THERMO-CHEMO-MECHANICAL MODELING OF A HALL-HÉROULT CELL THERMAL BAKE-OUT

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Plan

- Introduction
- Aspects of Cell Mechanical Behavior
- Finite Element Demonstration Slice Model
- Thermal Bake-out Results
- Conclusions and Future Work

Introduction (1)

- Start-up has a strong influence on pot life.
- Typically, the first phase of start-up is the preheating.
- Main objectives:
  - Avoid bath freezing on cathode block at pour-in
  - Avoid cathode block cracking
  - Avoid gaps that would allow infiltrations.

Introduction (2)

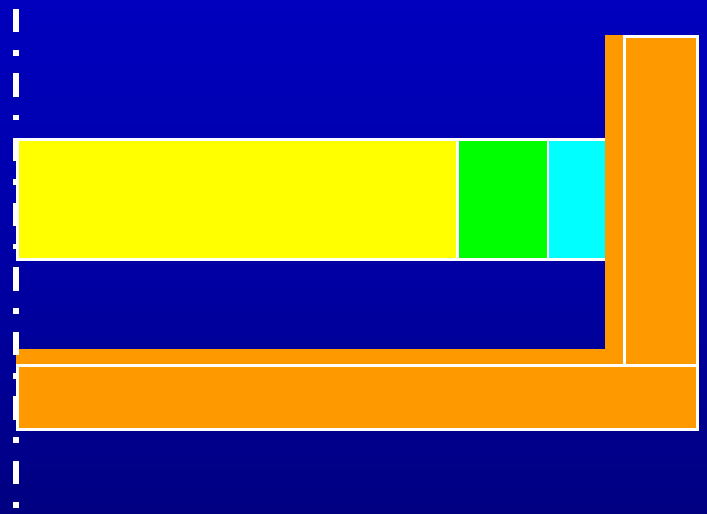
- Ideal preheating is:
  - Fast (for metal production)
  - Smooth (for cell performance and life).
- Optimal preheating strategy elusive.
- Numerical modeling is a powerful analysis tool.

Aspects of Cell Mechanical Behavior

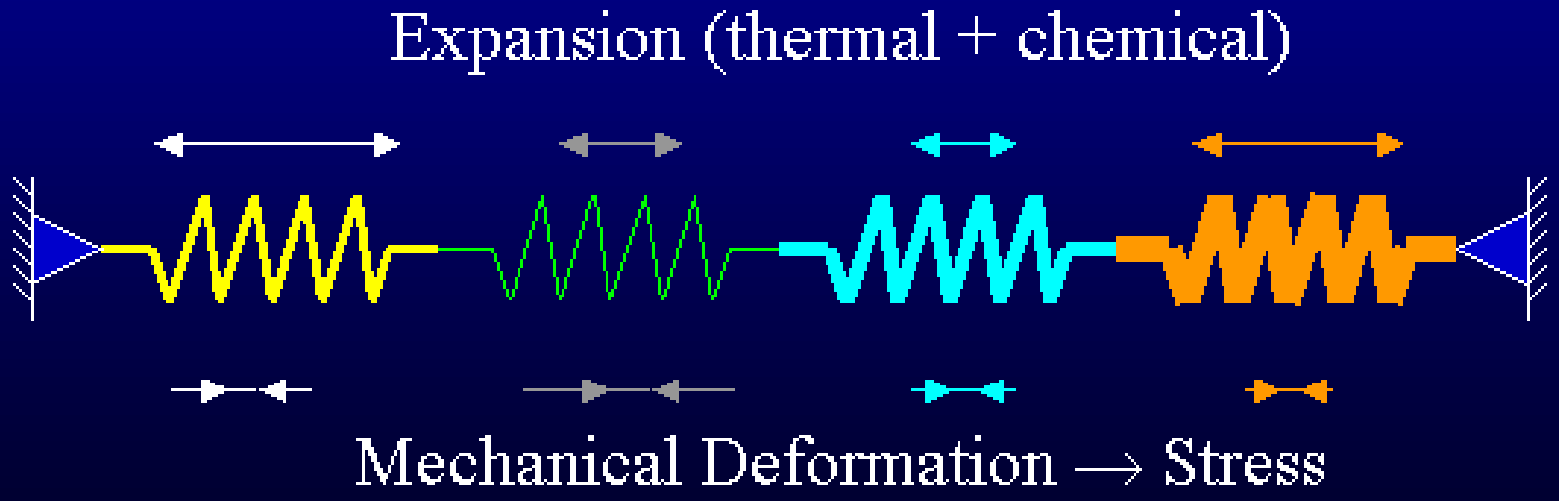
- **Cell construction**
  - Contact interfaces.
- **Lining mechanical behavior**
  - Prebaked carbon blocks, castables …
- **Irreversible time-response**
  - E.g. Baking of ramming paste.
- **Lining / pot shell interaction**
  - Strain-driven problem.

Aspects of Cell Mechanical Behavior

Lining / pot shell interaction

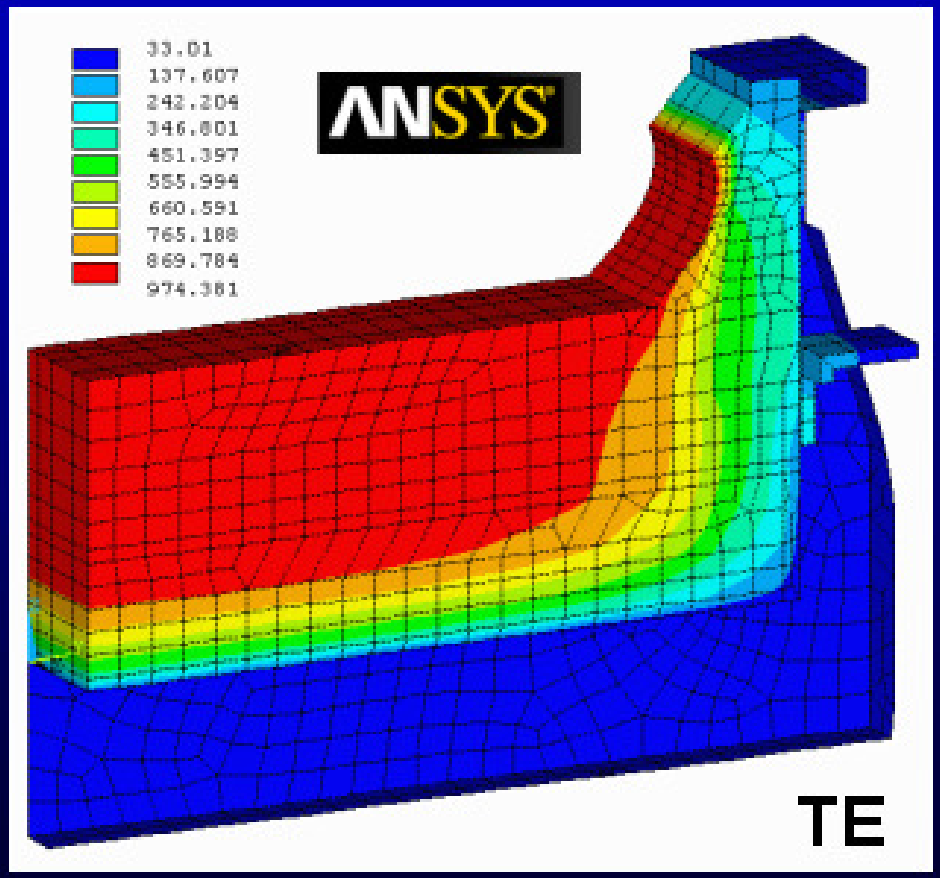


- High stresses can lead to permanent deformation.
- Time-dependent strain
- Non-linear



FE Demonstration Slice Model

- VAW 300 kA PFPB design (JOM 1994) adapted by Dupuis (GéniSIM)



