Numerical Modelling of Casting Powders and Slag Infiltration

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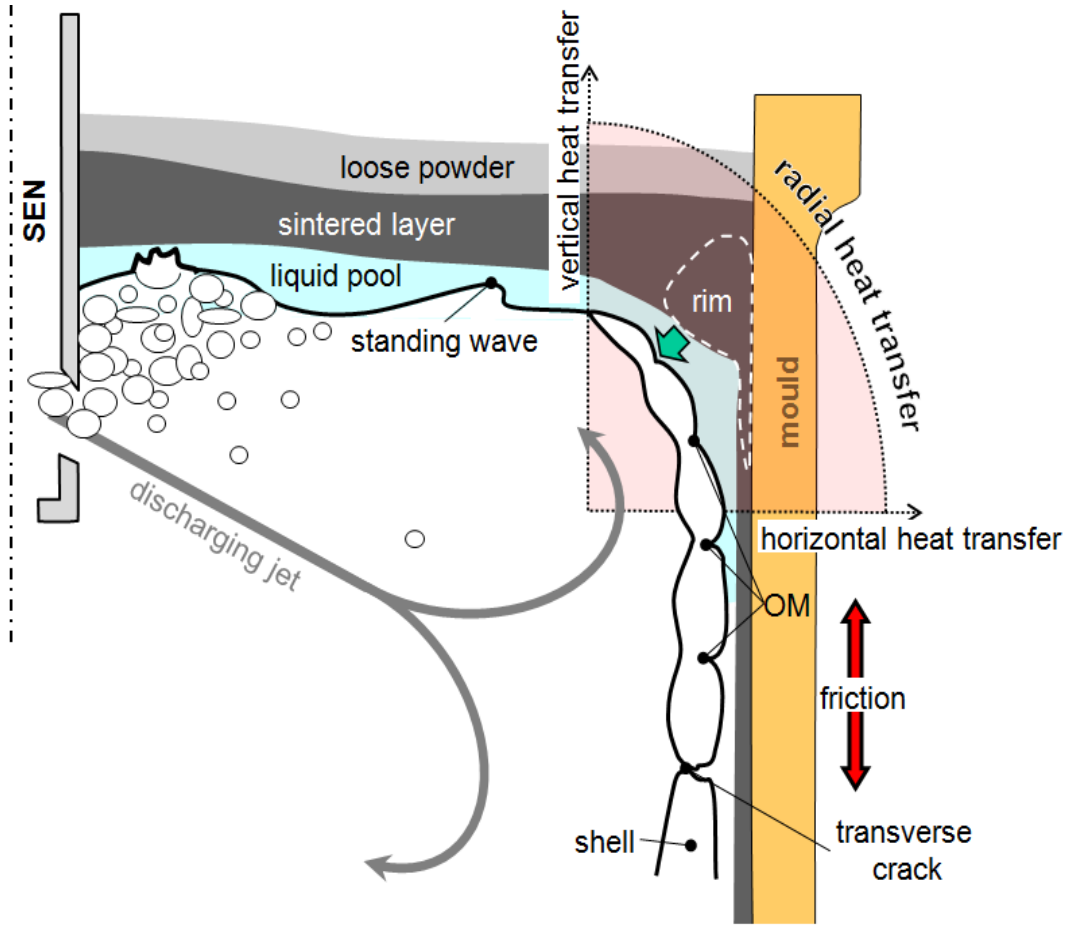
European Commission
Research Fund for Coal & Steel

Introduction

- Numerical models are useful to analize slag infiltration
- Traditional modelling approaches split vertical and horizontal heat transfer
- Solidification in the meniscus occurs along the radius and is affected by the slag infiltration dynamics
- Transient behaviour of the slag-bed must be included in the calculations



Key Lubrication concepts

Dedicated to the memory of Professor Kenneth C. Mills

Review

Key Lubrication Concepts to Understand the Role of Flow, Heat Transfer and Solidification for Modelling Defect Formation during Continuous Casting

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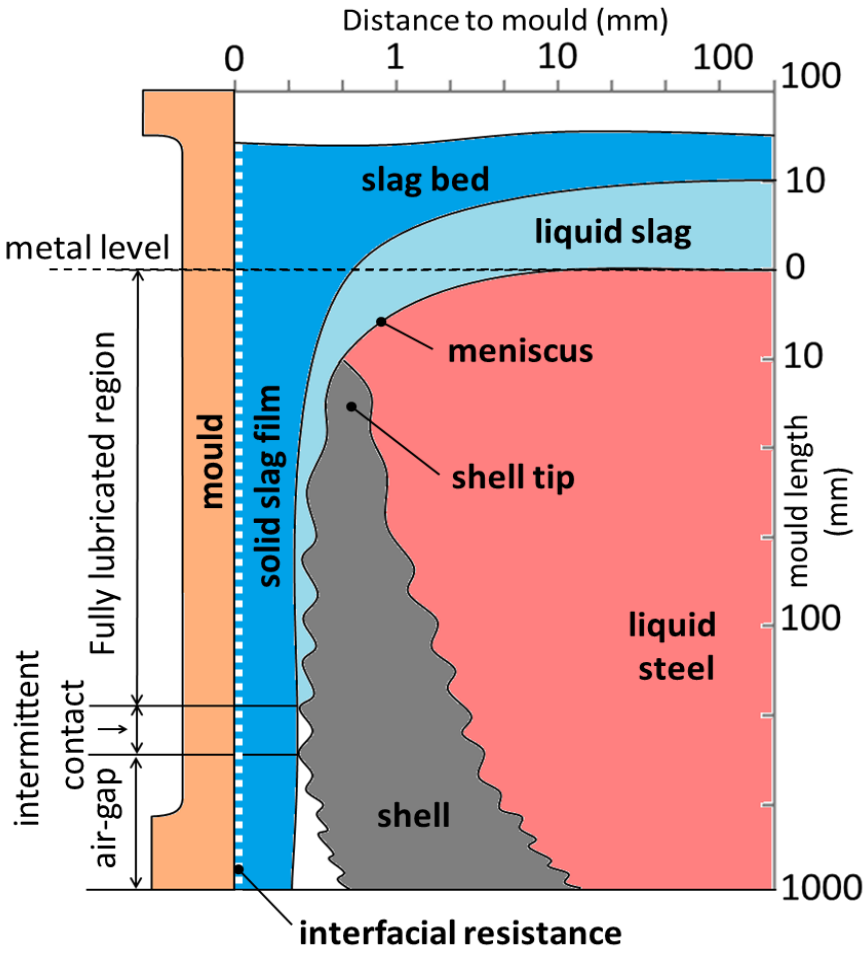
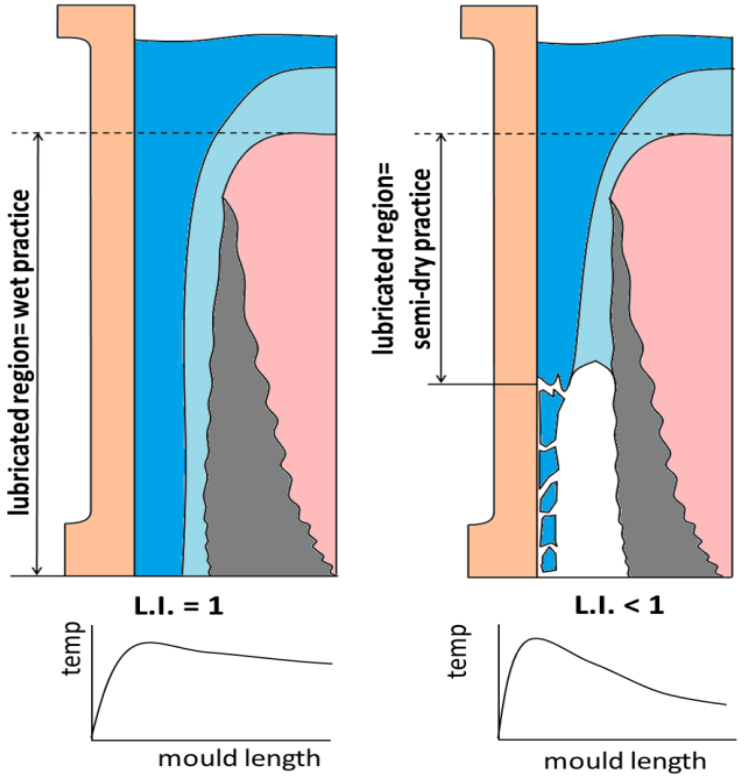
https://en.wikipedia.org/wiki/Ken_Mills

