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Heat transfer and distortion of a beam-blank mold: plant measurements and model computations

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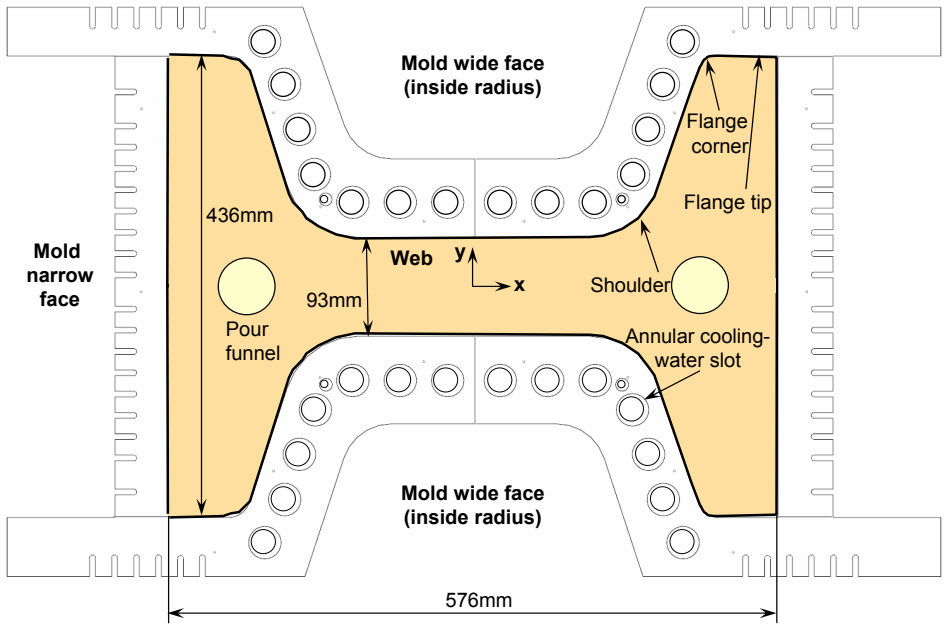
Objective

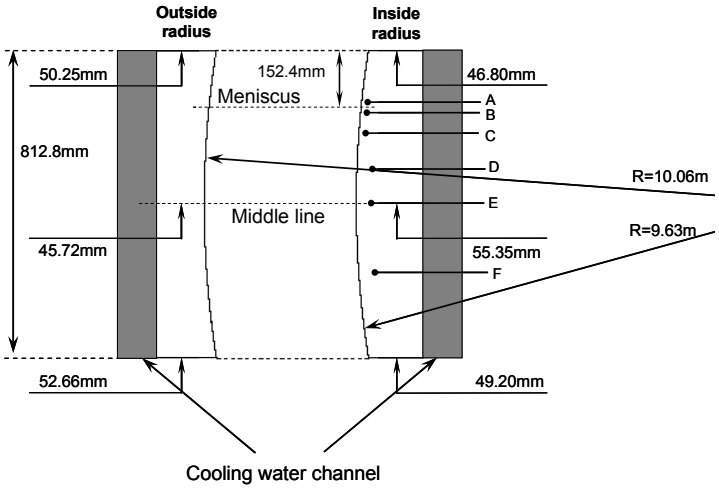
- Analyze a beam blank mold (Steel Dynamics, Inc.) with a numerical model to investigate:
  - Mold temperatures
  - Mold cracking
  - Thermal distortion of the mold and water box
- Incorporate the distortion results into a coupled thermal-stress model of the solidifying shell

