CCC Annual Report

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Molding Filling and Temperature Simulation of Continuous Casting

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Objectives

- Explore mold filling and thermo-mechanical behavior of a typical slab mold during startup.
  - First step: Use ProCAST to simulate coupled heat flux, temperature and fluid flow during the filling stage of continuous casting
  - Enable subsequent calculations of thermal distortion, which affects mold taper and may cause problems such as breakouts and cracks.

Outline

- The application of ProCAST in continuous casting
- Geometry, materials properties and boundary conditions in the model
- Thermal and fluid simulation
- Heat flux results
- Temperature results
- References

The application of ProCAST in the continuous casting

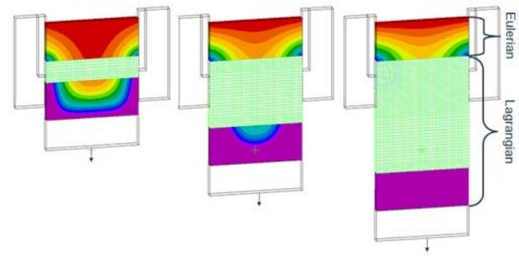
ProCAST is a commercial software using the Finite Elements Method (FEM). It allows the steady/none-steday state modeling of thermal heat transfer (heat flow), fluid flow, including mold filling, stresses fully coupled with the thermal solution.

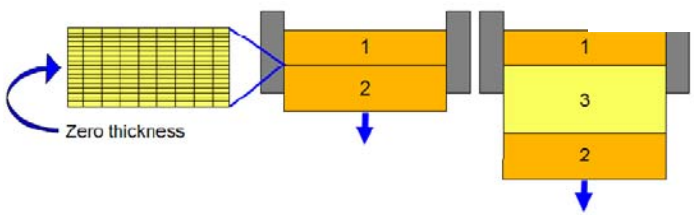
ProCAST provides a very prominent fluid flow equation to simulate the filling of mold, which is complete Navier-Stokes flow equations coupled with 3-D energy equation. Actions of fluid free surface is controlled by volume of fluid method（VOF）. These make it able to simulate accurate thermal and fluid results during the entire process of filling.

The application of ProCAST in the continuous casting

Using none-steady calculations in this case to model start-up thermal behaviors of the continuous casting .

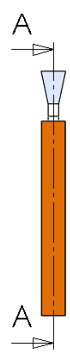
The calculations use MILE algorithm (Mixed Lagrangian-Eulerian), an accordion should be established to introduce new layers of elements.

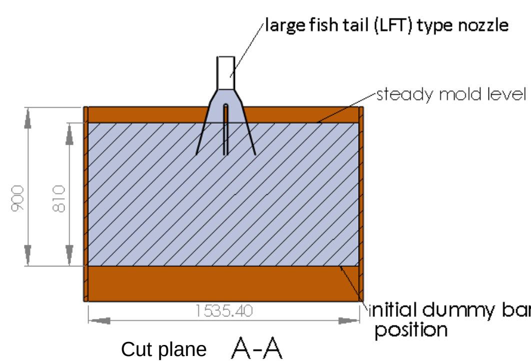


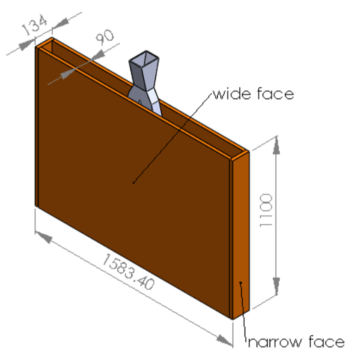


Mold Geometry

Ref. (3)







