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Thermal distortion of a slab mold with cavity for electromagnetics

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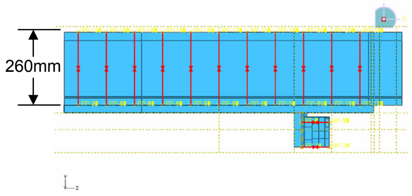
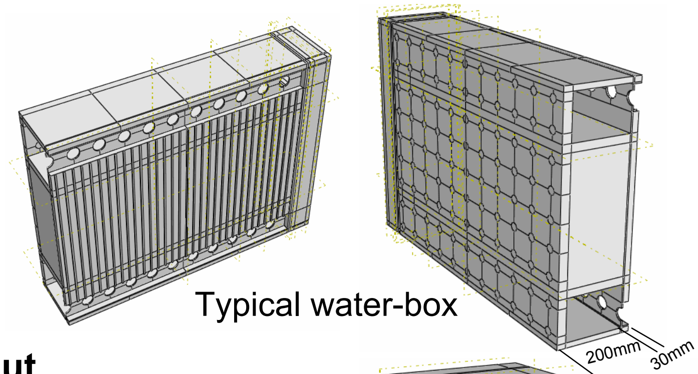
- Continuous Casting Consortium Members
- National Center for Supercomputing Applications (NCSA) at UIUC
- HKS (ABAQUS)
- Mr. Kim From POSCO provides blueprints for the model with electromagnetic brake
- Other Graduate students, especially Lance Hibbeler and Lyric Shi

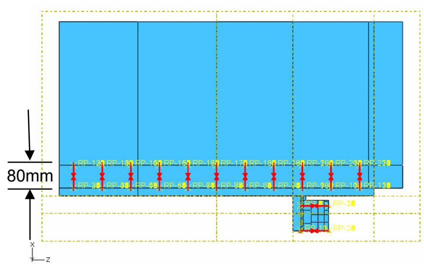
Mold Construction

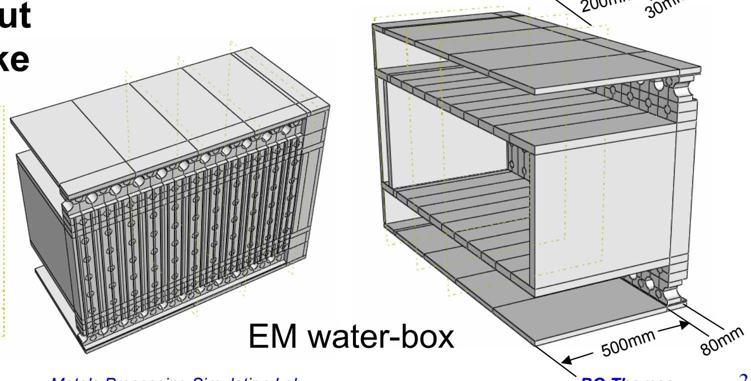
Conventional Mold





Mold with hollowed-out water box for EM Brake





Objective

To predict distortion of slab molds, with and without hollowed-out region to hold an EM Brake.

Thermal-distortion Model

- Governing equations
  - Steady Heat conduction

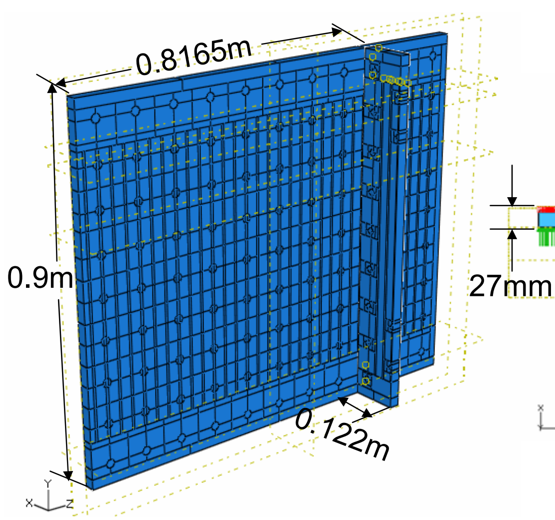
$$\nabla \bullet k \nabla T = 0$$

  - Mechanical equilibrium with thermal distortion

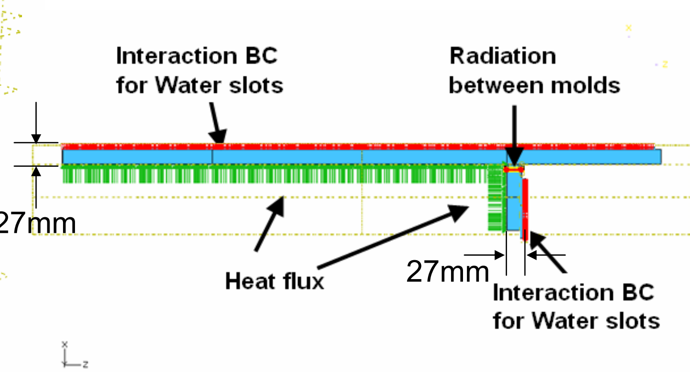
$$\varepsilon_{total} = \varepsilon_{elastic} + \varepsilon_{thermal}$$