Key Lubrication concepts



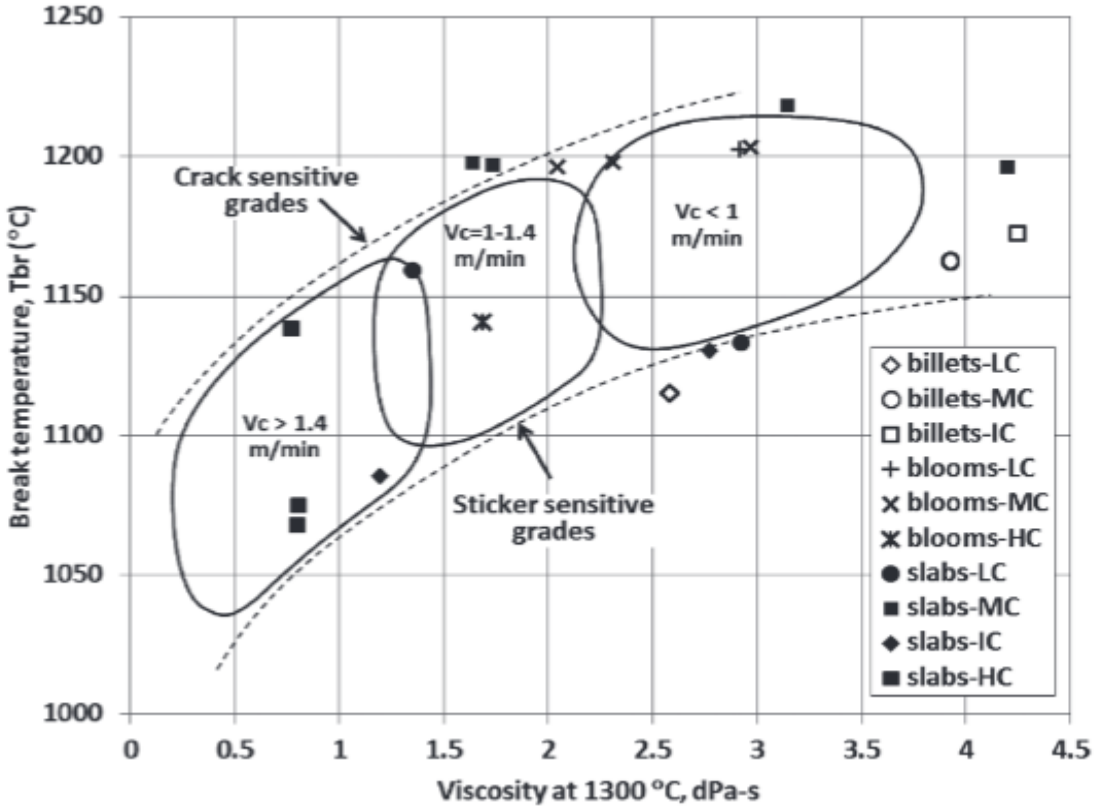
$$L.I = \frac{\text{fully lubricated region}}{\text{effective mould length}}$$



Lubrication:
wet practice vs normal practice

Thermo-physical properties of slags

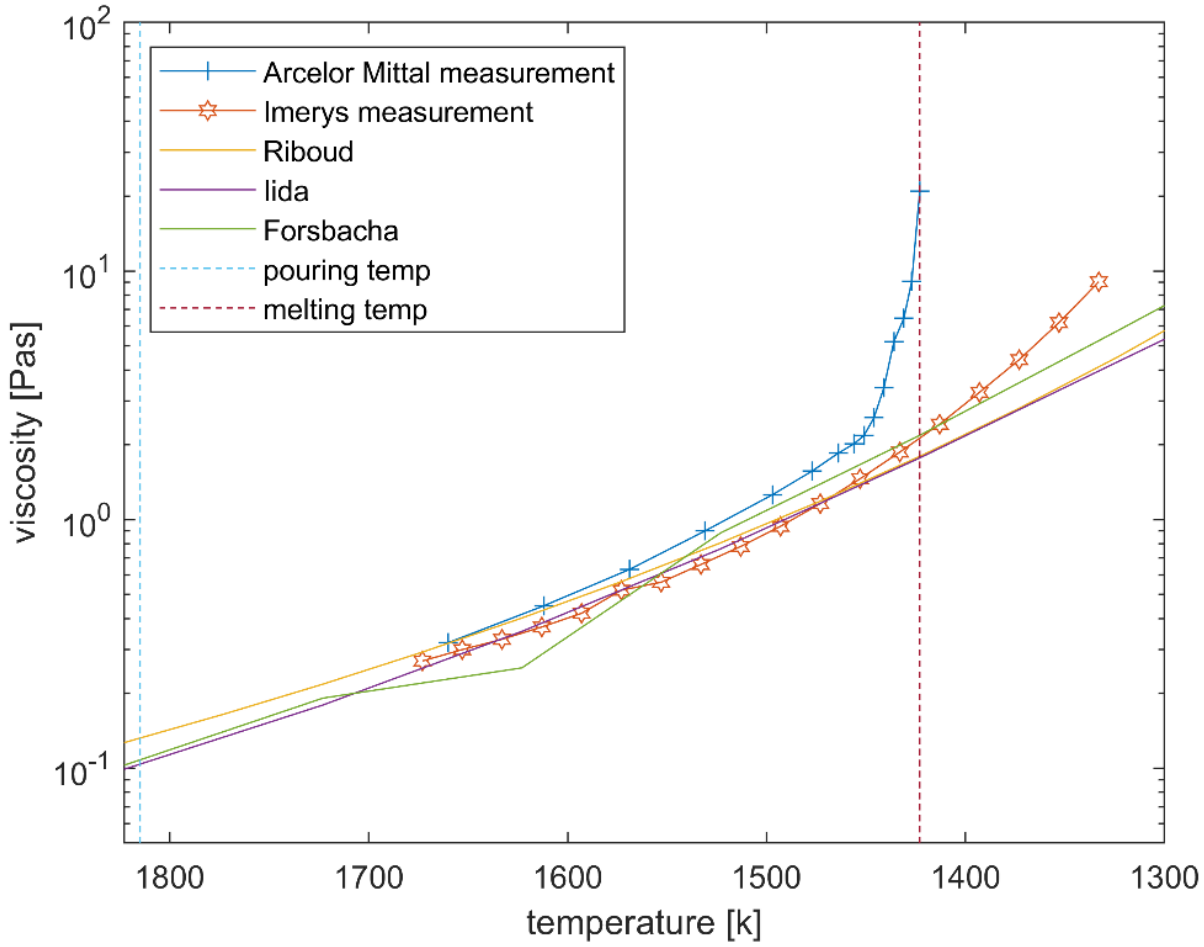
- Viscosity & break temperature
- Thermal Conductivity, Crystallization and Radiation
- Interfacial Contact Resistance and Cooling Rate
- Interfacial Tension