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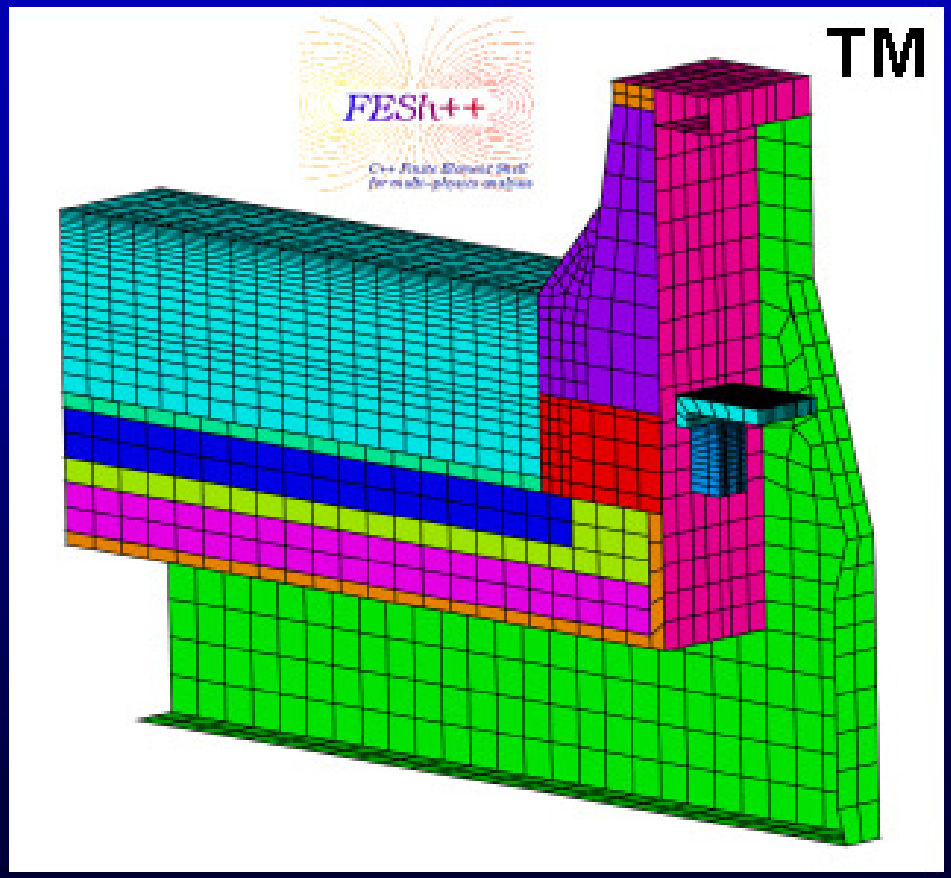
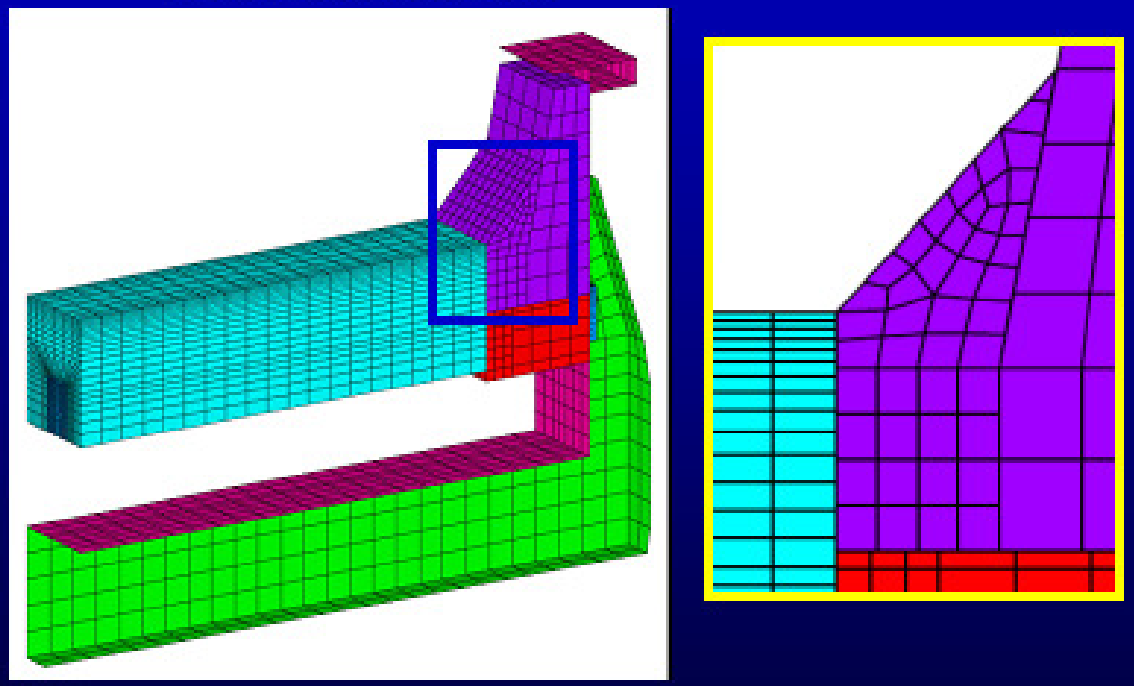