- Assumptions
  - 3-D elastic model
  - Temperature independent material property
- Finite-element model
  - ABAQUS 6.7
  - Standard 8-node "brick" elements

Thermal Model

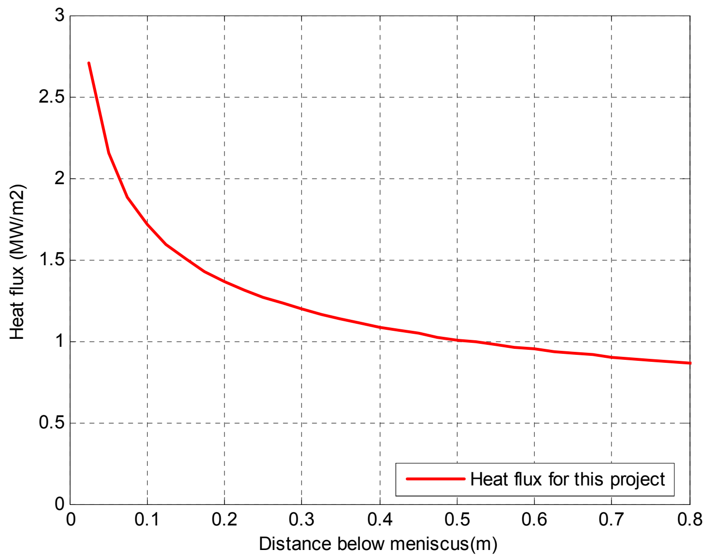


3D geometry



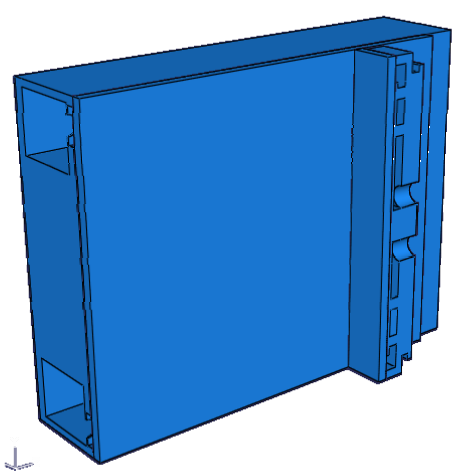
Boundary conditions

Heat flux down mold

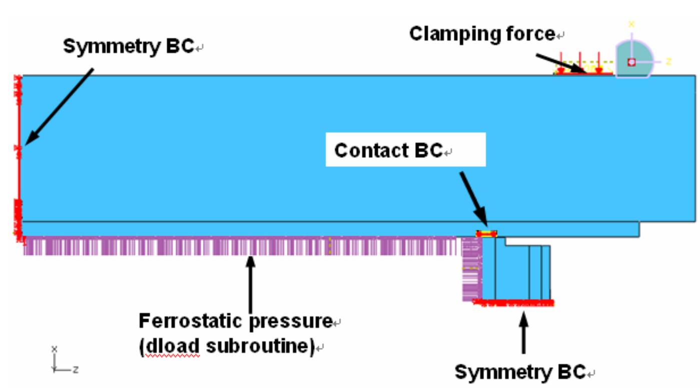


Li, C. and B.G. Thomas, "Analysis of the Potential Productivity of Continuous Cast Molds", The Brimacombe Memorial Symposium, (Vancouver, Canada, October 1-4), G. Irons & A. Cramb, eds., Canadian Institute of Mining, Metallurgy, and Petroleum, Montreal, Canada, 2000, pp. 595-611

Stress Model



3D geometry



Boundary conditions

Mold Geometries

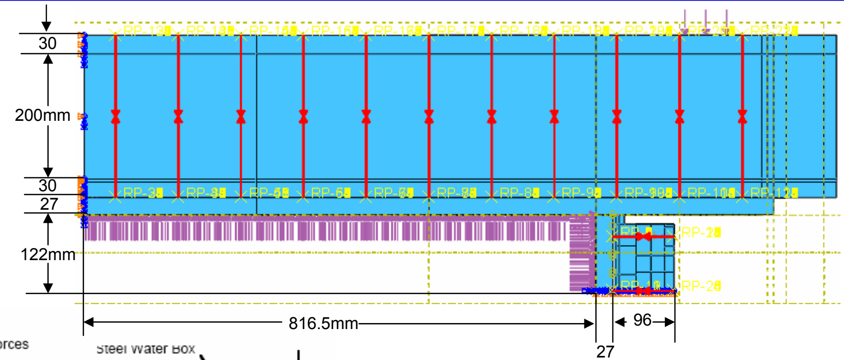
Slab width	1633mm
Slab thickness	244mm
Mold height	900mm
Cu plate thickness	27mm
Distance between slots	6~7mm
Distance between bolts	100mm
Bolt diameter	16mm
Bolt length	
Model with typical water box	260mm
Model with EM water box	80mm
Bolt prepress	18147.6N
Wide face water box plate thickness	
Model with typical water box	30mm
Model with EM water box	80mm
Water box stiffening frame length	
Model with typical water box	200mm
Model with EM water box	500mm