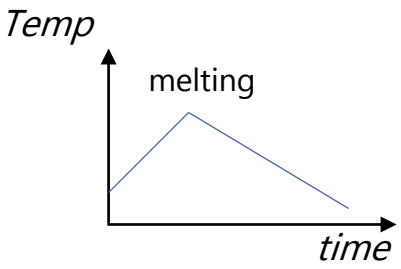


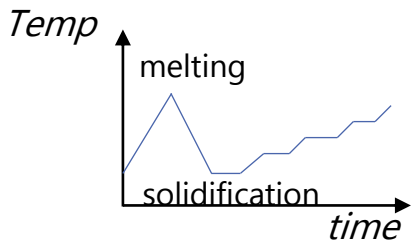
Slag viscosity

Comparison of models vs measurements

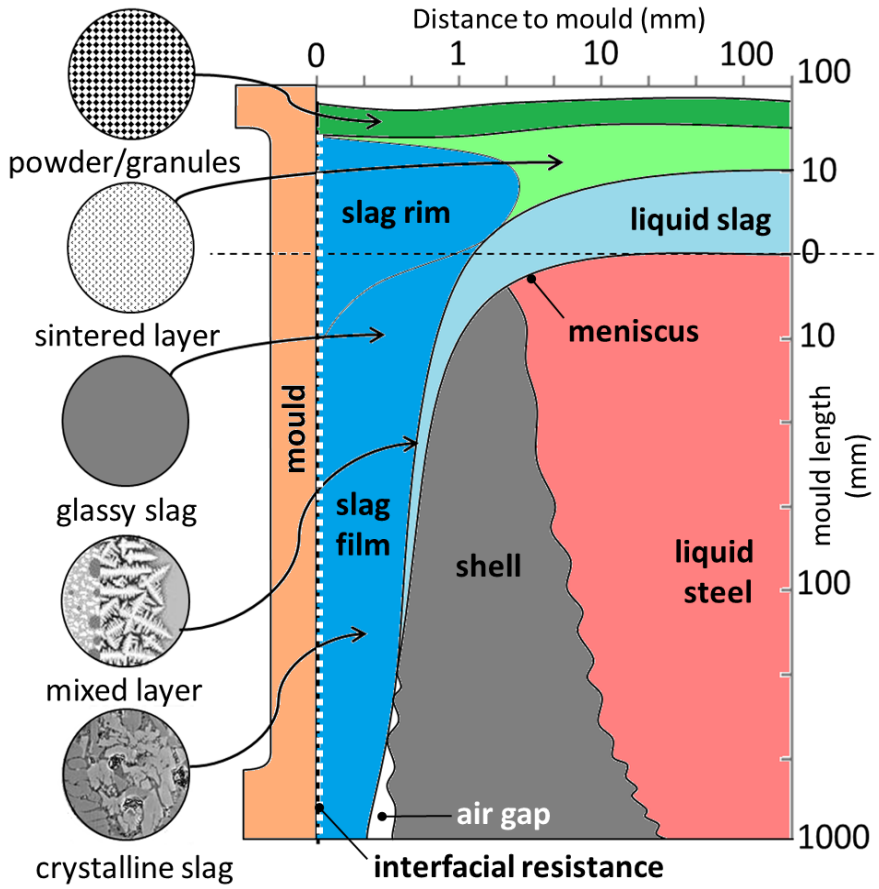
Viscosity



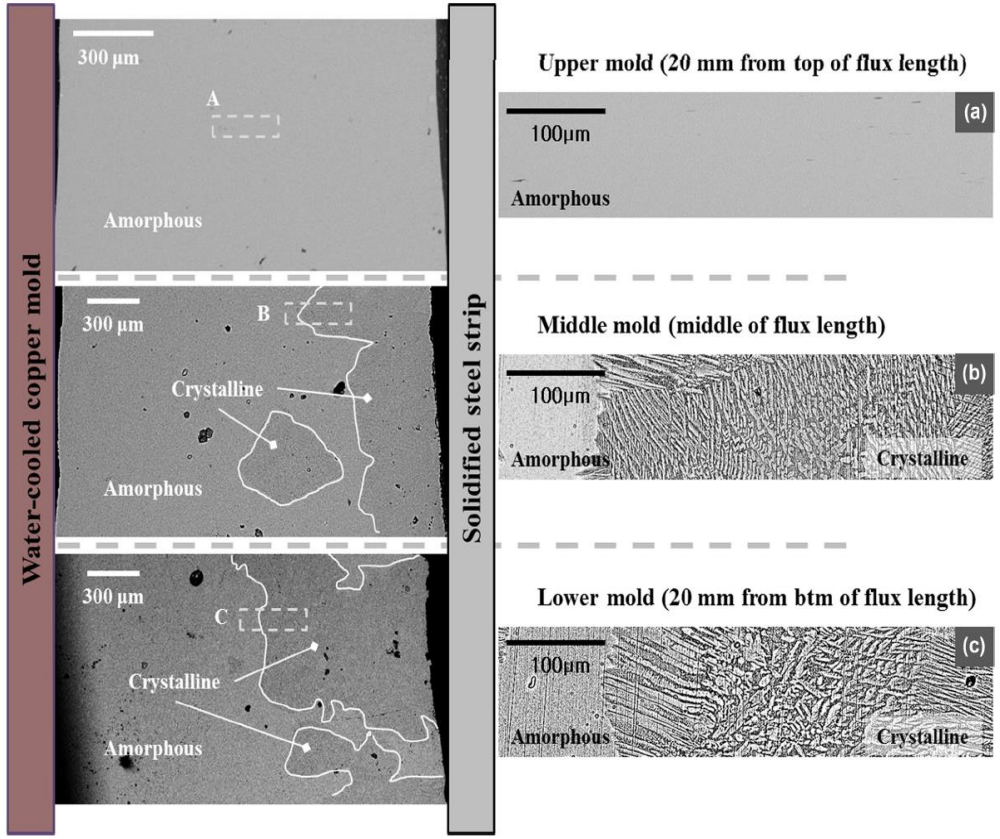




Dynamic slag behaviour during CC



Slag film evolution



Yonsei CC simulator samples

[Met. Mater. Int., Vol. 20, No. 6 (2014), pp. 1103~1114]

Effect of interfacial resistance (r_{int})

- **rint** has a strong effect on shell thickness and heat transfer

- Effect becomes more important for thin slag films (i.e. more crystalline)

- Rint should be measured independently from film thickness

- Samples from industrial caster and simulator exhibit similar characteristics such as rugosity and cracking susceptibility.