Beam Blank Mold



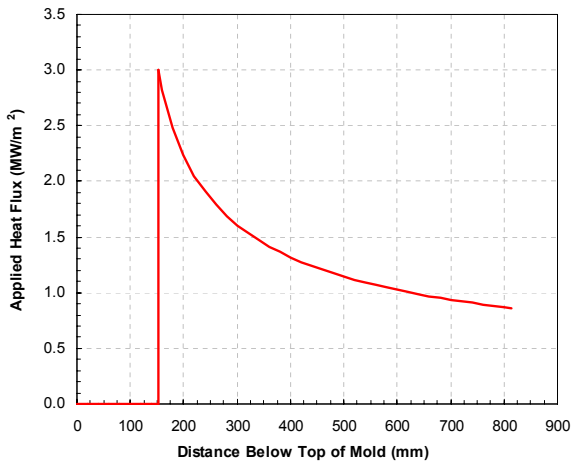
Heat Flow Into Mold

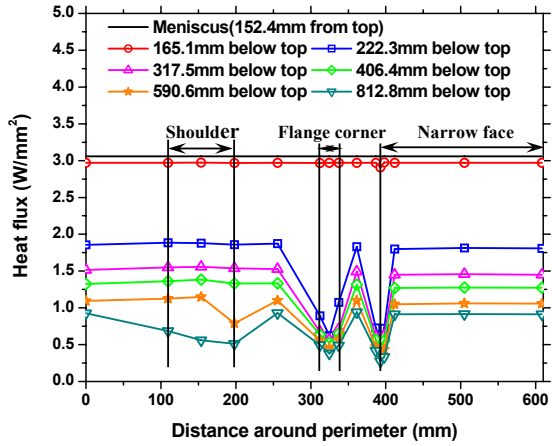
- Previous modeling work, combined with plant measurements, yields a validated heat flux profile down the mold



Heat Flux Validation

	Experimental (kW)	Mold Model (kW)	Error
Wide Face	1112	1205	+8.3 %
Narrow Face	651	634	-2.6 %
Total	1764	1839	+4.3 %

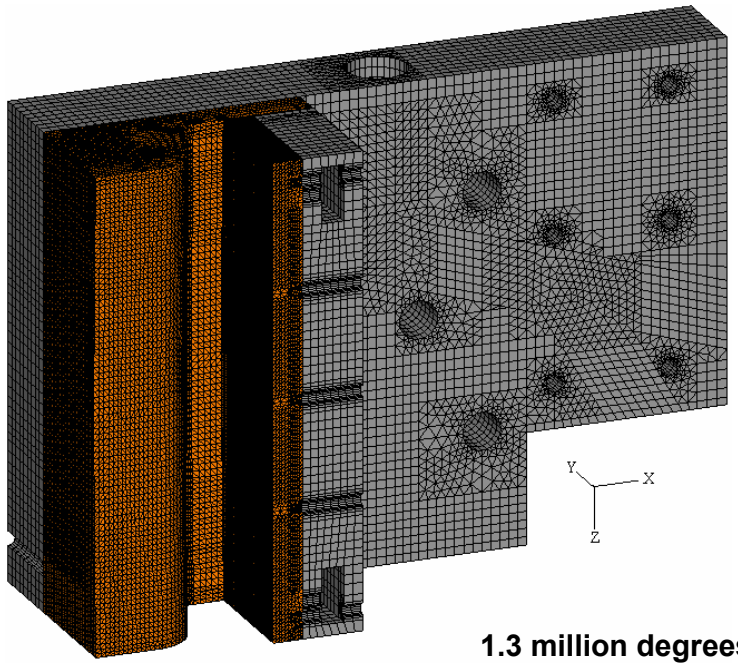




Other Model Parameters

WF water channel convection coefficient	45 kW/(m²·K)
WF water temperature	33.35 ºC
NF water channel convection coefficient	34 kW/(m²·K)
NF water temperature	34.48 ºC
Copper thermal conductivity	350 W/(m·K)
Copper elastic modulus	115 GPa
Copper Poisson's ratio	0.33
Copper coefficient of thermal expansion	$17.0 \cdot 10^{-6}$ 1/ºC
Steel water box elastic modulus	200 GPa
Steel water box Poisson's ratio	0.26