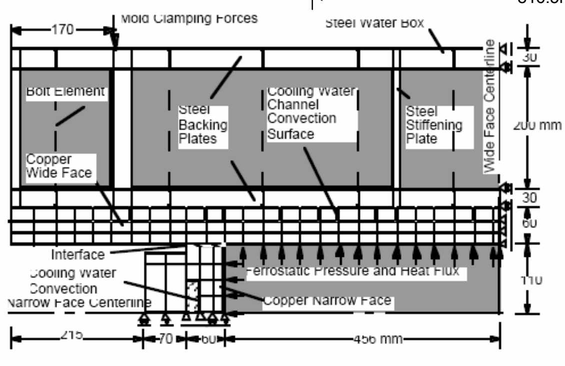
Material Properties and Operation Conditions

Property	units	steel	copper
Density	kg/m^3	7500	8960
Young's modulus	GPa	200	128
Poisson ratio		0.3	0.34
Thermal expansion coefficient	K^{-1}	2.0×10^{-5}	1.8×10^{-5}
Thermal conductivity	$W/m\cdot K$	33	315

Water slot heat transfer coefficient	$35KW/m\cdot k$
Water temperature	40° C
heat transfer coefficient between molds (represents radiation)	$50W/m\cdot k$
Mold clamping force(200mm from the water box edge)	
Top(200mm from top)	$4.56KN$
Bottom(700mm from top)	$18.66KN$

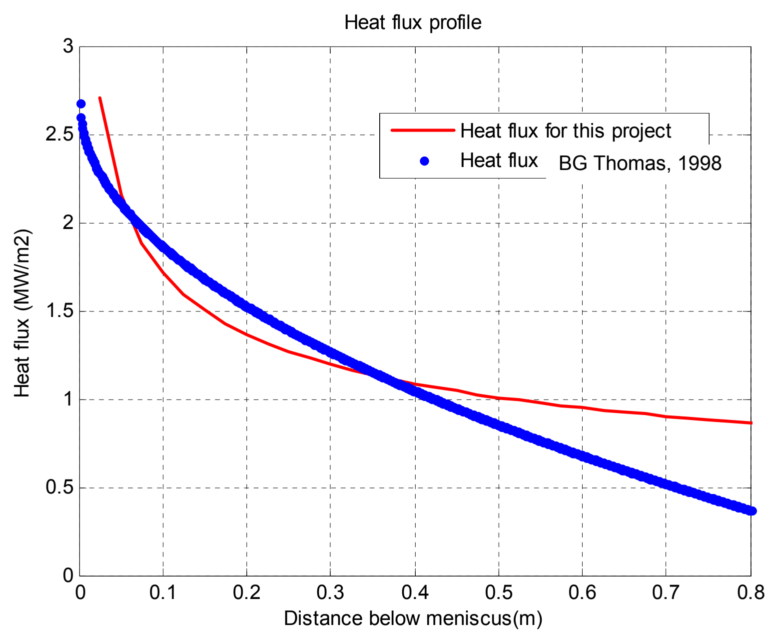
Compare with previous work



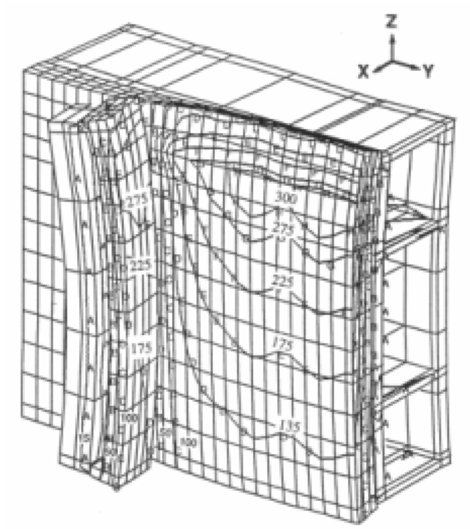


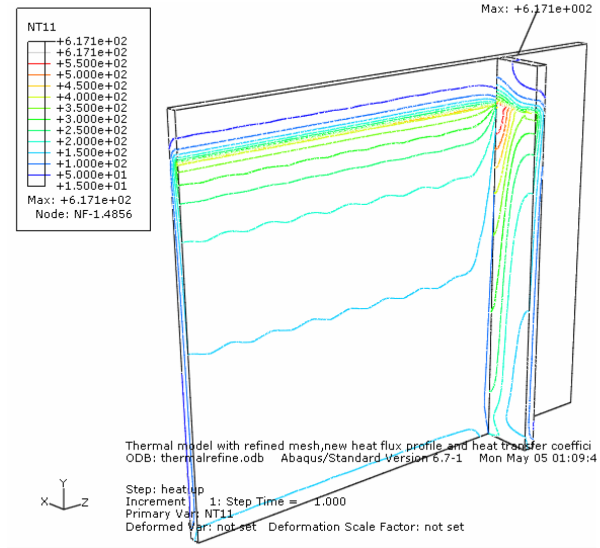
Thomas, B.G., G. Li, A. Moitra and D. Habing, "Analysis of Thermal and Mechanical Behavior of Copper Molds during Continuous Casting of Steel Slabs", Iron and Steelmaker (ISS Transactions), Iron and Steel Society, Warrendale, PA, Vol. 25, No. 10, 1998, pp. 127

