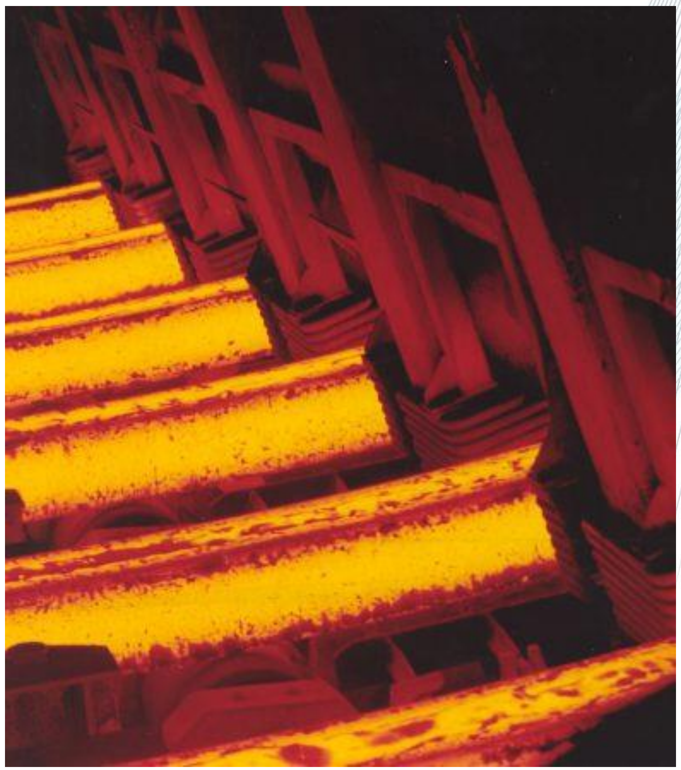
RealTimeCastSupport

Embedded real-time analysis of continuous casting for machine-supported quality optimisation



Webinar on 8th of September 2023

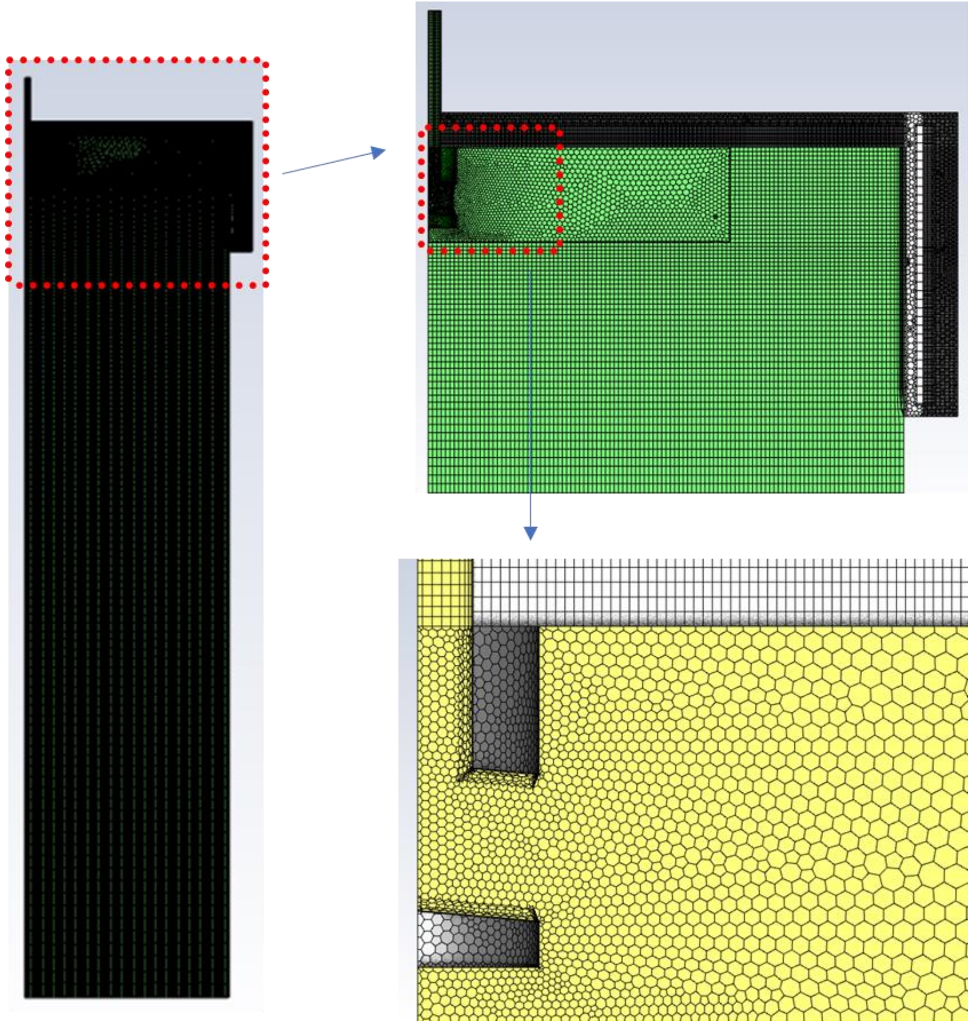
CFD based digital twin

Dr. Yalçın Kaymak (BFI)

BFI Excellence in Applied Research | VDEh-Betriebsforschungsinstitut GmbH

Stahl

Mesh, Material Properties and BCs



solid Cu mould is modelled

htc_spray=250W/m²·K T_inf=300K ε_{surf}=0.7

htc_surf=200W/m²·K T_inf=300K ε_{surf}=0.7

h_castingPowder=0.045m

rho=2500kg/m³, Cp=1200J/(kg·K), k=0.44 W/(m·K)

v_casting=0.005m/s, V_{ar}=4 Nlt/min

steel-melt: Cp:814J/kg·K, k:35W/mK,

mu:0.0055Pa·s, rho:7000kg/m³,β:0.00011854K^{-1}

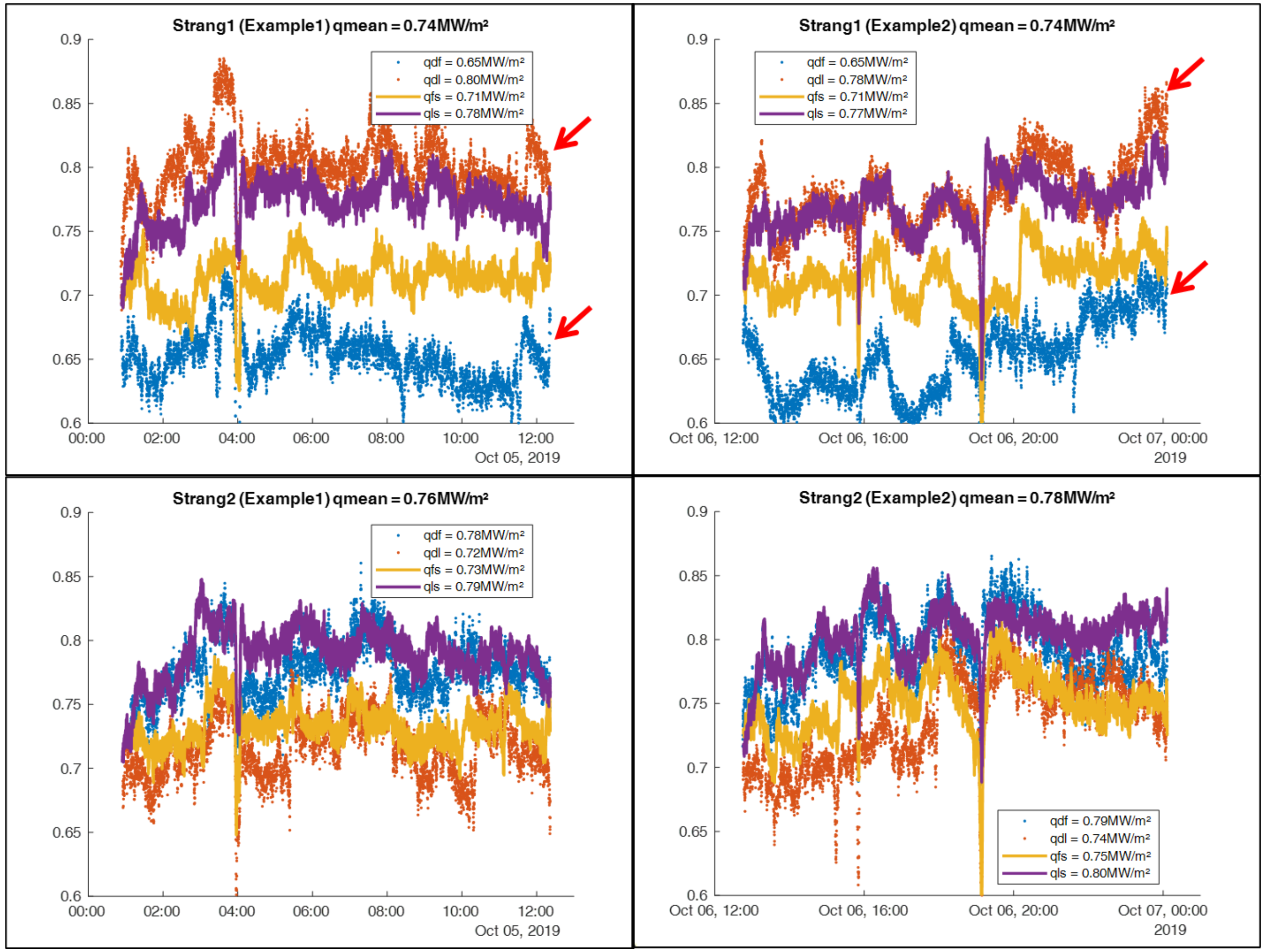
ΔH=238064J/kg, T_{Sol}=1761.41K, T_{Liq}=1794.21K

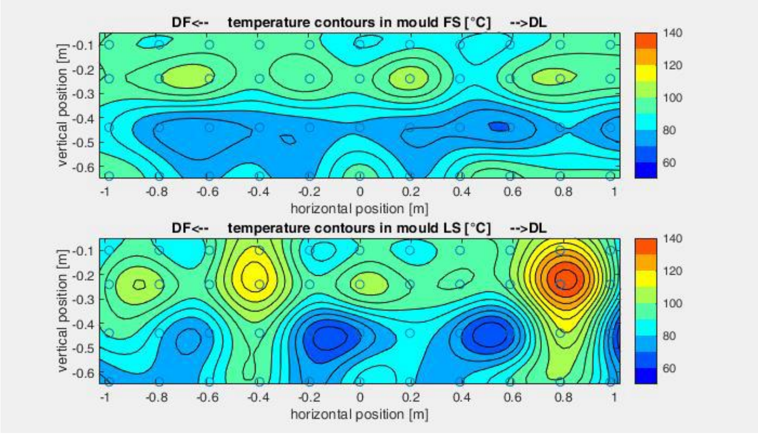
ke and sstkw turbulent models compared.