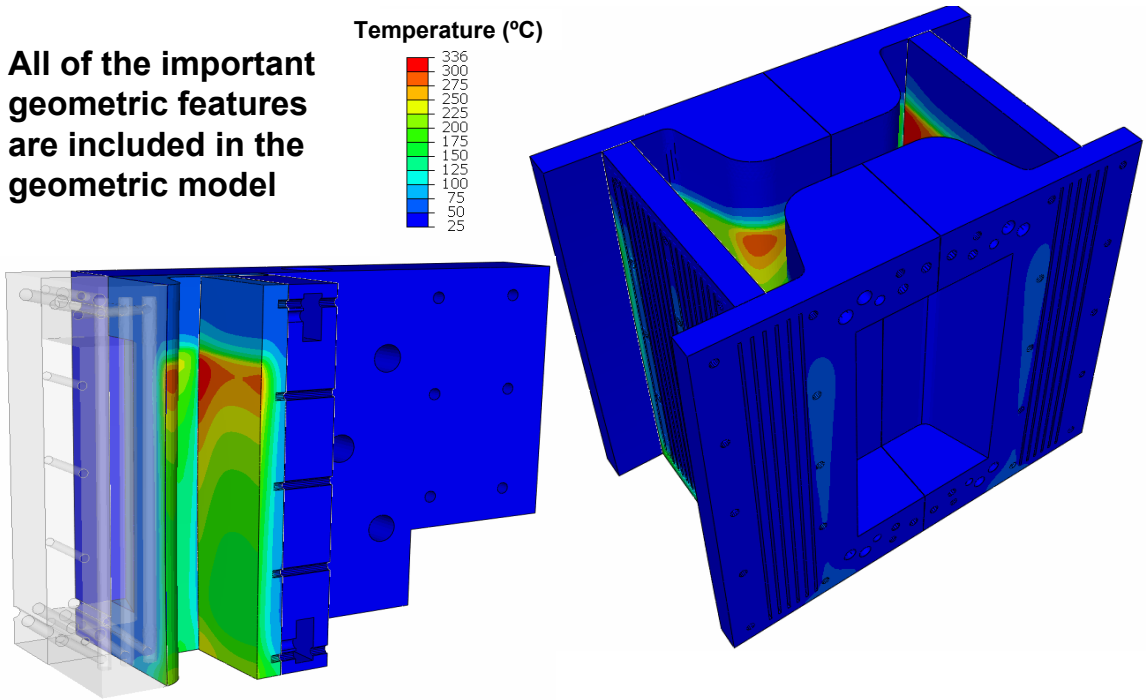
Finite Element Mesh



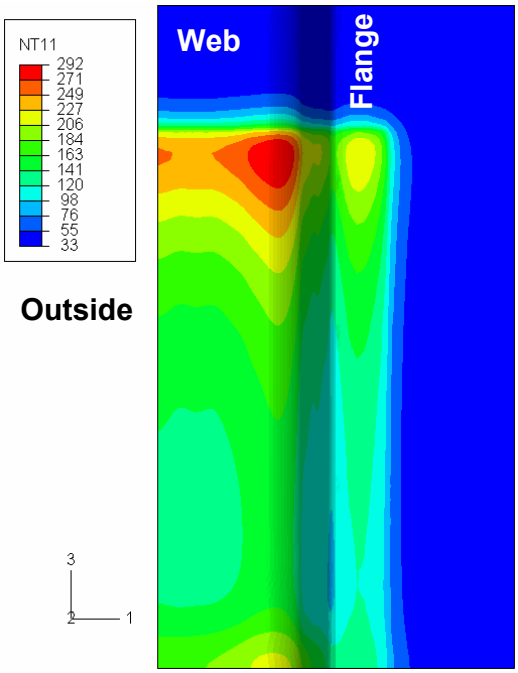
1.3 million degrees of freedom

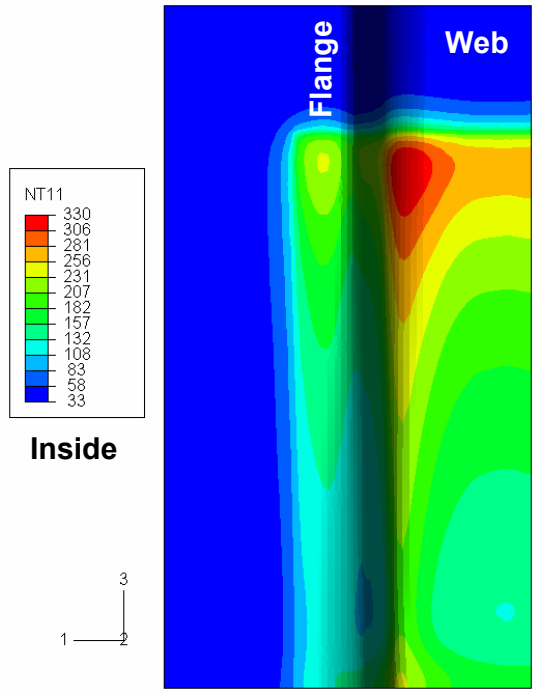
Mold Temperatures

All of the important geometric features are included in the geometric model

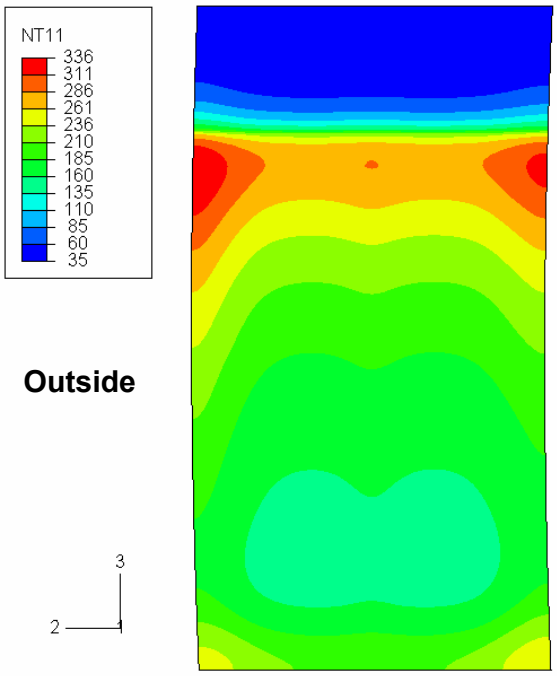


Wide Face Temperatures

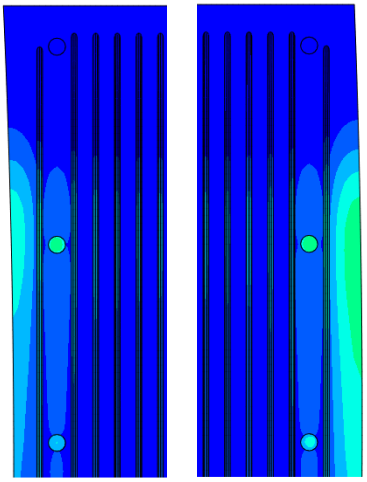




Narrow Face Temperatures

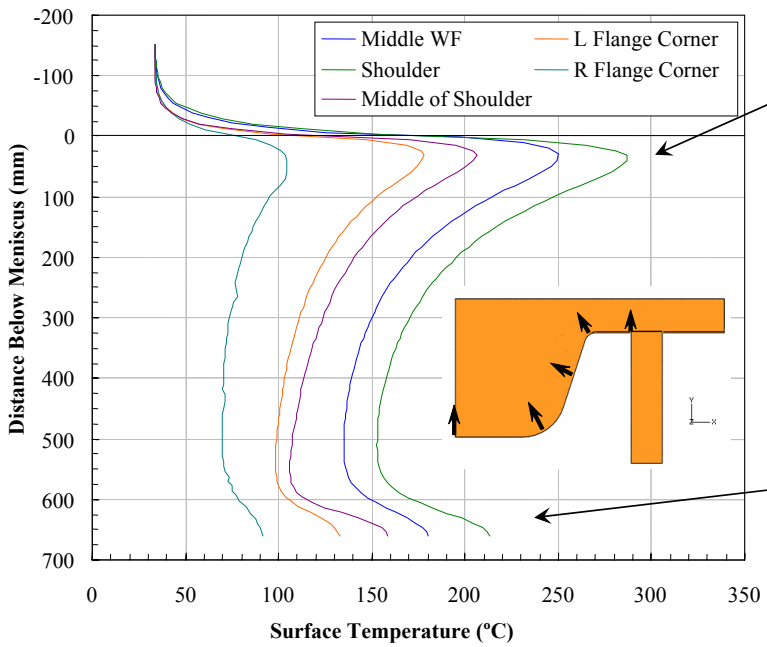