FE Demonstration Slice Model

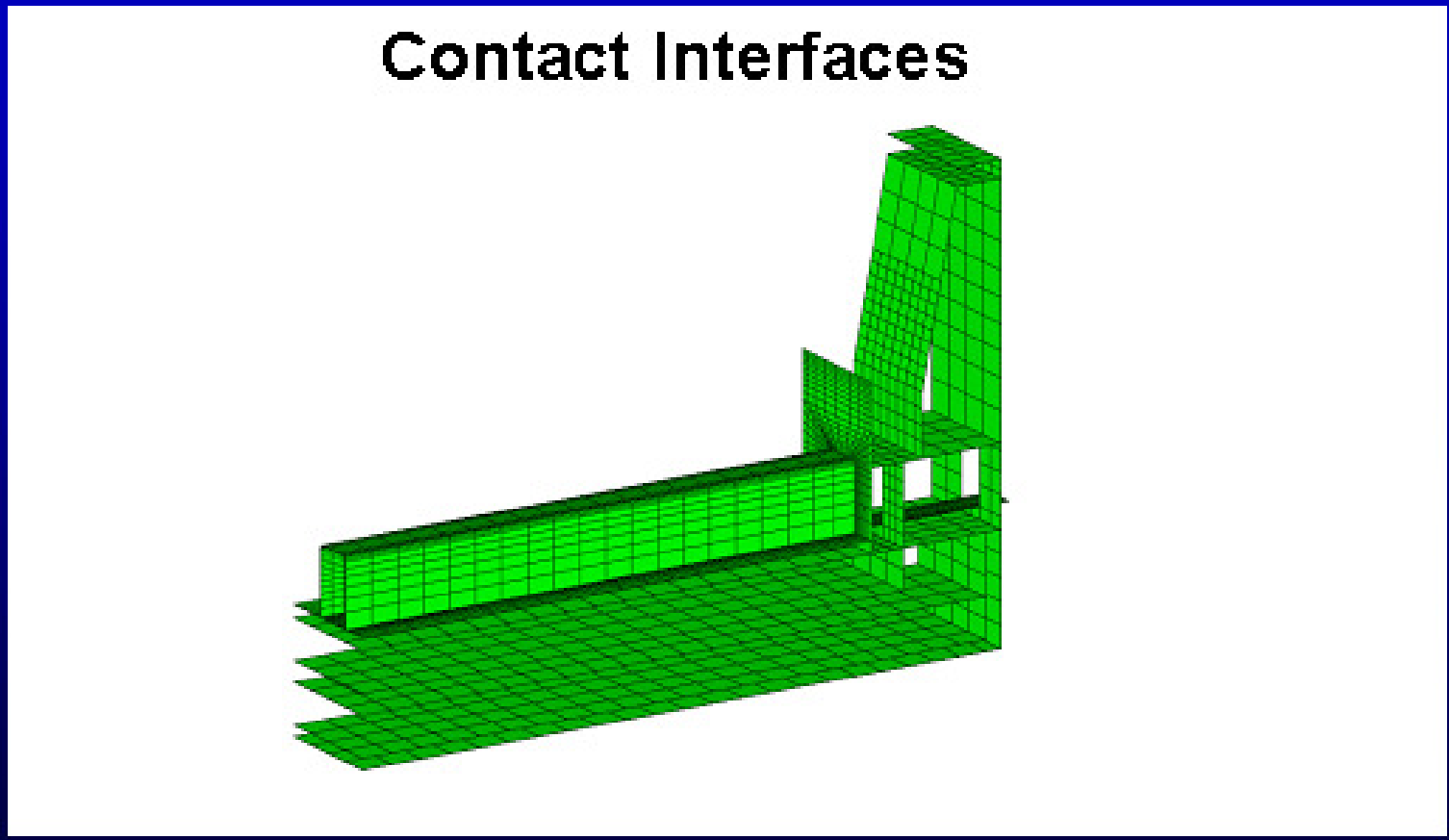
Modeling Approach

Mechanical



FE Demonstration Slice Model

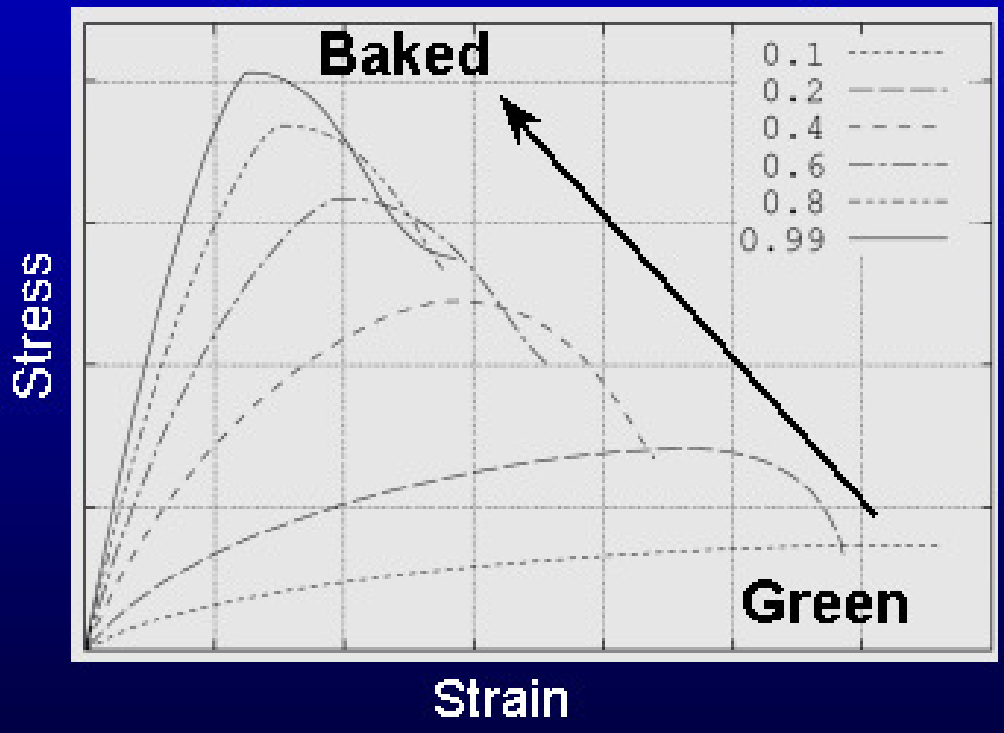
Modeling Approach



FE Demonstration Slice Model
Lining Mechanical Material Models

- Quasi-brittle
  - Cathode block
  - Sideblock
  - Castable
- Reactive Quasi-brittle*
  - Ramming paste
- Elastic
  - Steel shell
  - Collector Bar
  - Cast iron
  - Pier

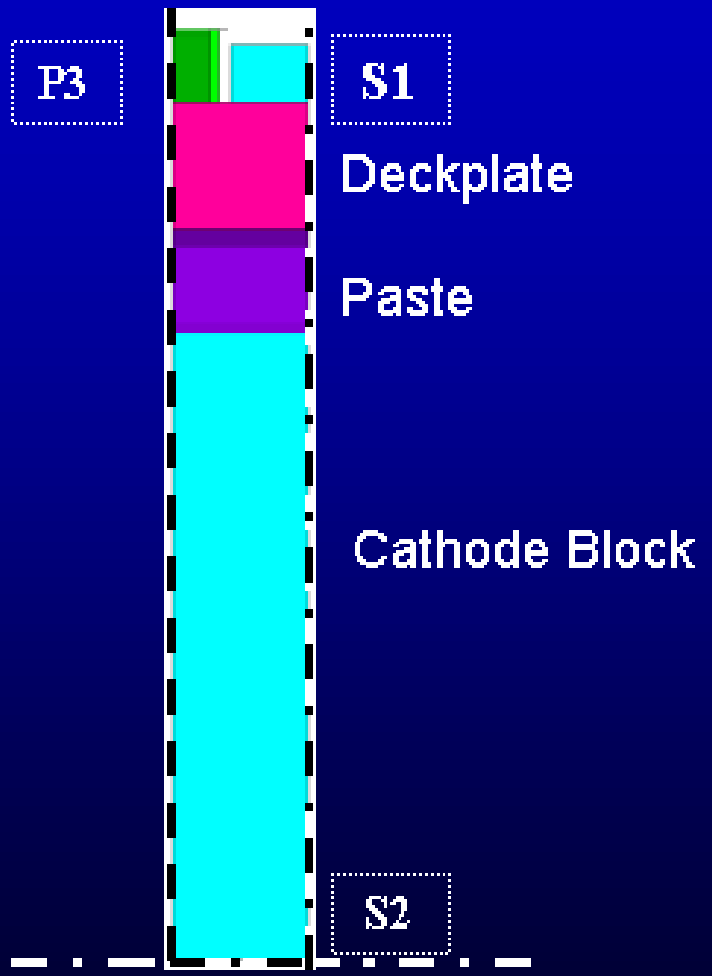
Ramming paste Uniaxial Compression



* *Richard et al., TMS 2005*

FE Demonstration Slice Model
Boundary Conditions – Mechanical

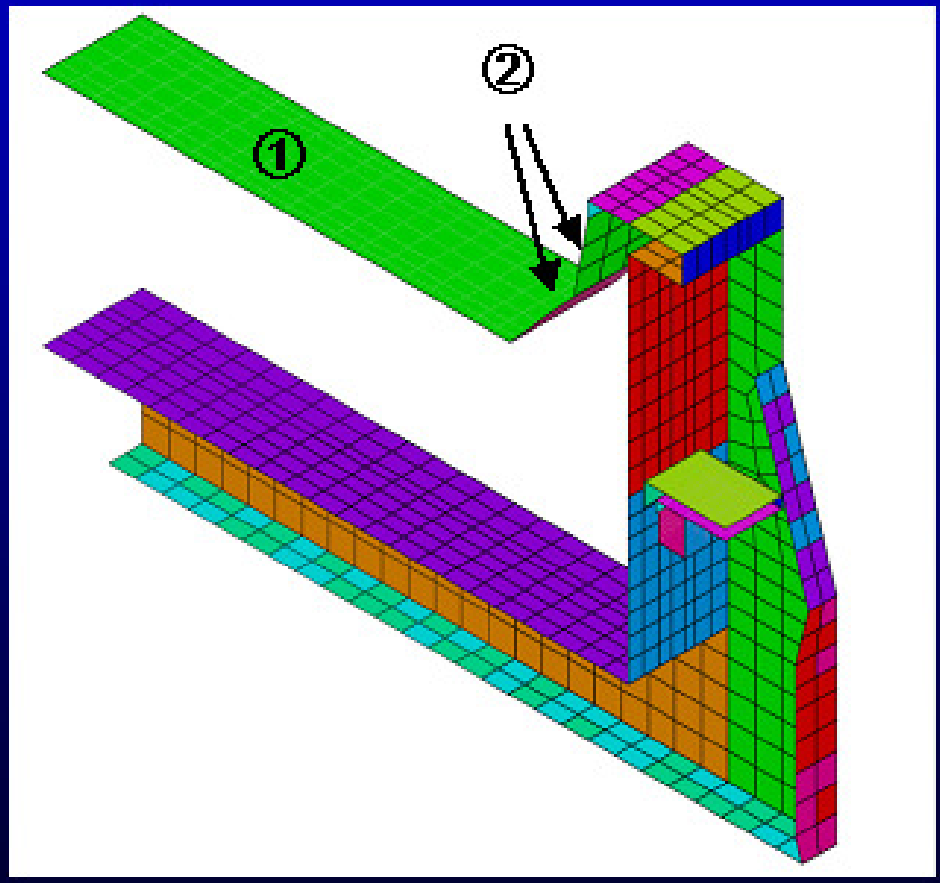
- Symmetry on S1 and S2
- *In reality, conditions on P3 depend on shell and lining interaction*
- Extreme cases for P3
  - Symmetry
  - Free
- Gravity load



FE Demonstration Slice Model
Boundary Conditions – Thermal

- ① Linear T_∞ ramp-up
  - h = 650 W/m^{2}K
  - T_{final} = 955°C
- ② Insulated ramming paste and sidewall
  - h = 1 W/m^{2}K
- Natural equivalent convection for all other surfaces

