University of Liège

Thermal Analysis of Solidifying steel shell in Continuous Casting Process

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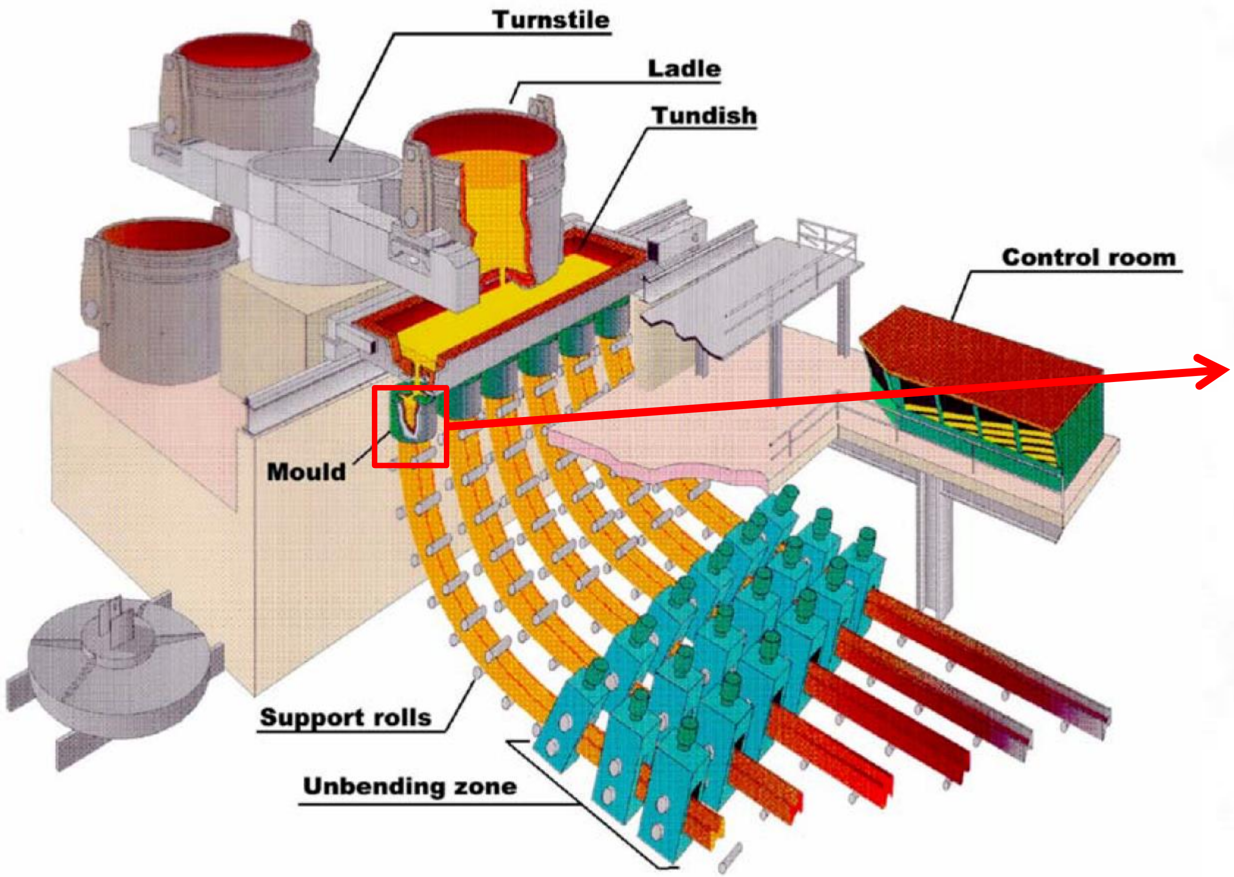
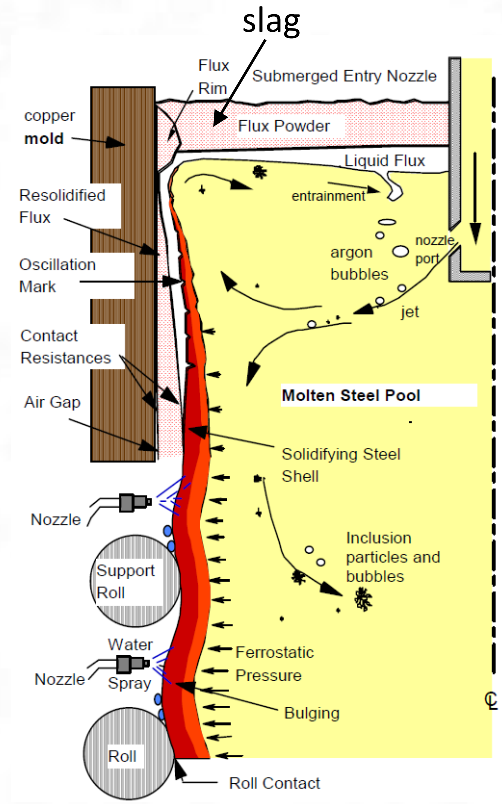
Recherche et Technologie en Wallonie DG06

Steel Continuous Casting

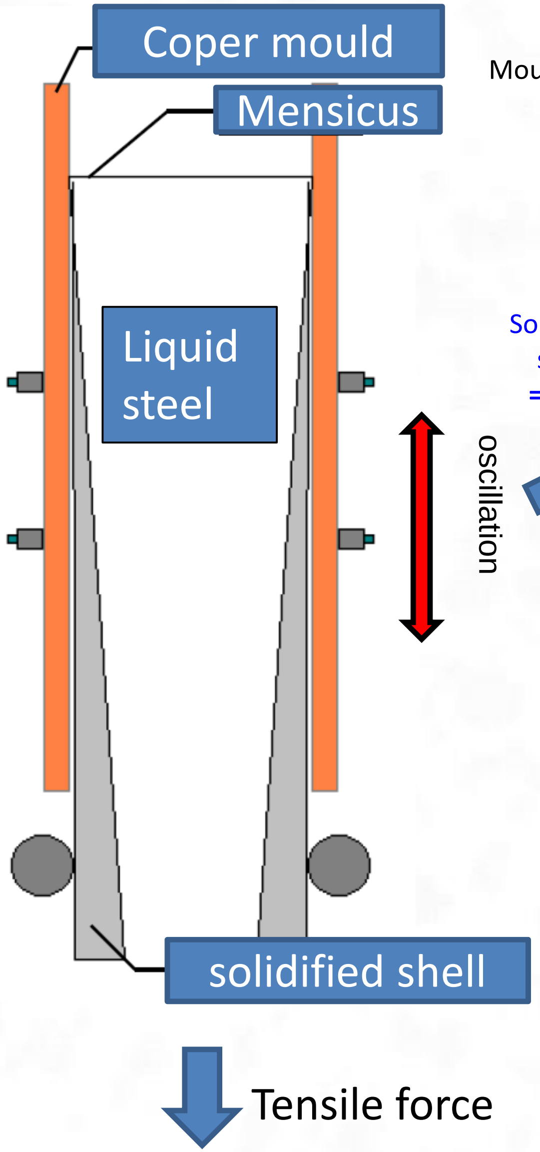


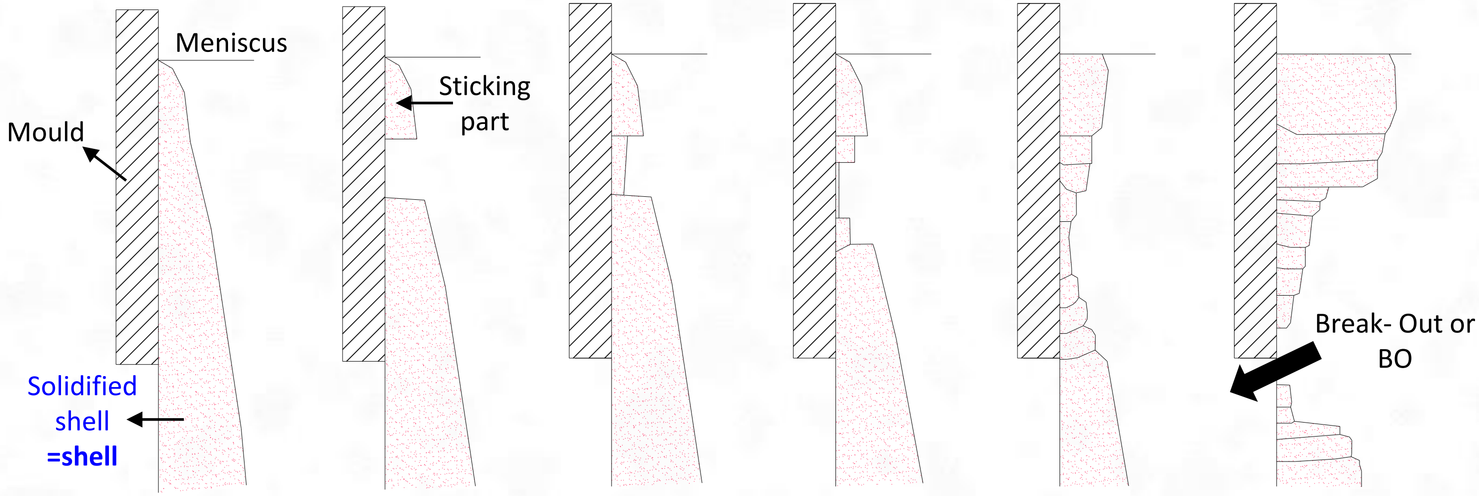


Real world: liquid and solid states –thermo-mechanical model should predict the steel shell behaviour