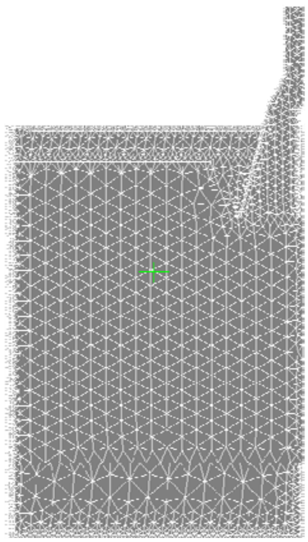
Units: mm

Material properties

	Cp (J/Kg·K)	λ (w/m·K)	Initial T (℃)	Density (Kg/m^3)	Melting point(℃)	dynamic viscosity (Kg/m·s）	Latent heat (KJ/Kg)
Mold-CuCrZr	385	350	30	8900			
steel	661	33	1550	7400	1495	0.006	272

Model Domain and Mesh

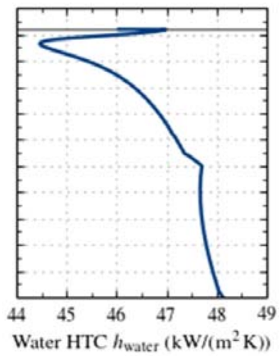
- To lessen calculation, the model is ¼ of the real mold.
- This mesh has total 126692 elements and 31260 nodes.
- Elements size range from 2mm to 20mm in both mold and steel regions.
- 5 elements through the thickness of the mold wall
- Assume Reduced Order Model (ROM) to simulate mold as rectangular block, with slots as BCs.

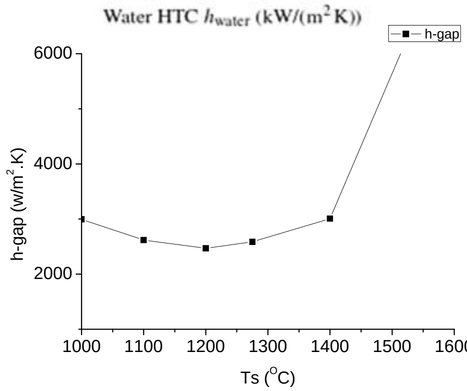


Boundary conditions

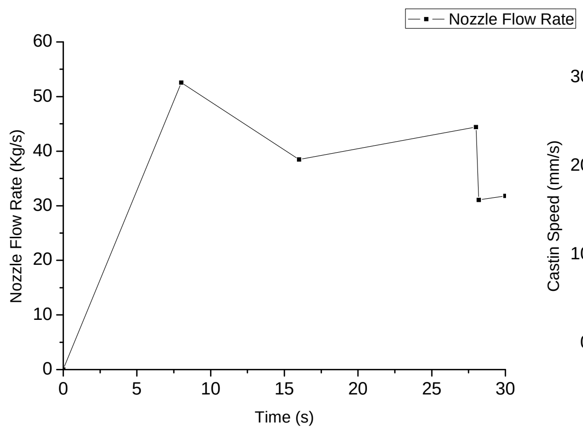
- Heat transfer coefficient to cooling water from Hibbeler Ref.(1) – see Figure.
- Heat transfer coefficient from ROM mold wall ~60 kW/m^2K
- Heat flux across the interfacial gap between steel shell and mold, q_{int}, is given by an effective heat-transfer coefficient (h_{gap}) between the surface temperature of the steel shell (T_s) and the hot face of the mold wall (T_{hot}), h_{gap} according to formula 1. (From Hibbeler Ref.(1), and Meng Ref.(4))