DPM is used for Ar injection

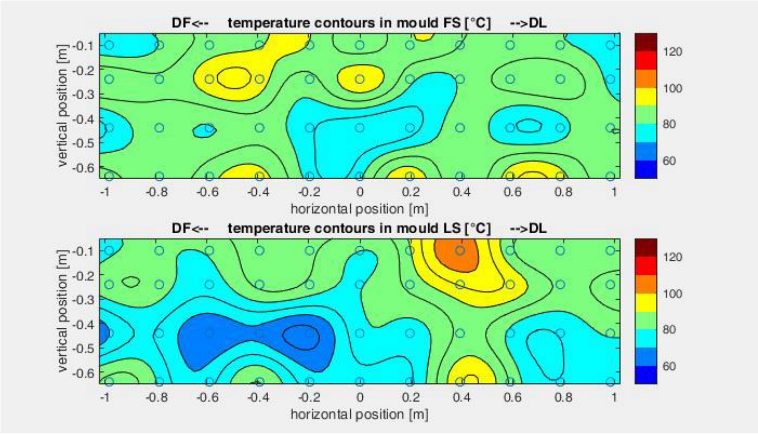
Material data is obtained
from IDS16 software for
Low-alloyed steel: C = 0.06 wt%,
Ni = 0.25 wt%, Mn = 1.60 wt%,
Si = 0.20 wt%, Cu = 0.25 wt%, …

Mould cooling data and mould temperature analysis



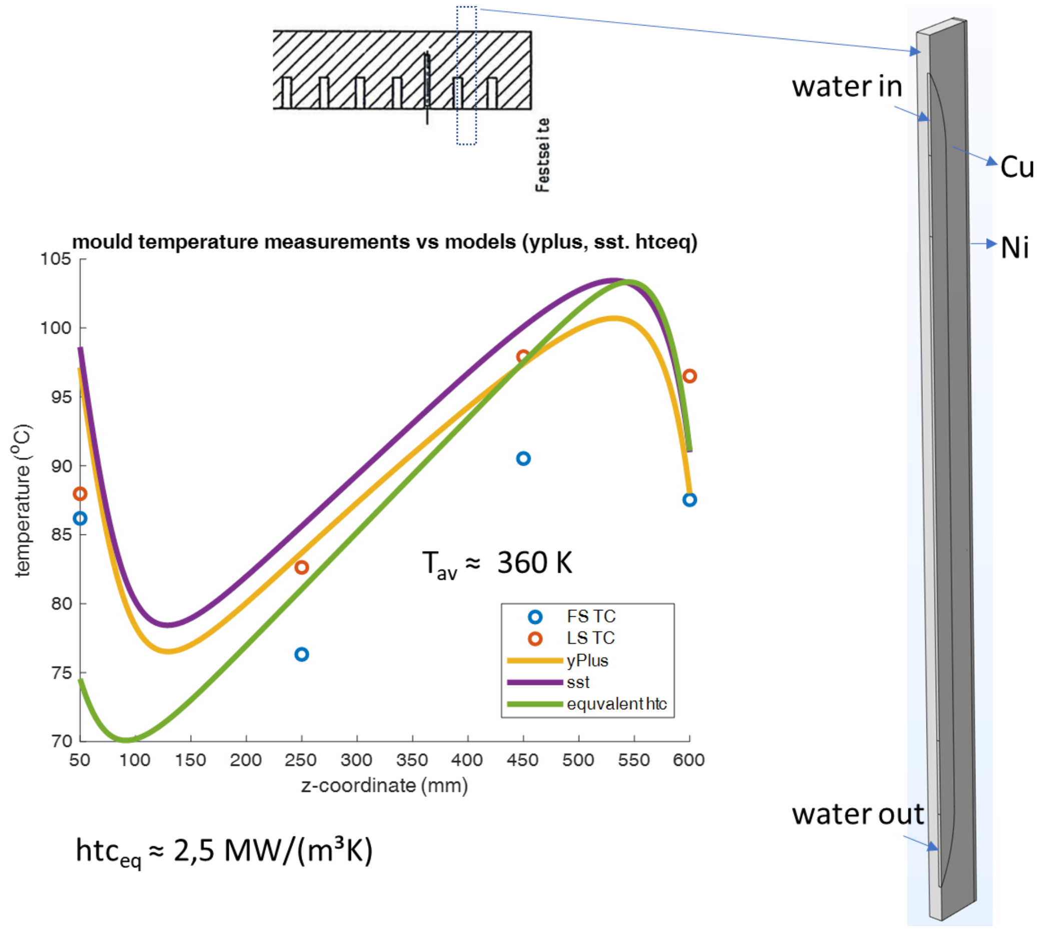


Stang1.avi



Strang2.avi

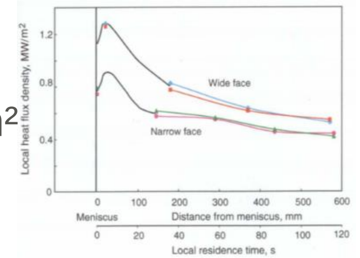
Heat transfer at single cooling rib of the Cu-mould



$htc_{eq} \approx 2{,}5$ MW/(m³K)

some model assumptions:

- uniform velocity inlet (using total flow rate)
- linear heat flux variation at hot side having contact to steel melt
  at mould bottom, z=0mm → q=0.45 MW/m²
  at melt surface, z=620mm → q=1.05 MW/m²
  (which corresponds to the total heat flux
  to the cooling water ≈ 0.75 MW/m²)



- no deposit accumulation at the water to copper interface
- no wear of the nickel layer
- curved inlet/outlet regions are simplified for the equivalent htc estimation model

- htc_eq is further used in the fluent CFD model for the calibration of thermal resistances between the mould and solidified steel shell

Calibration of heat resistance between Cu-mould and the solidified steel shell

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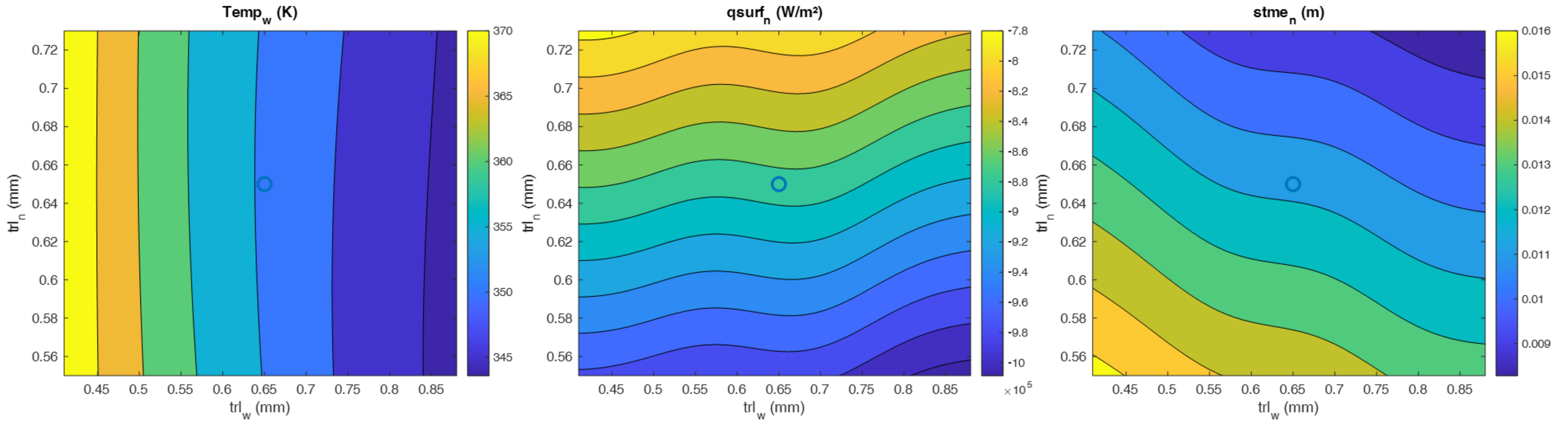
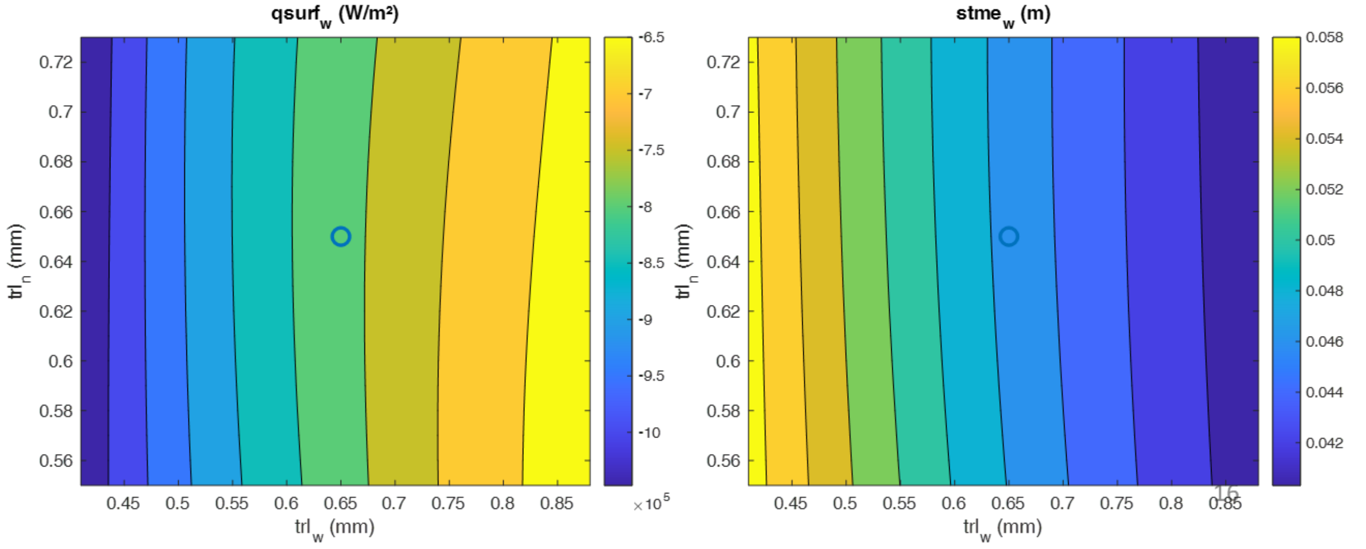


