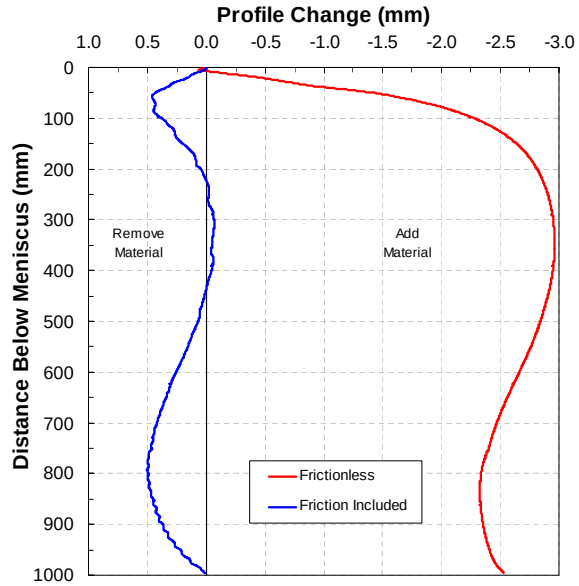




Reduce NF taper by 0.05-0.1 %/m to reduce wear at end of narrow face and tendency to squeeze the shell

Taper Design Alternative





Alternative approach is to stay with 1%/m NF taper and change NF machining practice

Water Box Design Considerations

- Shorter bolts are 4 times stiffer than long bolts
  - Places that tend to distort the most have weakest support
- Increase thickness of front water box plate and stiffeners to increase resistance to bending
- Previous work shows thicker water box plates better controls the distortion (Z. Yuan, CCC Meeting 2008)

Future Work

- Speed up analysis time
  - ABAQUS/Explicit shows promise
    - Better parallelization, much more robust contact
    - Must be transient simulation, but mass scaling helps
- Investigation of:
  - Mold life and creep behavior
  - Different funnel geometries
  - Different casting conditions (speed, width, etc.)
  - **Effect of mold friction on shell shrinkage**
- Use distortion results in shell models

Results in a Lagrangian Frame

Hot face temperature and position changes according to what the traveling slice domain would "see"

Acknowledgements

- Continuous Casting Consortium Members (ABB, Arcelor-Mittal, Baosteel, Corus, LWB Refractories, Nucor Steel, Nippon Steel, Postech, Posco, ANSYS-Fluent)
- Corus IJmuiden R&D staff and plant personnel
- National Center for Supercomputing Applications (NCSA) at UIUC – “Cobalt” cluster
- Dassault Simulia, Inc. (ABAQUS parent company)