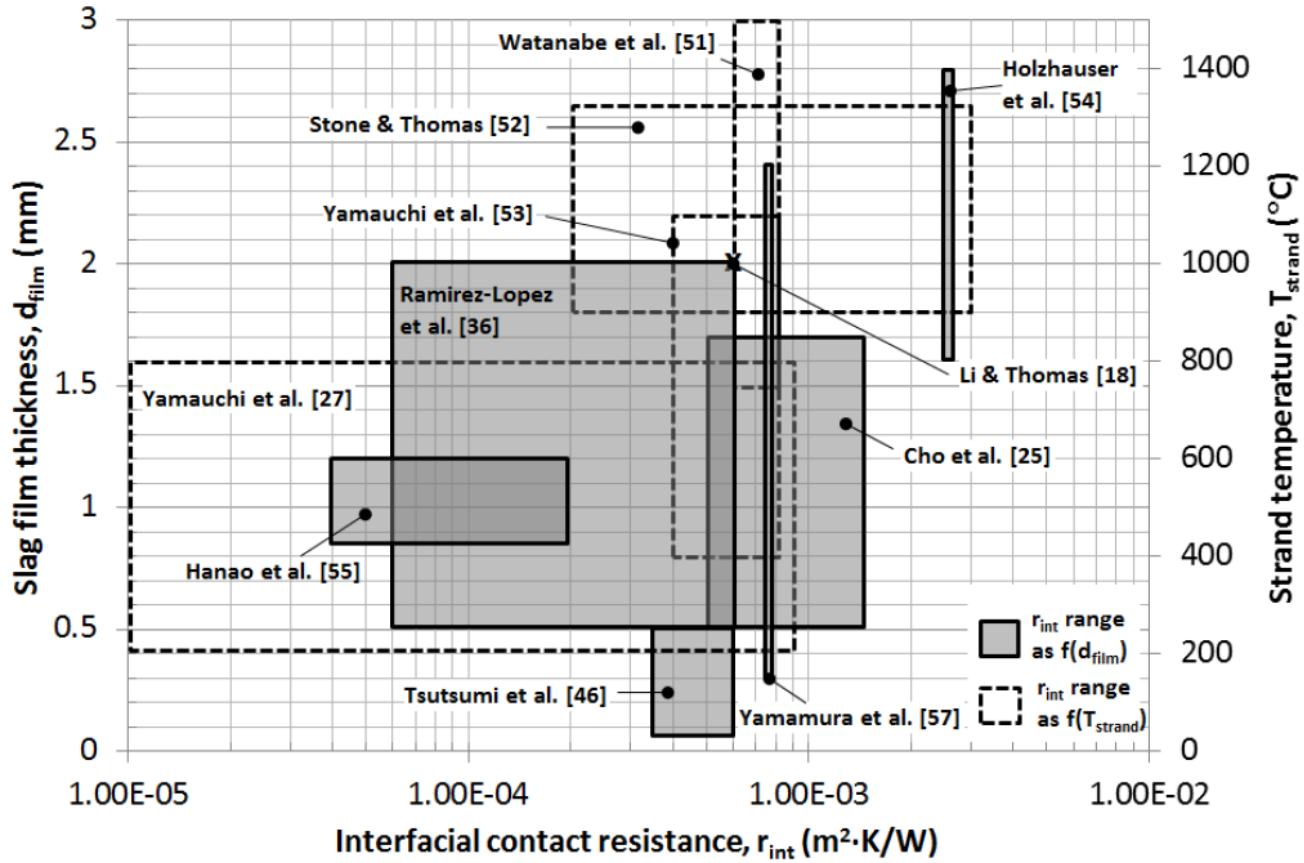
caster slag films

crystalline samples

simulator samples

glassy samples

Interfacial contact resistance (r_{int})

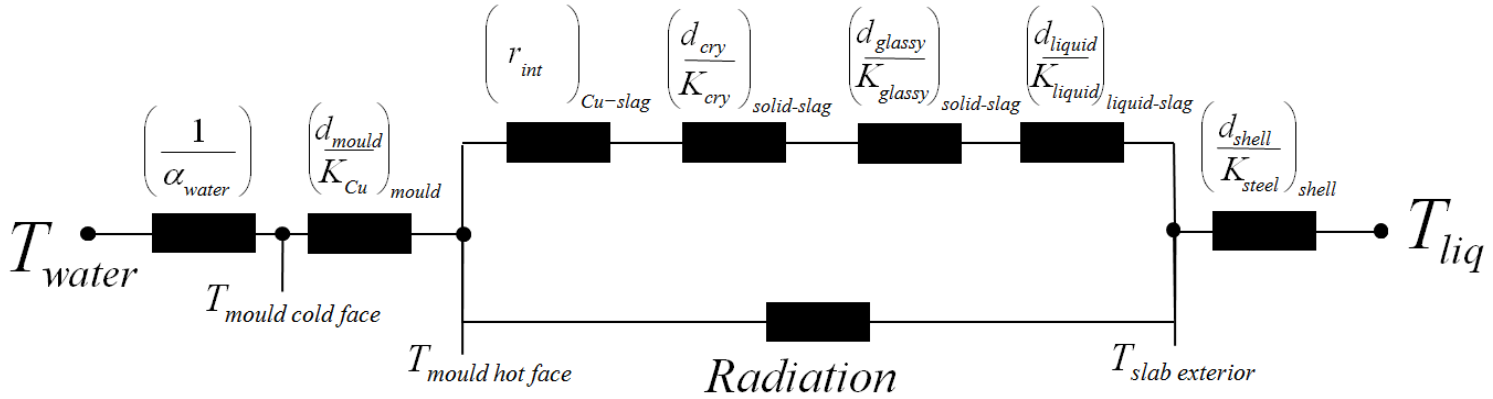


Interfacial contact resistance ranges obtained by laboratory tests and industrial sampling as well as used in numerical models (dotted boxes: experimental/plant; grey boxes: numerical modelling

Modelling Slag Infiltration

Slag modelling approach

Traditional algebraic approach:

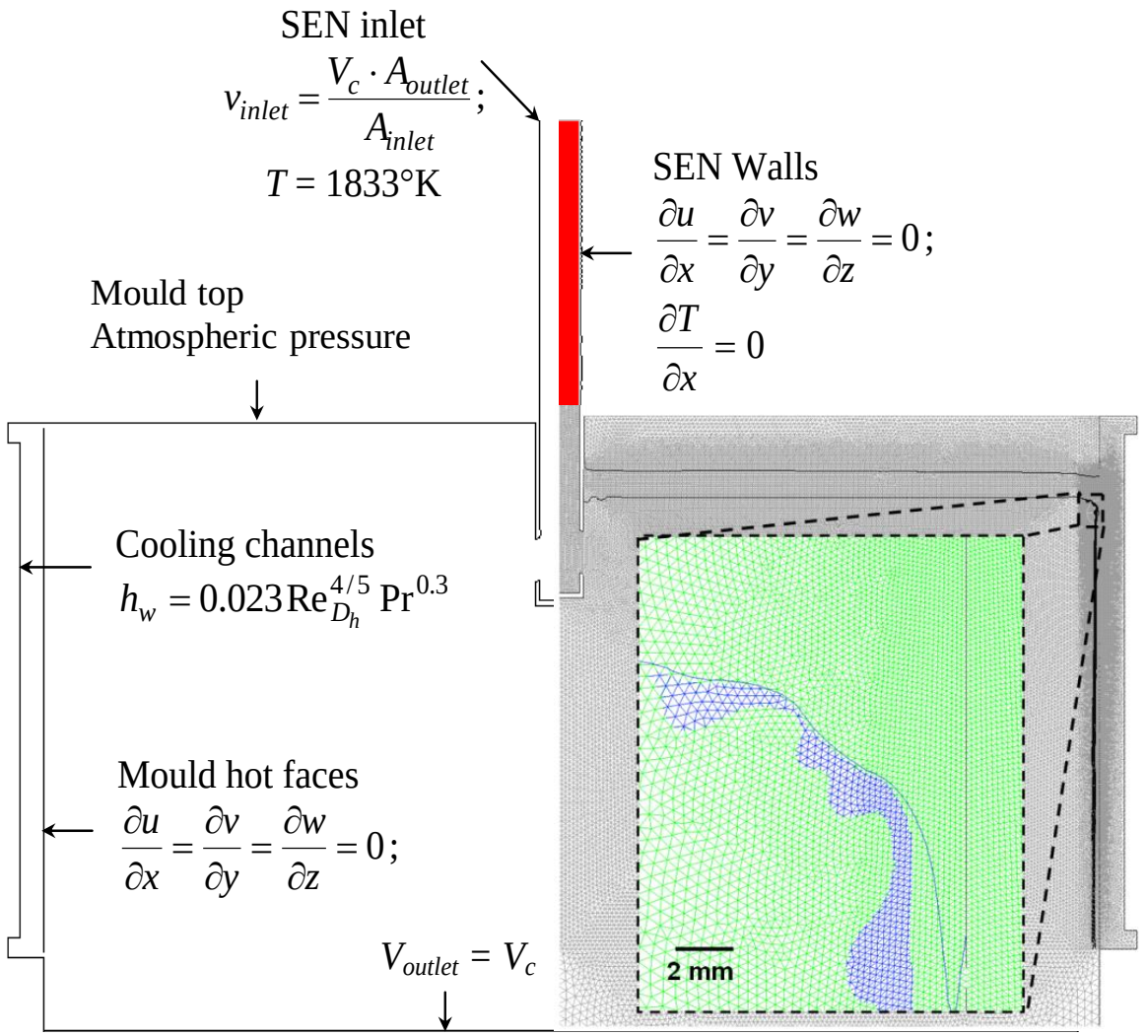


SWERIM model:

$$\overbrace{r_{int} + \left(\frac{d_{cry}}{K_{cry}}\right)_{solid-slag} + \left(\frac{d_{glassy}}{K_{glassy}}\right)_{solid-slag} + \left(\frac{d_{liquid}}{K_{liquid}}\right)_{liquid-slag}}^{r_{film}} = r_{int} + \frac{d_{film}}{K_{eff}}$$

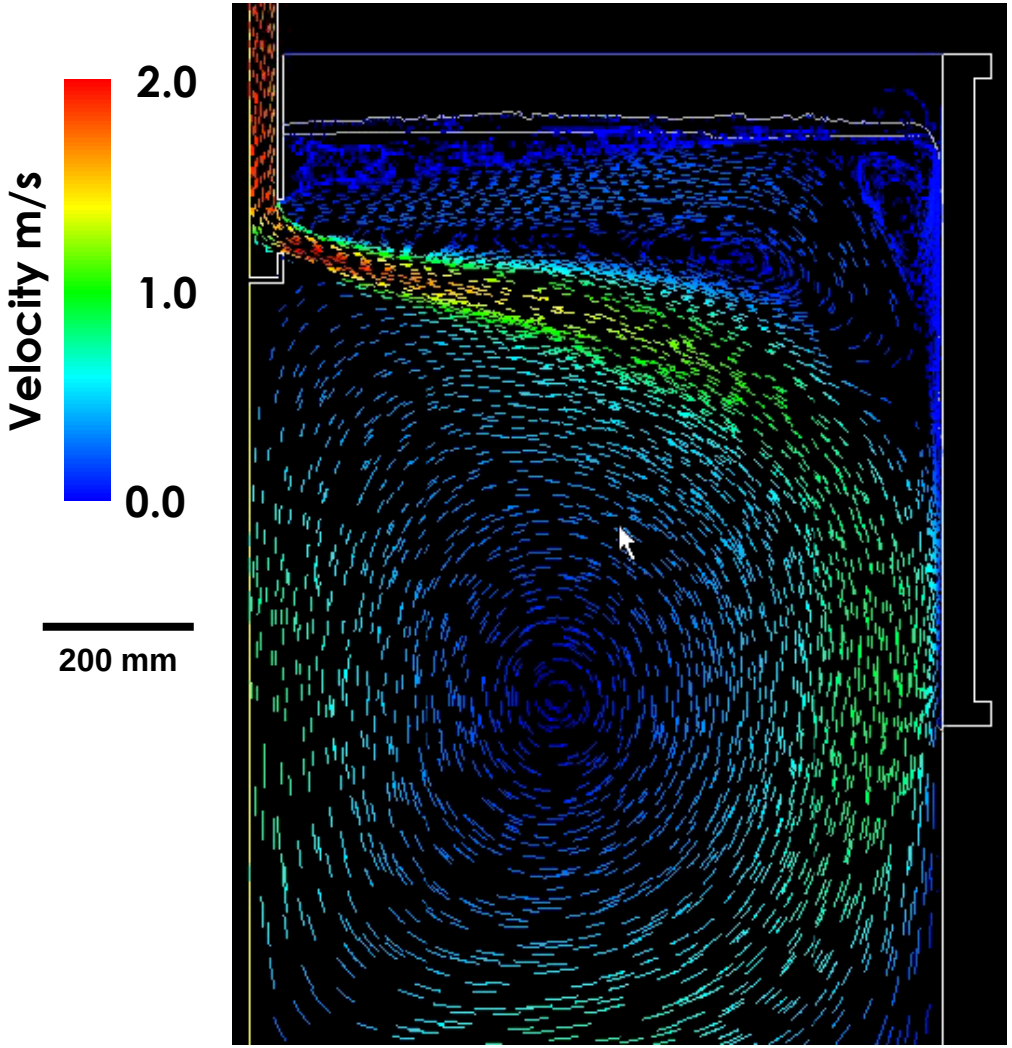
Approach

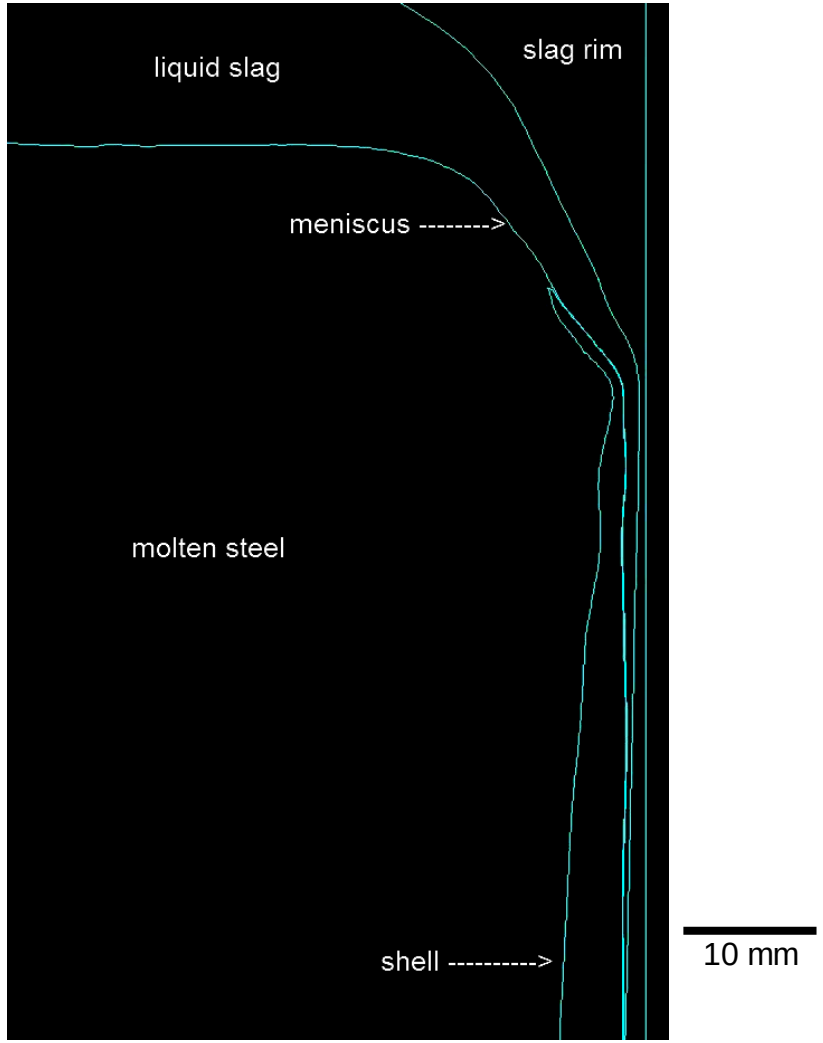
- Multiphase (slag+steel+gas)
- Slag behaviour (solid+liquid)
- Transient
- Mould oscillation
- Extremely fine mesh in the slag film (ca. 50 μm)
- Heat transfer & solidification
- 2D or 3D