Heat Flux Comparison



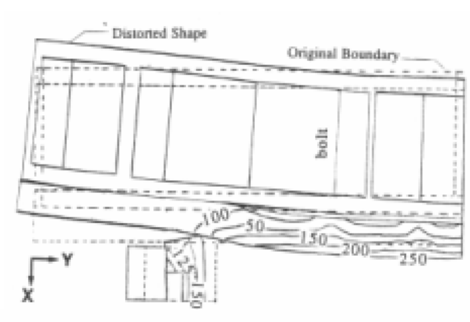
Temperature Comparison

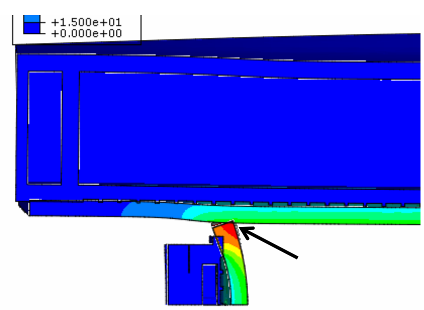


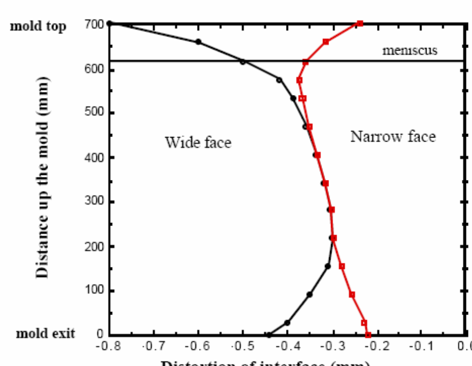


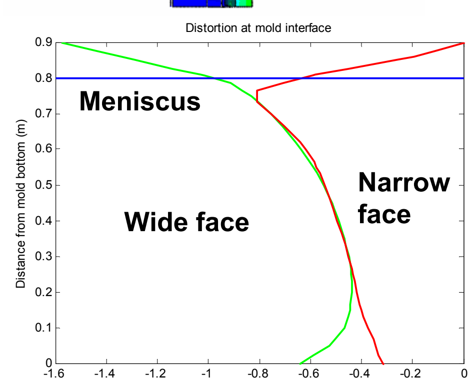
BG Thomas et al", ISS Transactions, 1998.

Distorted Shape Comparison









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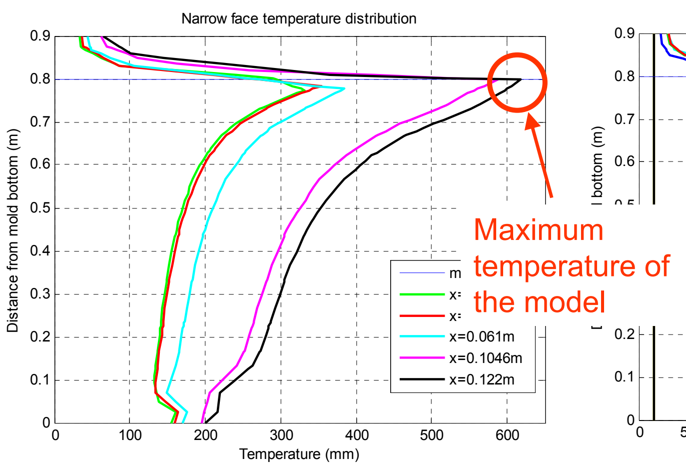
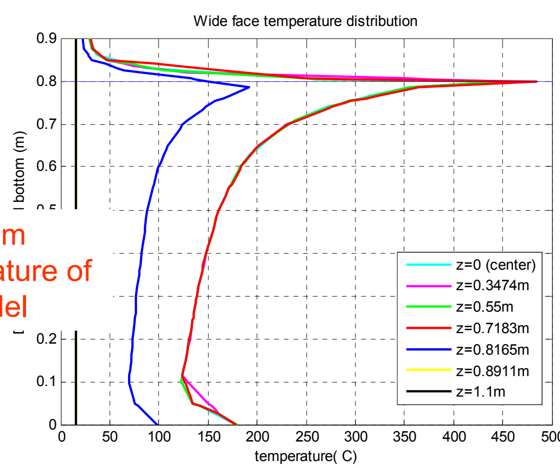
Model Validation

- Similar geometry and similar heat flux profile.
- Similar temperature contours.
- Higher heat flux near the meniscus results in a higher maximum temperature.
- Similar distortion.
- New wide face distorts more due to larger width.
- Similar gaps between WF and NF at top and bottom;
- **Conclusion**: New model is valid and can be used for further study.