$$q_{\text{int}} = h_{gap}(T_s - T_{hot}) \quad \text{formula 1}$$

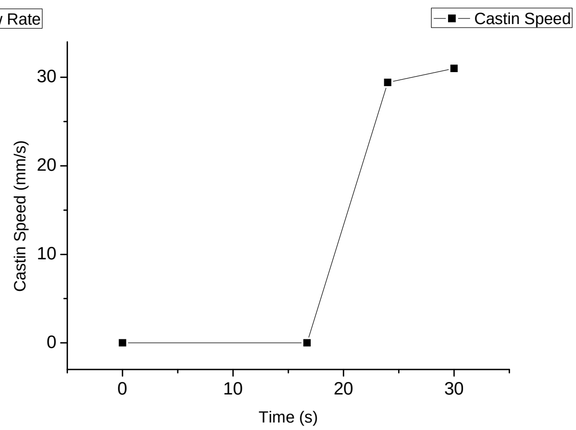




Casting parameters



flow rate (kg/s) entering the domain through the nozzle vs. time

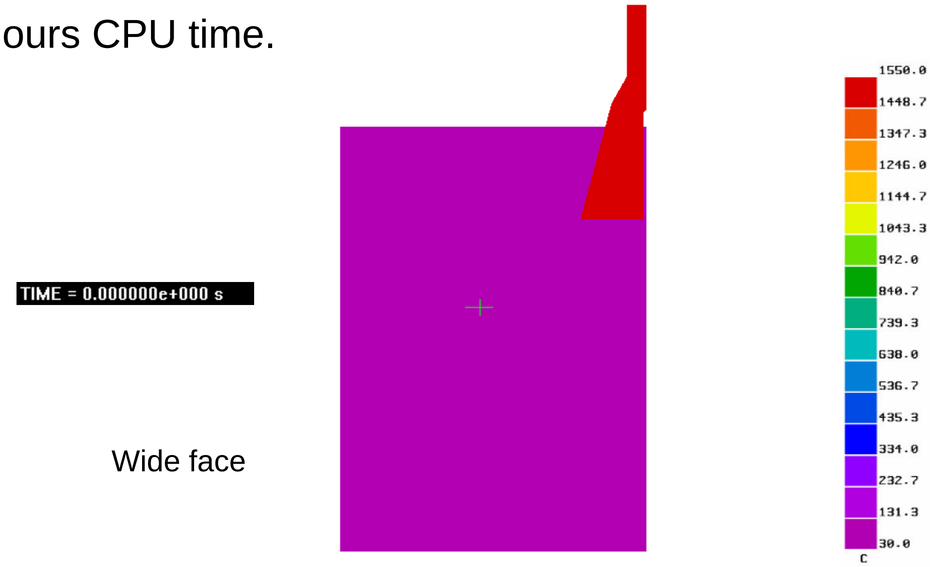


Casting speed vs time

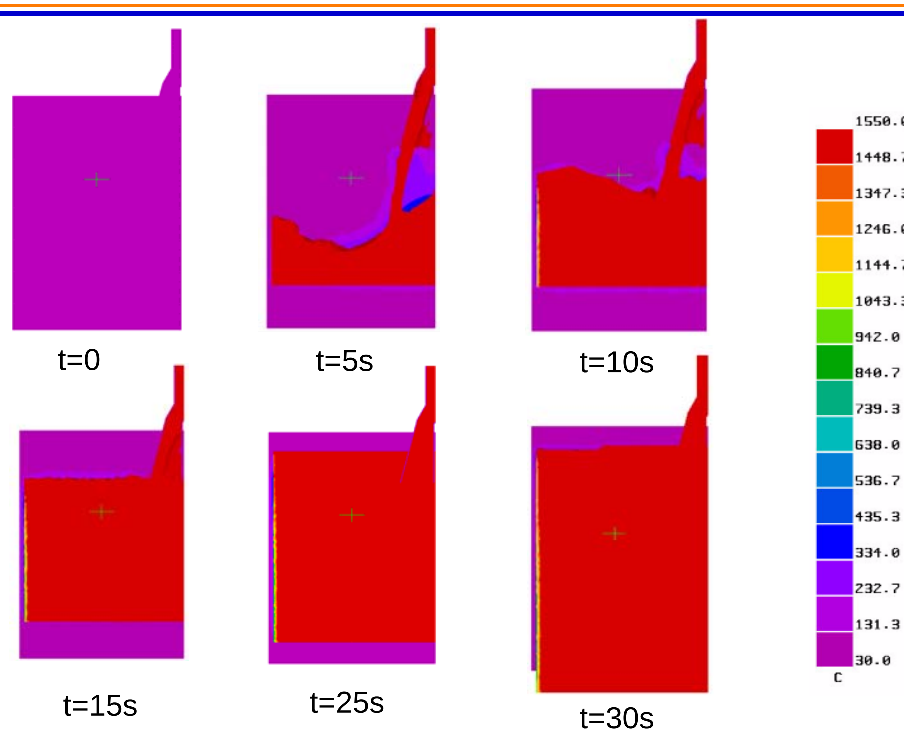
From Hibbeler, ECCC, 2014, Ref. (2)

