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Thermomechanical Behavior of a Wide Slab Casting Mold

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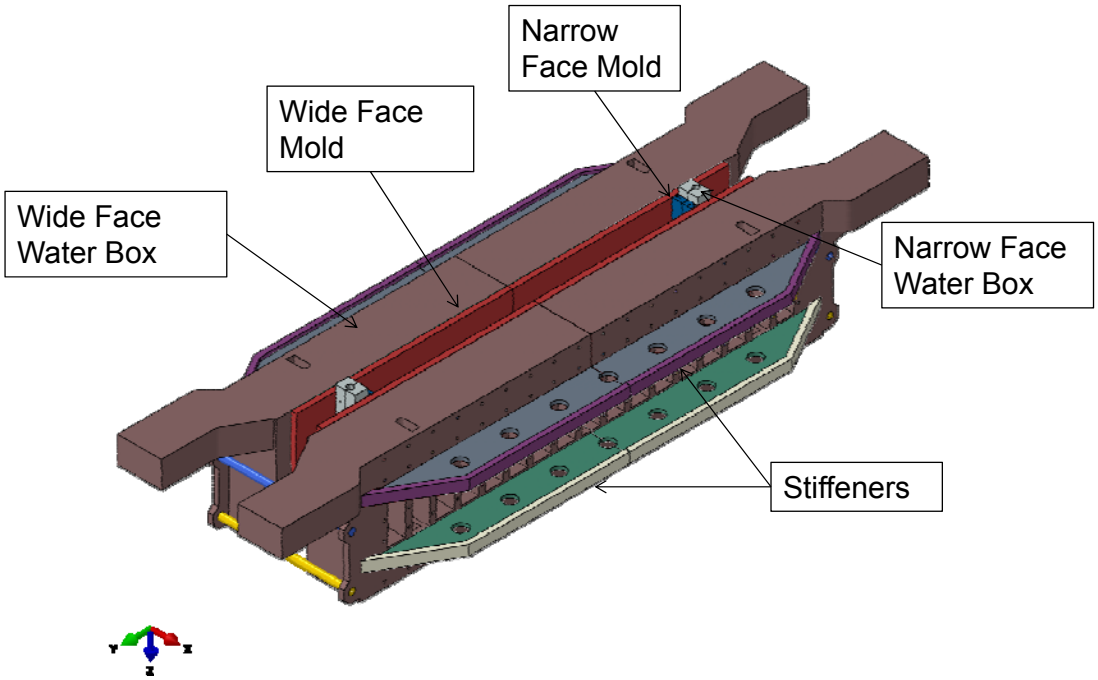
Introduction

- Previous work on thermomechanical behavior of continuous casting molds:
  - I. V. Samarasekera, D. L. Anderson, and J. K. Brimacombe, "The Thermal Distortion of Continuous-Casting Billet Molds." *Metallurgical Transactions B* **13**:1 (1982), p. 91—104.
  - T. G. O'Connor and J. A. Dantzig, "Modeling the Thin-Slab Continuous-Casting Mold." *Metallurgical and Materials Transactions B* **25**:3 (1994), p. 443—457.
  - B. G. Thomas, G. Li, A. Moitra, and D. Habing, "Analysis of Thermal and Mechanical Behavior of Copper Molds during Continuous Casting of Steel Slabs." *Iron & Steelmaker* **25**:10 (1998), p. 91—104.
- Mold geometry has been shown to be important, but very few geometries have been investigated

Objectives: Calculate temperature & distorted shape

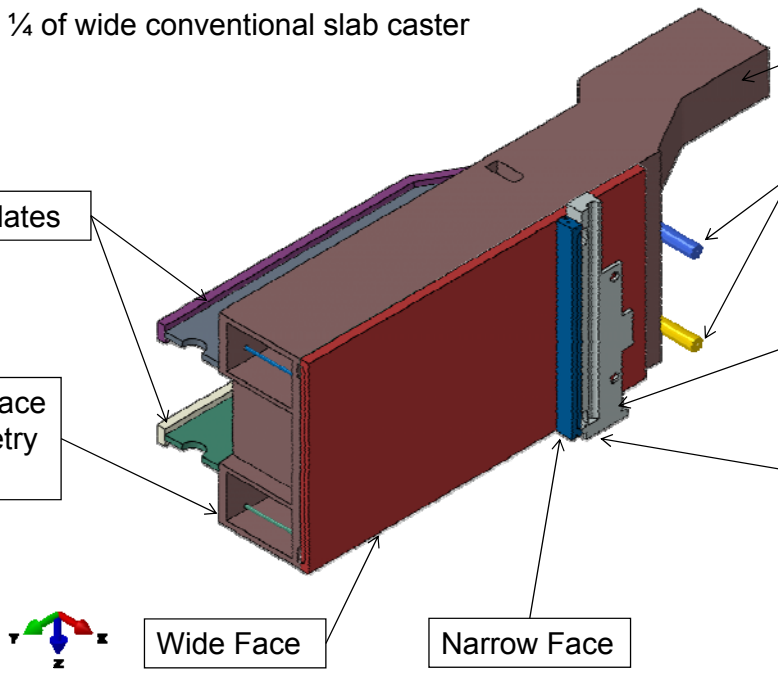


Model Description

- Thermomechanical behavior of a wide slab caster mold and waterbox
- Due to symmetry, model only one quarter
- Create thermal model of narrow face and wide face copper plates
- Based on temperature results, create mechanical model of copper plates, associated water boxes, bolts, stiffener plates, and tie rods, with proper contact and clamping forces