trl: thermal resistive layer

mould temperature (K)
wide ≈ 355 (360 → meas.)

heat flux (MW/m²)
wide ≈ 0.77 (0.75 → meas.)
narrow ≈ 0.87 (0.75 → meas.)

shell thickness (mm)
wide ≈ 47 (30 ? → meas.)
narrow ≈ 12 (15 ? →meas.)



Model sensitivity study

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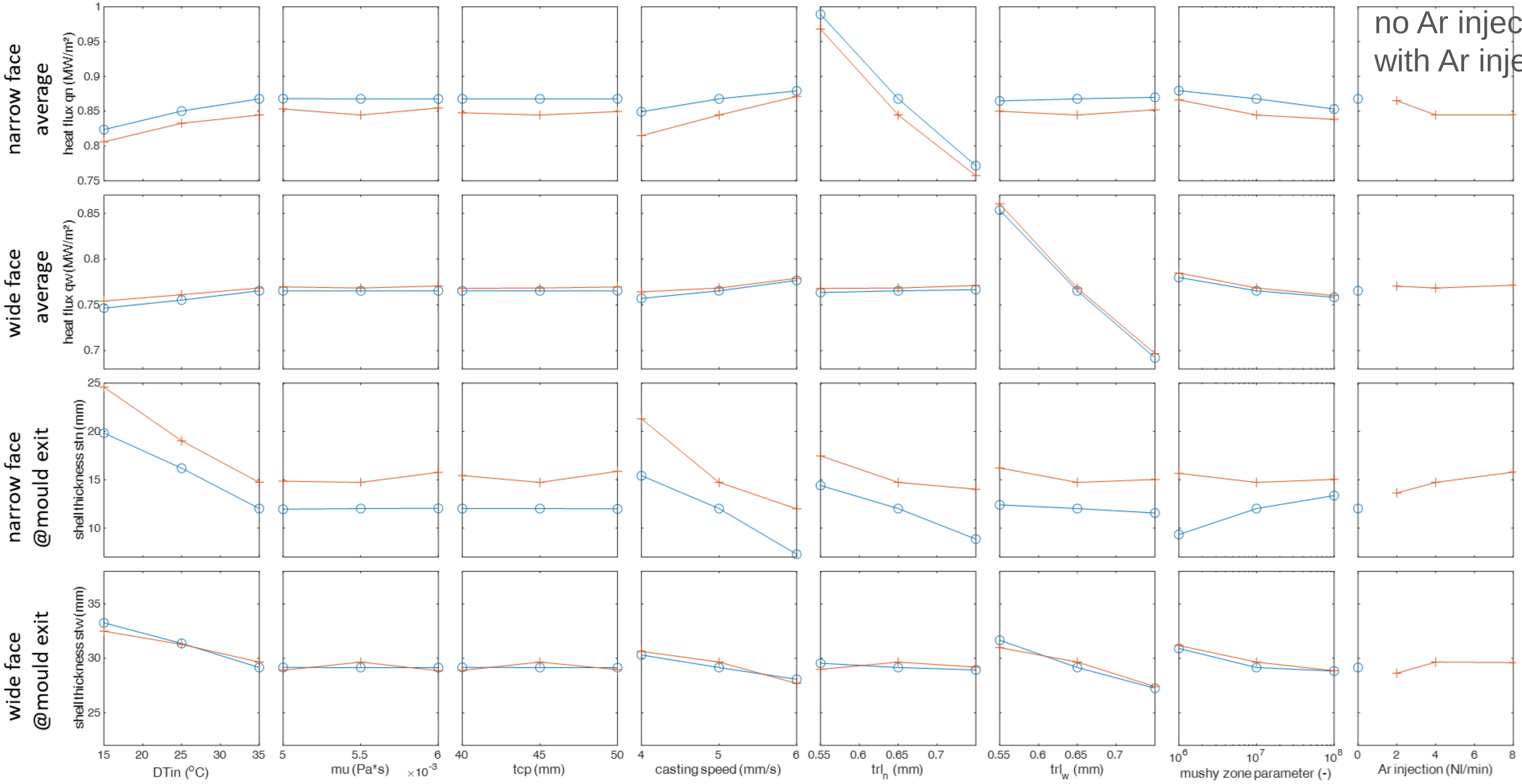
no Ar injection → blue
with Ar injection → red



inlet super heat

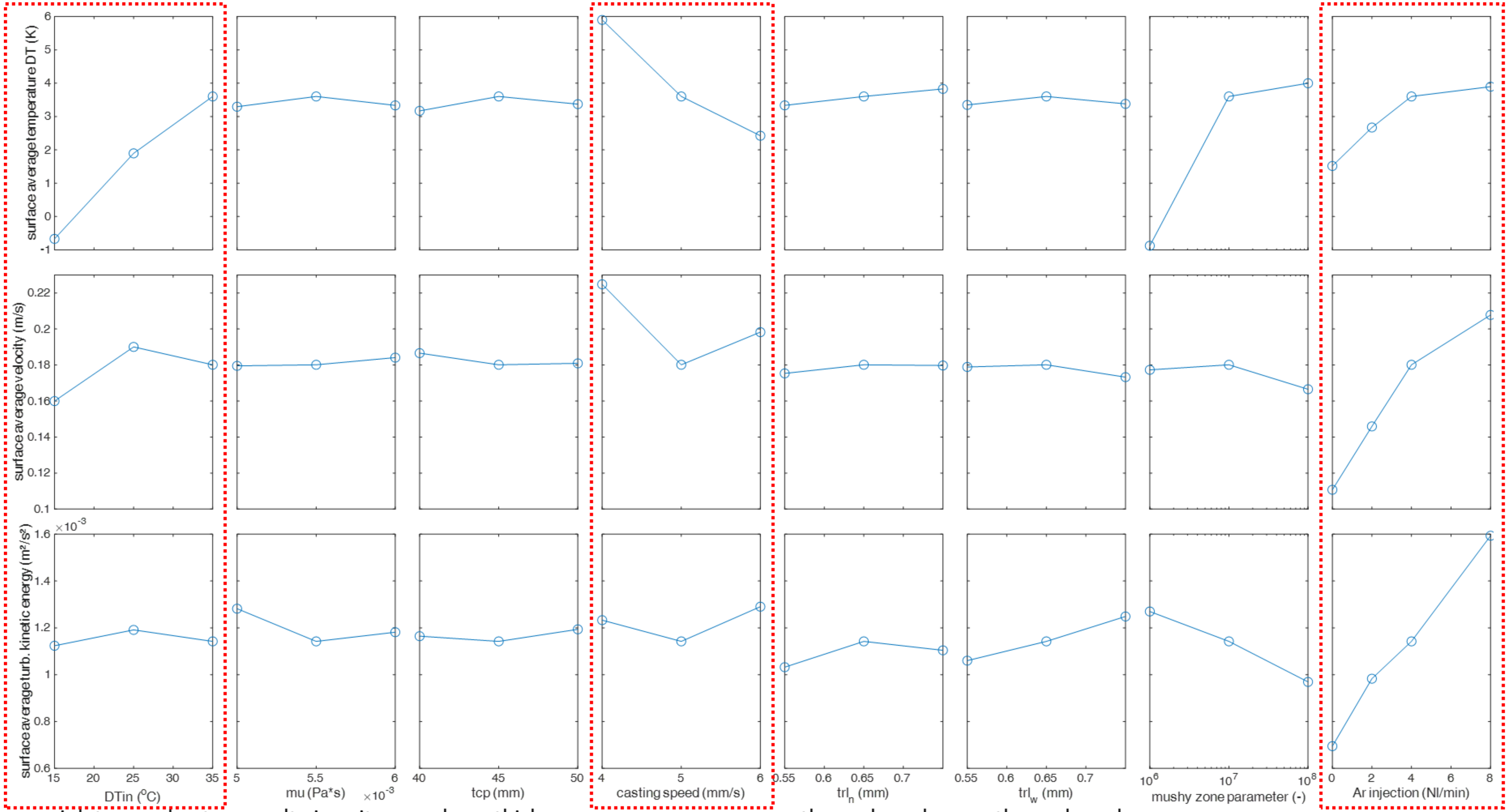
melt viscosity

layer thickness casting powder

thermal res. layer narrow face

thermal res. layer wide face

Parameters influencing top-freezing



inlet super heat | melt viscosity | layer thickness casting powder | thermal res. layer narrow face | thermal res. layer wide face