Thermal and fluid simulation

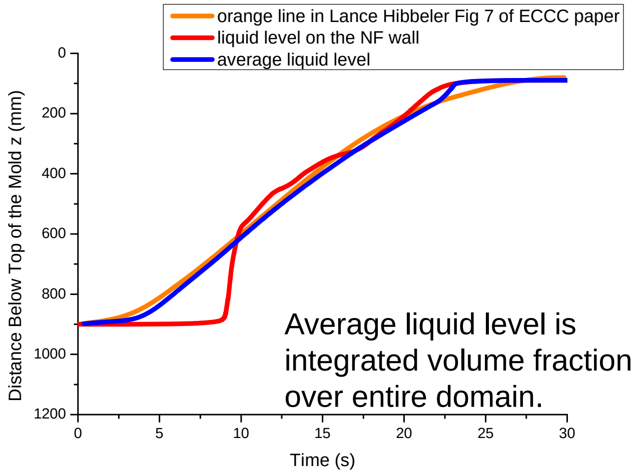
- The simulation of filling in the wide face are shown in the right.
- The simulation time of 30s need 10 hours CPU time.



Instantaneous liquid level profiles during mold filling



Liquid Level History Results



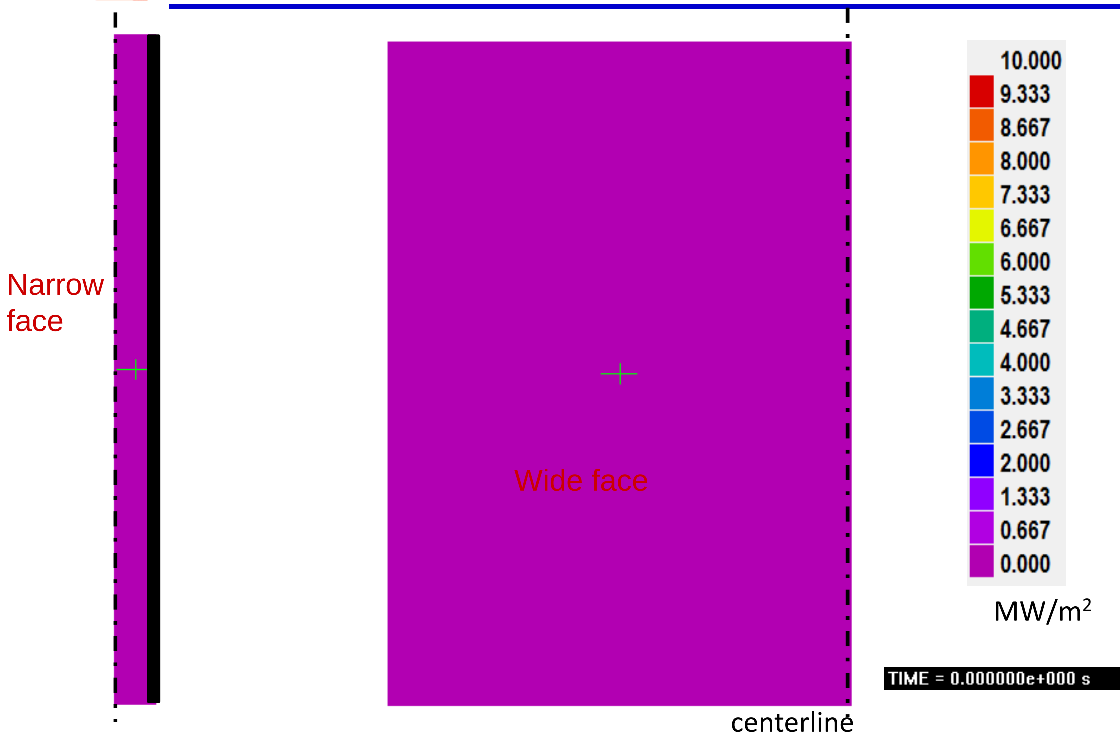
Simulated average liquid level is validated by match with average from Hibbeler, Ref. (2)