Modeling Domain

Domain: ¼ of wide conventional slab caster

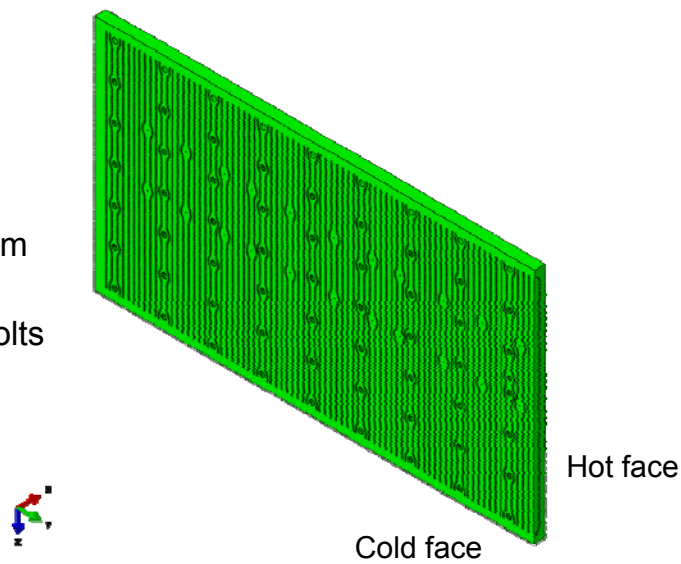


Casting Conditions

Parameter	Value	Unit
Casting speed	1.092	m/min
Steel grade (peritectic)	0.21	wt. %C
Steel pour temperature	1532	°C
Steel liquidus temperature	1512	°C
Slab width	2464	mm
Slab thickness	158	mm
Meniscus (Below Top of Mold)	100	mm

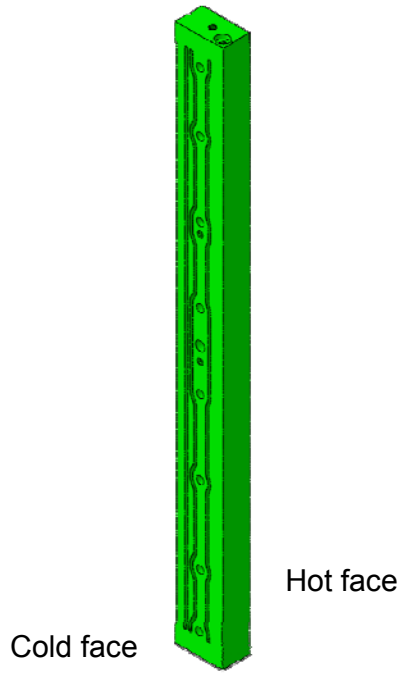
Wide Face Copper Plate

- Height: 904 mm
- Width: 3350 mm
- Thickness: 42-42.5 mm
- Channel Depth: 22 mm
- Channel Width: 5 mm
- Channel Length: 848 mm
- Channel Spacing: 20.89 mm (center to center)
- Slalom channels around bolts and thermocouples
- Bottoms of channels are rounded



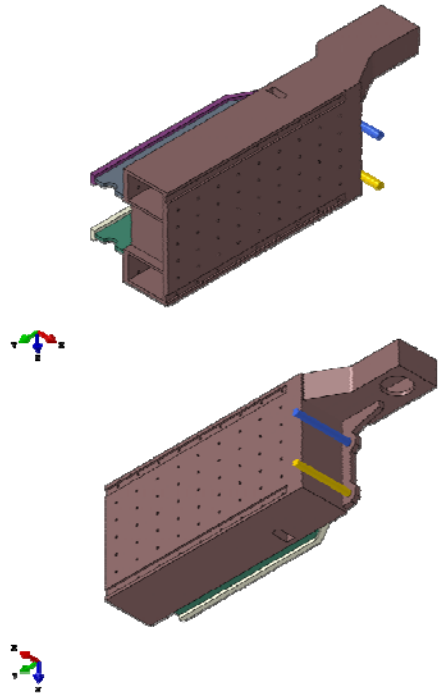
Narrow Face Copper Plate

- Height: 904 mm
- Width: 157-158 mm
- Thickness: 45 mm
- Channel Depth: 22 mm
- Channel Width: 5 mm
- Channel Length: 848 mm
- Channel Spacing: 20.89 mm (center to center)
- Slalom channels around bolts
- Hole running along height acting as a water channel
- Bottoms of channels are rounded



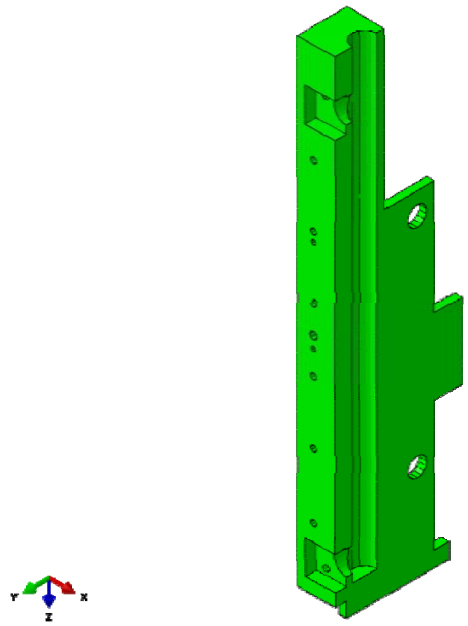
Wide Face Water Box Assembly

- YZ Plate Thickness: 40 mm
- Width: 3580 mm
- Height: 902 mm
- Thickness: 405 mm
- Two stiffeners each composed of two welded pieces are welded on to the water box
- Two tie rods are attached to the holes in the water box



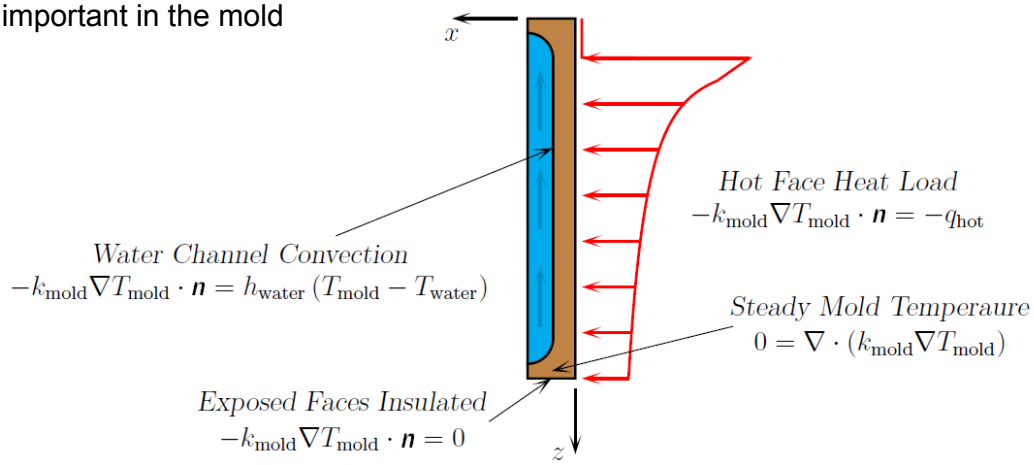
Narrow Face Water Box

- Width = 149 mm
- Thickness = 100 mm
- Height = 956 mm
- Back Plate Thickness = 30 mm
- Back Plate Height = 640 mm