Hotter regions due to absence of water channels near edges; outside radius generally hotter because of more copper



Back of NF Inside Radius **Back of NF Outside Radius**

Hot Face Temperatures

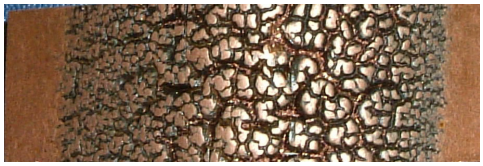


Maximum temperature at the shoulder

The water channels end a few mm below mold exit, which causes the bottom of the mold to get hotter

Mold Cracking

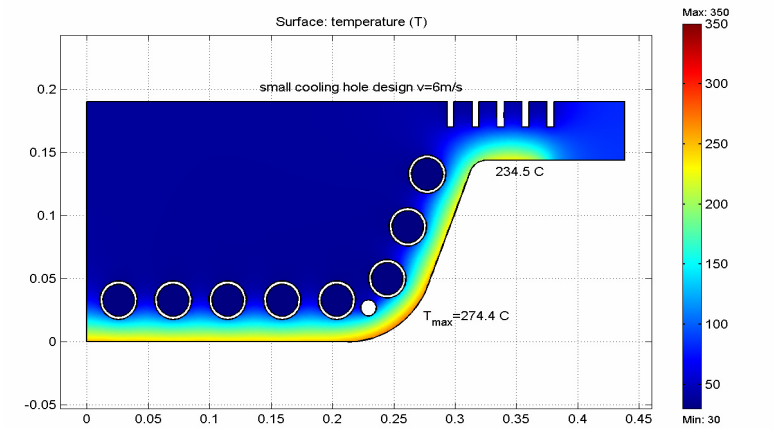
- The hot spots predicted on the mold hot face in the meniscus area correspond to cracks that have occurred in practice