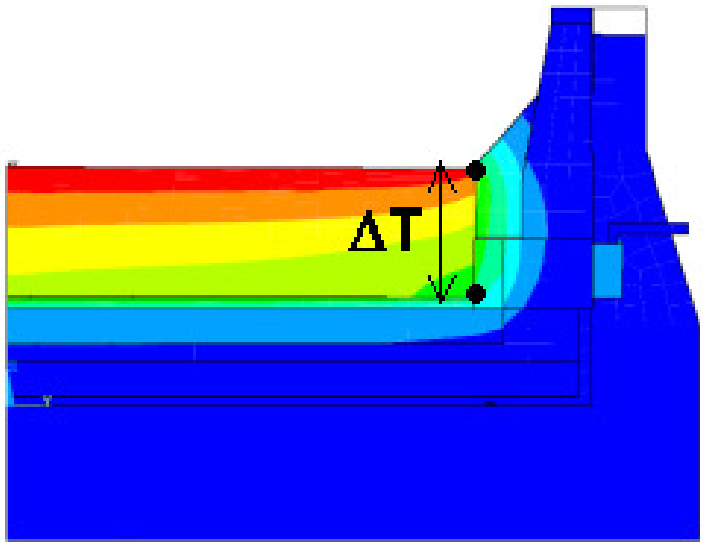
Thermal Convection Surfaces

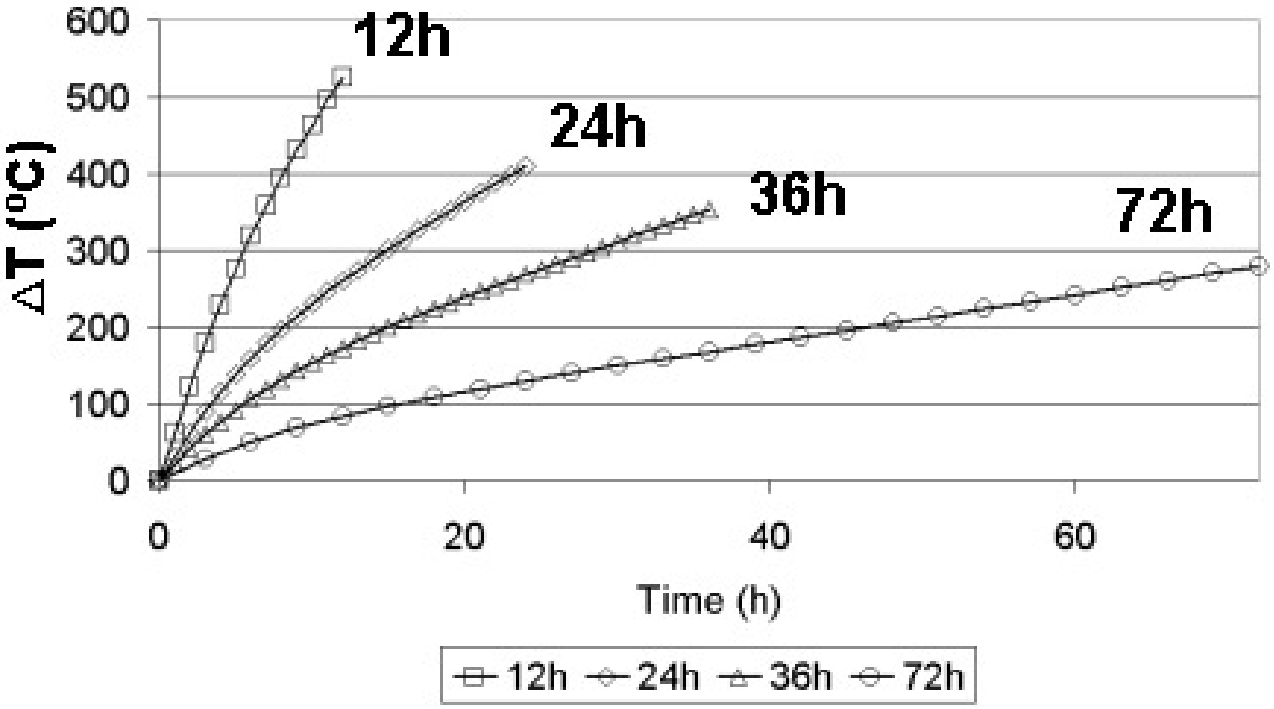


Thermal Bake-out Results

Temperature Gradient in Cathode Block

- As expected, faster preheating leads to higher temperature gradients





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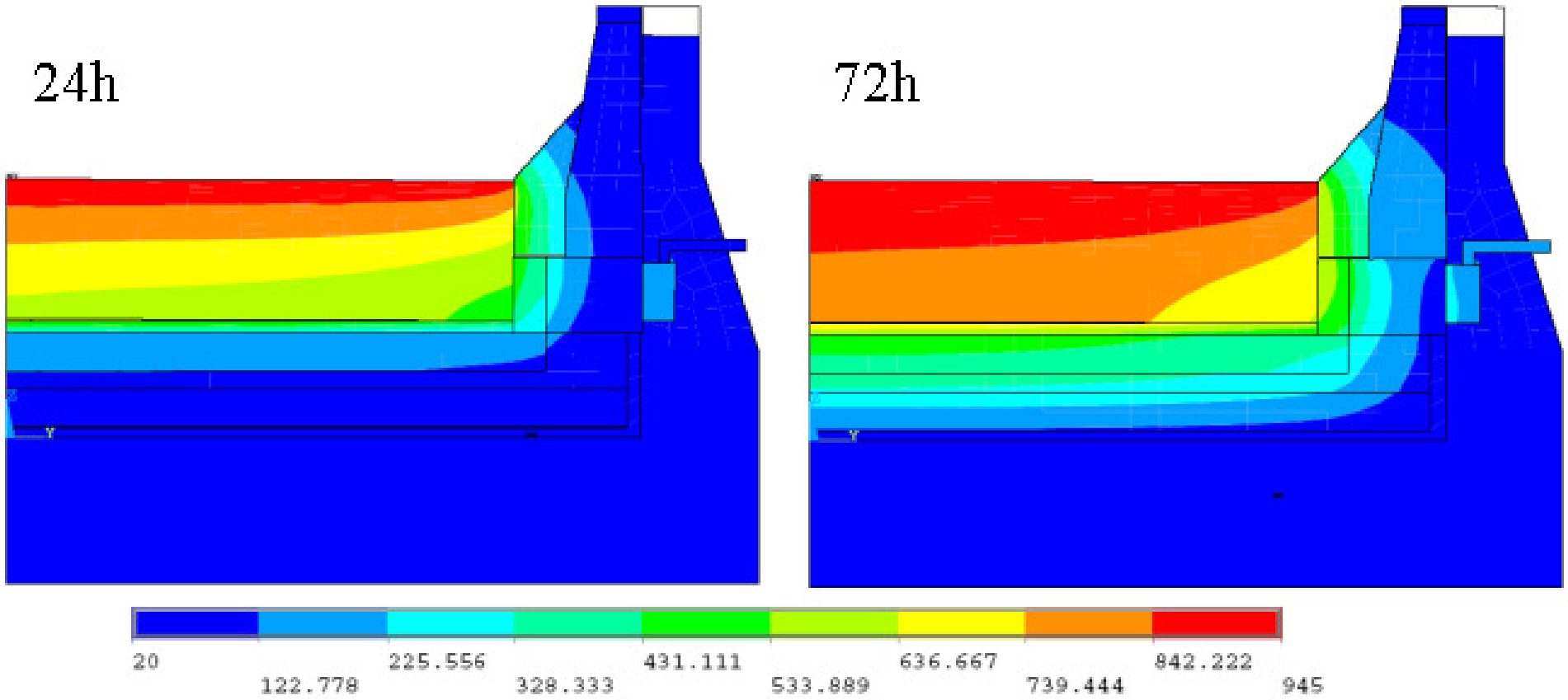
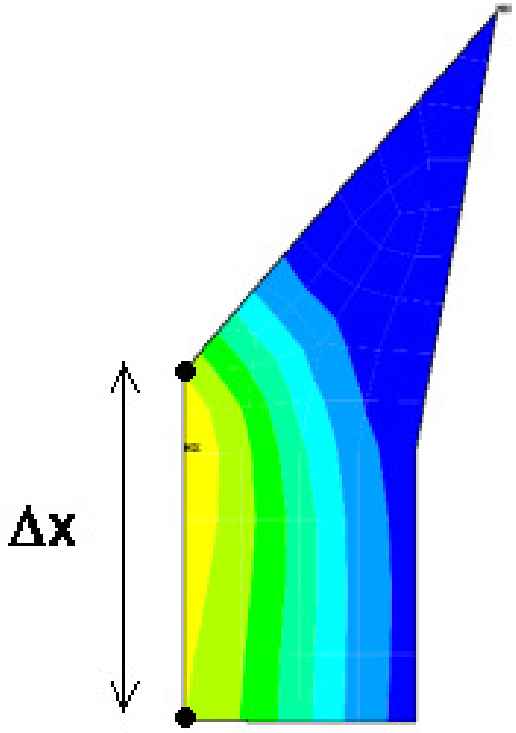
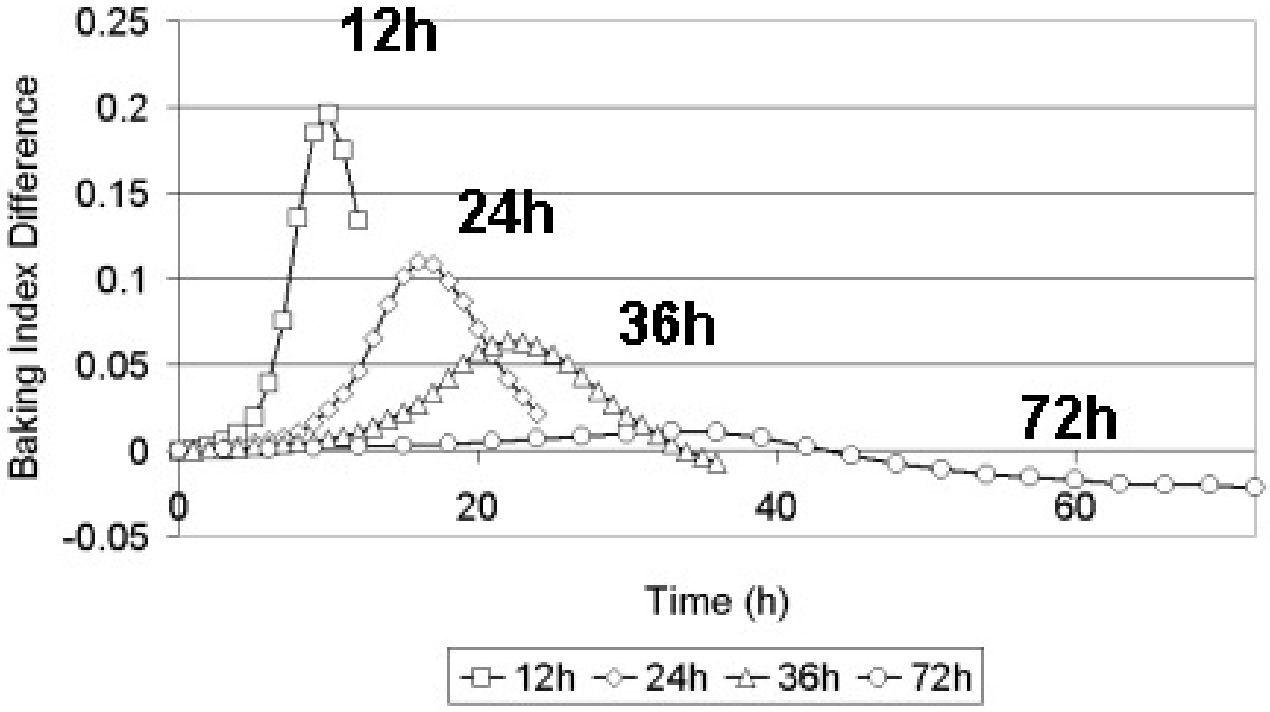