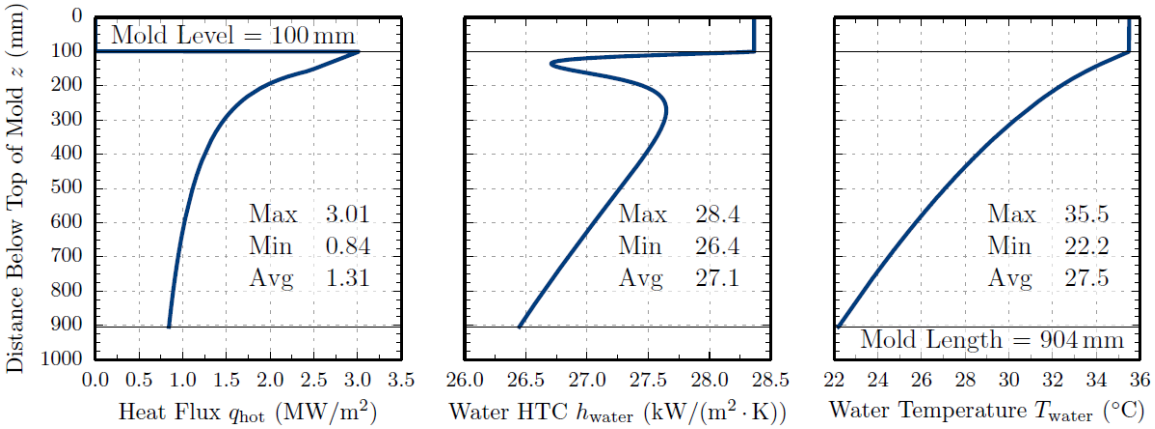
Heat Transfer Model Equations

Thermal effects are only important in the mold



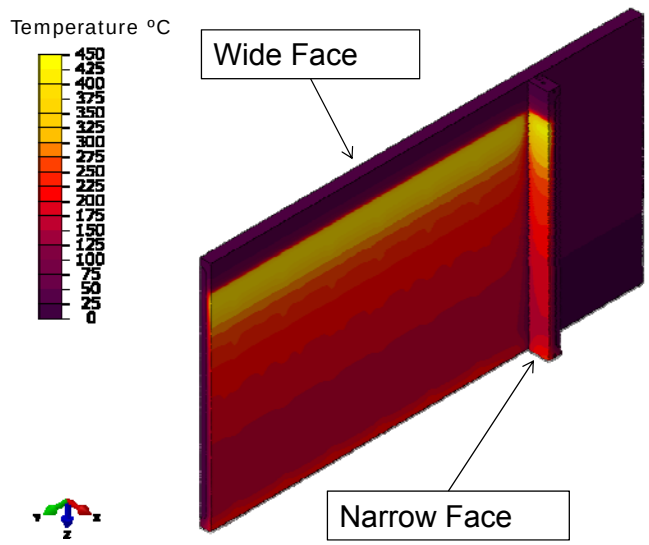
BCs (from CON1D)

- All thermal boundary conditions are based on the CON1D outputs
- Same on wide face and narrow face
- Applied by ABAQUS subroutines DFLUX for heat flux and FILM for water convection
- Heat flux applied below meniscus and inside slab width