[D. Lorento, 2004]

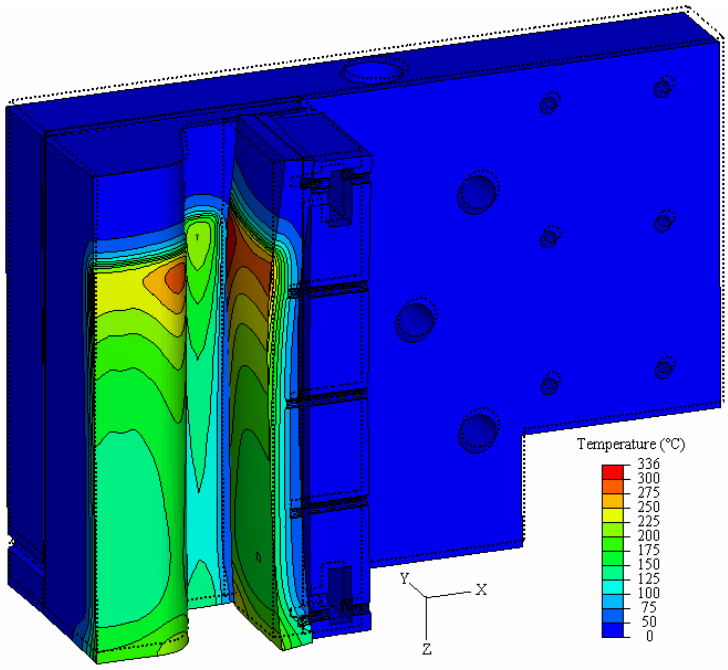
Solution to Hot Face Cracking

- Adding a water channel at the "shoulder" of the mold reduces the maximum hot face temperature at the meniscus 40 ºC

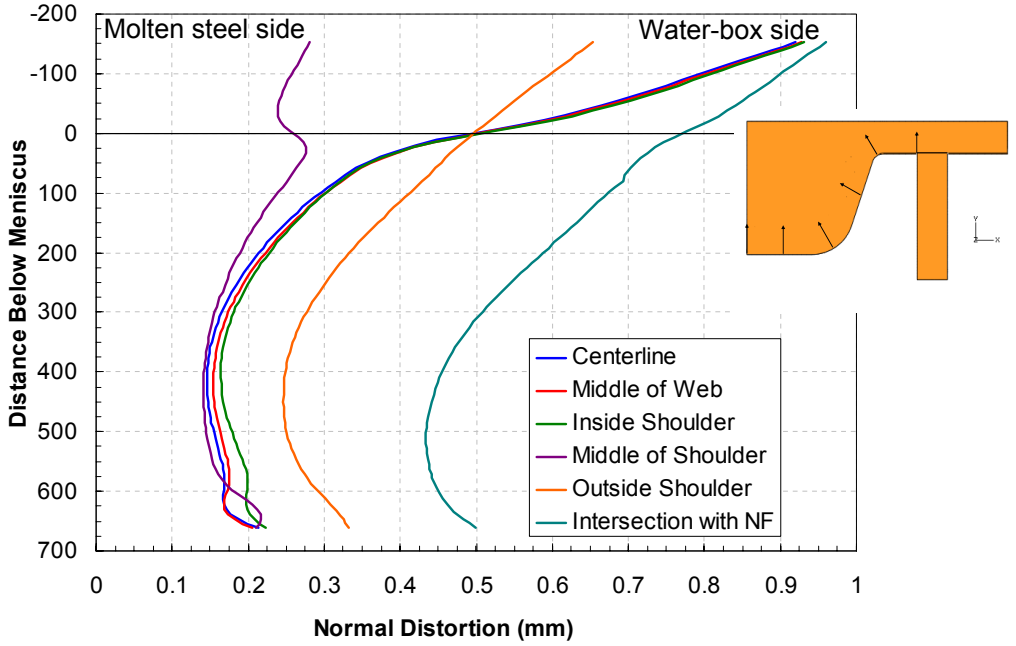


Thomas, B.G., J. Jiang, and D. Lorento,", Proc. 5th European Continuous Casting Conf., (Nice, France, 20-22 June 2005), Inst. Maters, Minerals & Mining, Paris, 2005, Session 16, pp. 139-147.