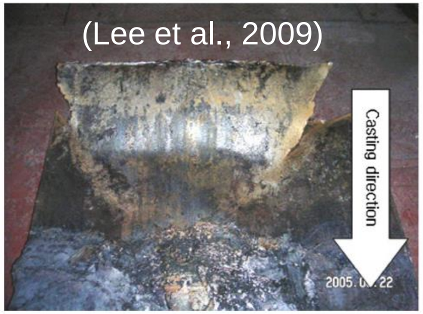
Current model: thermal approach (liquid steel is present however no fluid mechanic analysis), however temperature measurements within the mould validate the results

Sticking Break-Out phenomenon (BO)





Effect of sticking event and appearance of tearing



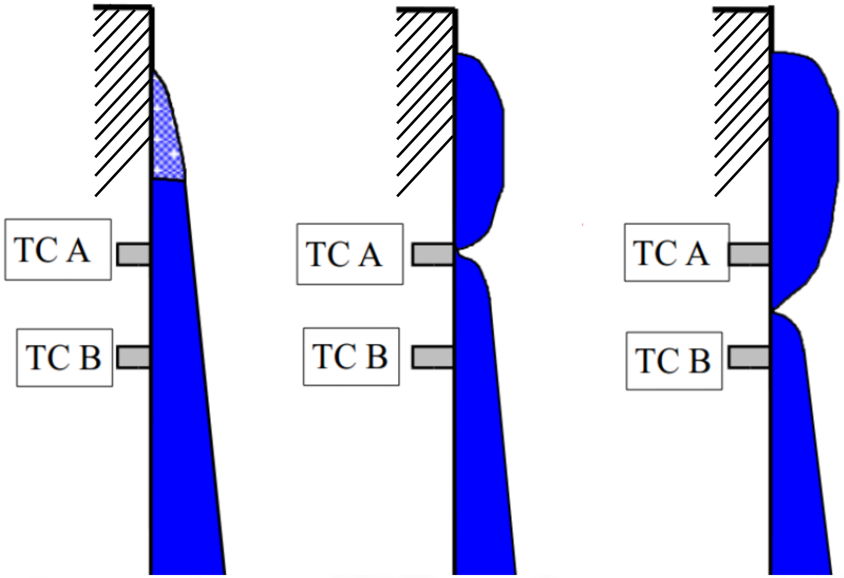
Research objectives:

Analysis of the correlation between the mould tp° field and the BO defect

→*Warn to the operator to adapt casting process features*

EBDS product
= tp° mould measurement by optical fibers
= **BO detection system** called "Emerald"
http://www.ebds-engineering.com/en/

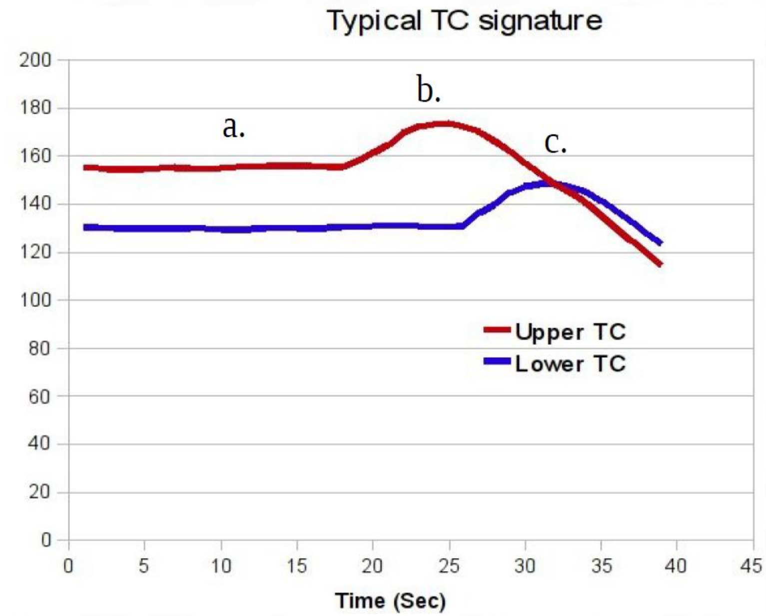
Mould TP° measurement & Model challenges



Broken shell in the top of the mould

Tp° Data

Non calibrated tp° values just relative evolution



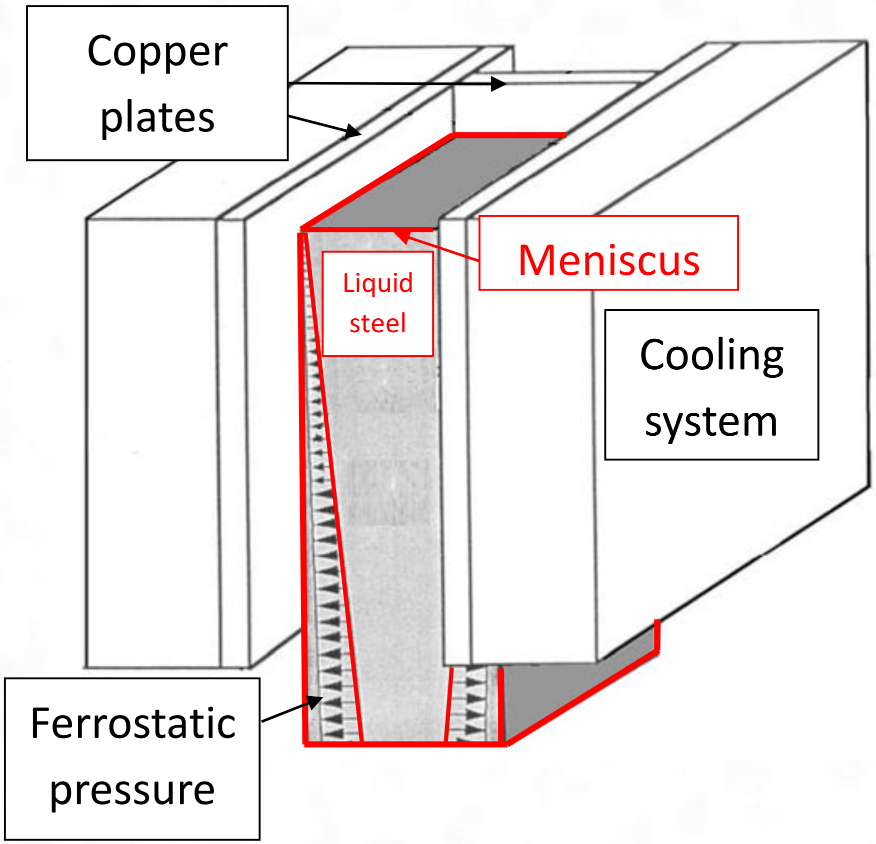
Variation of temperature with time for some positions

2D Thermal Finite Element model

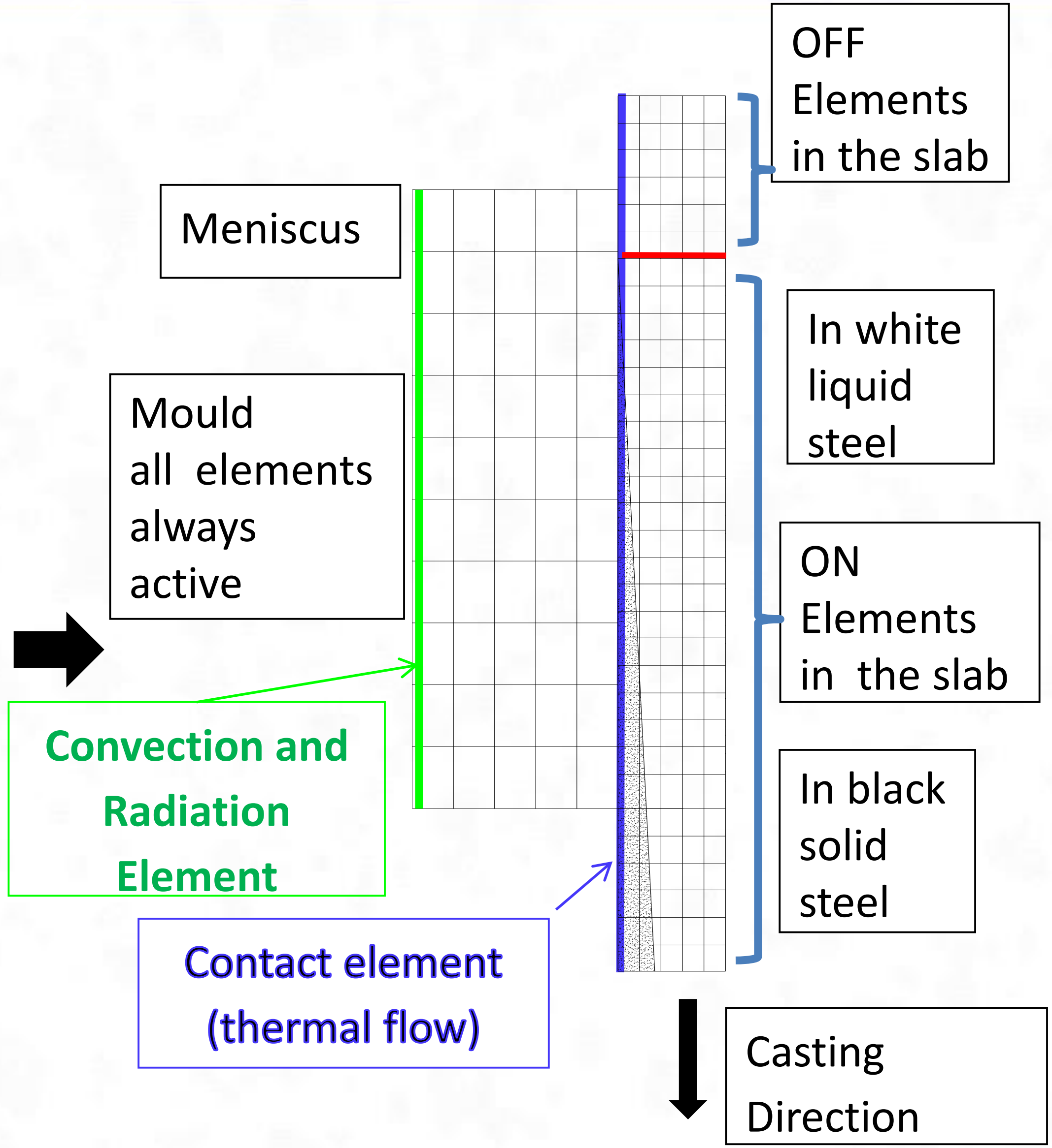
- Multiple solid to liquid contact with the mould
- Crack detection criterion → crack propagation
- Lagrangian code however liquid steel movement have to be implemented
- Thermo-physical data and boundary conditions

CMAM Pascon, F., Habraken, A. (2007).