Level on the NF wall has delay for filling before rising quickly

Almost stable level during latter stages of filling

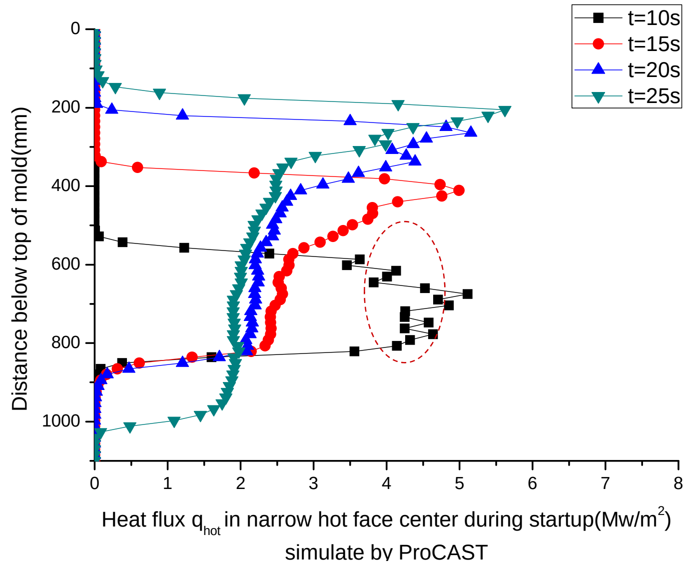
Liquid level touched the wide face

Heat flux results (contour maps)



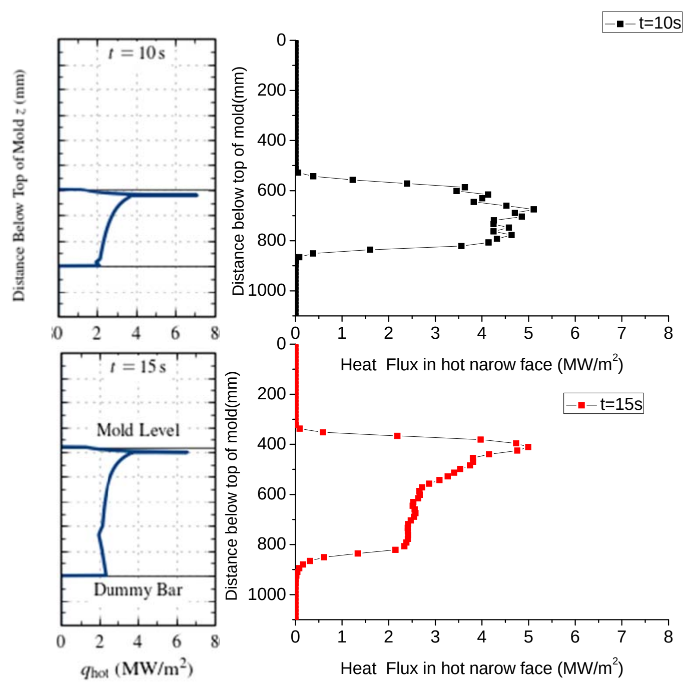
Heat flux results (profiles down NF)

- Heat flux region logically follows rising liquid level.
- At t=10s during initial stages of filling, heat flux is almost uniform down mold walls. Except, liquid level fluctuates, causing small heat flux variations at the narrow face
- Later, peak heat flux is found at liquid level, and drops slightly with distance below.