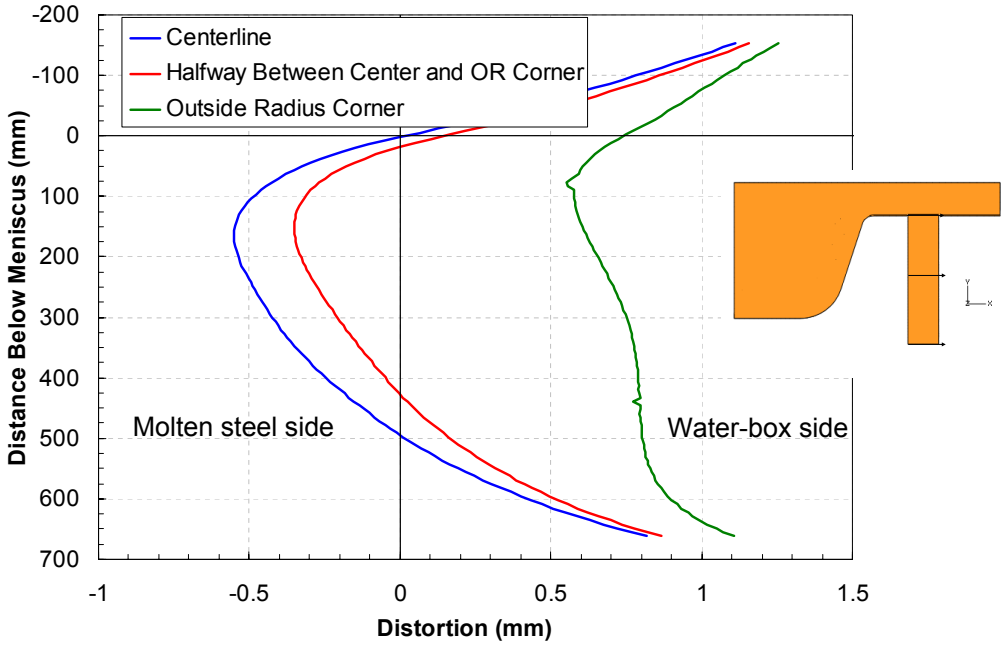
Mold Thermal Distortion



Wide Face Distortion



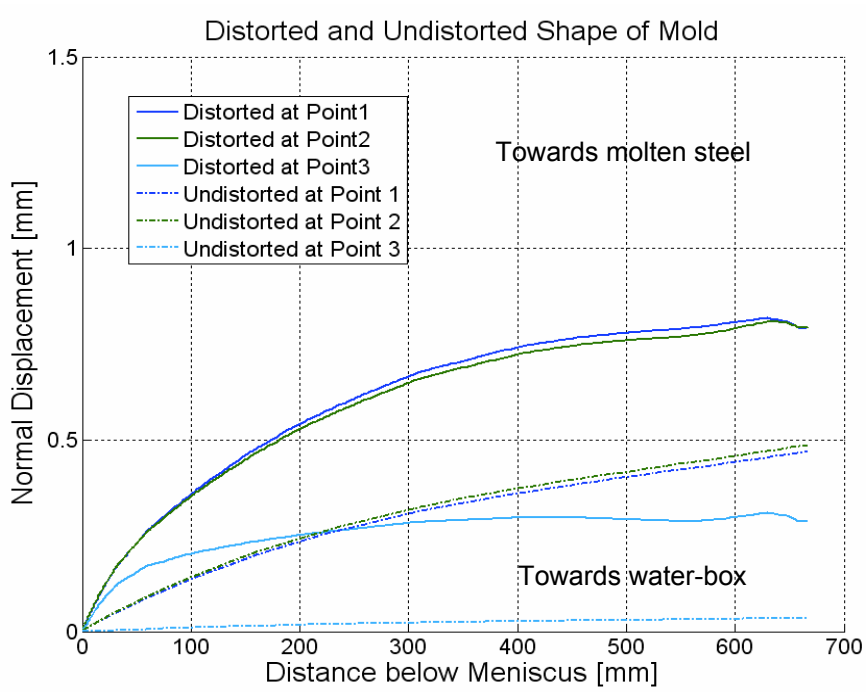
Narrow Face Distortion

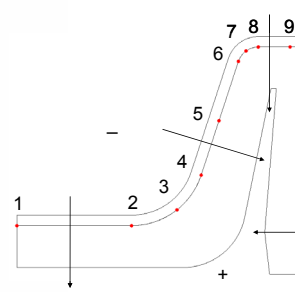


Translating the Mold Distortion

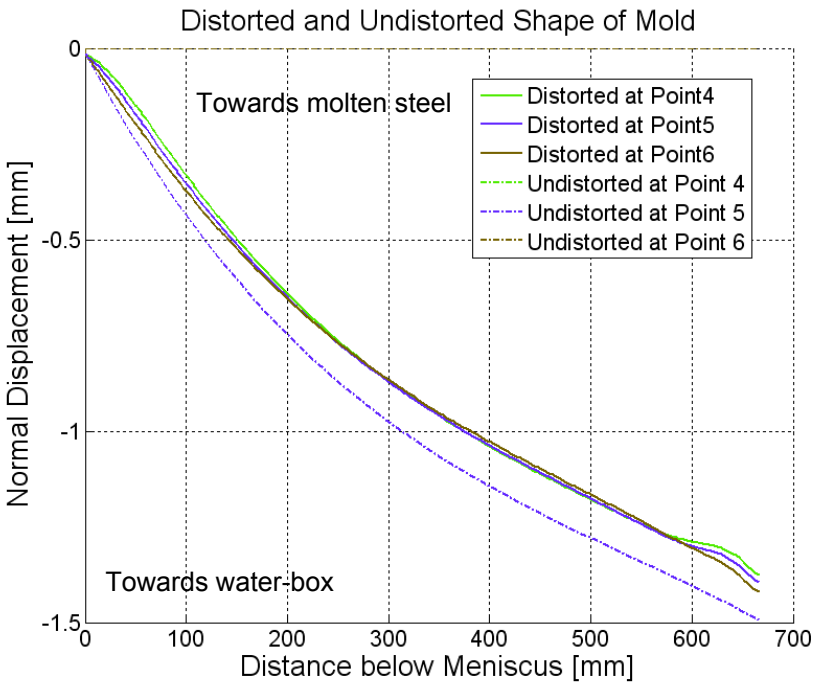
- In the two-dimensional models of the solidifying shell, the effects of the mold changing shape with distance down the mold are incorporated with displacement functions