Thermal Bake-out Results
Ramming Paste Baking

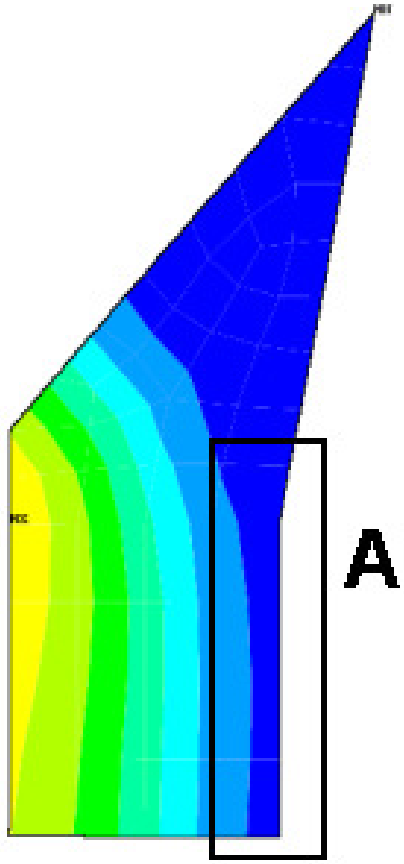
- Fast preheating leads to small baking extent and large baking gradient





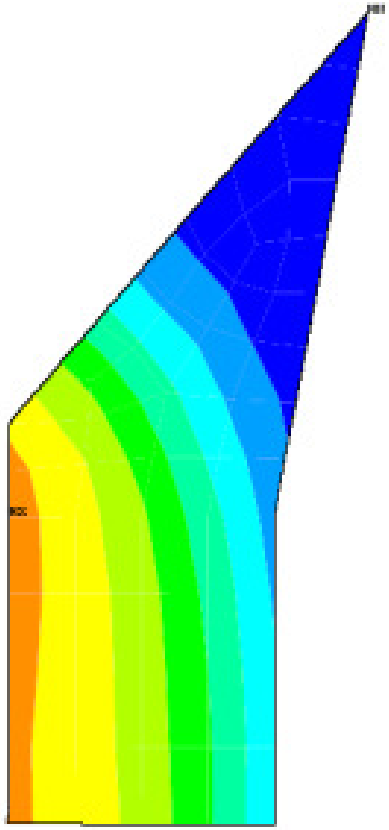
Thermal Bake-out Results
Ramming Paste Baking