Thermal Model



Narrow Face

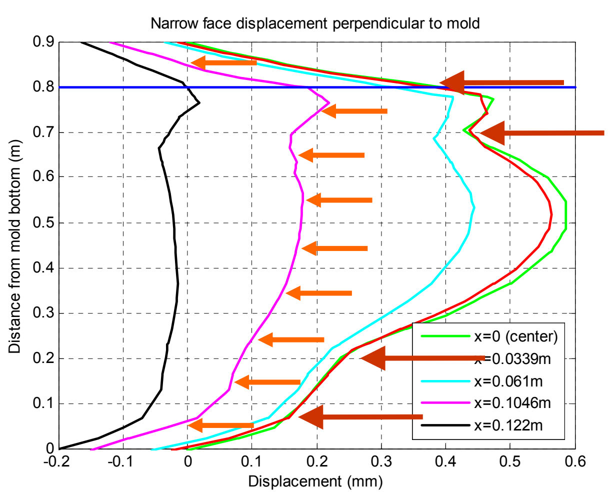


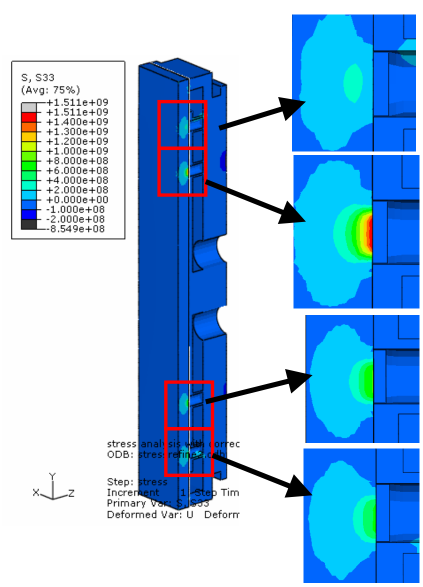
Wide Face

Thermal Model

- The highest temperature in each mold is just below meniscus.
- The maximum temperature in the whole model is at the edge narrow face just below the meniscus (owing to gap that forms between NF and WF).