2D FEM Thermal simulation



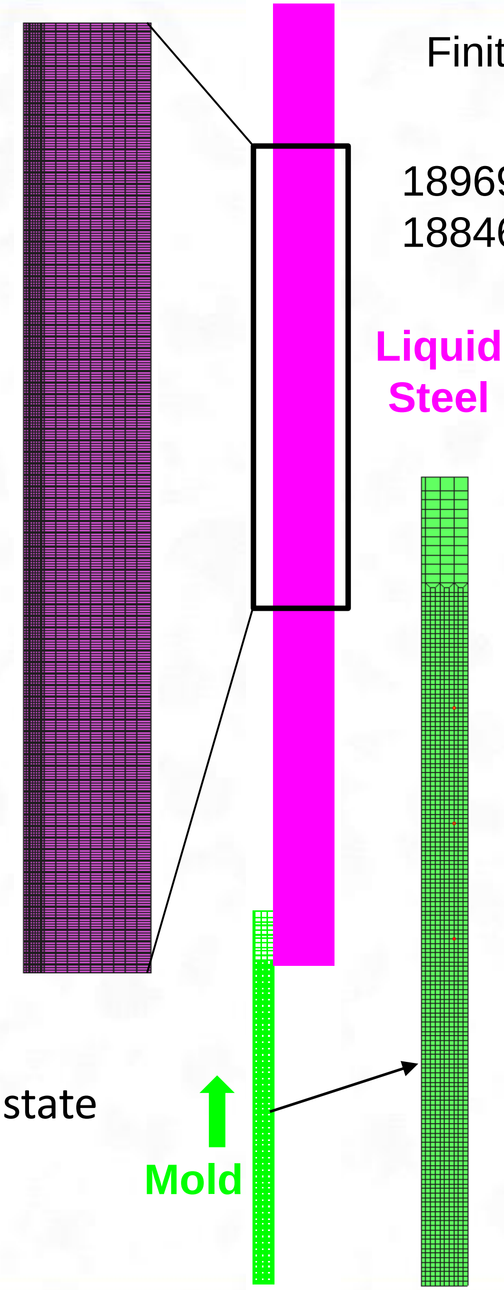
Schematic representation of CC problem



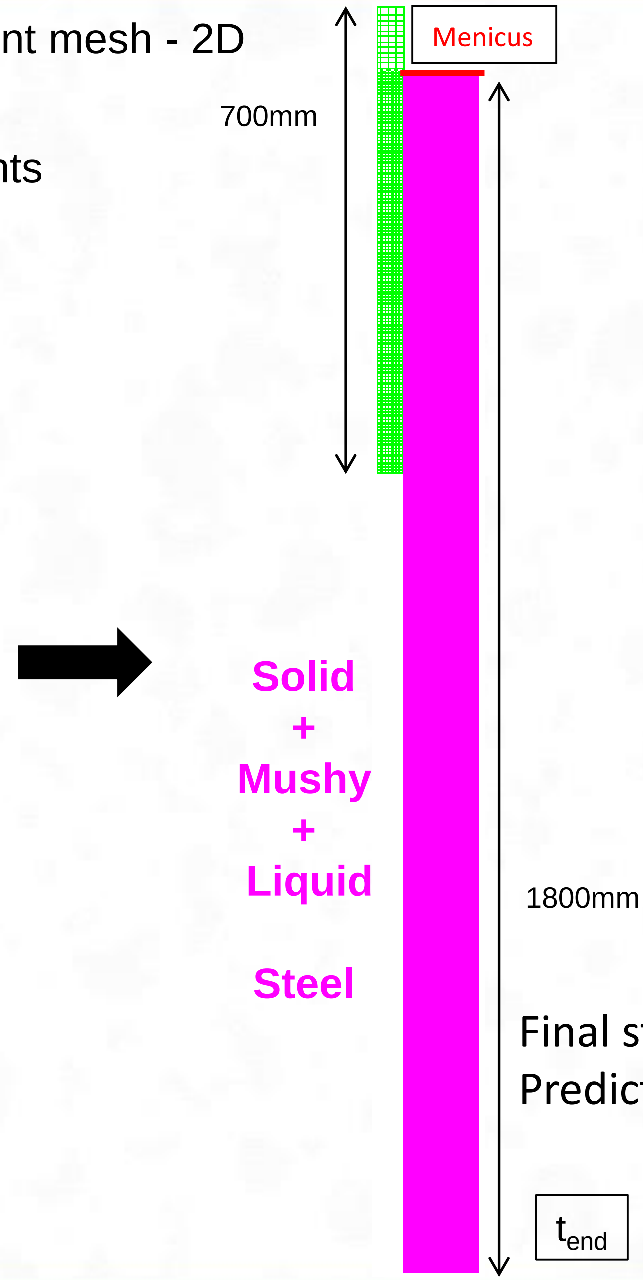
2D finite element model of the continuous casting