24h



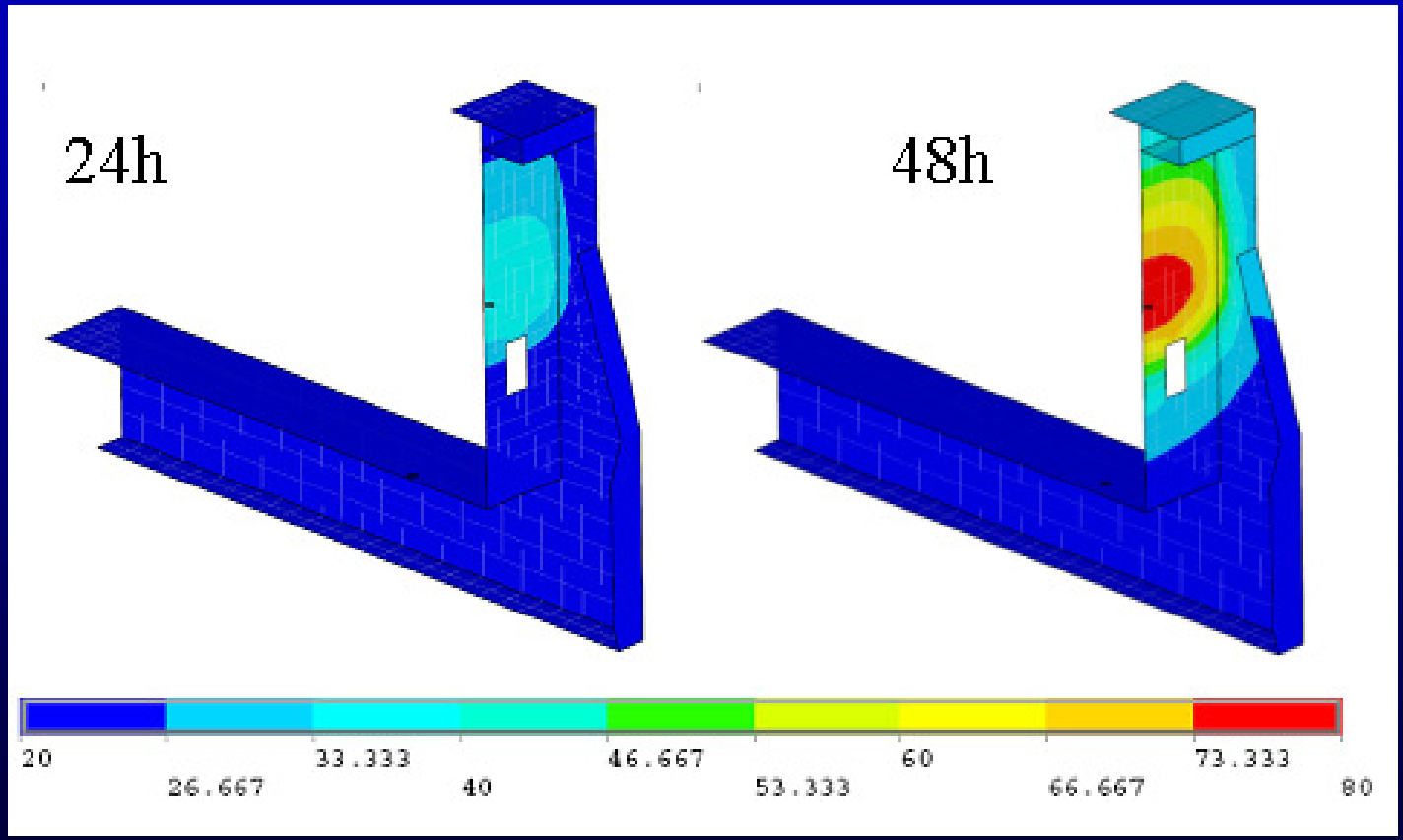
Almost green

72h



Thermal Bake-out Results

Lining Relative Displacement (Amplified 10X)



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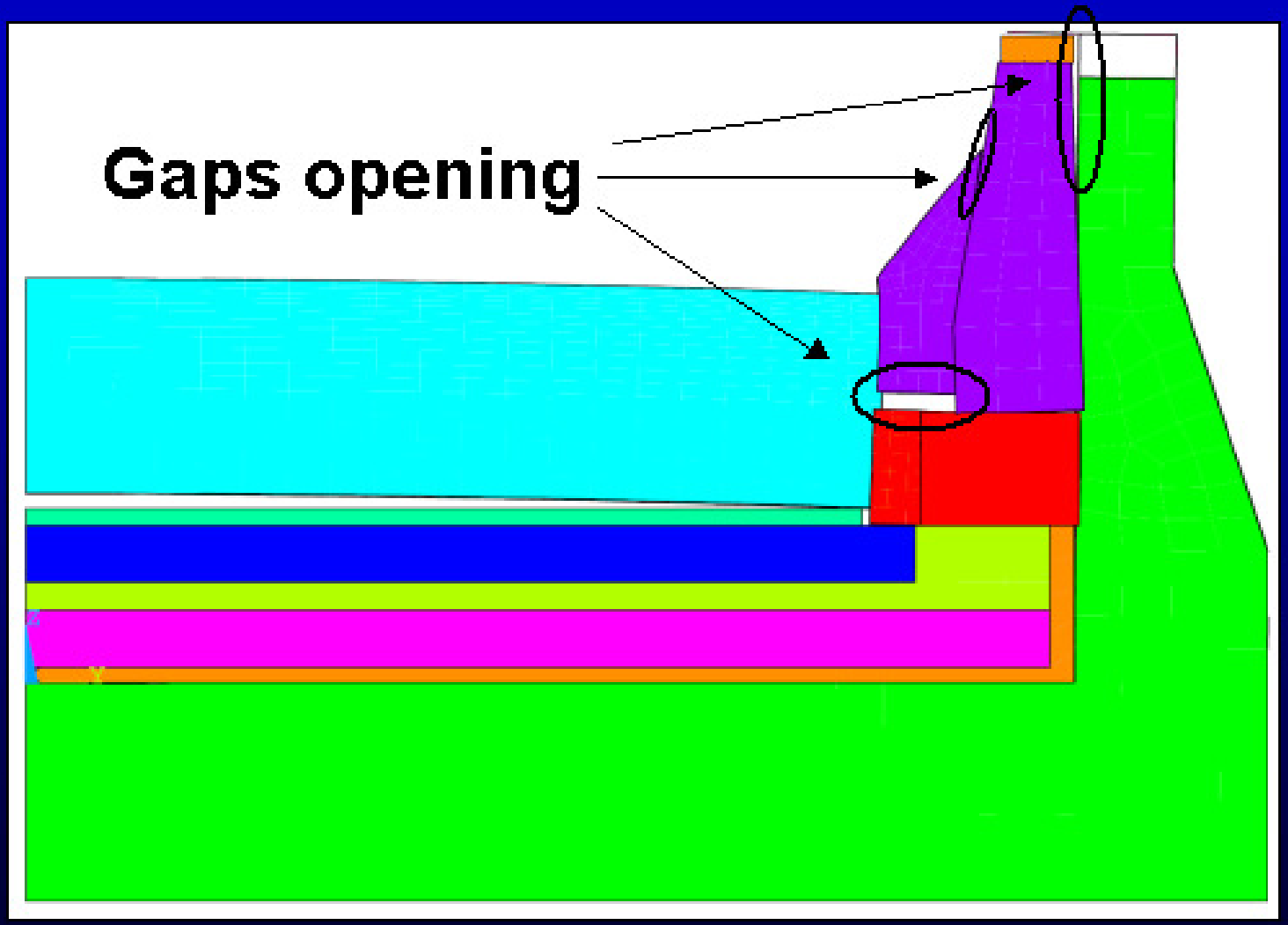

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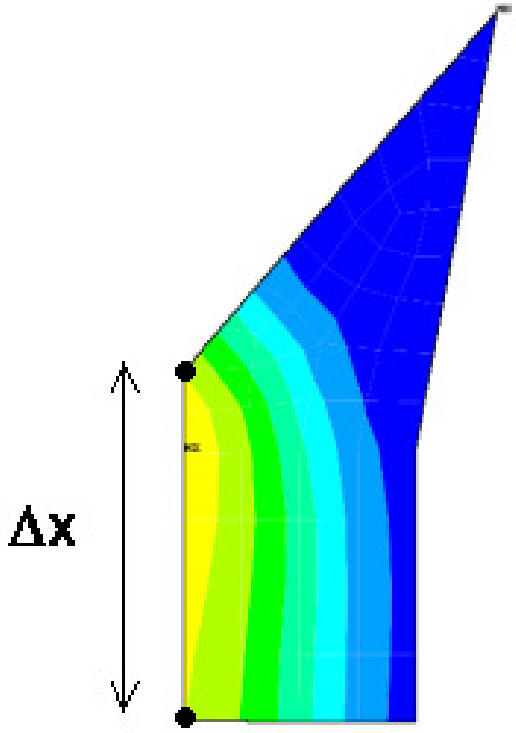
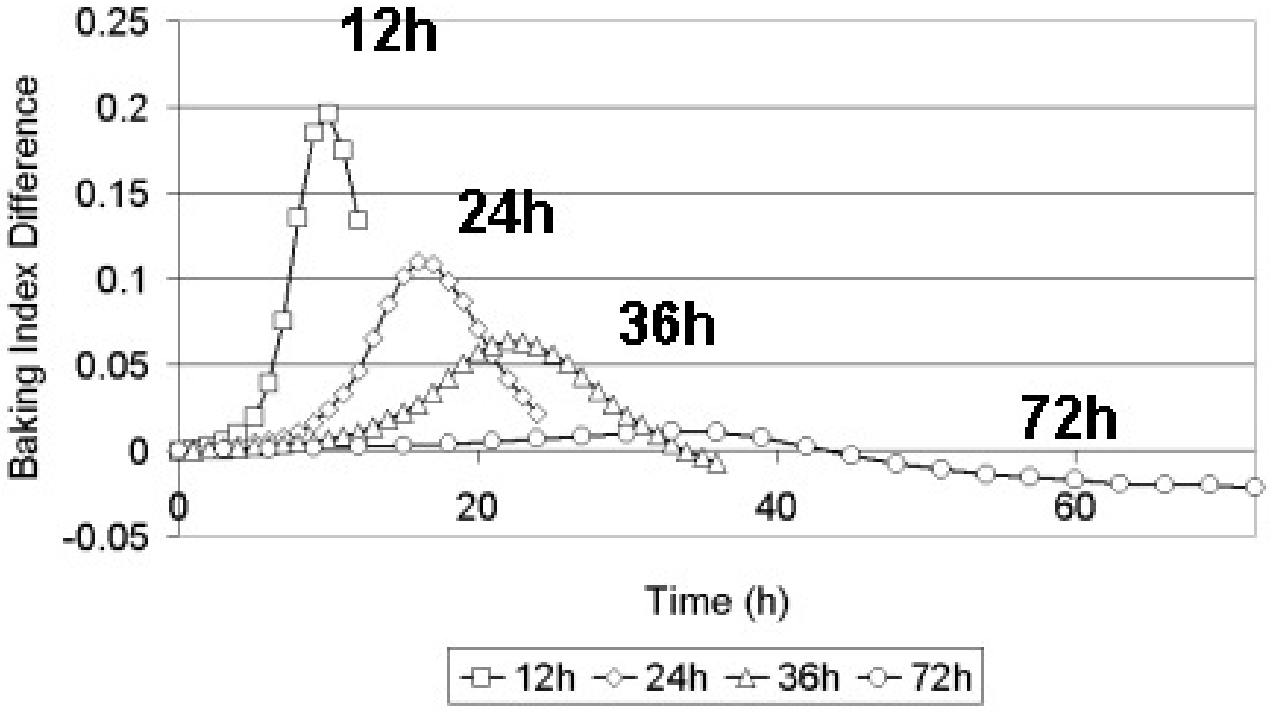
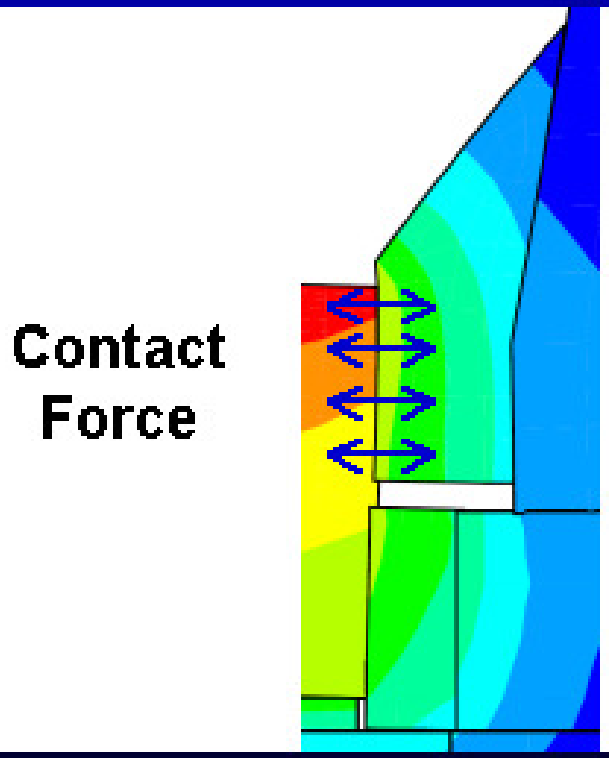