Narrow Face Stress Analysis

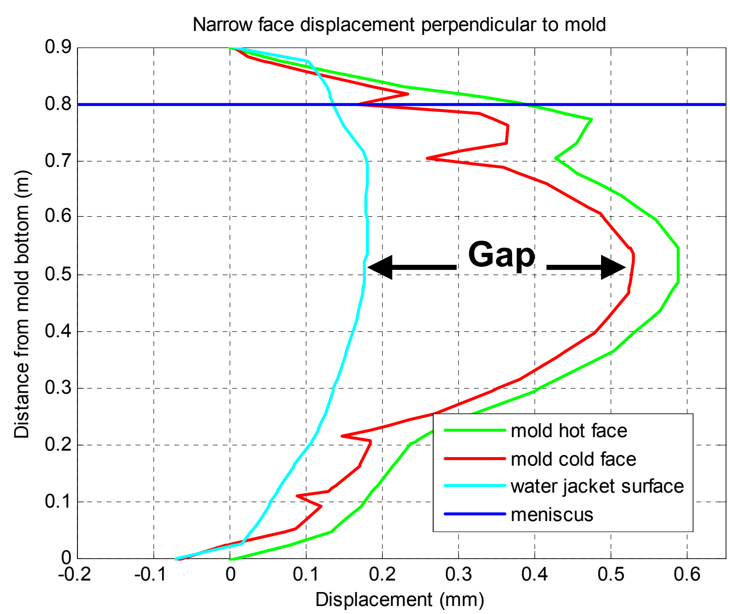




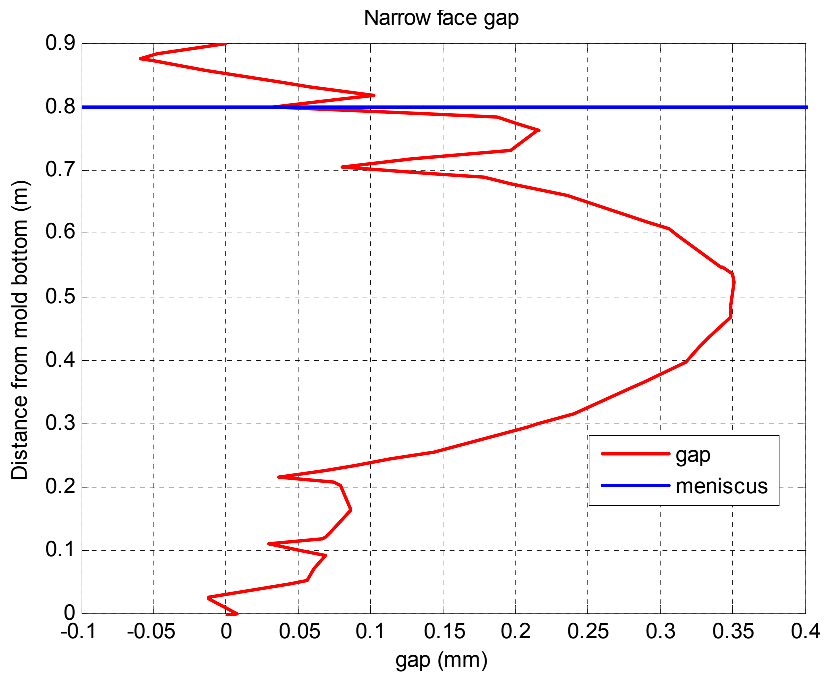
Narrow Face Stress Analysis

- All the curves have a peak just below the meniscus (owing to the temperature peak)
- Bolts tend to lessen distortion: cause minimums in the distortion profile.
- More bolts and even distribution would reduce the distortion
- More bolts and even distribution would reduce the stress (the maximum stress is 1.51GPa, causing yielding of the copper)

Narrow Face Shape



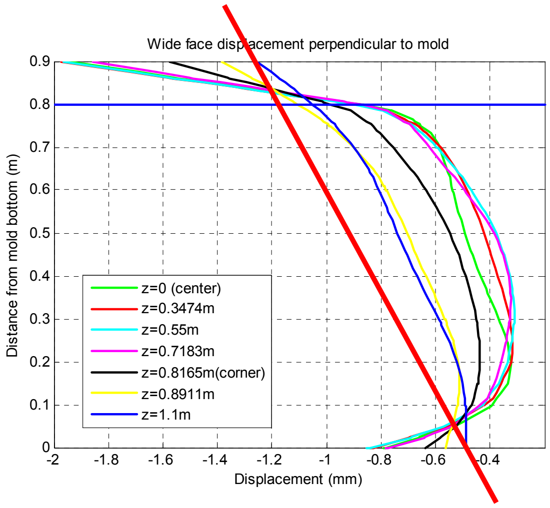
Narrow Face Gap



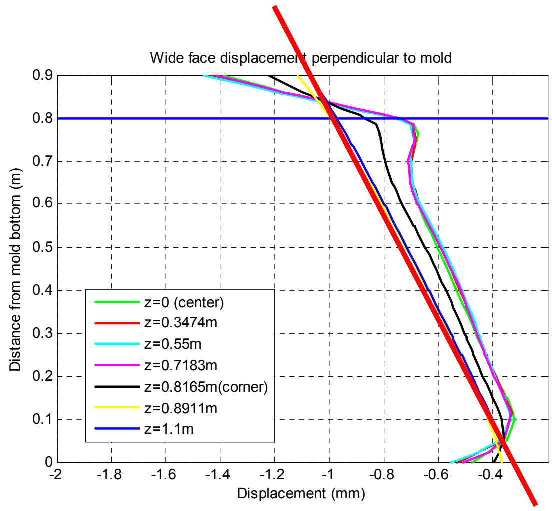
Narrow Face Shape

- Gap forms between the narrow face mold and water box.
- Water box thickness increases due to temperature increase, which stretches the bolts.

Wide Face Stress Analysis



Model with typical water box

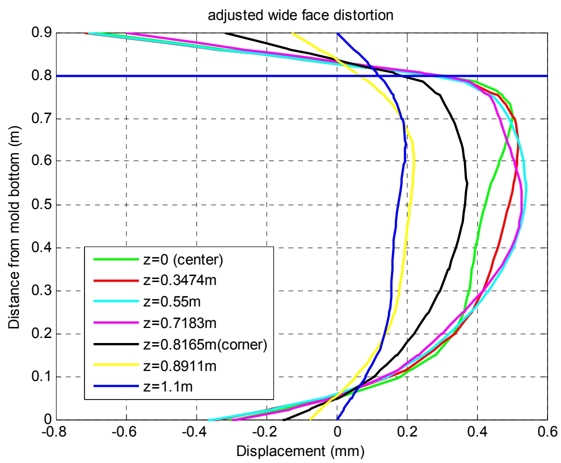


Model with EM water box

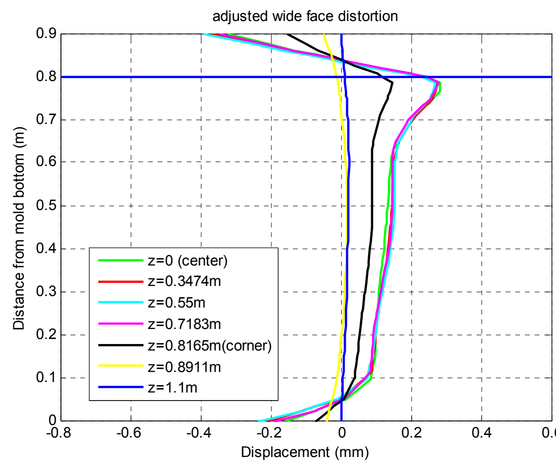
Wide Face Stress Analysis

- The whole wide face mold is tilted.
- Assuming mold shape is kept more vertical, plots are redrawn to show the thermal distortion.