Finite Element mesh - 2D

18969 elements
18846 nodes



Initial state

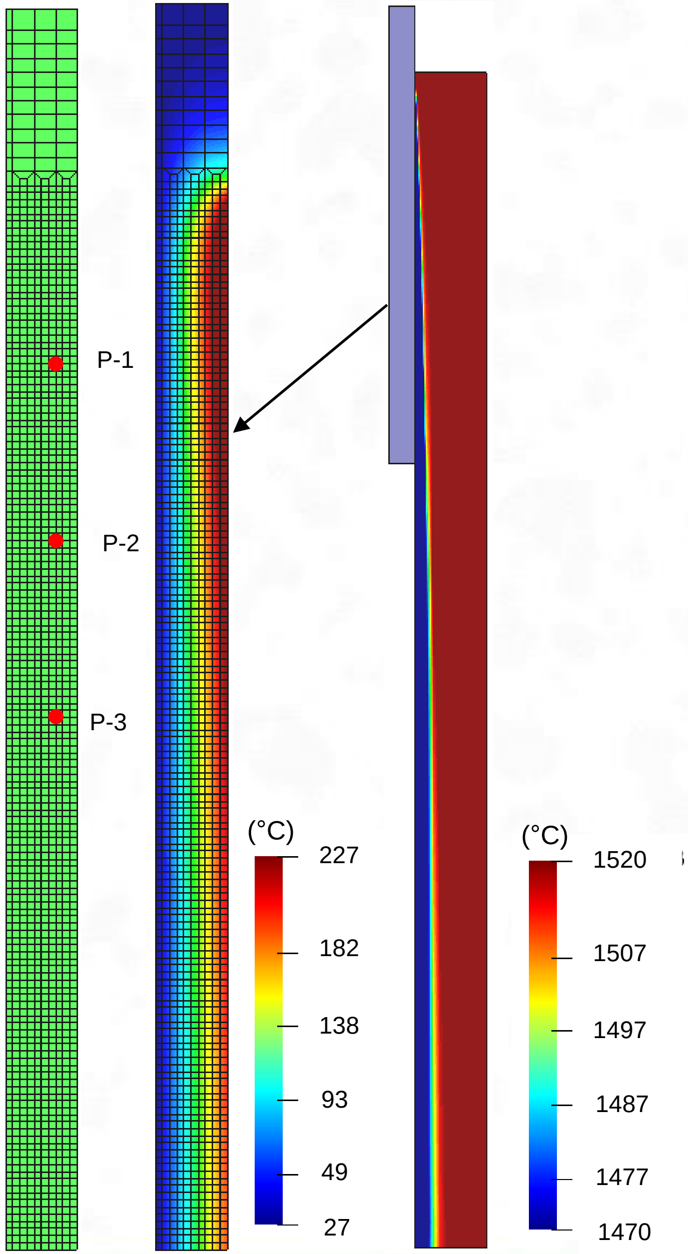


Final state.
Predictions are stationary

Thermal properties of low carbon steel from

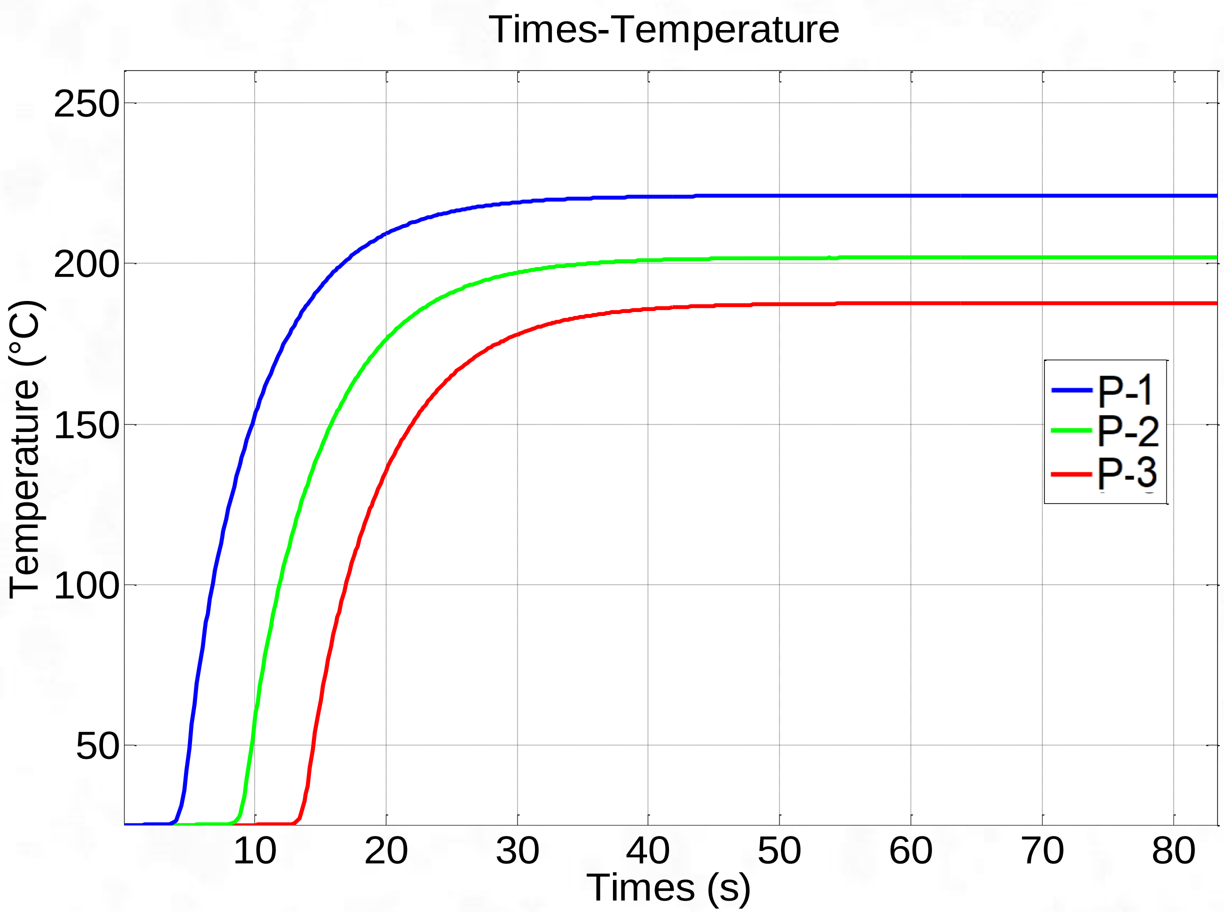
Pascon, F., Habraken, A. (2007). Finite element study of the effect of some local defects on the risk of transverse cracking in continuous casting of steel slabs. *Computer Methods in Applied Mechanics and Engineering, 196*, 2285-5599.

Thermal simulation for steady state



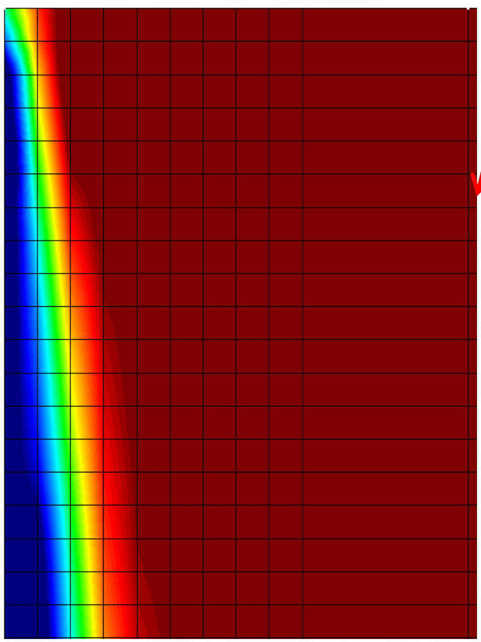
The chosen parameters

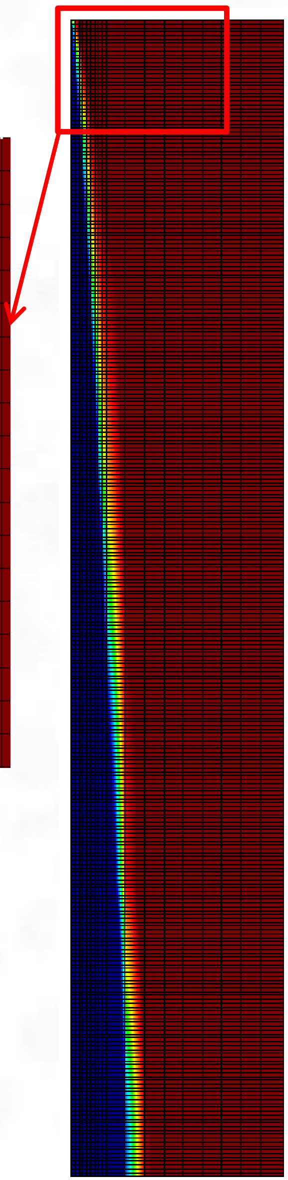
Speed casting (m/min)	Convection *h* (mW/mm²K)	Thermal resistance of Contacts R (mW/mm²K)
1.3	200	2.35



steady state after 50s

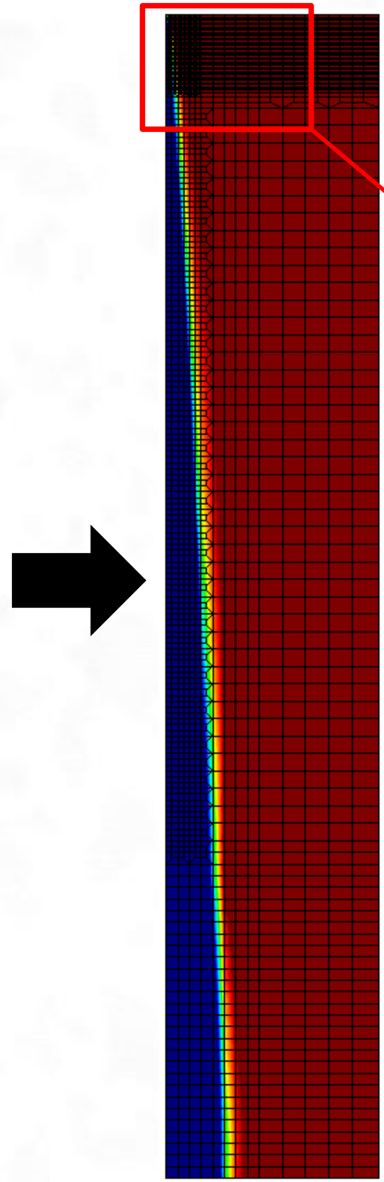
Remeshing step

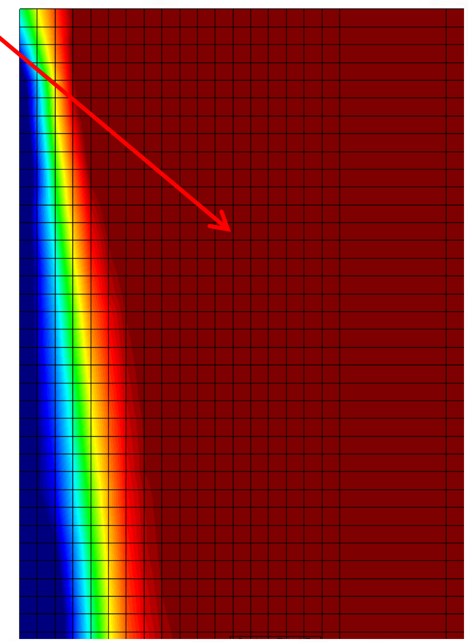




Old mesh

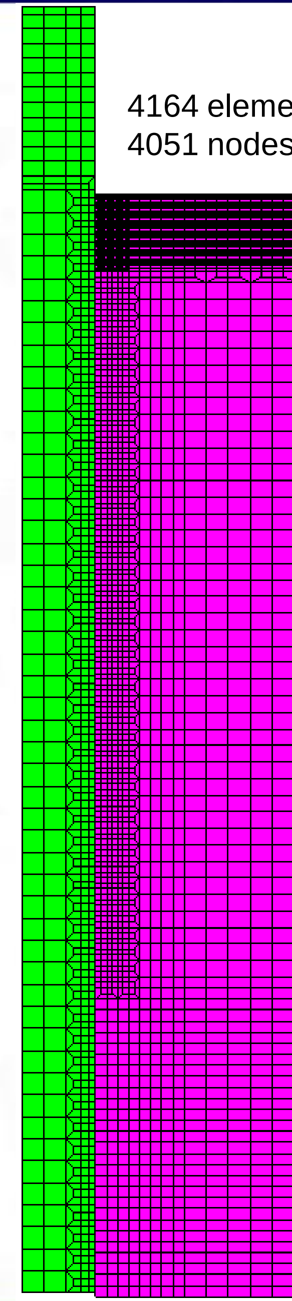
Thermal field at the end of steady simulation at 83s