Additional CFD study
for the effect of the SEN geometry

SEN-A: smaller outflow port

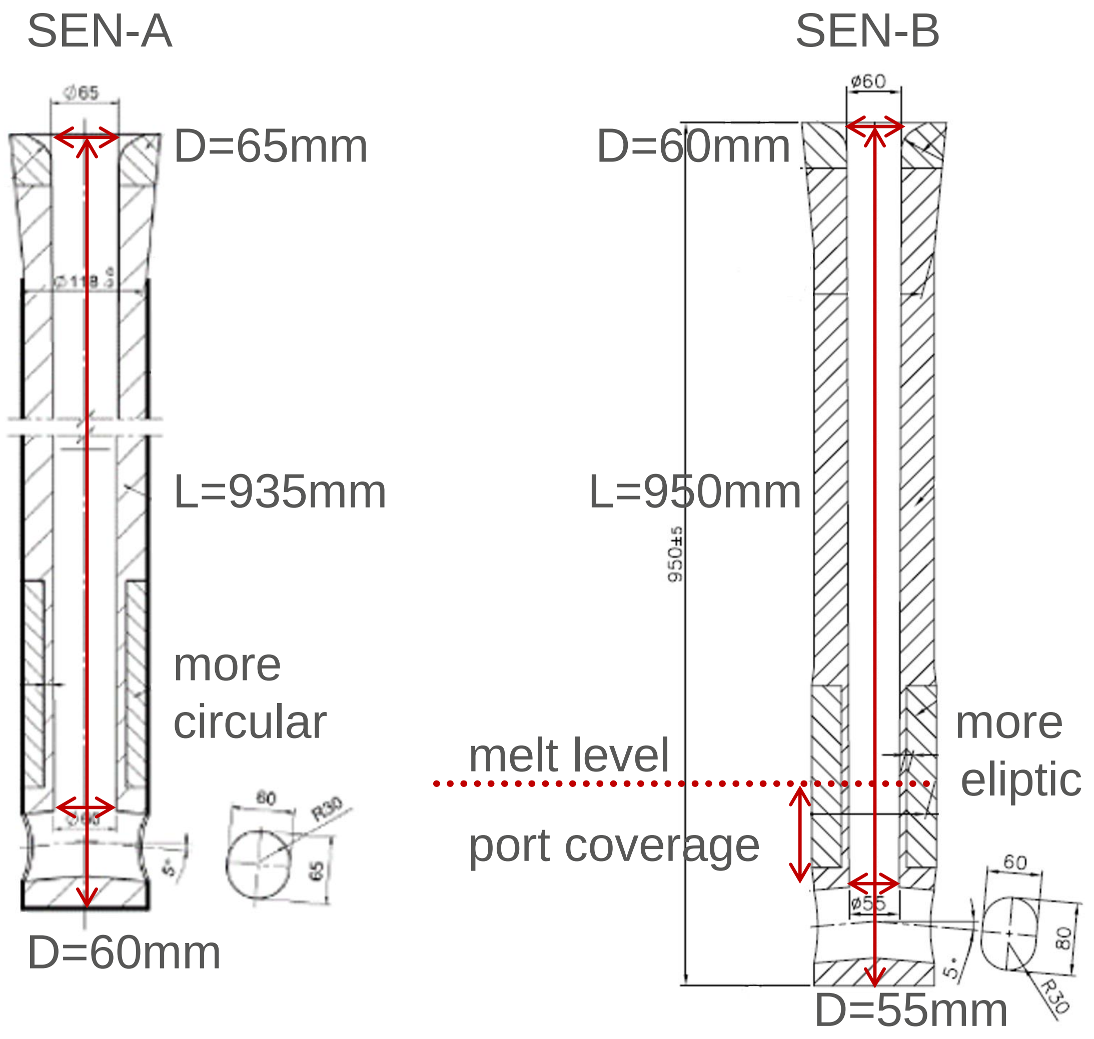
SEN-B: smaller inner diameter

4 computations are performed

- SEN-A, port coverage: 80mm, format:400er
- SEN-B, port coverage : 80mm, format :400er
- SEN-B, port coverage : 120mm, format :400er
- SEN-B, port coverage : 120mm, format :600er

Targets:

- How the flow field in mould is affected
- How the steel shell formation is affected
- How the heat-fluxes and top-freezing are affected

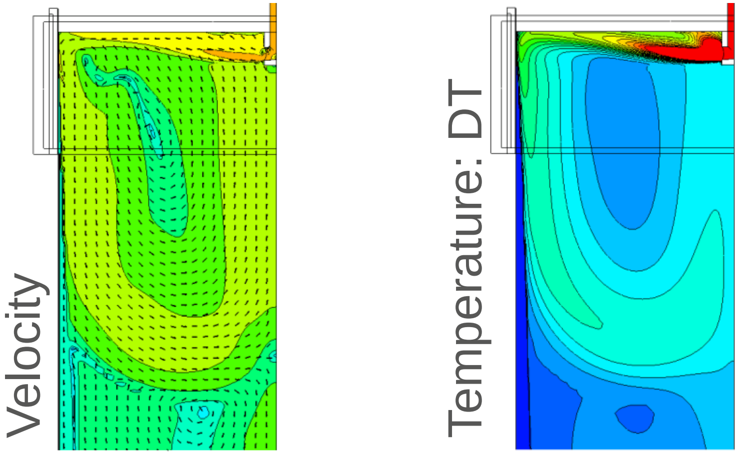


Main boundary conditions and model parameters

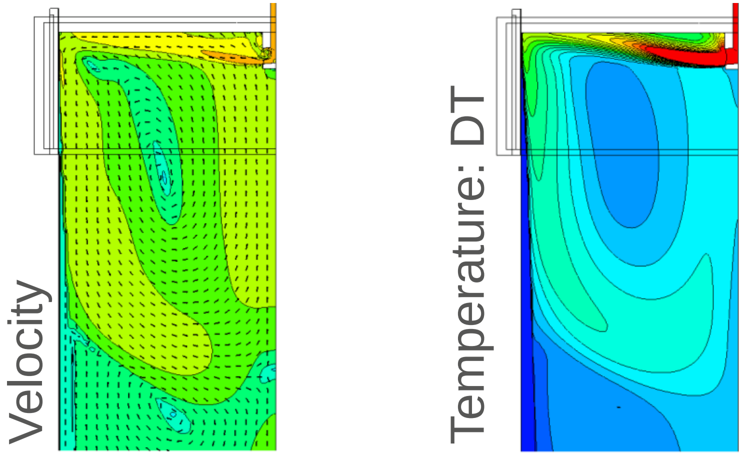
- solid Cu mould is modelled
  trl=0.65mm (thermal resistive layer, i.e., slag layer thickness between melt and mould)
- htc_spray=250W/m²·K T_inf=300K (secondary cooling) ε_{surf}=0.7
- htc_surf=200W/m²·K T_inf=300K (top surface) ε_{surf}=0.7
- tcp=45mm (thickness of casting powder layer at top)
- rho=2500kg/m³, Cp=1200J/(kg·K), k=0.44 W/(m·K) (casting powder properties)
- v_casting=0.3m/min for 400er, 0.15m/min for 600er (casting speed)
- V_{ar}=4 Nlt/min (Ar injection rate at SEN)
- DTin=35K (inlet super heat)
- steel-melt properties:
  Cp:814J/(kg·K), k:35W/(m·K), (specific heat capacity and heat conductivity)
  mu:0.0055Pa·s, rho:7000kg/m³,β:0.00011854K^{-1} (viscosity, density and vol. exp. coefficient)
  ΔH=238064J/kg, T_{Sol}=1761.41K, T_{Liq}=1794.12K (solidification enthalpy and temperatures)
- Turbulence model: sstkw with 2^{nd} order schemes (Fluent 2023R1)
  mesh size: ca. 2.6 – 3.1 Mio. cells , stationary solver with pseudo time-steps
  initial 4096 iterations without DPM (i.e., noAr) + 4096 iterations with DPM.

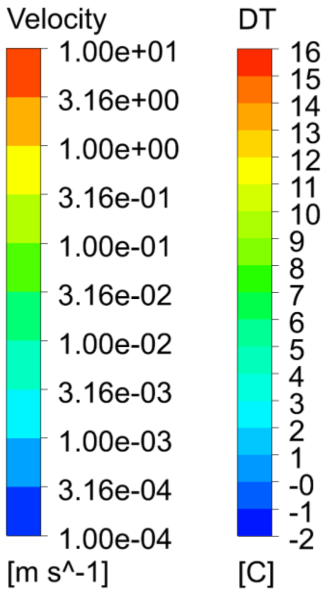
How the flow field in mould is affected i.e., velocity and temperature fields