Distorted shape after tilted



Model with typical water box

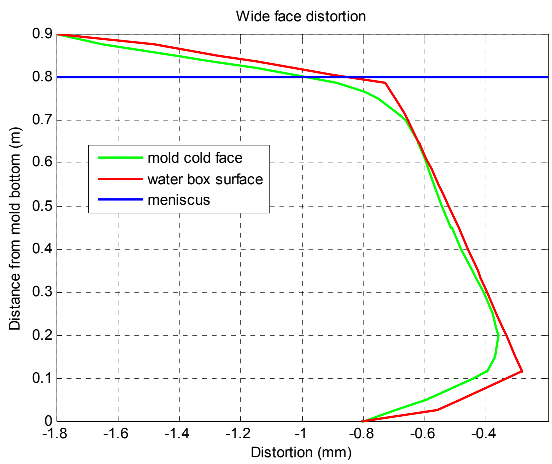


Model with EM water box

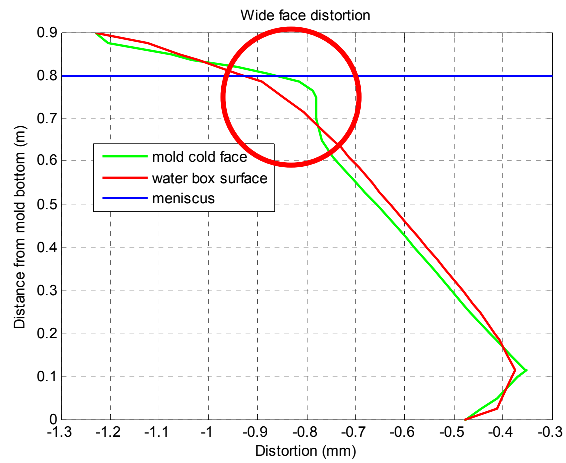
Distorted shape after tilted

- Mold for EM Brake has less distortion!
- The thicker the water box plate is, the more rigid, and less it bends.
- The shorter the bolts are, the harder for them to elongate.
- A thicker plate and shorter bolts will lead to a flatter mold (less distortion).