New mesh

Finer mesh near sticking zone



4164 elements
4051 nodes

2D Model Methodology: start with an accurate thermal field

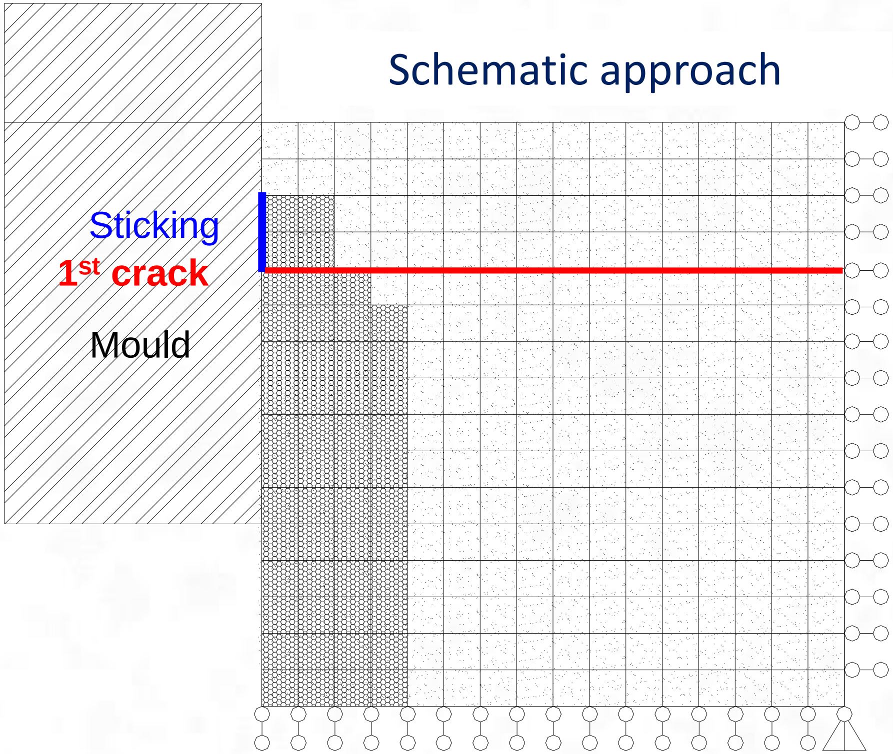
The thermal stationary field in a refined mesh (closed to meniscus)

= initial state where the user decide

1st sticking part location

1st crack position

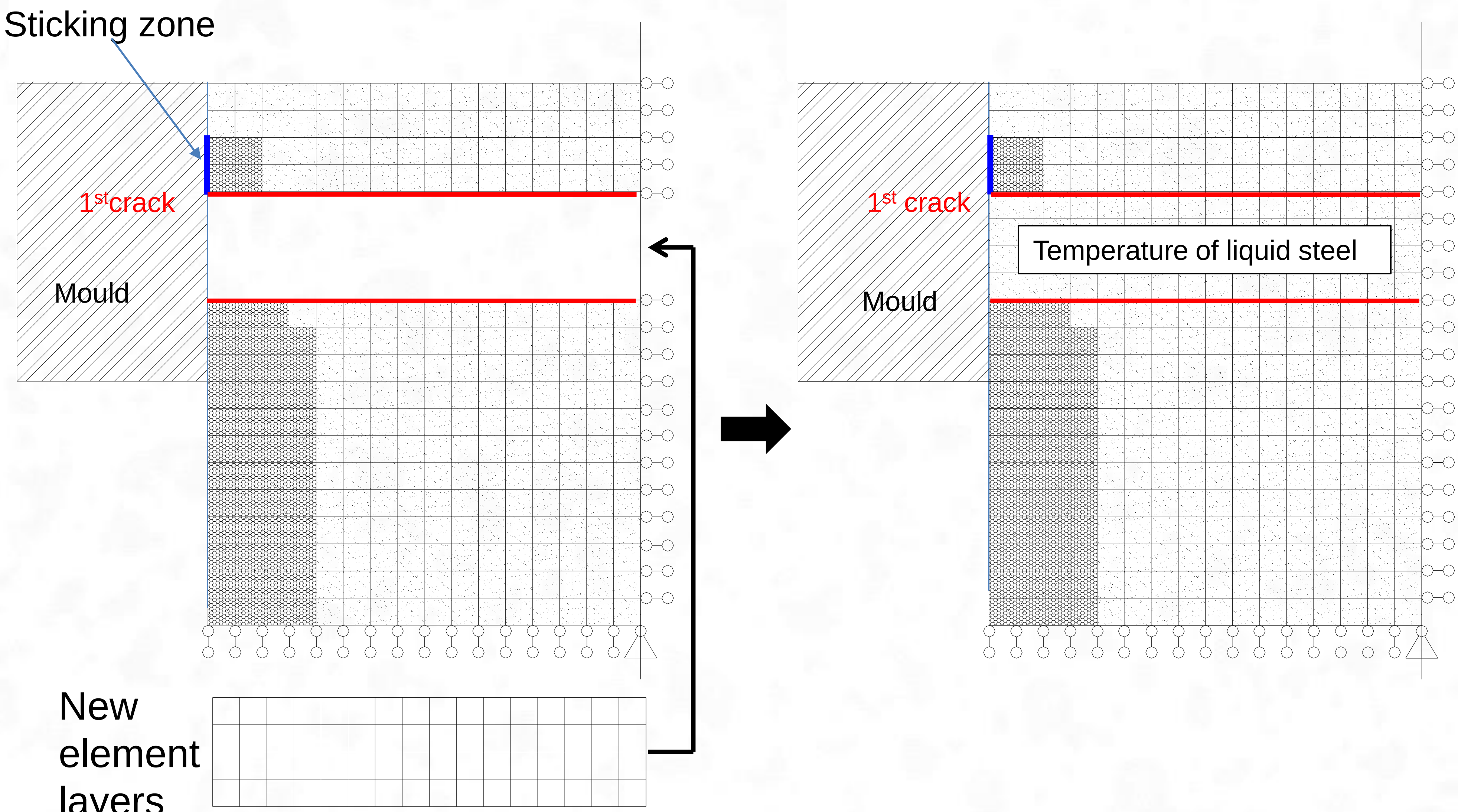
Step 2 (crack in a refined mesh close to meniscus)



Model Methodology: add liquid elements within 1st crack

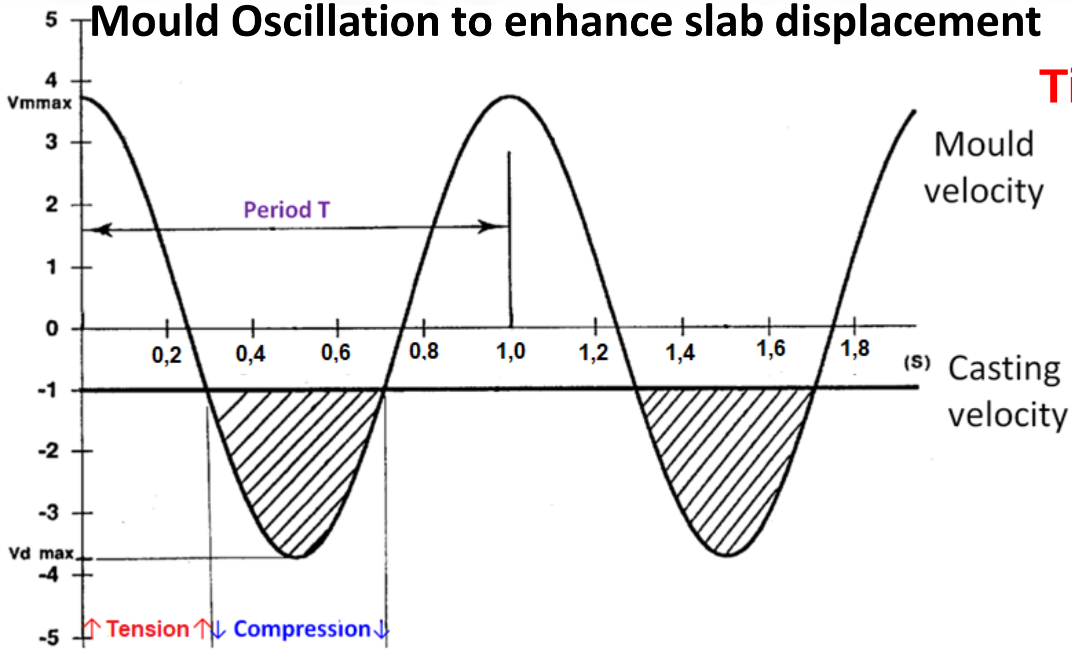
Step 3

Birth element technique to add liquid elements inside the crack



Links of craks and mould oscillations

Mould Oscillation to enhance slab displacement



Negative Strip Time or **NST:**
The mold go down faster than the slab
→high risk of cracks

$$\text{NST} = \frac{1}{\pi f}\arccos\left(\frac{V_0}{2\pi f A}\right)$$

NST: Negative Strip Time (s)
A : Oscillation Amplitude
V_0: Casting velocity
f : Oscillation Frequency
T : Oscillation Period

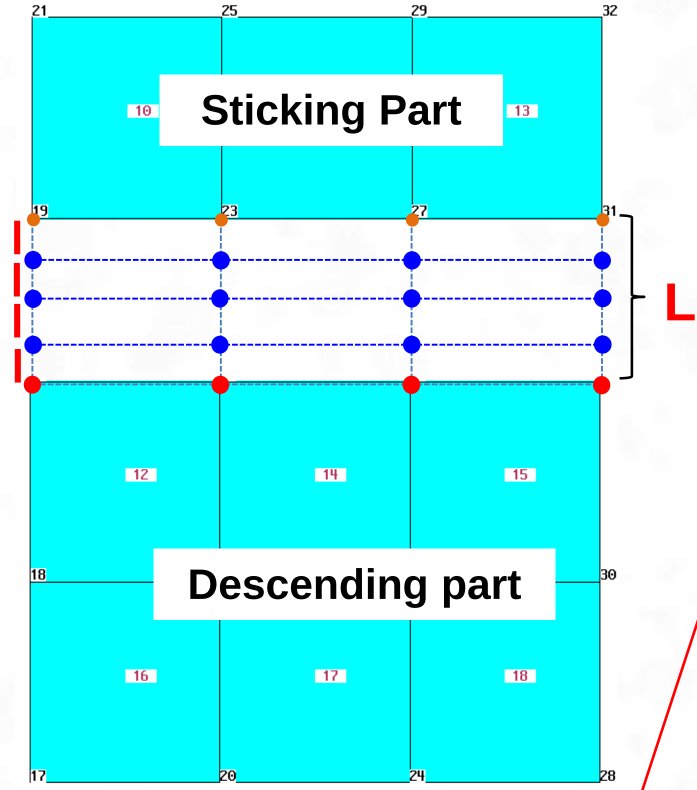
In practice

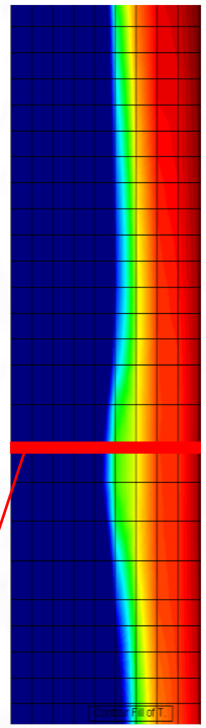
$$\frac{NST}{T} = 28\% \rightarrow 35\%$$