SEN-A, port coverage: 80mm, format:400er

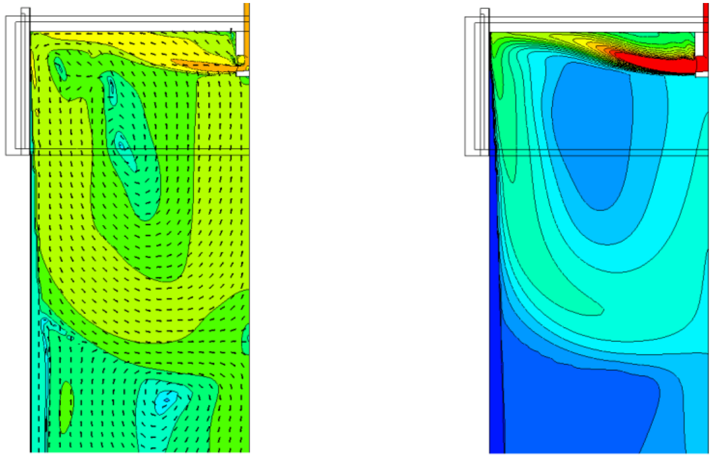


SEN-B, port coverage: 80mm, format:400er

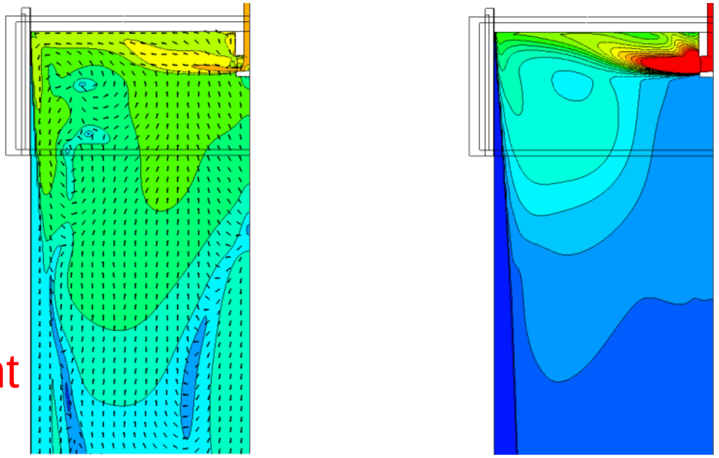




SEN-B, port coverage: 120mm, format:400er



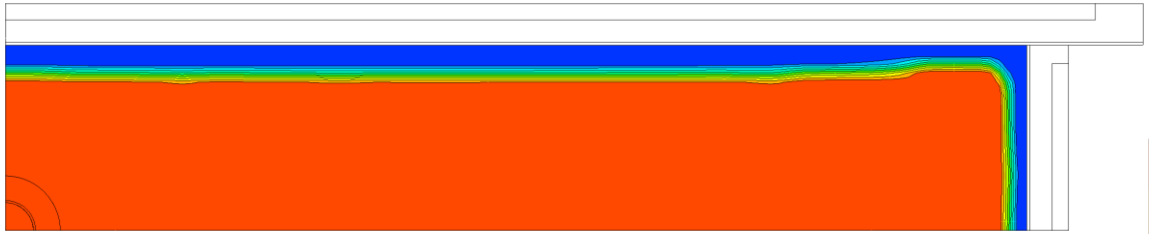
SEN-B, port coverage: 120mm, format:600er



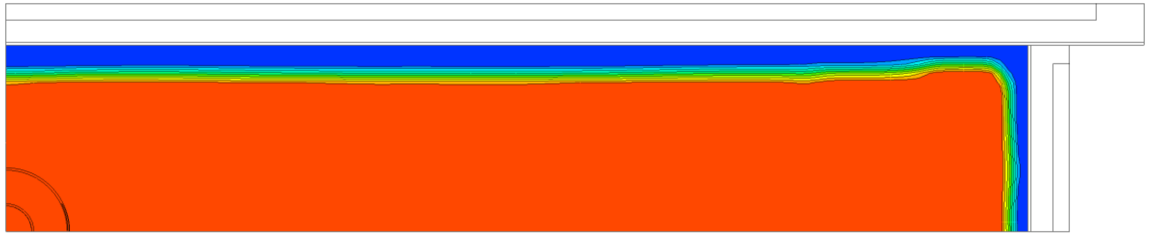
Velocity and Temperature distribution is quite different for the 600er format!

How the steel shell formation is affected i.e., shell thickness at mould exit

SEN-A, port coverage: 80mm, format:400er

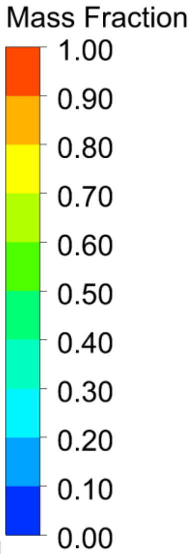


SEN-B, port coverage: 80mm, format:400er

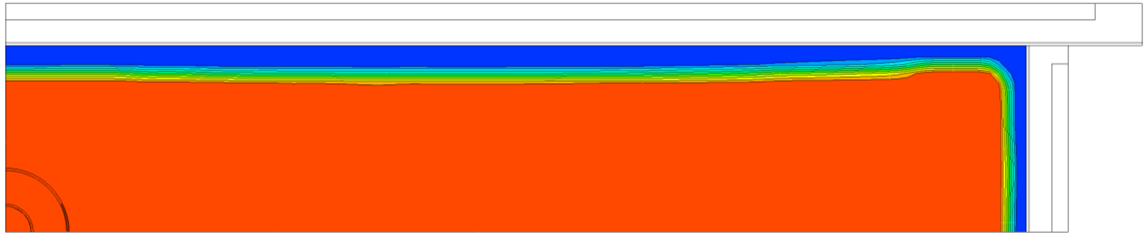


400er format 0.30 m/min → 7.7 kg/s

600er format 0.15 m/min → 5.775 kg/s

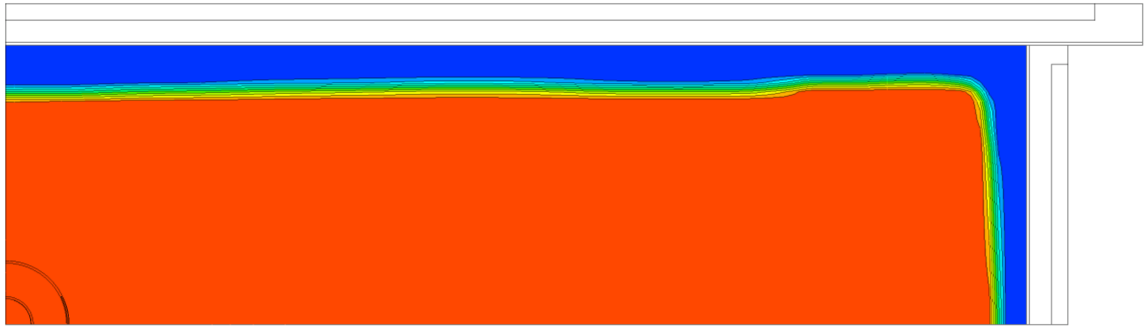


SEN-B, port coverage: 120mm, format:400er



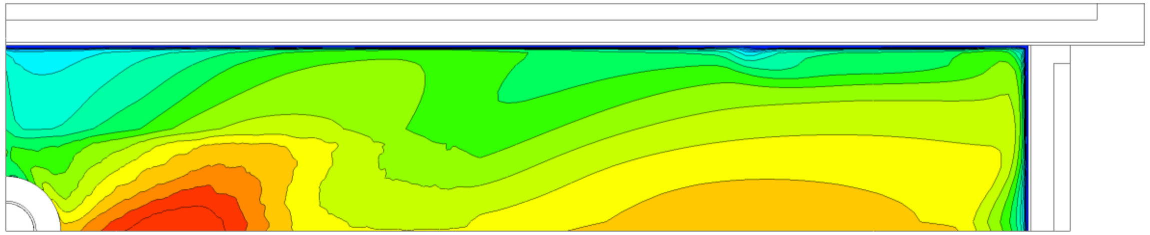
SEN-B, port coverage: 120mm, format:600er

Steel shell is thicker as the mass flow rate less!

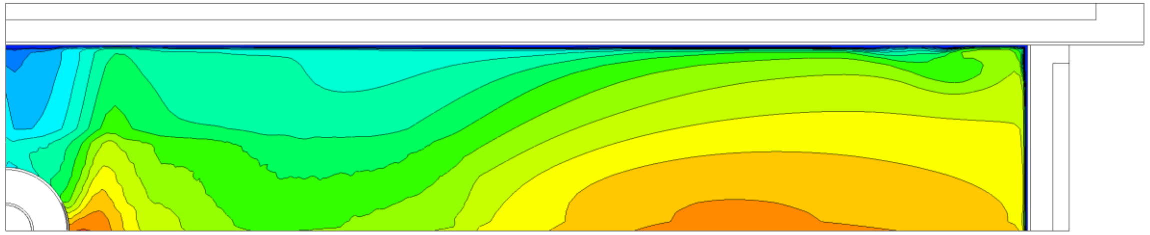


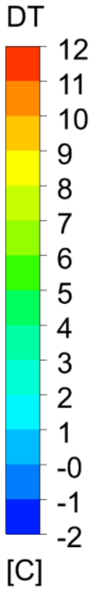
How the heat-fluxes and top-freezing are affected i.e., melt temperature at top, below casting powder

SEN-A, port coverage: 80mm, format:400er

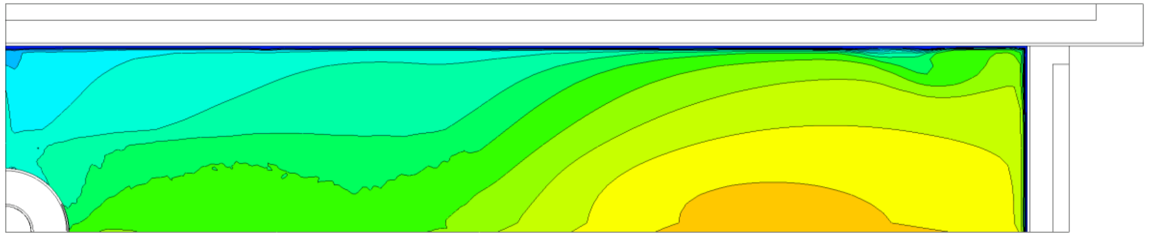


SEN-B, port coverage: 80mm, format:400er



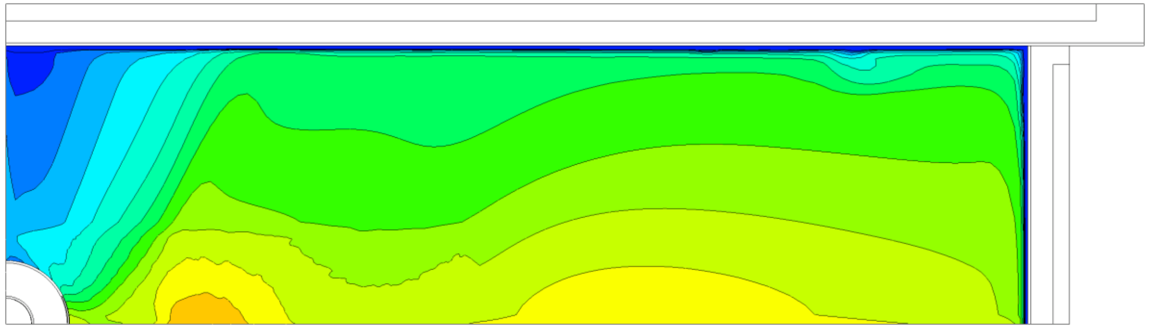


SEN-B, port coverage: 120mm, format:400er



for larger port coverage,
top-freezing danger slightly increases!