- The distorted shape of the mold is processed to create a displacement field relative to the shape at the meniscus
  - Double linear interpolation of the undistorted hot face *coordinates* subtracted from the distorted hot face *coordinates*

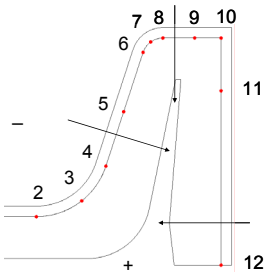
Displacement (Web)



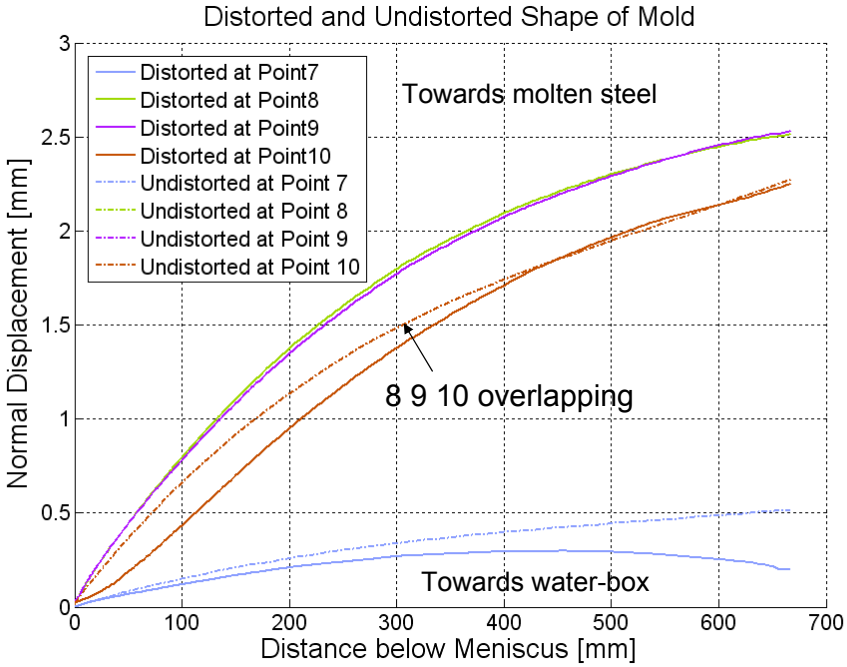


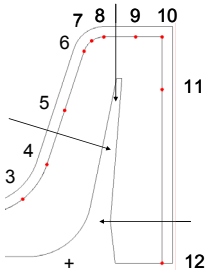
Displacement (Slant)