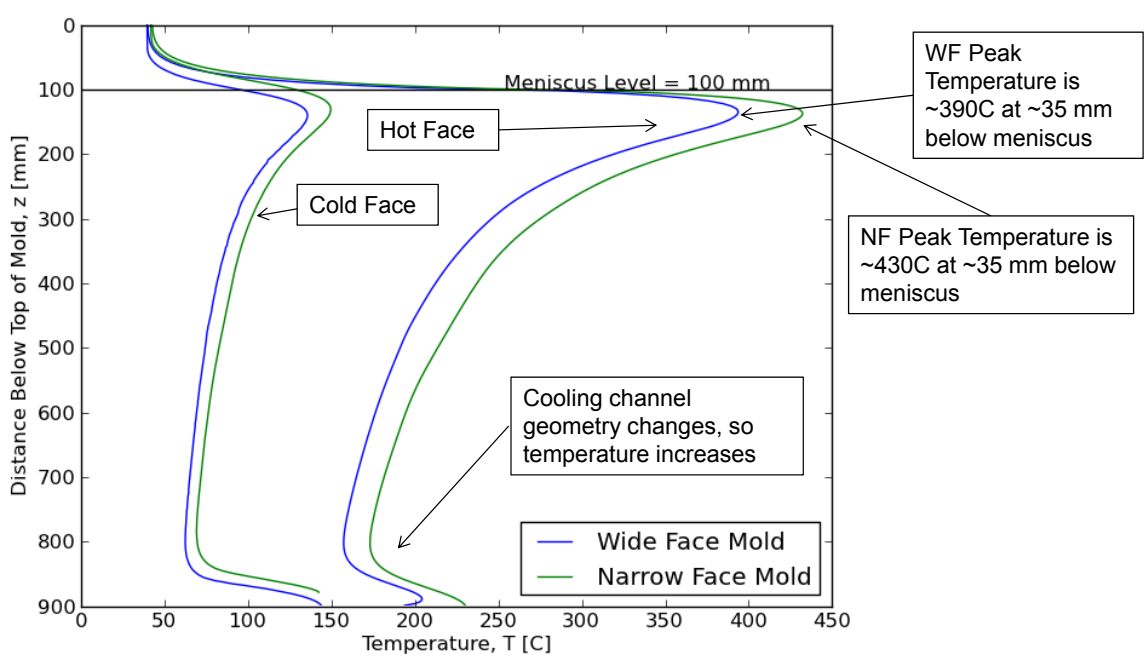


Thermal Model Results

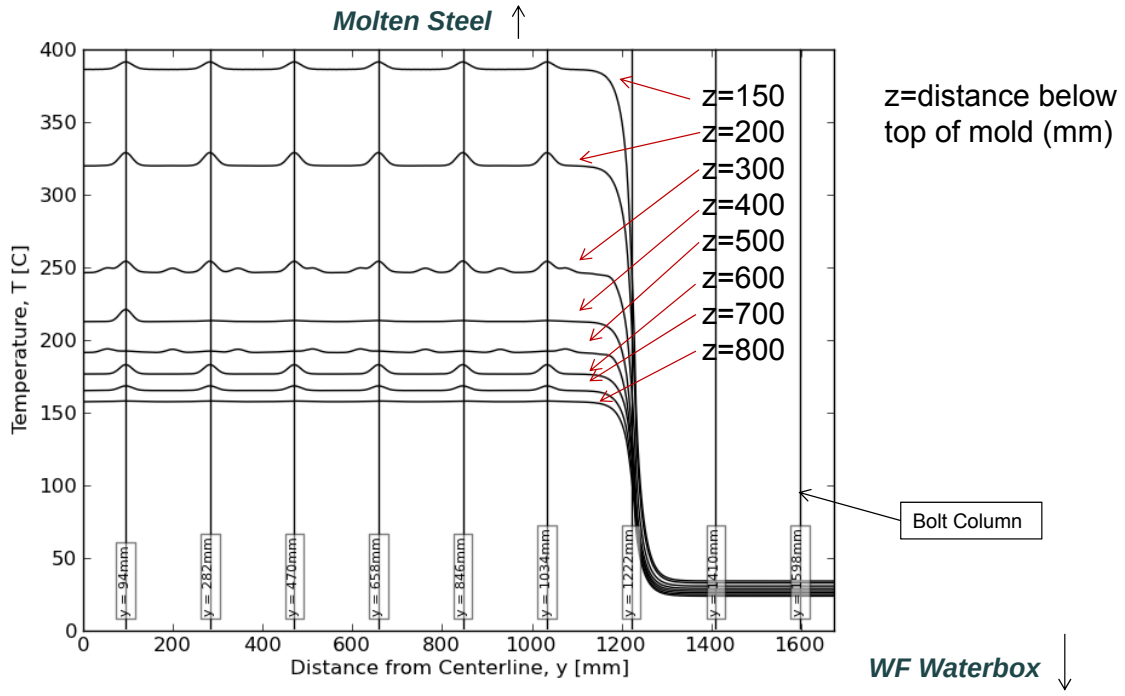
- Highest temperatures found around meniscus
- Hot face temperature increases near
  - Bolt holes
  - Thermocouple holes
  - Channels at mold exit
- Water boxes stay near ambient temperature
- Due to gap between the narrow and wide face molds (verified in mechanical model), heat flow between NF side and WF can be neglected



Wide and Narrow Face Mold Temperatures at Center Line



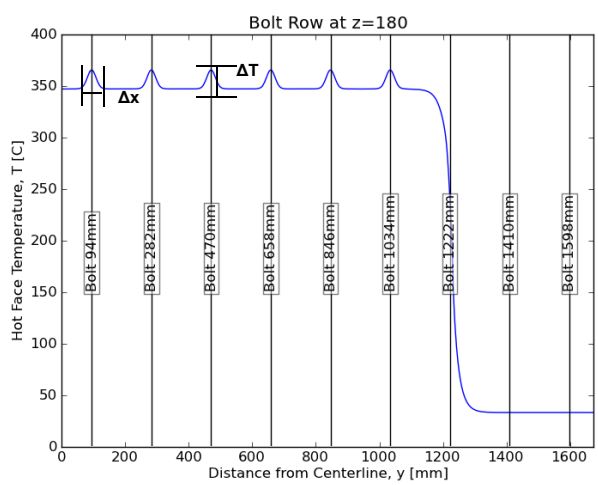
Hotface Temperature across WF at different heights



WF Cu Temperature Variation

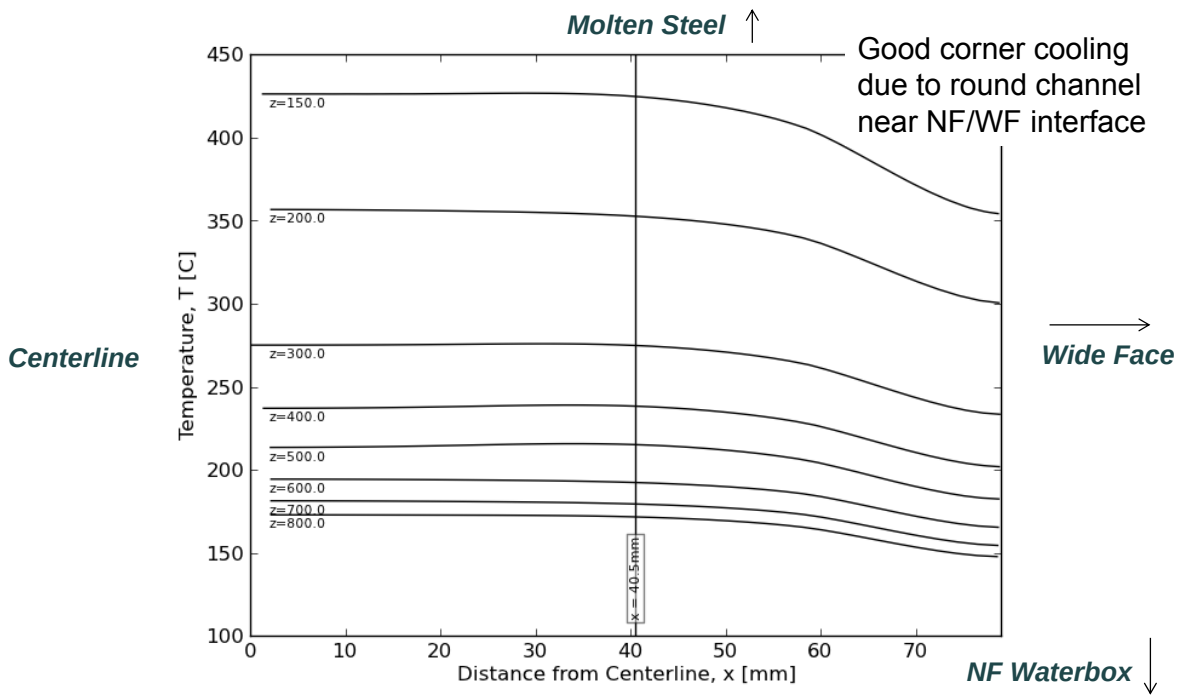
Extra spacing for bolts causes hotspots on WF with ΔT that varies down mold