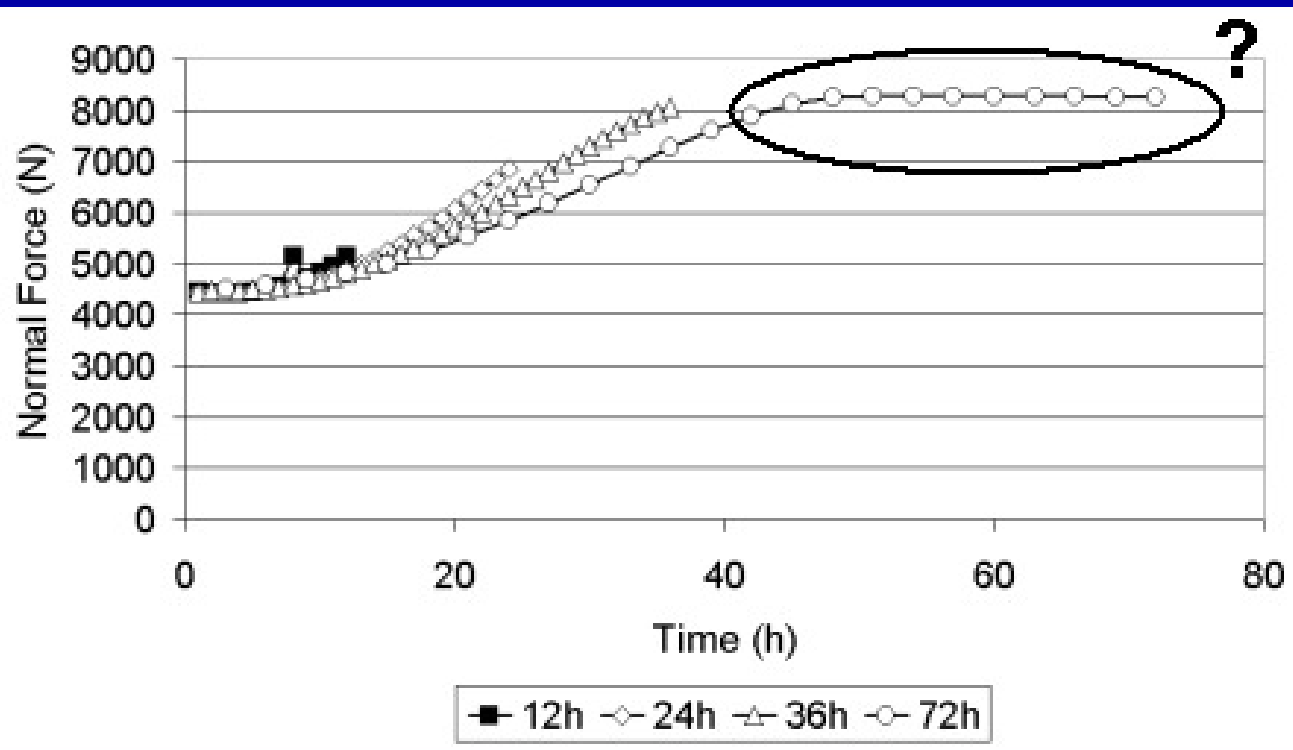


Thermal Bake-out Results

Block/Paste Normal Contact Force

- Stiffer and stronger ramming paste can support higher contact pressure.





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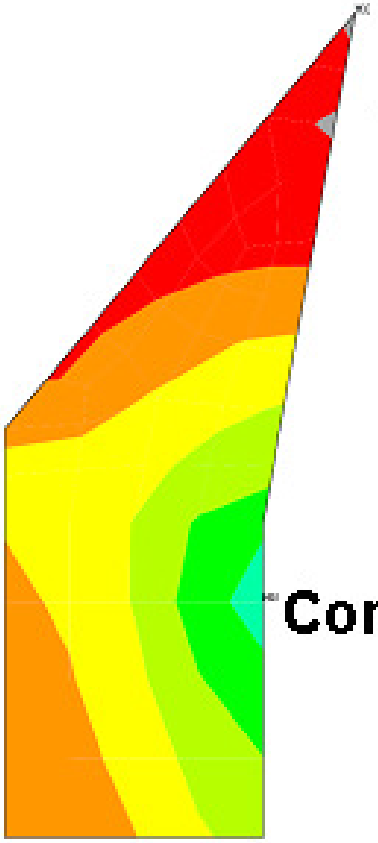
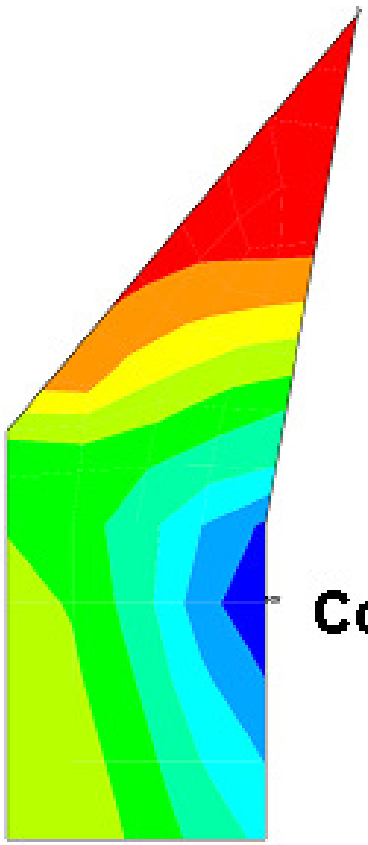