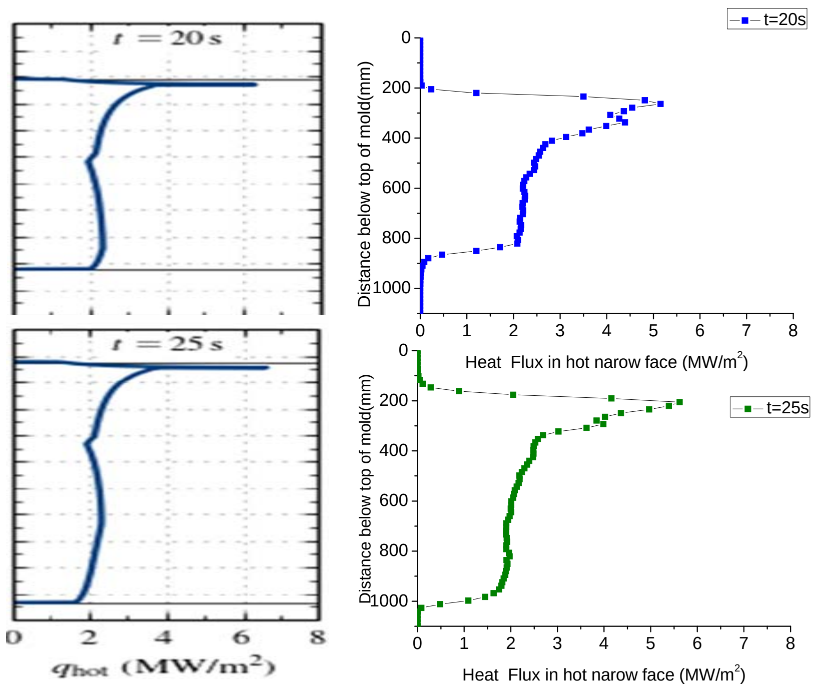


Heat flux results

- The graphs are comparison between simulated narrow-face center heat flux results and data mentioned in the paper.
- Heat flux was obtained along the centerline of hot narrow-face nodes.

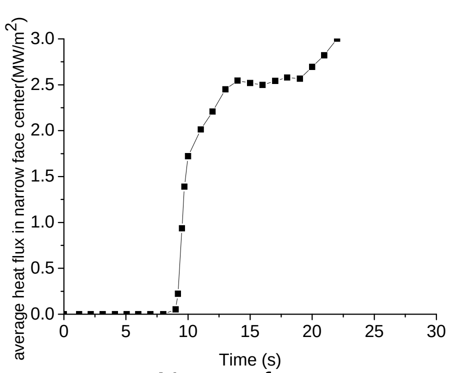


Heat flux results

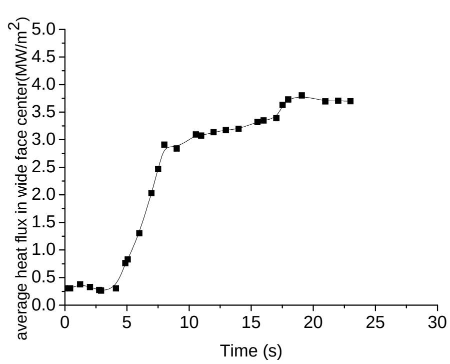


Heat flux results

Hot face heat flux



Narrow face



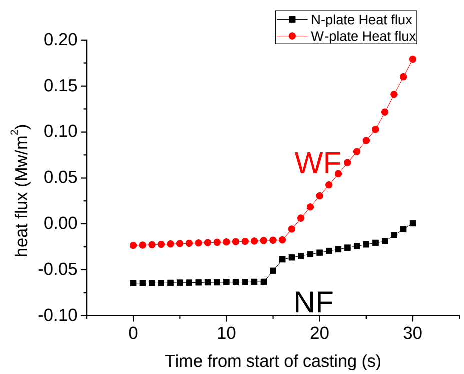
Wide face

Average heat flux results are evaluated as integral average. The parameters used in the model such as h_{water}, water temperature are applied for steady state during continuous casting (From Hibbeler, ECCC, 2014, Ref. (2)).