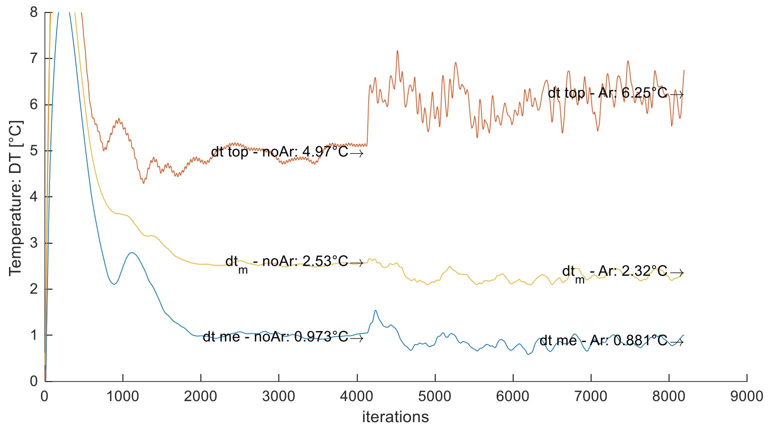
SEN-B, port coverage: 120mm, format:600er



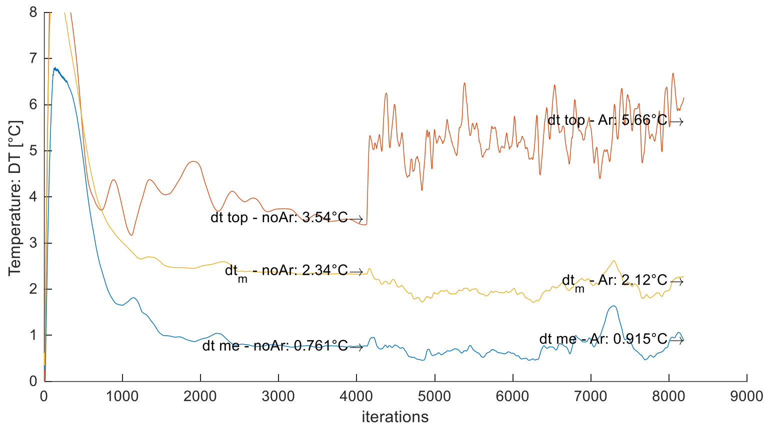
for larger format,
top-freezing danger further increases!

Average melt temperatures at top, mould exit and mould

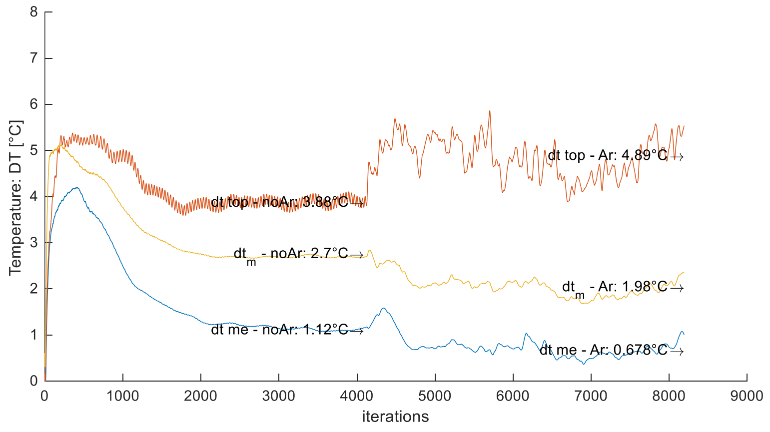
SEN-A, port coverage: 80mm, format:400er



SEN-B, port coverage: 80mm, format:400er

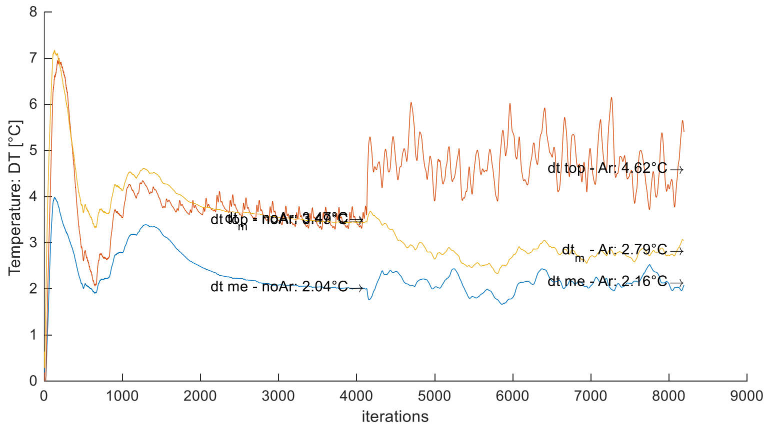


SEN-B, port coverage: 120mm, format:400er



for larger port coverage, top-freezing danger slightly increases!

SEN-B, port coverage: 120mm, format:600er



How the heat-fluxes and top-freezing are affected i.e., heat flux from steel melt to Cu-mould

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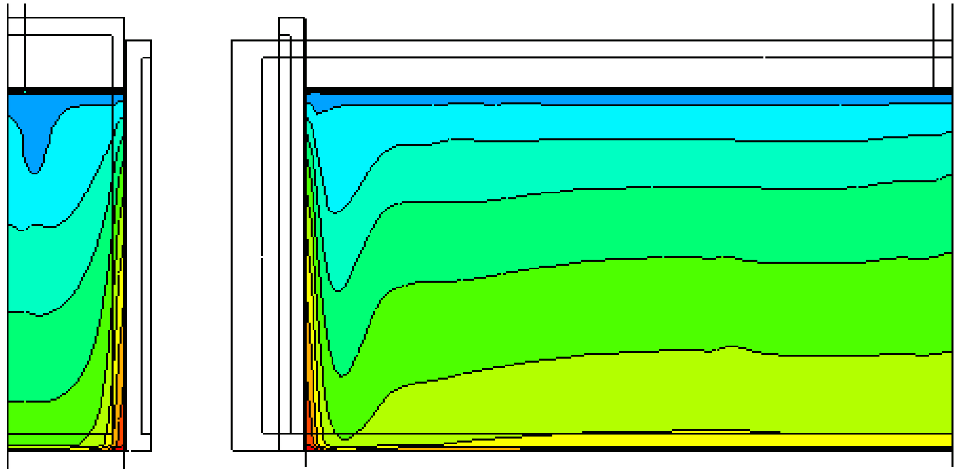
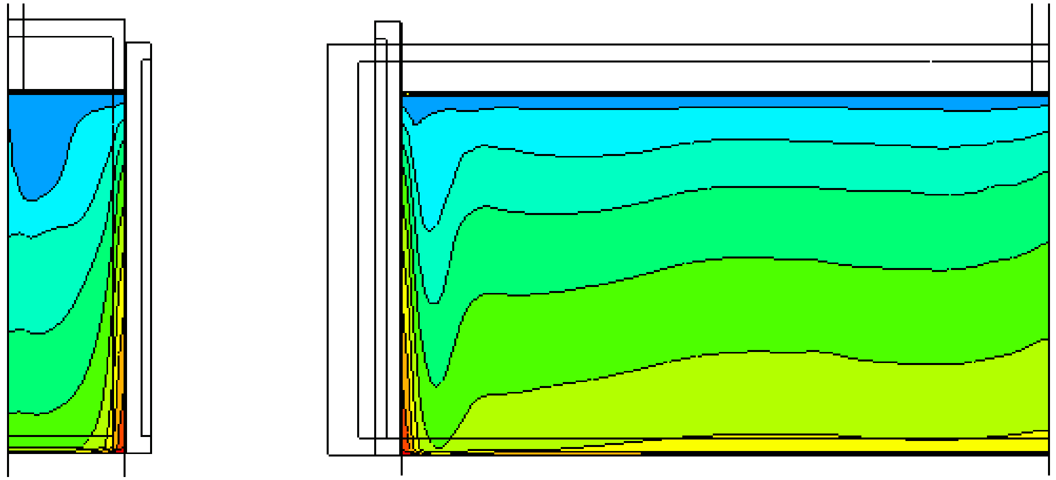
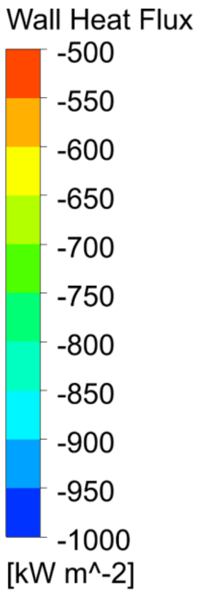
SEN-A, port coverage: 80mm, format:400er