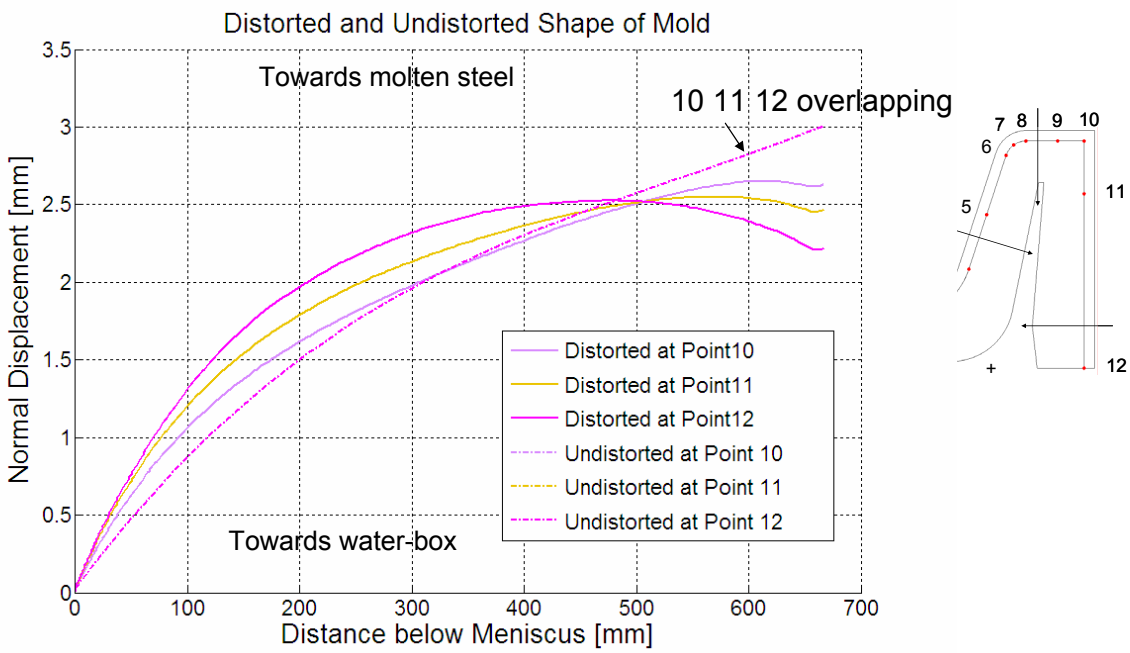


Displacement (Flange)





Displacement (NF)



Mold Distortion Results

- Mold generally bows outwards towards the shell, with a small twisting motion
- Web-region distortion is about 0.4mm, which effectively doubles the taper
- Slant region (between shoulder and inner-flange corner) distorts about 0.2mm towards the steel, which slightly lessens the negative taper
- Flange region distorts about 0.2mm, which only slightly increases the taper.
- Corner experiences negligible distortion (well-cooled)
- Narrow face distortion increases taper curvature, causing ~0.5mm more distortion at 1/3 down mold, and ~0.5mm less at bottom (causing negative taper)

Conclusions

- Thermal distortion of a beam blank mold has been calculated, using an experimentally validated heat flux profile
- Locations on the hot face furthest away from the water channels become very hot, especially near the meniscus
  - Problem solved by more and/or smaller water channels in key areas (eg. Shoulder region)
- As the mold heats up, it generally bows outward towards the shell, with a small twisting motion, modifying the taper slightly
- The distorted shape has been successfully processed into displacement functions for use in a two-dimensional Lagrangian model of the shell

Acknowledgements

- Continuous Casting Consortium Members
  (Nucor, Postech, LWB Refractories, Corus, Labein, Goodrich, Arcelor-Mittal, Baosteel, Steel Dynamics, Postech, ANSYS)
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