Z (mm)	ΔT (°C)
180	18.4
316	12.4
452	11.3
508	8.7
724	7.8
860	11.8

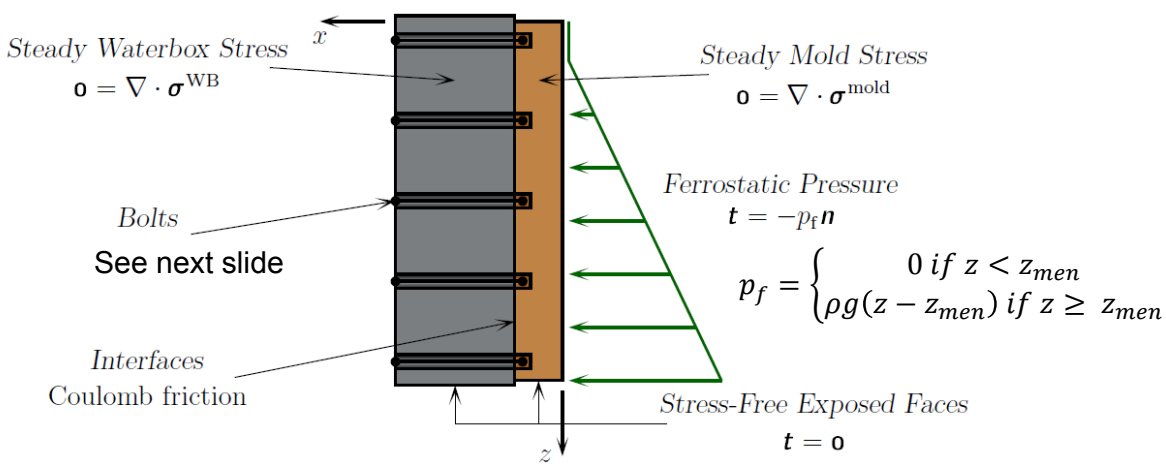


- Δx is approximately 50 mm for all bolt holes
- Local variations will affect the shell growth although how much is not known

Hotface Temperature across NF at different heights



Mechanical Boundary Conditions



Total WF ferrostatic force = 57.8 kN per face
Total NF ferrostatic force = 3.71 kN per face

Bolt Details

Bolt	Threads	Torque (Nm)	Force (kN)	Pre-Stress (MPa)
Wide Face	M20x2.5	120	9.75	61.32
Narrow Face	M12x1.75	68	11.74	103.77
Upper Tie Rod			18.2	8.57
Lower Tie Rod			68.0	32.02

- Bolts and tie rods are modeled as truss elements
- The truss elements were given a pre-stressed based on the table above
- μ_{thread}=0.16, μ_{head}=0.6, β=cos(30°)

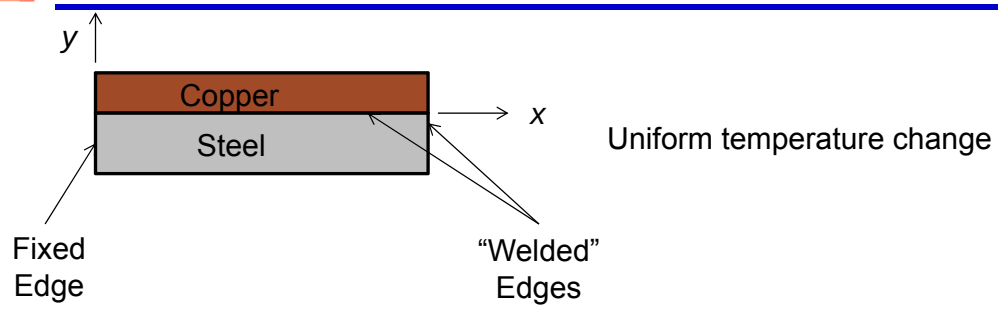
$$F_{\text{bolt}} = \tau_{\text{bolt}} \Big/ \left(\frac{\mu_{\text{thread}} \pi d_{\text{pitch}} + \beta p_{\text{thread}}}{\beta \pi d_{\text{pitch}} - \mu_{\text{thread}} p_{\text{thread}}} \frac{d_{\text{pitch}}}{2} + \mu_{\text{head}} \frac{d_{\text{head}}}{2} \right)$$

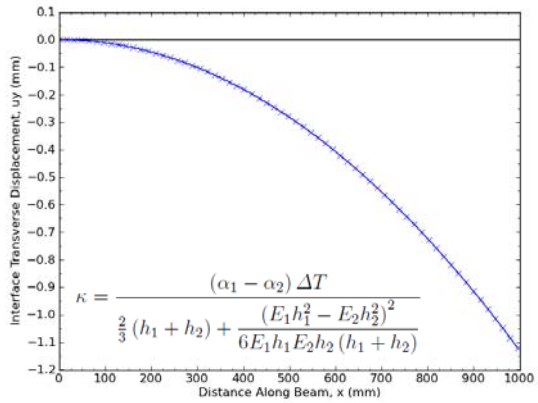
Thermal-Mechanical Models

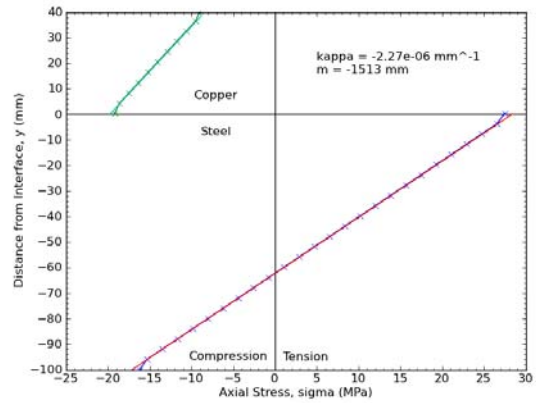
- Molds have been modeled as
  - Elastic ← *Correctly captures operating shape* (Current Work)
  - Elastic-plastic ← *Necessary for mold life predictions*
  - Elastic-plastic-creep ← *Most appropriate*
- Properties either constant or temperature-dependent, but always small-strain isotropic
  - Elastic modulus
  - Yield strength
  - Coefficient of thermal expansion