Multi-scale predictions

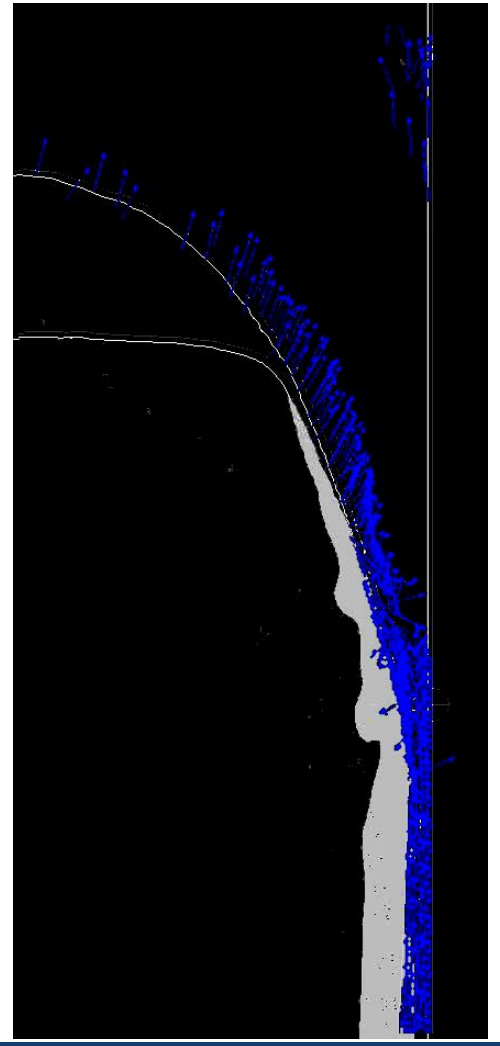
2D model

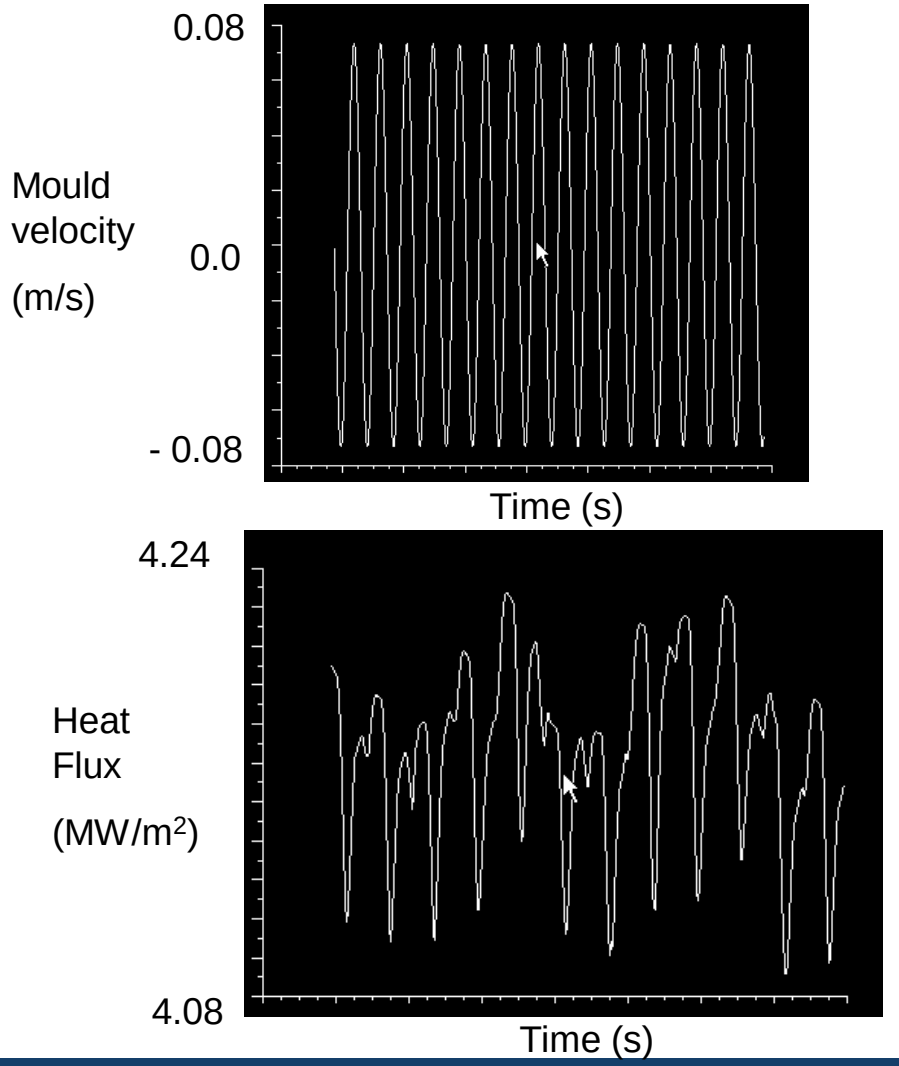




Mould oscillation

Heat transfer during solidification

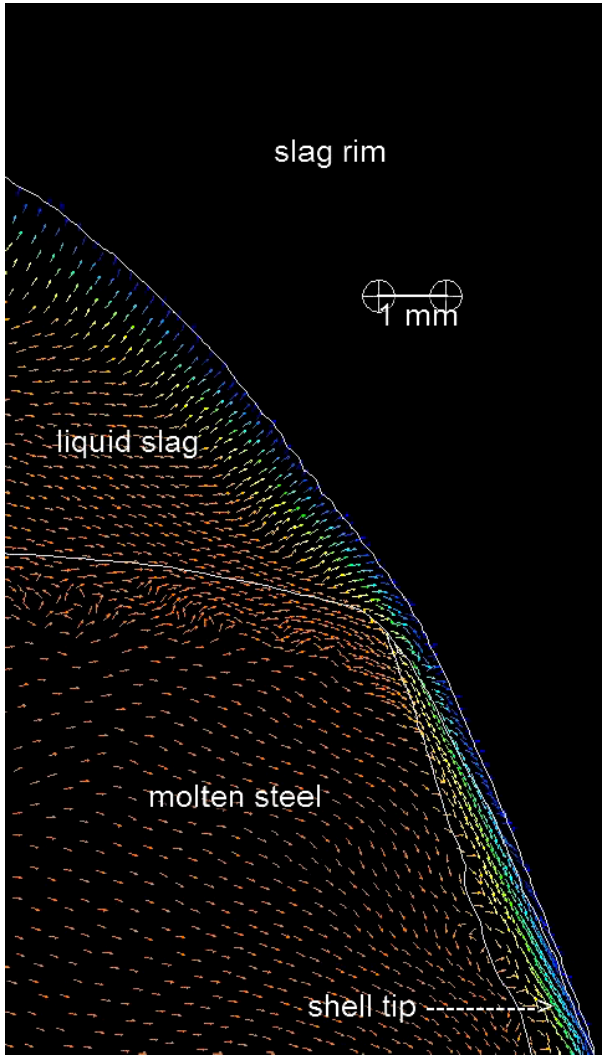


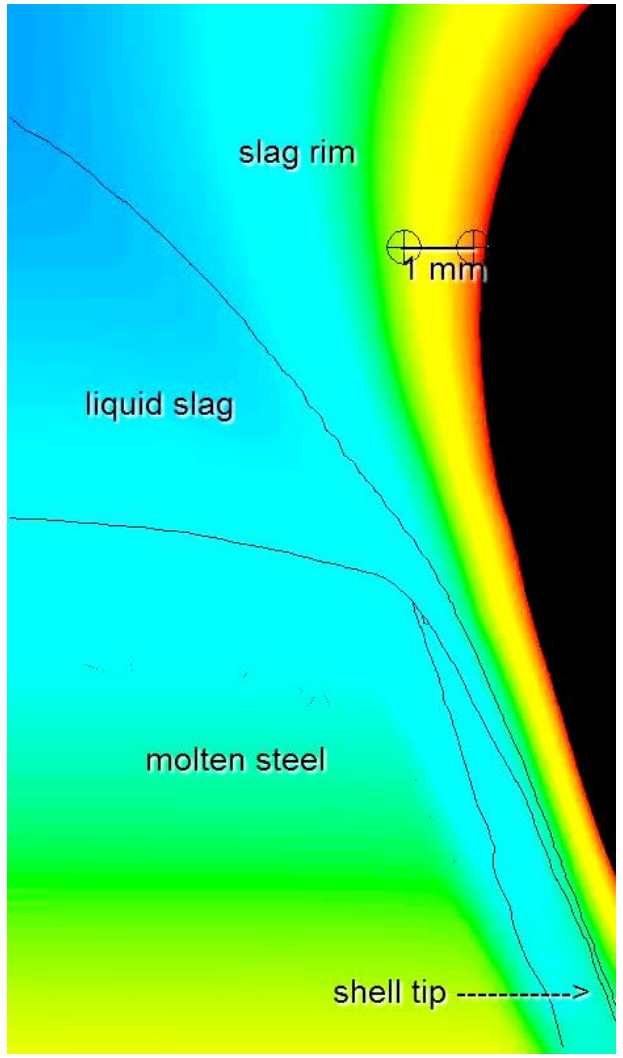


Multi-scale predictions