Tension

Compression

72h



Tension

Compression

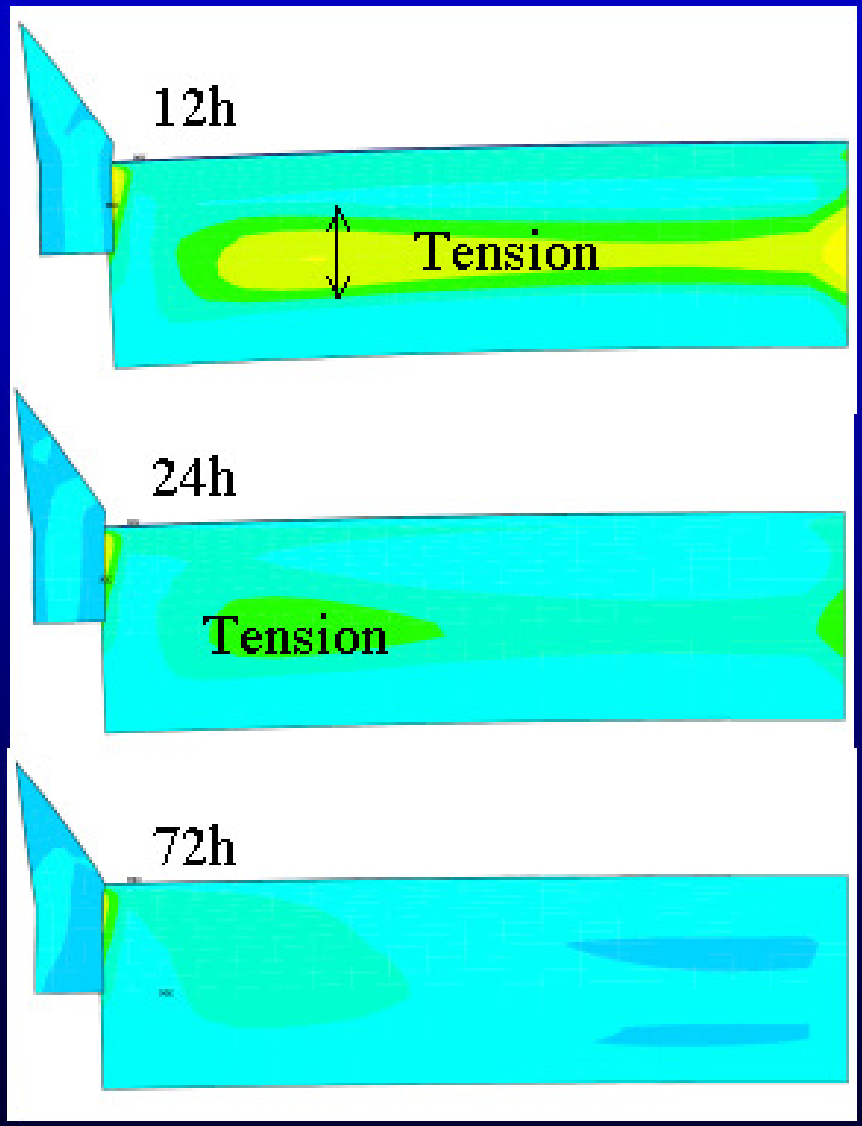
Irreversible Creep Strain

Thermal Bake-out Results

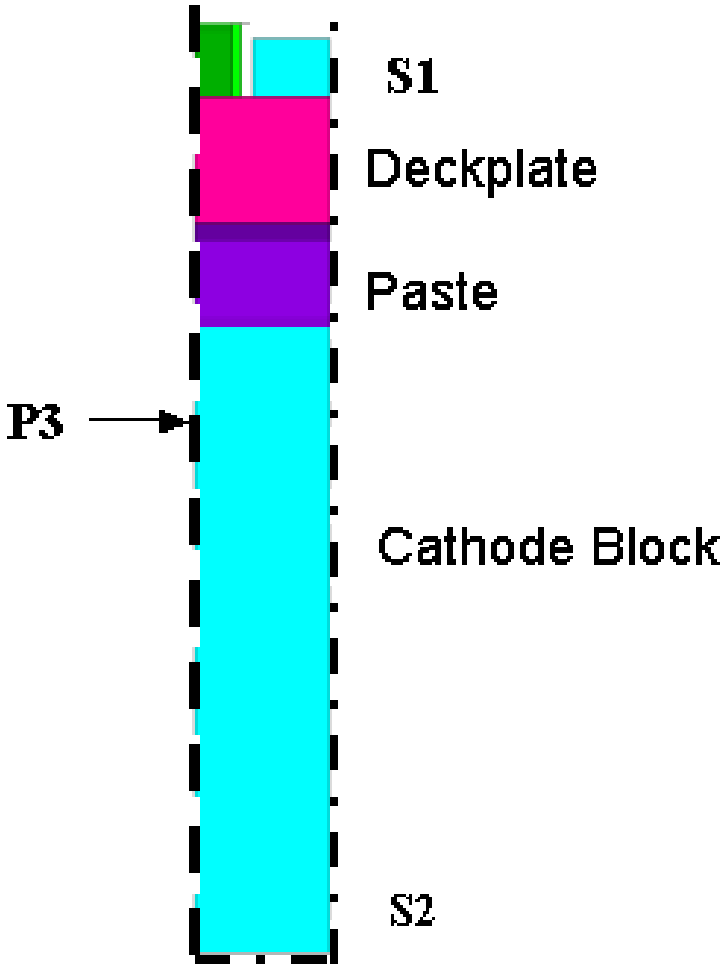
Cathode Block Stress

- Large thermal gradient through block causes tension zones.
- For the scenarios considered, not sufficient to crack the cathode block.

•However…

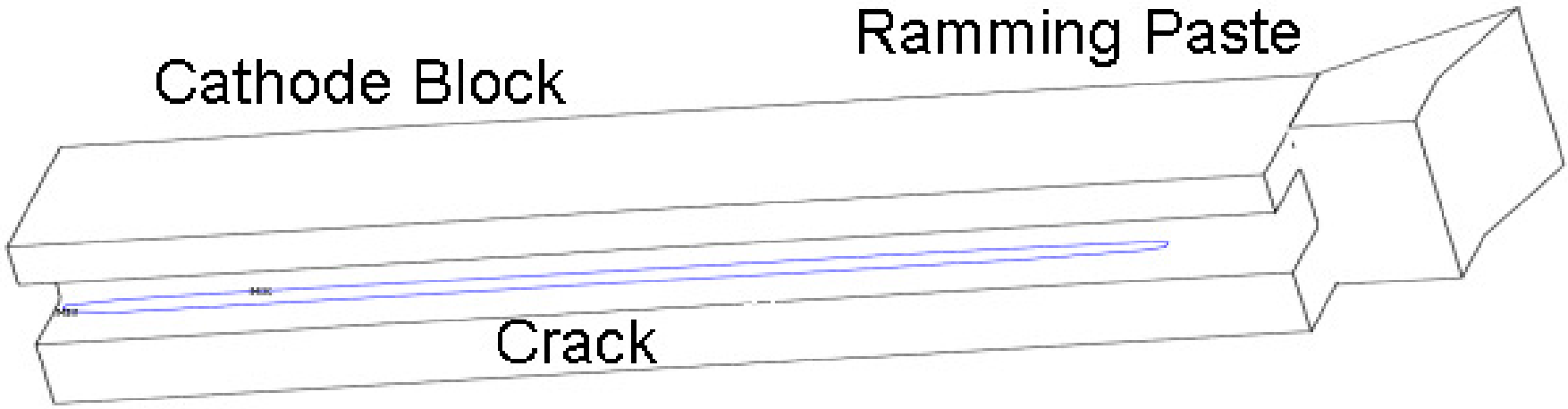


Thermal Bake-out Results
Boundary Conditions on P3



Thermal Bake-out Results
Boundary Conditions on P3

- When P3 is free, no cracking.
- When P3 is a plane of symmetry, cracking !



Conclusion (1)

- A transient coupled TM model of a cell slice thermal preheating was built using the in-house code FESh++.
- Key features include:
  - Quasi-brittle material model for carbon
  - Ramming paste baking
  - Contact interfaces.
- Reproduces qualitatively the observed behavior in terms of thermal gradients.

Conclusion (2)

- In addition, the preheating rate affects :
  - Block / paste contact pressure
  - Ramming paste baking extent and uniformity
  - Stress state in the lining.
- A slice model is not sufficient to predict the stress state in the cathode block.
- Expansion relief along the length of the cell is necessary to prevent block cracking.

On-going and Future Work

- Implementation of a parallel solver in FESh++.
- Extension of the model to a quarter–cell.
- Modeling of an electrical preheating.

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