Mechanical Model Verification

Bimetallic Strip







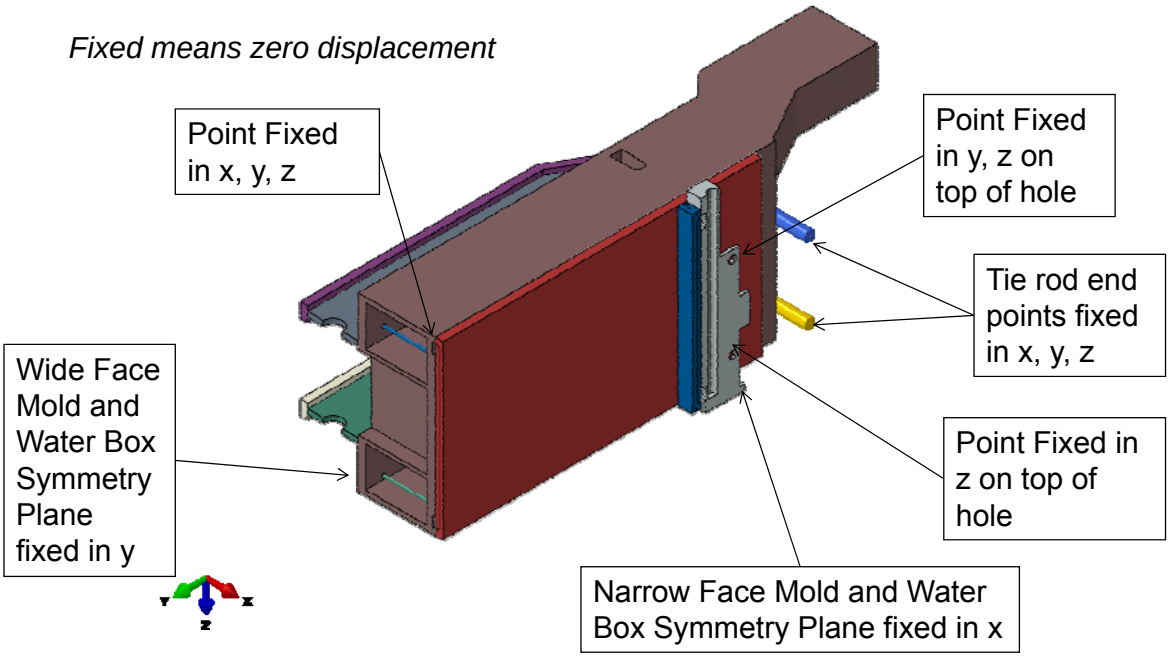
Model Verification

Bimetallic Strip

Parameter	Value	Unit
Length	1000	mm
Temperature change	200	K
Copper		
Height	40	mm
Young's modulus	117.2	GPa
Poisson's ratio	0.181	--
Expansion coefficient	18.0	um/m/K
Steel		
Height	100	mm
Young's modulus	200	GPa
Poisson's ratio	0.3	--
Expansion coefficient	16.5	um/m/K