2D model

Velocity

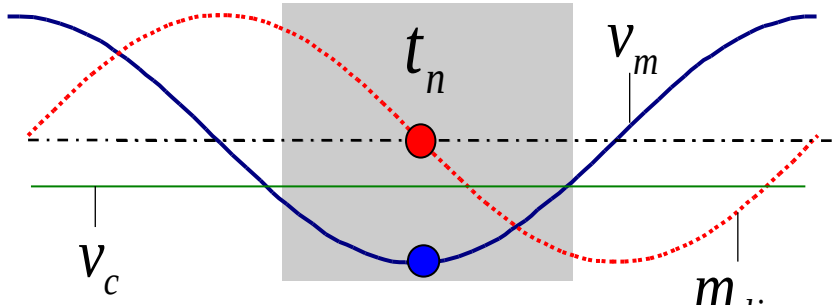


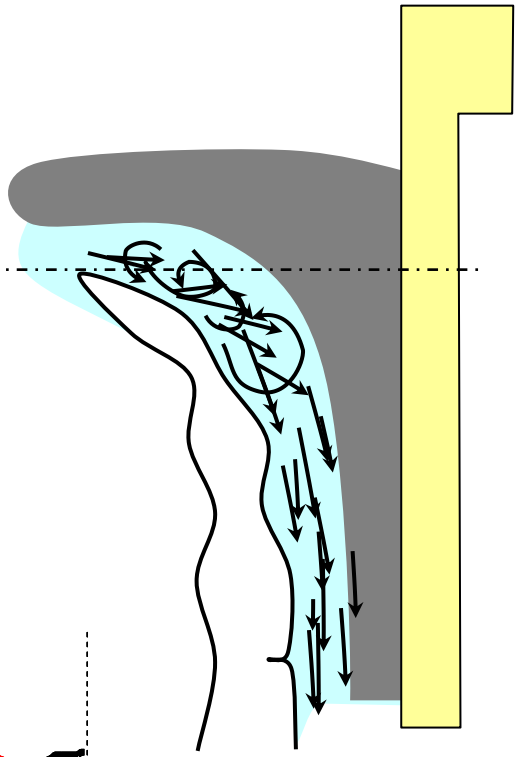


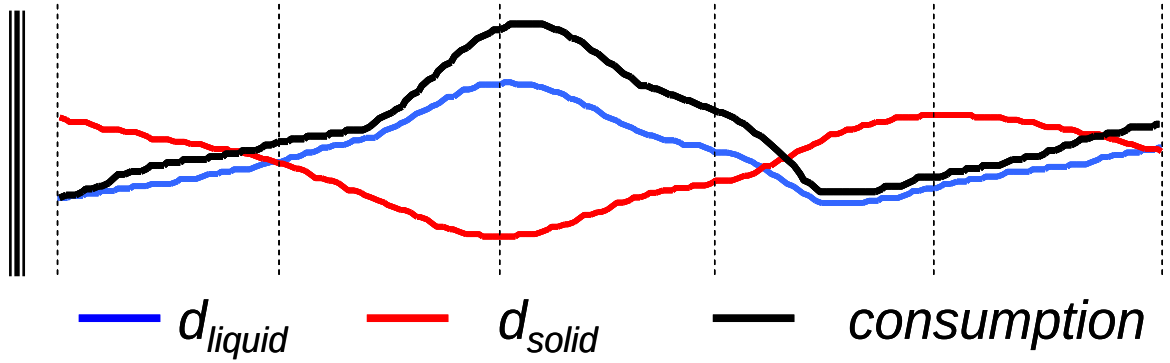
Pressure

Infiltration mechanism

Sample Oscillation mode

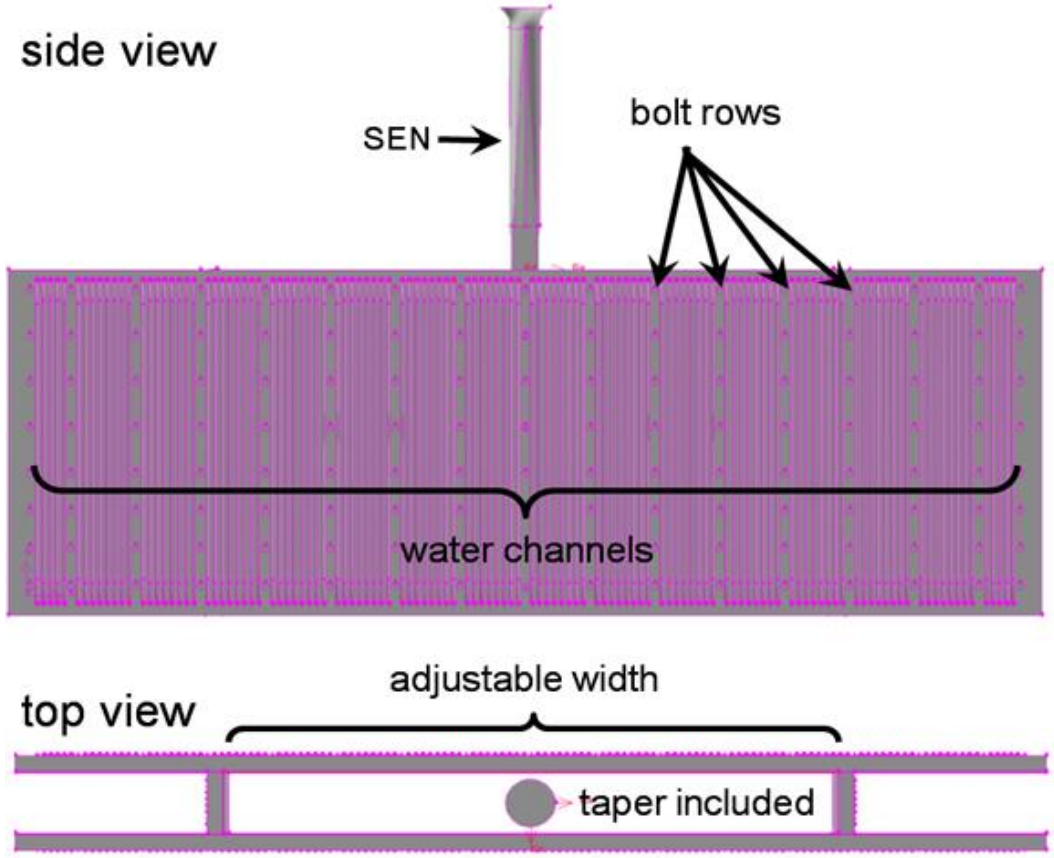


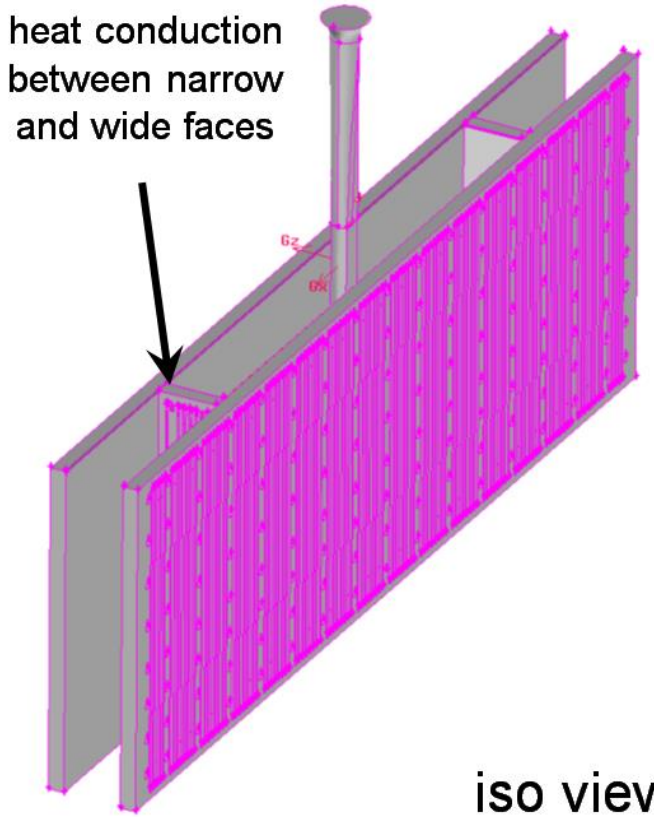