Model constraints

Time for solidification < Negative Strip Time

L< or = Vcasting× Tperiod of Oscillation



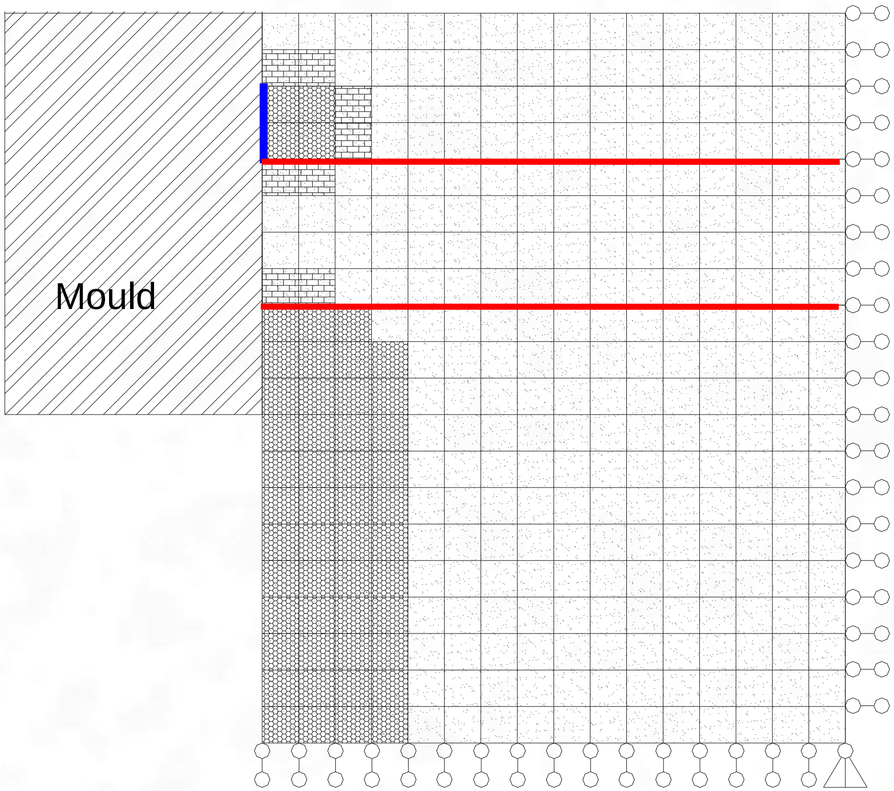


Rupture criteria for 2D FE thermal model
= thinnest section of the shell

↑ *higher oscillation Frequency* ↓ *NST (K. C. Mills et al. 1999)*

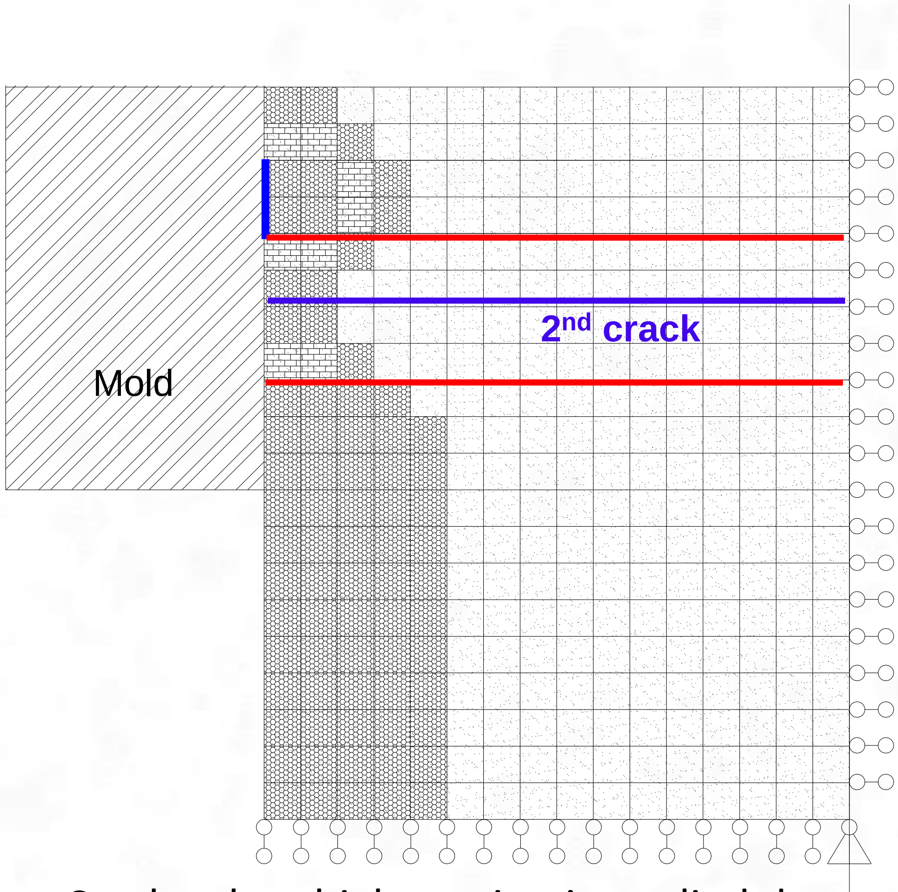
Model Methodoly: formation of a new solid shell

Step 4: Liquid elements solidify



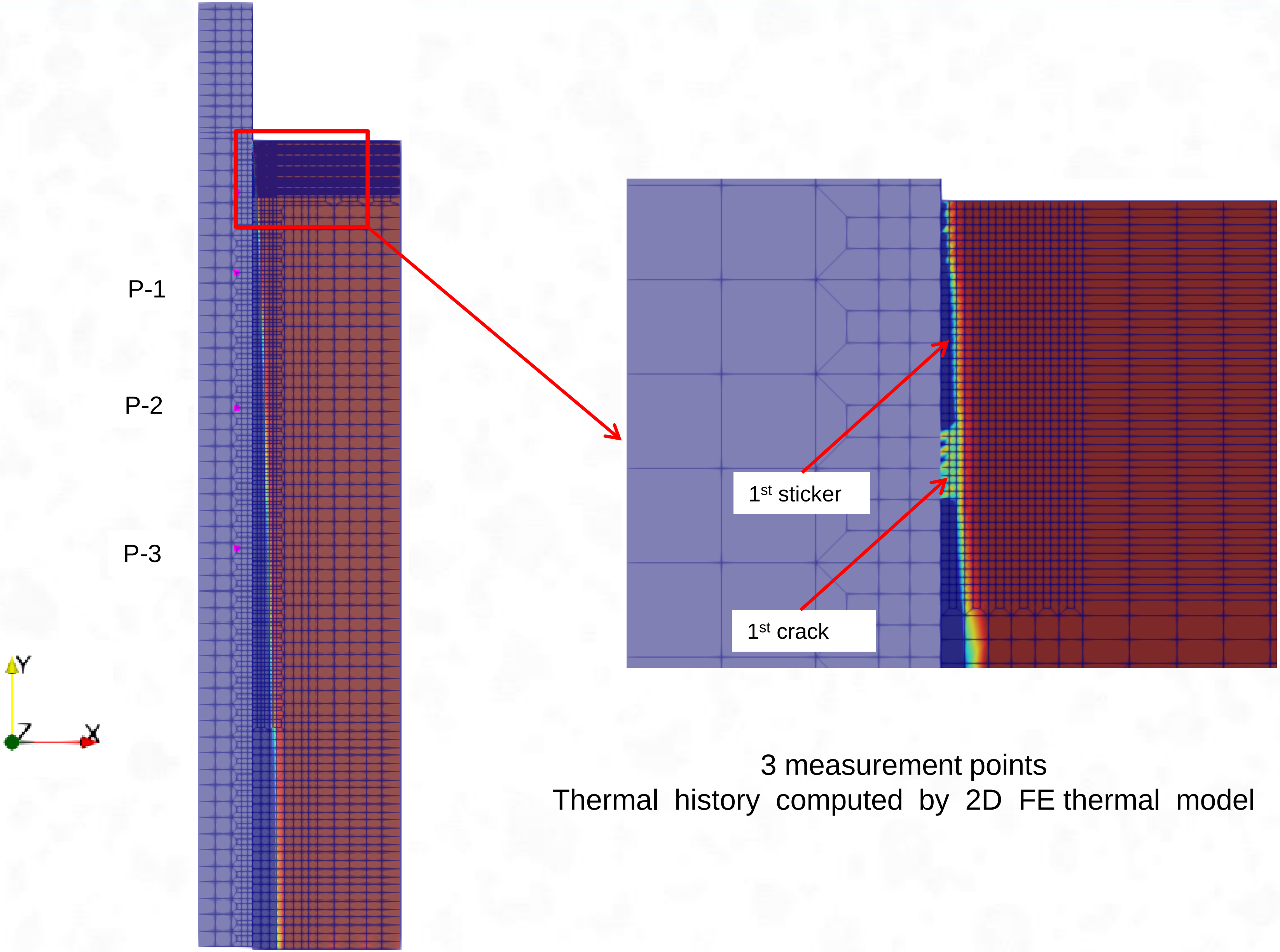
Solidification time = “negative strip time” (link with mould oscillation)