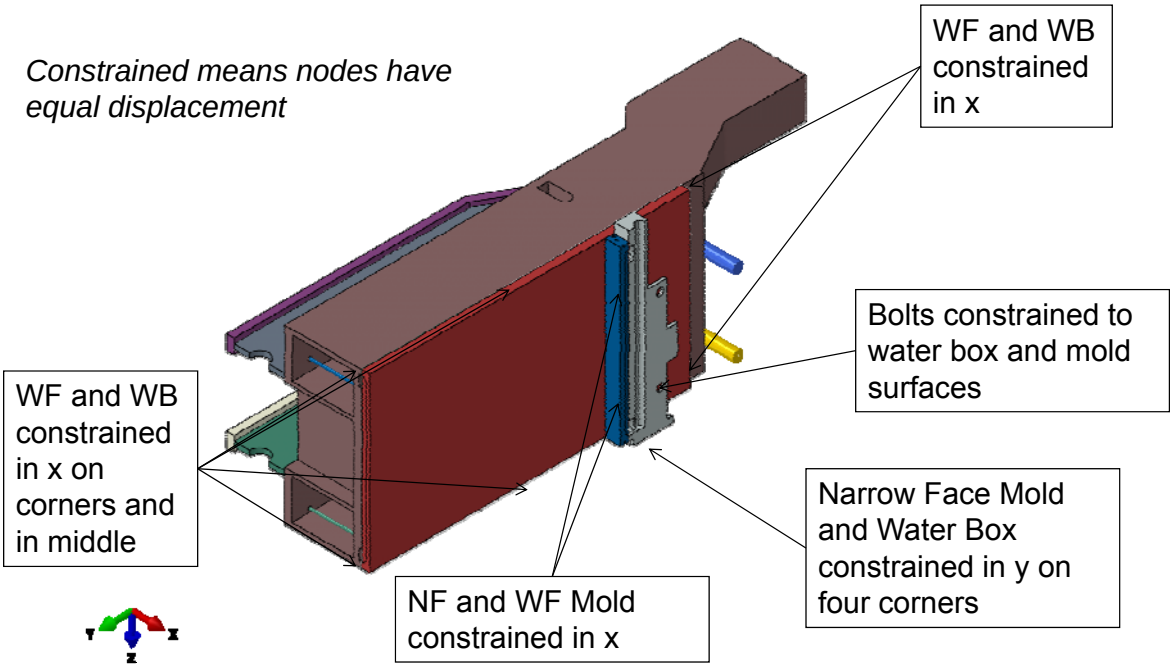
Fixed Boundary Conditions

Fixed means zero displacement

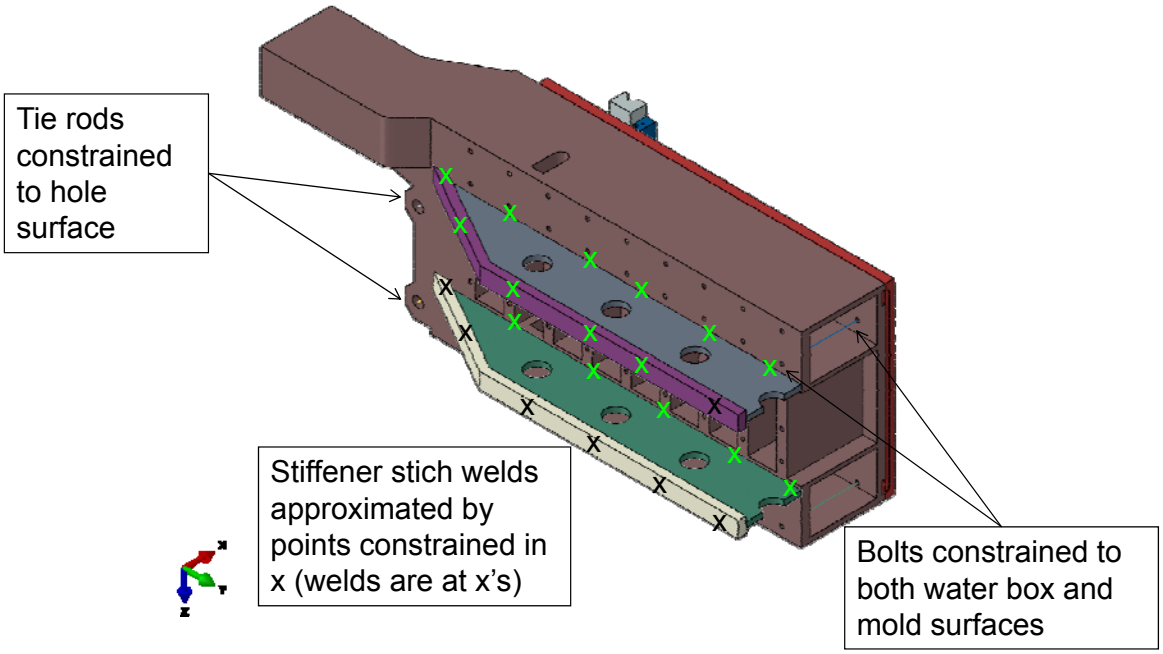


Constraints to define contact between parts

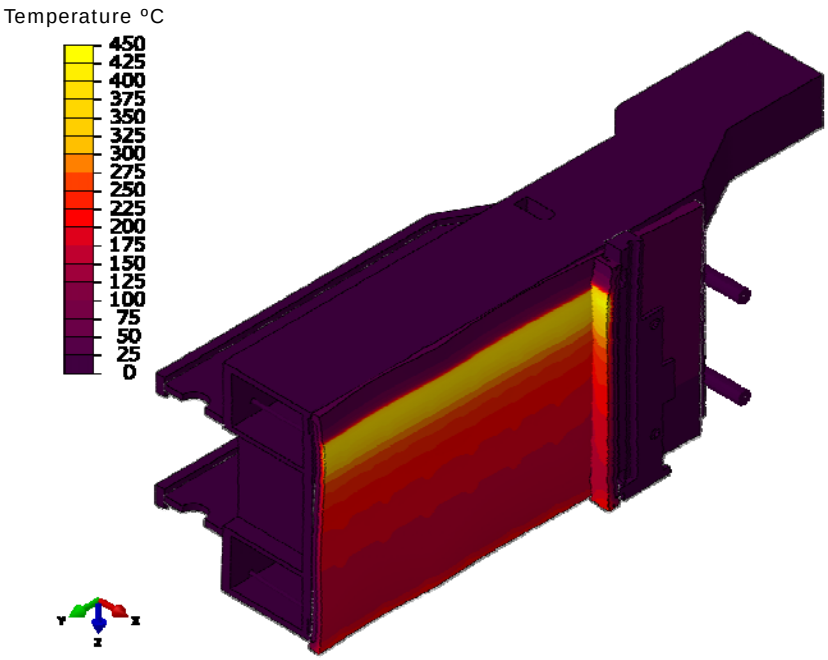
Constrained means nodes have equal displacement