Wide Face Shape



Model with typical water box

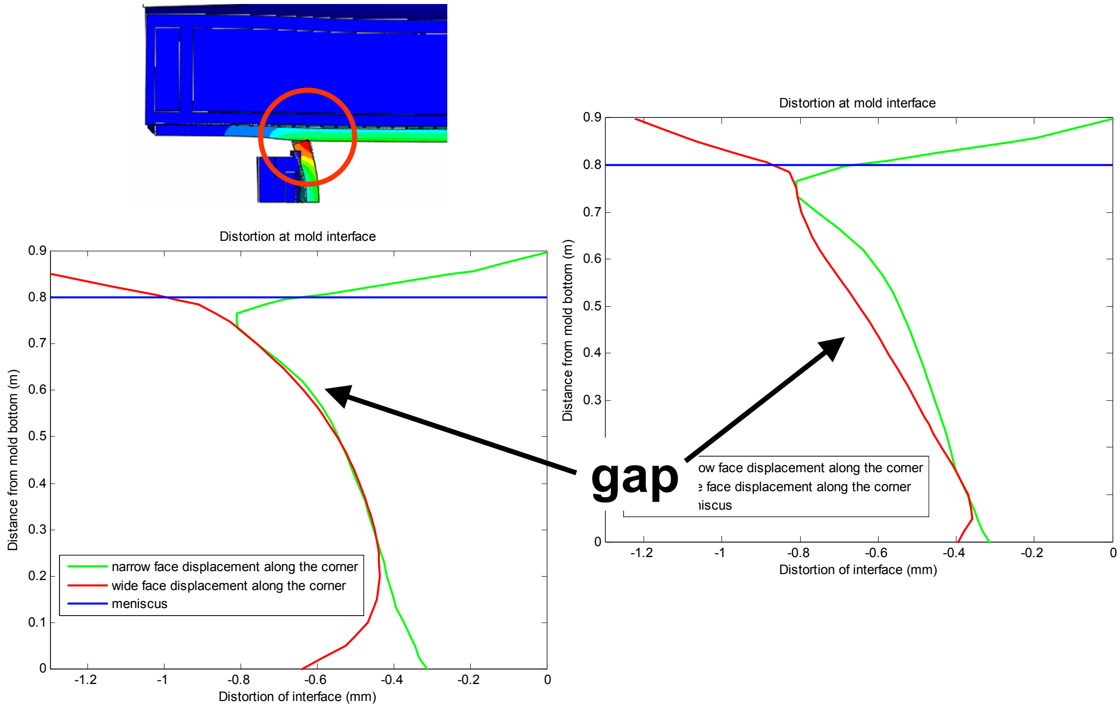


Model with EM water box

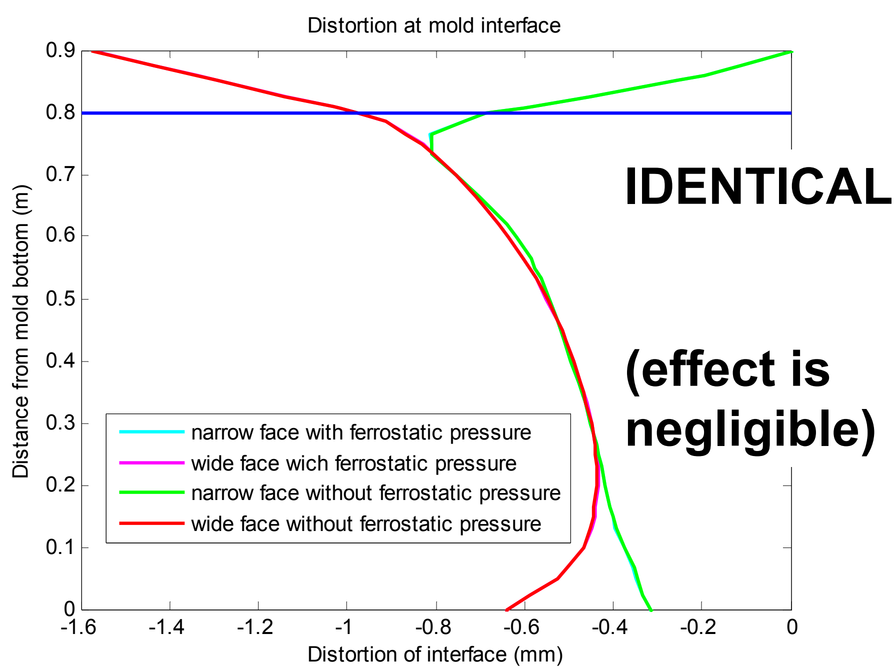
Wide Face Shape

- No gap for the wide face model with typical water box
- Constraints will not change the edge shape, just lead to transportation and rotation;
- Gap exists in the wide face mold model for the EM brake. Because the water box plate is too thick to bend.
- thick water box plate has both good and bad effects.

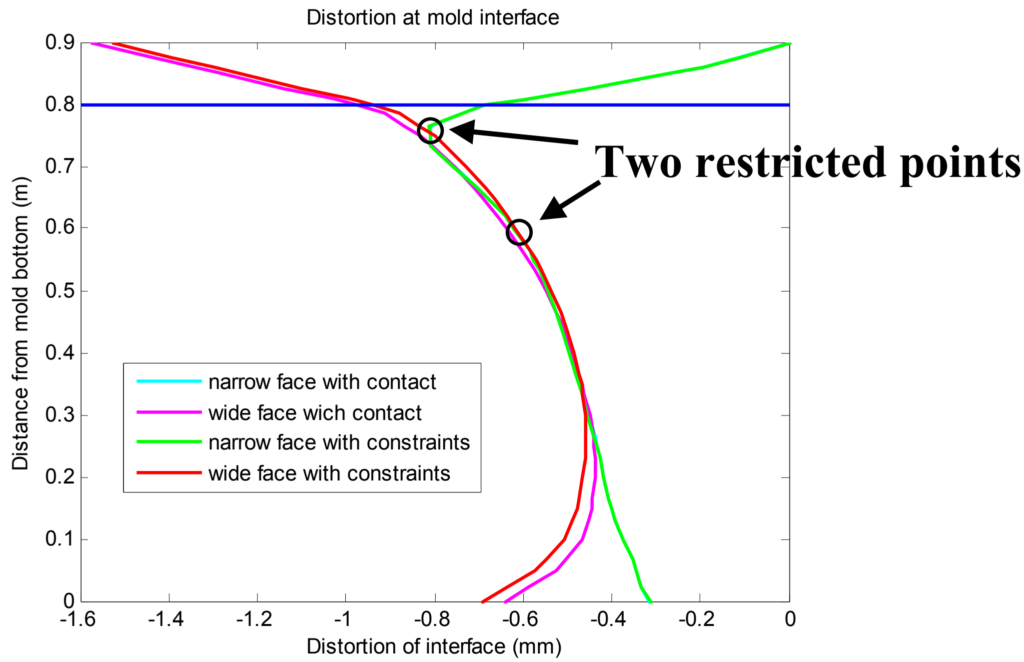
Mold interface



Ferrostatic Pressure effect



Constraints



Mold Interface

- The gap is not caused by the ferrostatic pressure
- Constraints will not change the shape of the interface.
- The achieve the balance, the mold must rotate to get the two points to contact.

Conclusions

- Water box for EM brake has thicker plate, shorter bolts and longer frame, which leads to less distortion.
- Evenly distributed bolts could better limit mold distortion, as well as derive a flatten surface and avoid stress concentration.
- Enough bolts should be assigned to avoid stress concentration.
- The thickness of the water box plate will greatly influent the mold distortion. A thicker plate would lead to a flatter mold.
- Gap might exist at the middle region of the corner, not only at the top and bottom.
- Depending on the water box structure and bolt distribution, gap may be created between the mold and water box.