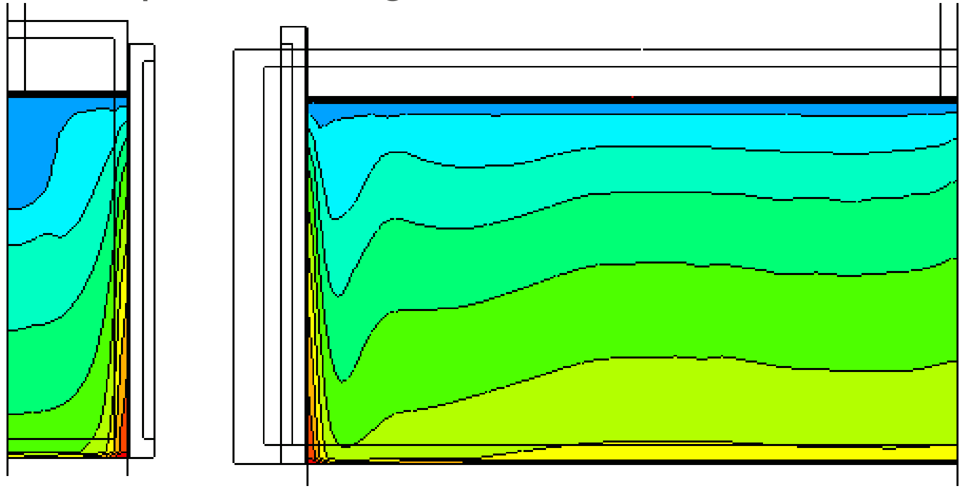


SEN-B, port coverage: 80mm, format:400er

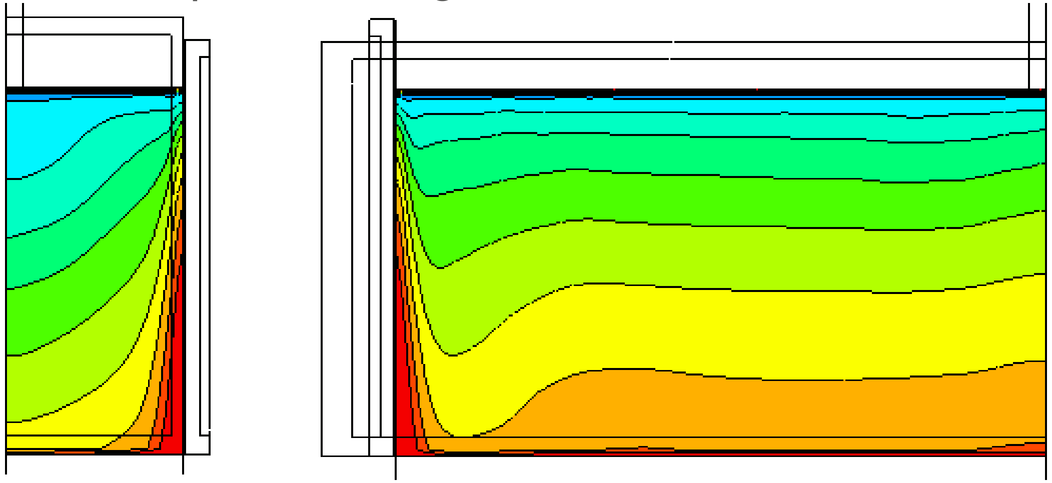




SEN-B, port coverage: 120mm, format:400er

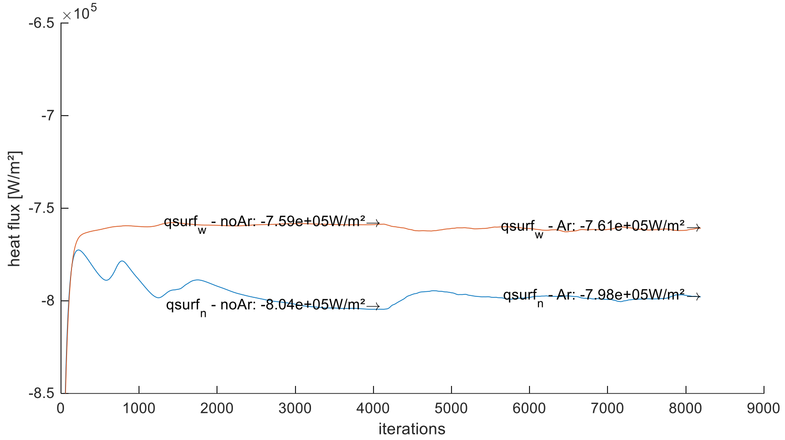


SEN-B, port coverage: 120mm, format:600er

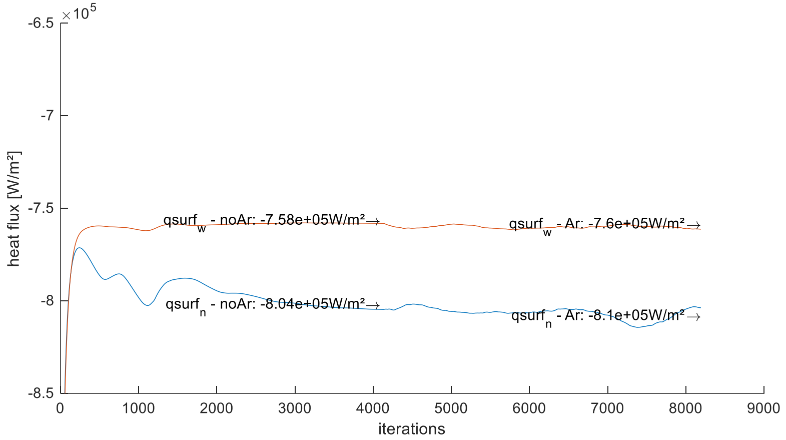


Average the heat-fluxes from steel melt to mould

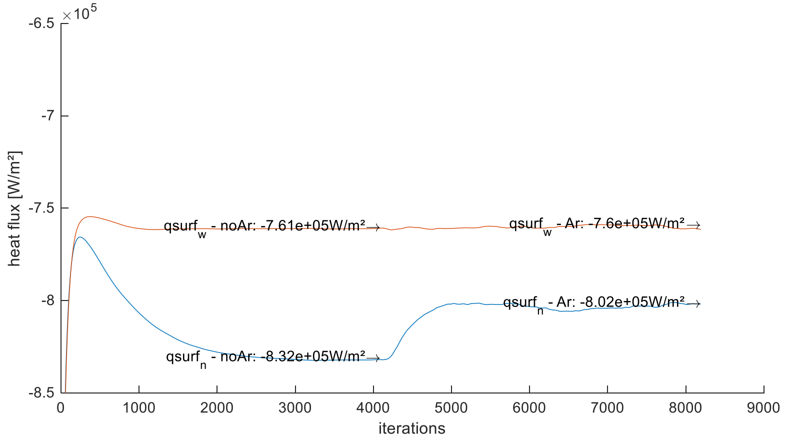
SEN-A, port coverage: 80mm, format:400er



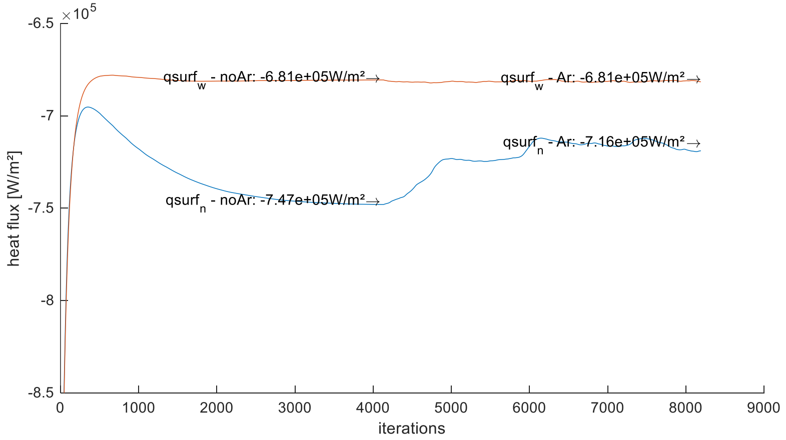
SEN-B, port coverage: 80mm, format:400er



SEN-B, port coverage: 120mm, format:400er



SEN-B, port coverage: 120mm, format:600er



Temperature in the Cu-mould narrow side 13mm from hot face and wide side 7mm from hot face

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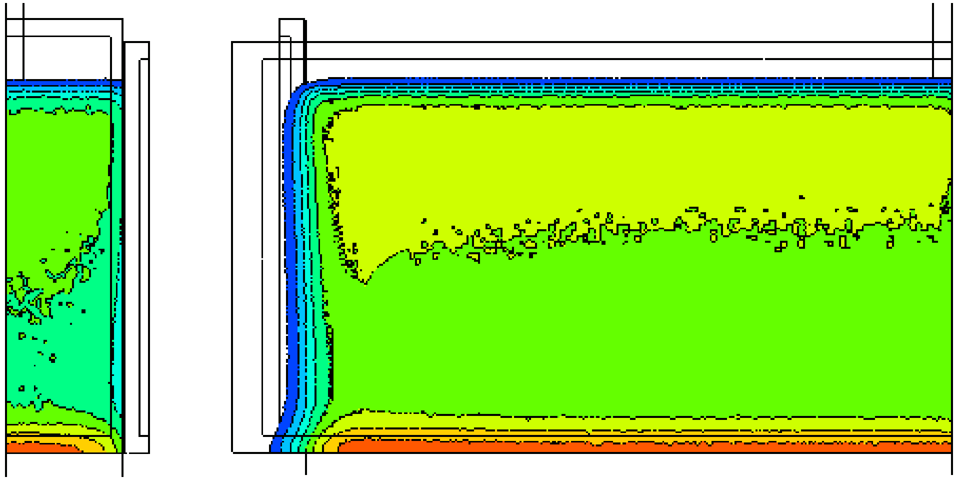
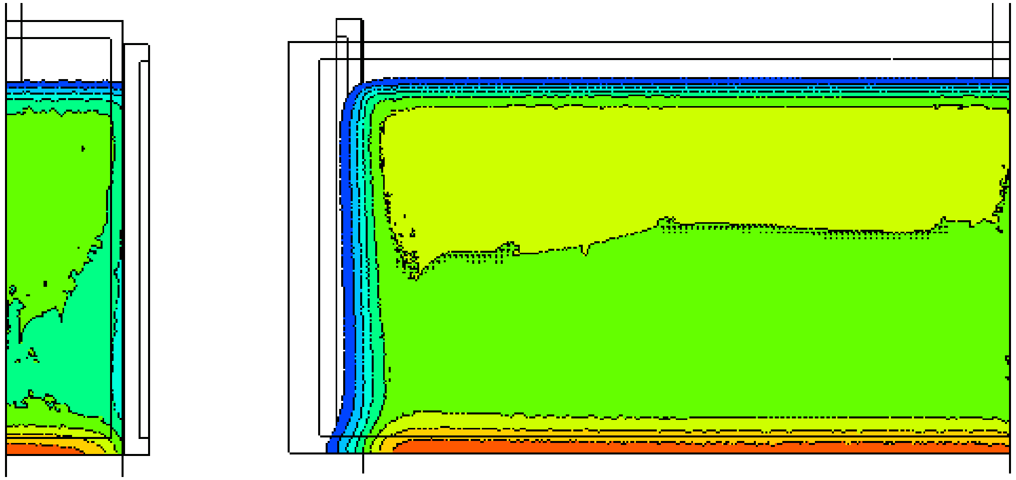
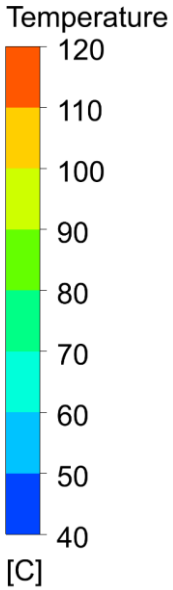
SEN-A, port coverage: 80mm, format:400er