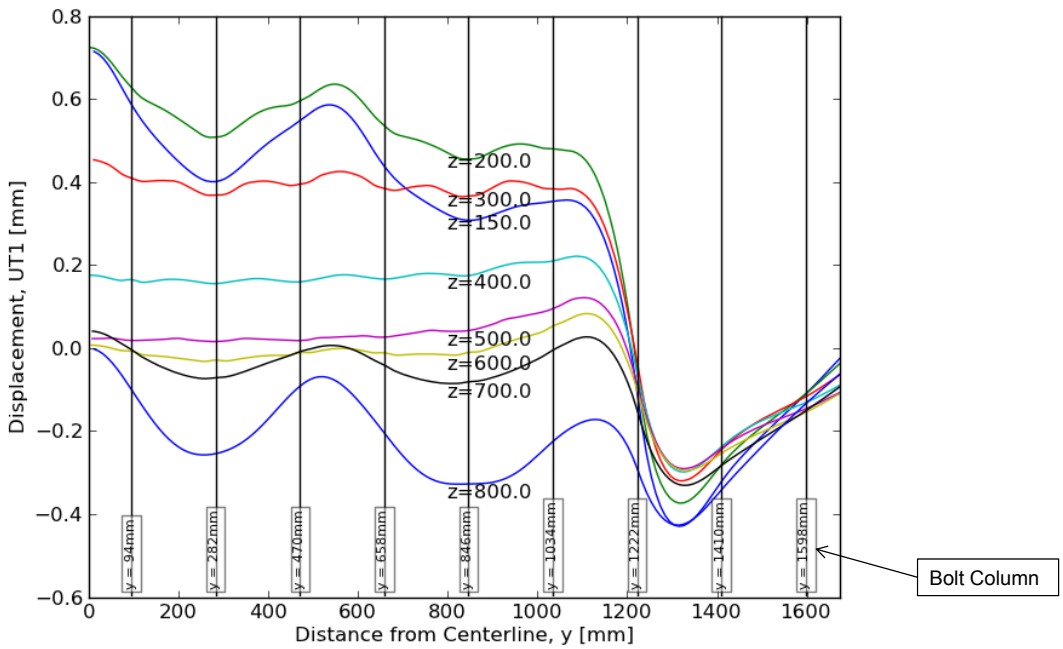
Additional Constraints



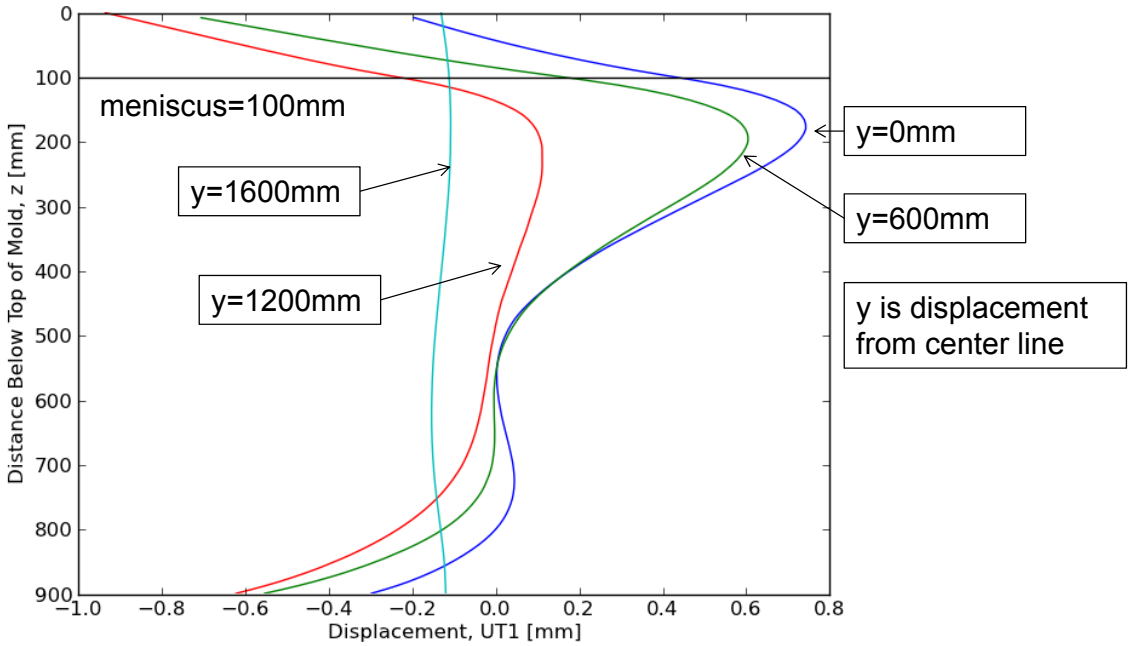
Thermal Distortion



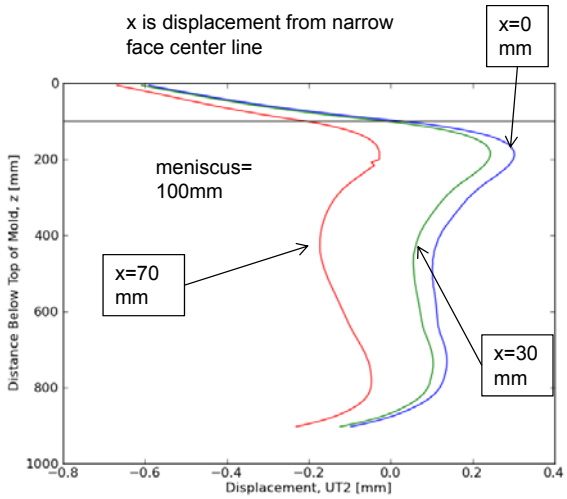
Hotface Distortion across WF at different heights

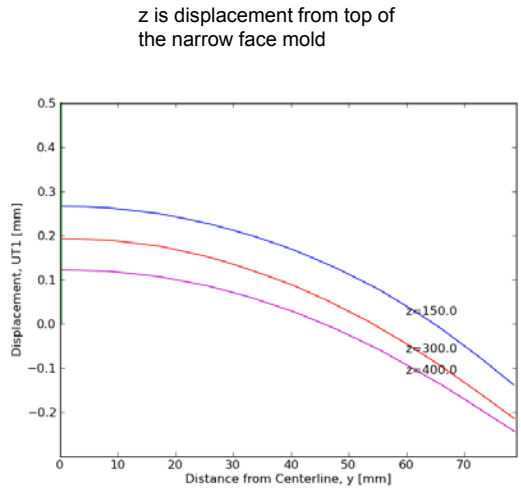


Hotface Distortion down WF at y values



Hotface Distortion on NF





- The mold is not distorting much because of the very stiff water box
- Distorts into a W

Conclusions and Future Work

- Investigated thermomechanical behavior of a wide slab casting mold
- Most thermal behavior is typical, but there are some anomalies of around 15°C near bolts
- The very rigid water boxes control the mold distortion, giving about 0.6 mm distortion on the NF and the WF about 0.7 mm towards the steel
- Next, look at effect of distortion on solidifying shell and operational practices such as clamping

Acknowledgments

- Continuous Casting Consortium Members (ABB, ArcelorMittal, Baosteel, Tata Steel, Goodrich, Magnesita Refractories, Nucor Steel, Nippon Steel, Postech/ Posco, SSAB, ANSYS-Fluent)

- National Center for Supercomputing Applications (NCSA), Blue Waters cluster