Step 5: 2nd crack event



Crack: when high tension is applied due to relative mold-strand velocity (mould oscillation) and where the temperature is the hottest

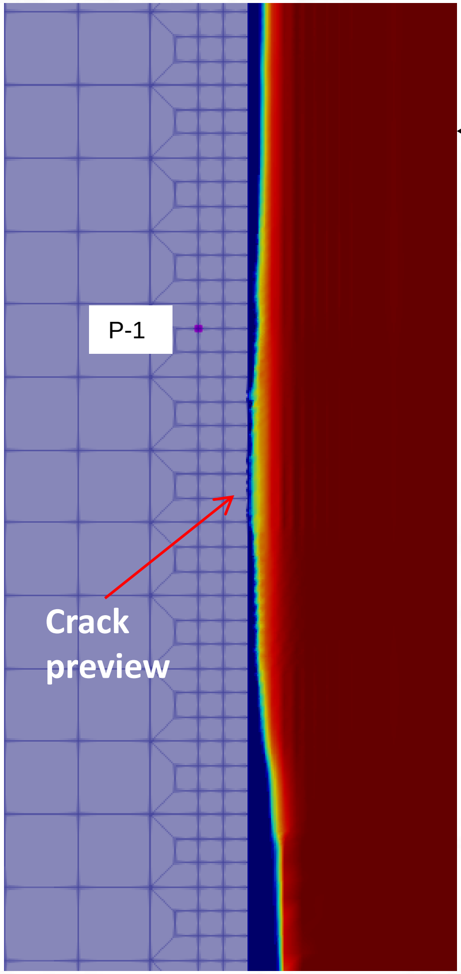
1st result of simulation

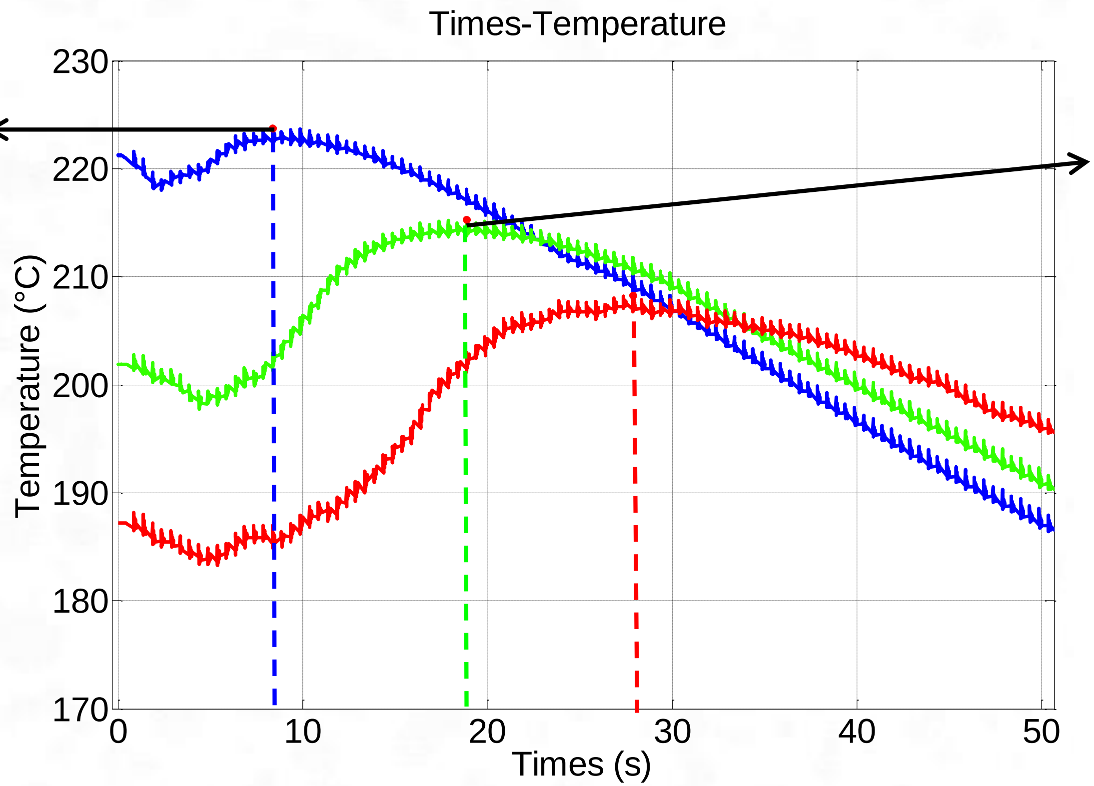


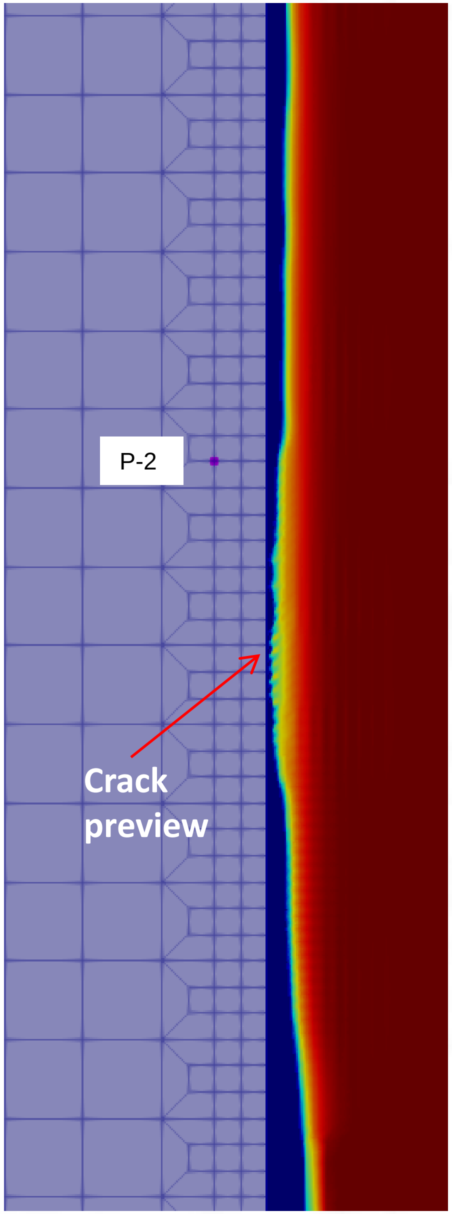
3 measurement points
Thermal history computed by 2D FE thermal model

Simulation results

Speed casting (m/min)	Oscillation Period (Hz)	Amplitude (mm)	Solidification Time -NST (s)
1.3	2	3.6	0.17





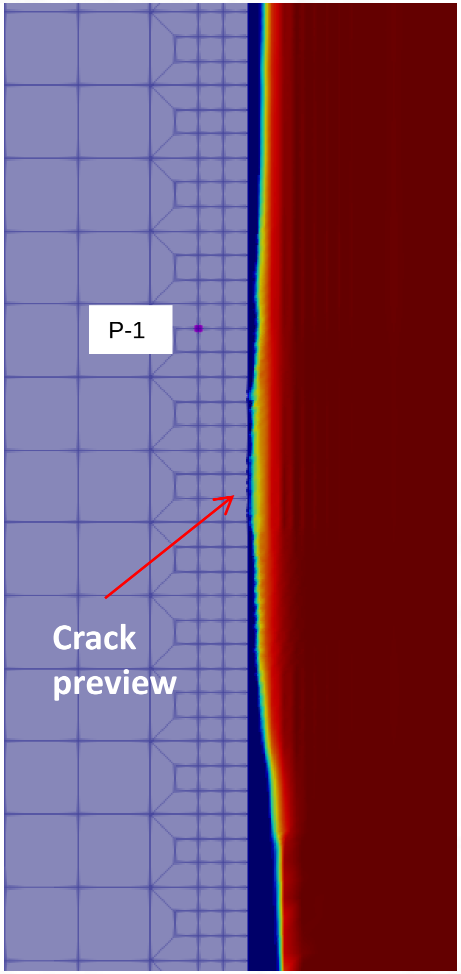


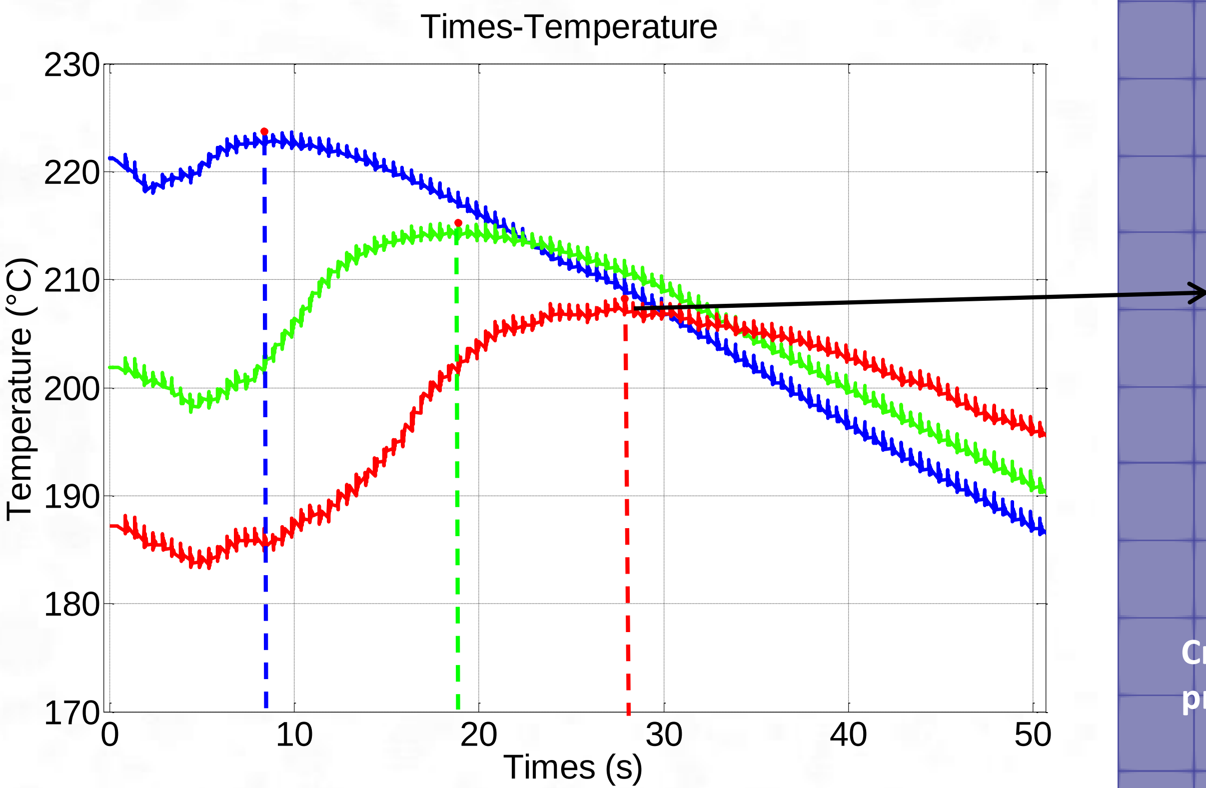
$V_{1\rightarrow2}$ = 46% V_{cast} $V_{2\rightarrow3}$ = 51% V_{cast}