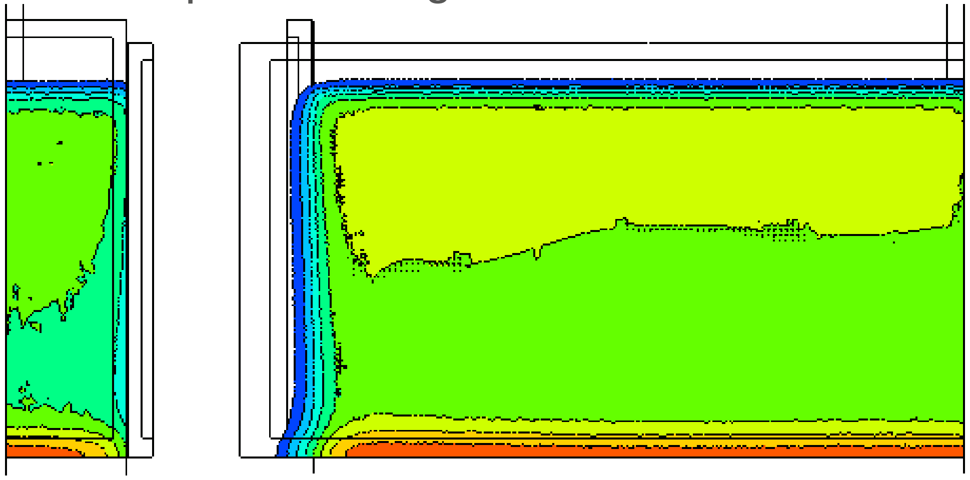


SEN-B, port coverage: 80mm, format:400er

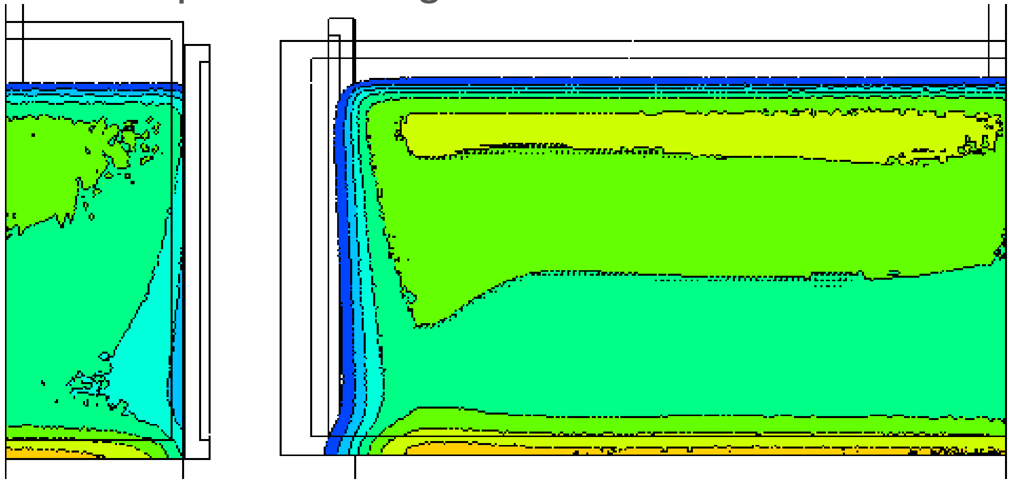




SEN-B, port coverage: 120mm, format:400er

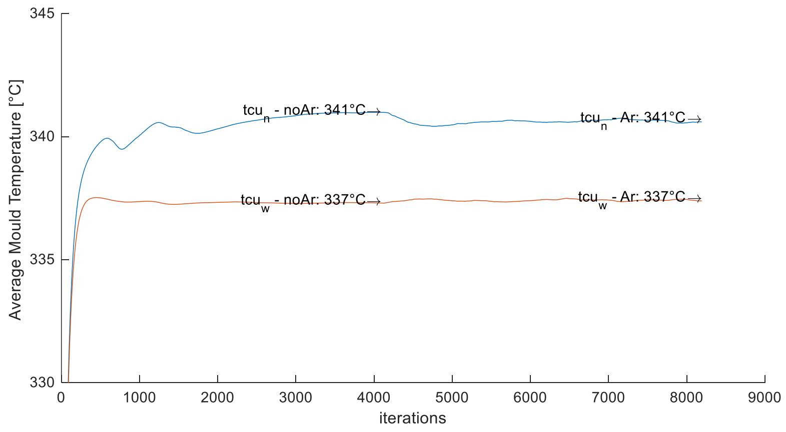


SEN-B, port coverage: 120mm, format:600er

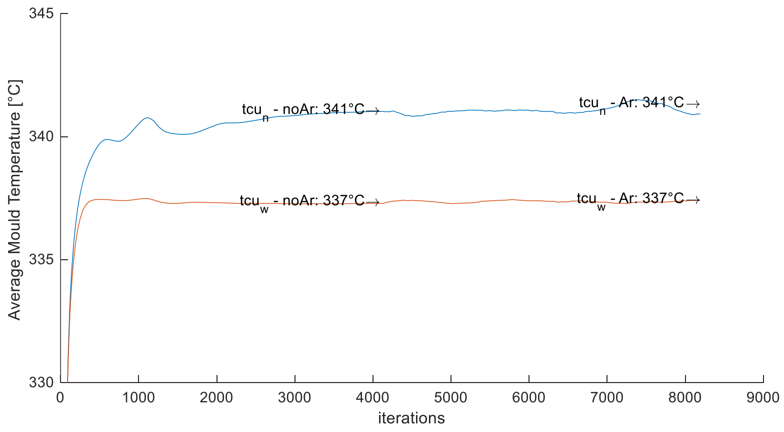


Average temperature in the Cu-mould

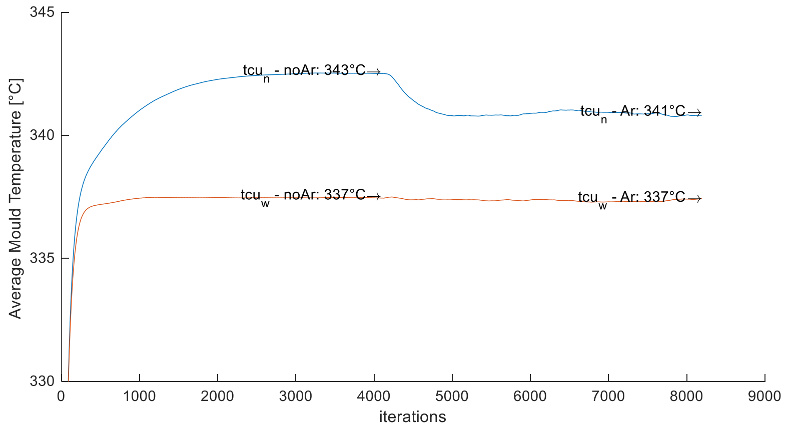
SEN-A, port coverage: 80mm, format:400er



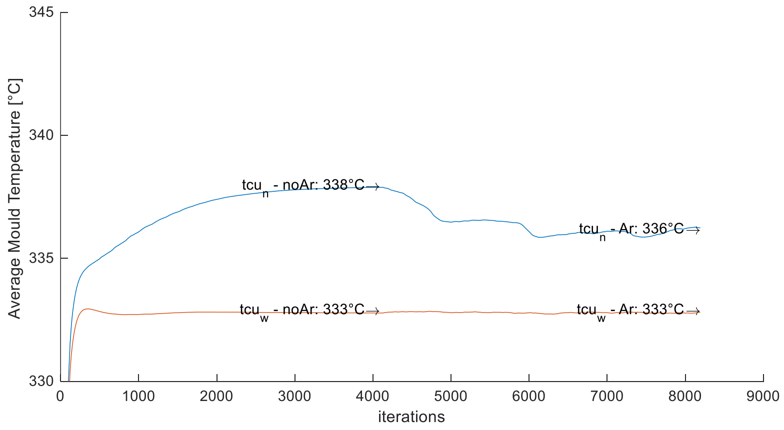
SEN-B, port coverage: 80mm, format:400er



SEN-B, port coverage: 120mm, format:400er



SEN-B, port coverage: 120mm, format:600er



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