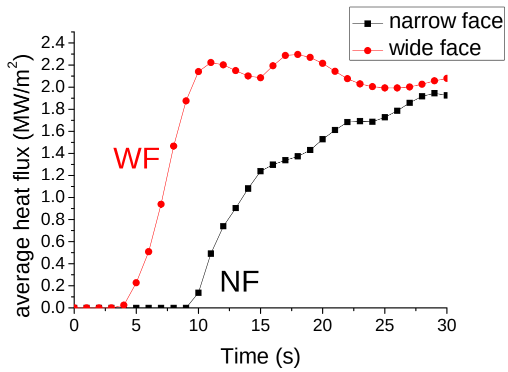
Heat flux results

Cold face heat flux

Measured

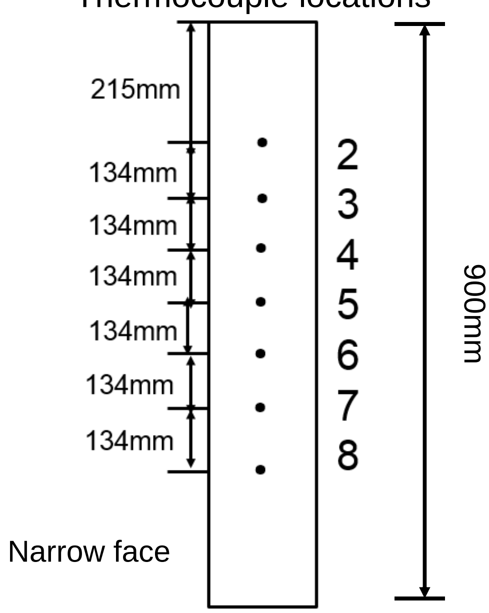


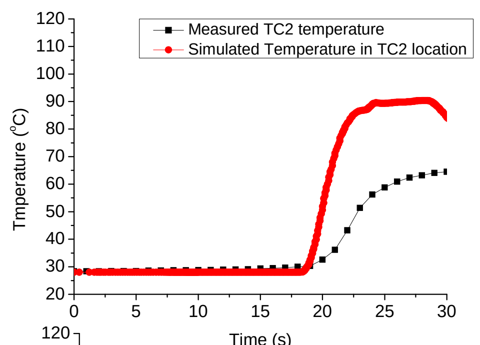
Simulated by ProCAST

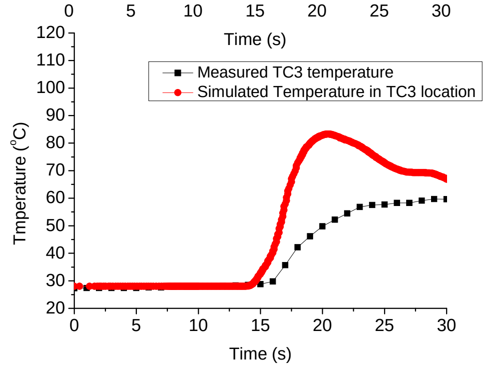


Temperature results

Thermocouple locations

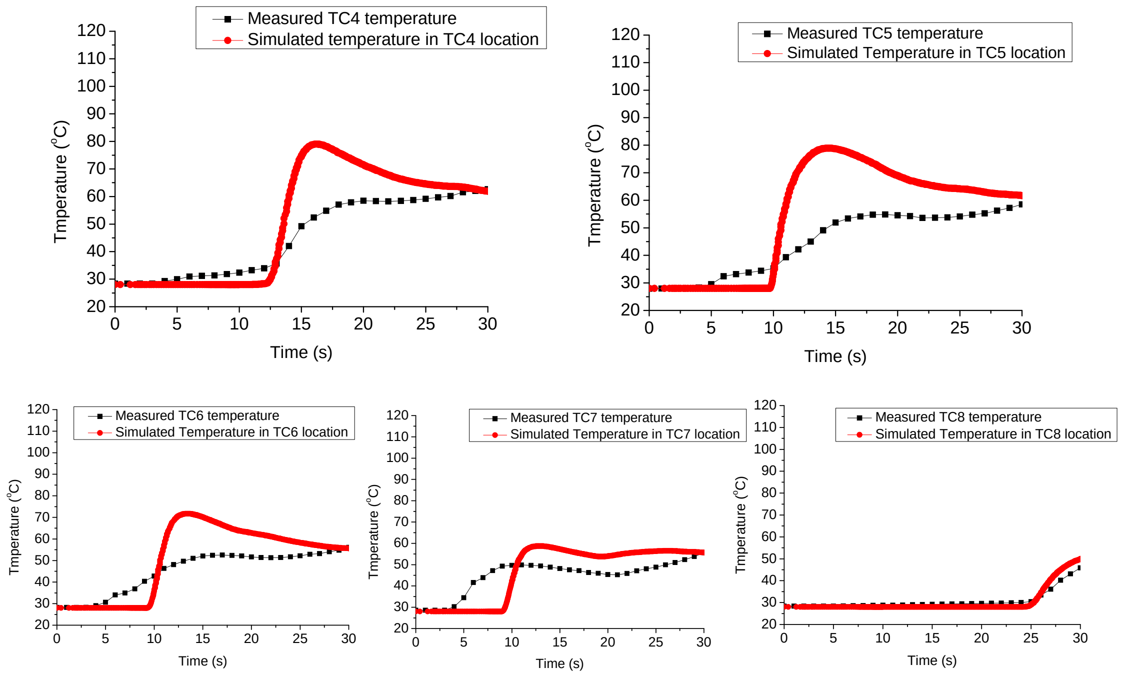






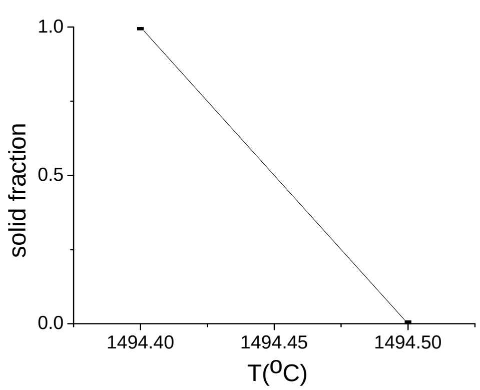
From Hibbeler, Metrans. B, 2012, Ref. (1)

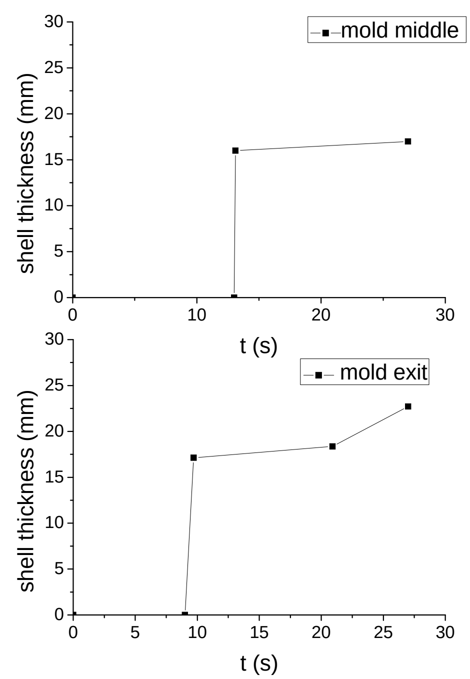
Temperature results



Shell thickness results

0.3 fraction solid is the definition of shell thickness





Conclusions

- ProCAST could be applied to simulate the startup phase of continuous casting.
- The heat flux results on mold hot face are comparatively consistent with water-heatup measurements.
- The temperature results are comparatively consistent with the TC measurements.
- Simulation results are useful to carry out subsequent calculations of thermal distortion on mold.

References

1. L.C. Hibbeler et al., The Thermal Distortion of a Funnel Mold. Metallurgical and Materials Transactions B, 2012. 43(5): p. 1156-1172.
2. L.C. Hibbeler et al., Simulation and online measurement of narrow face mold Distortion in Thin-slab casting. ECCC 2014 (European Continuous Casting Conference, Graz, Austria, June 23-26, 2014).
3. H.H. Visser et al., Implementation of four port submerged entry nozzle to improve the stability of the thin slab casting process at the ijmuiden dsp plant.
4. Y.T. Meng et al., Heat-transfer and solidification model of continuous slab casting: CON1D. Metallurgical and Materials Transactions B, 2003. 34(5): p. 685 - 705.