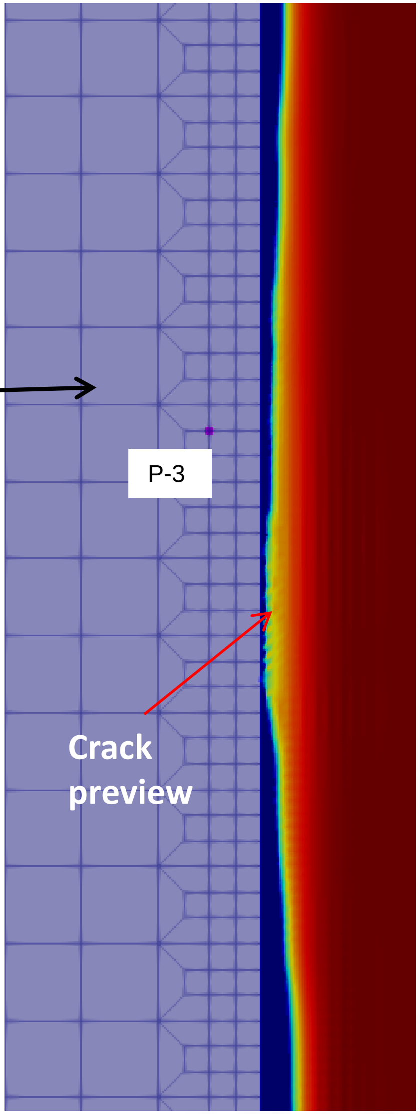
Thermal peak velocity

1st result of simulation

Speed casting (m/min)	Oscillation Period (Hz)	Amplitude (mm)	Solidification Time -NST (s)
1.3	2	3.6	0.17







Crack velocity V_{crack}= 62% V_{cast}

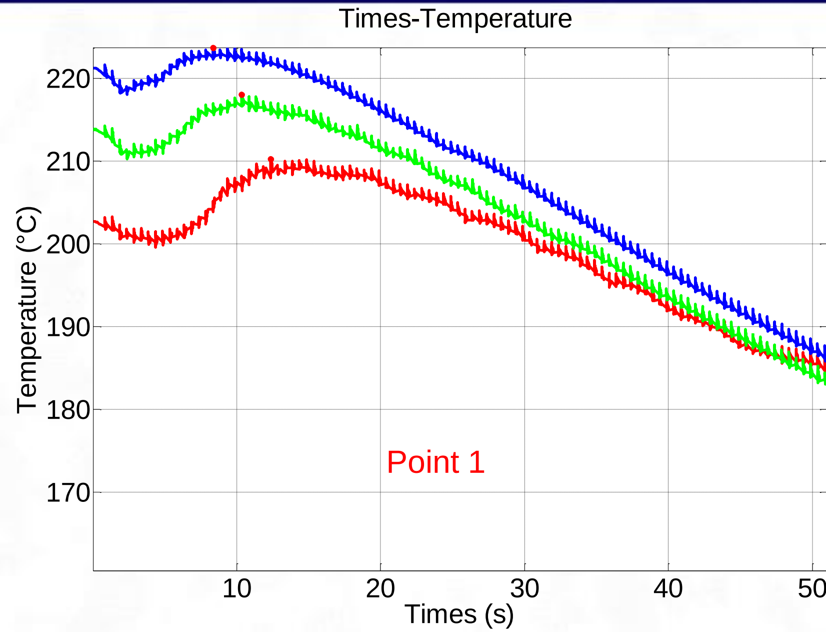
ΔT= 5°C -20°C

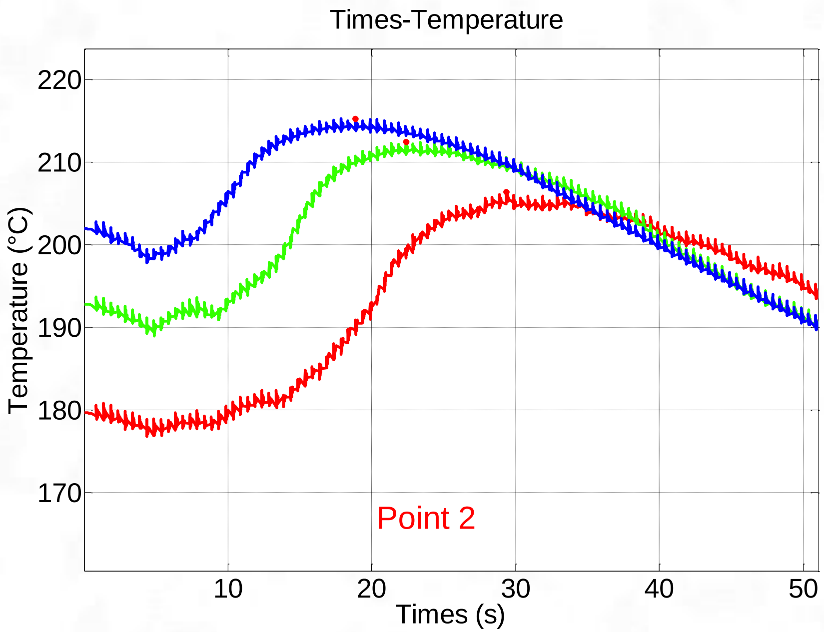
Influence of Casting speed

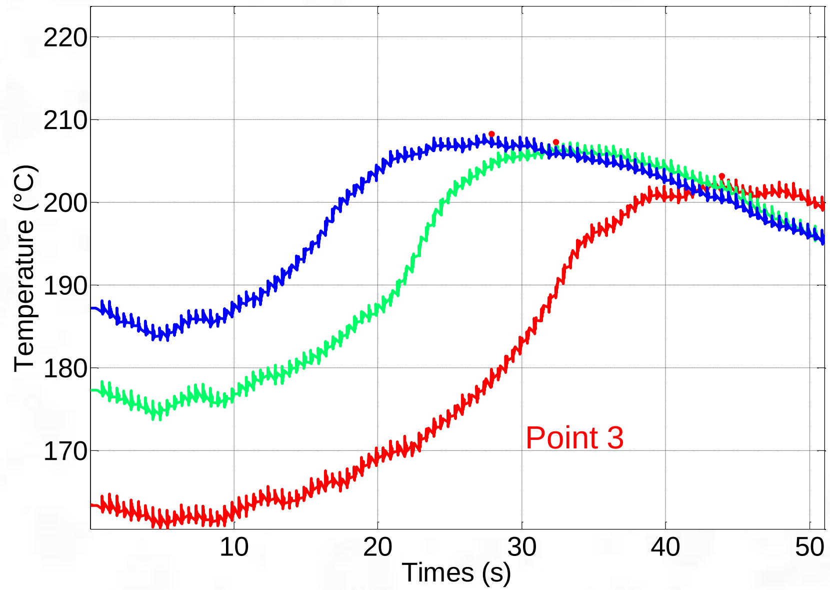
Speed casting (m/min)	Oscillation Period (Hz)	Amplitude (mm)	Solidification Time -NST (s)	*NST/T*	V_{crack}/V_{Cast}
0.7	2	2.0	0.173	34.6%	**59.8%**
1.0	2	2.9	0.174	34.8%	**62,1%**
1.3	2	3.6	0.170	34.2%	**63.9%**

Convection *h* *(mW/mm²K)*	Thermal resistance of Contacts R (mW/mm²K)
200	2.35

Casting Speed = 0.7m/min
Casting Speed = 1.0m/min
Casting Speed = 1.3m/min







Temperature Peak and Amplitude depends on Casting Speed

Conclusions and Perspective

2D thermal FE of the mould and the slab + calibration

→ **Tp° field validated by optical fiber measurement**

Sticking Break-Out phenomenon simulation

- Crack location is based on the thermal field
- Crack event is linked with the Negative Strip Time within oscillation cycle
- Birth element technique is used to fill the crack by liquid steel

Simulation results:

- Thermal peak velocities, peak shapes and amplitudes
- Fracture propagation velocity
  (crack propagation = 62% of the casting speed)

} recover trends observed by EBDS

- Sensitivity analysis confirms practice:
  A Slower casting velocity decreases the crack propagation velocity

Perspective: *local 3D thermo-mechanical study of the crack*