Extension to 3D

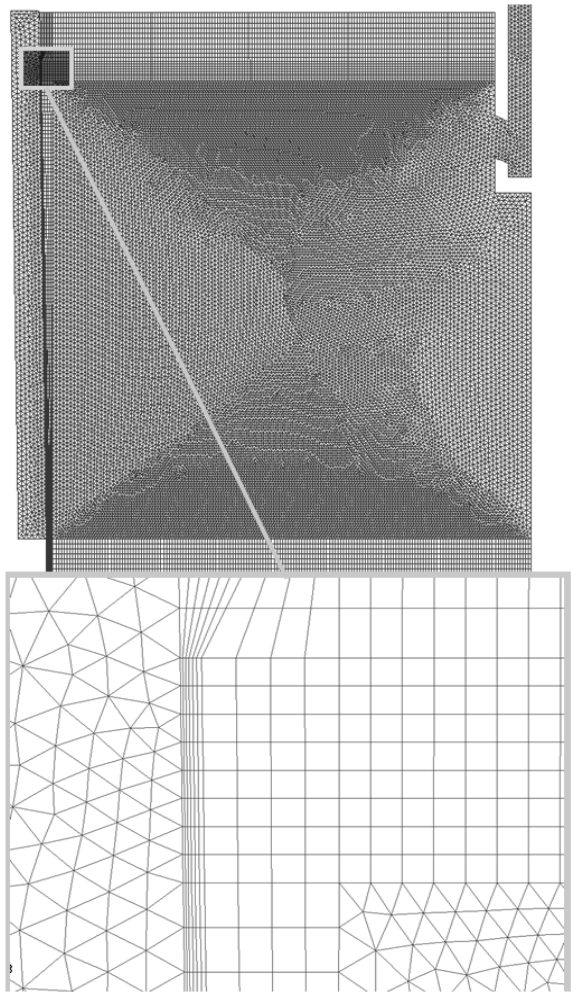
¼ slab model



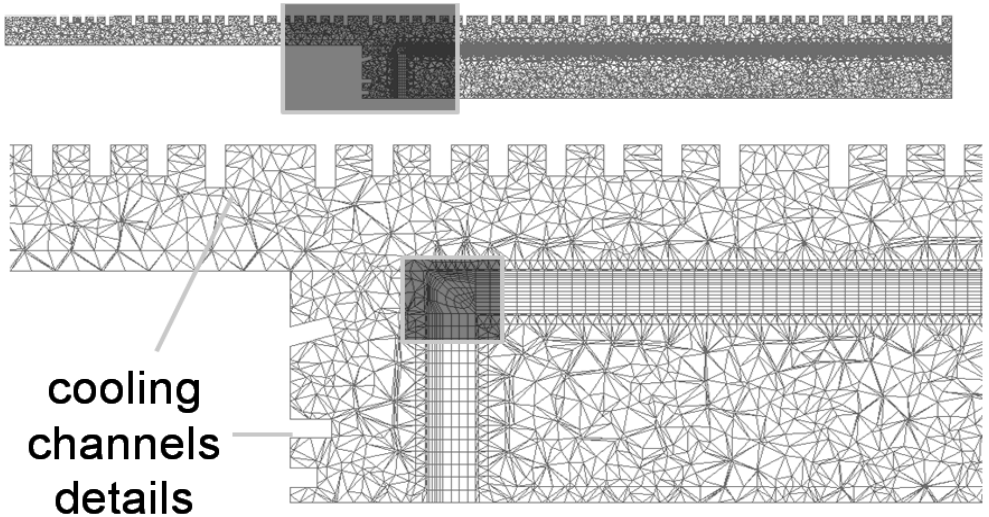


Meshing keypoints

Boundary layer in slag film

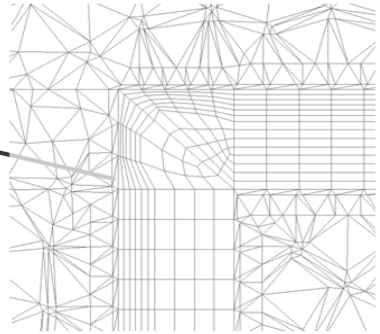


top view including wide and narrow face



cooling channels details

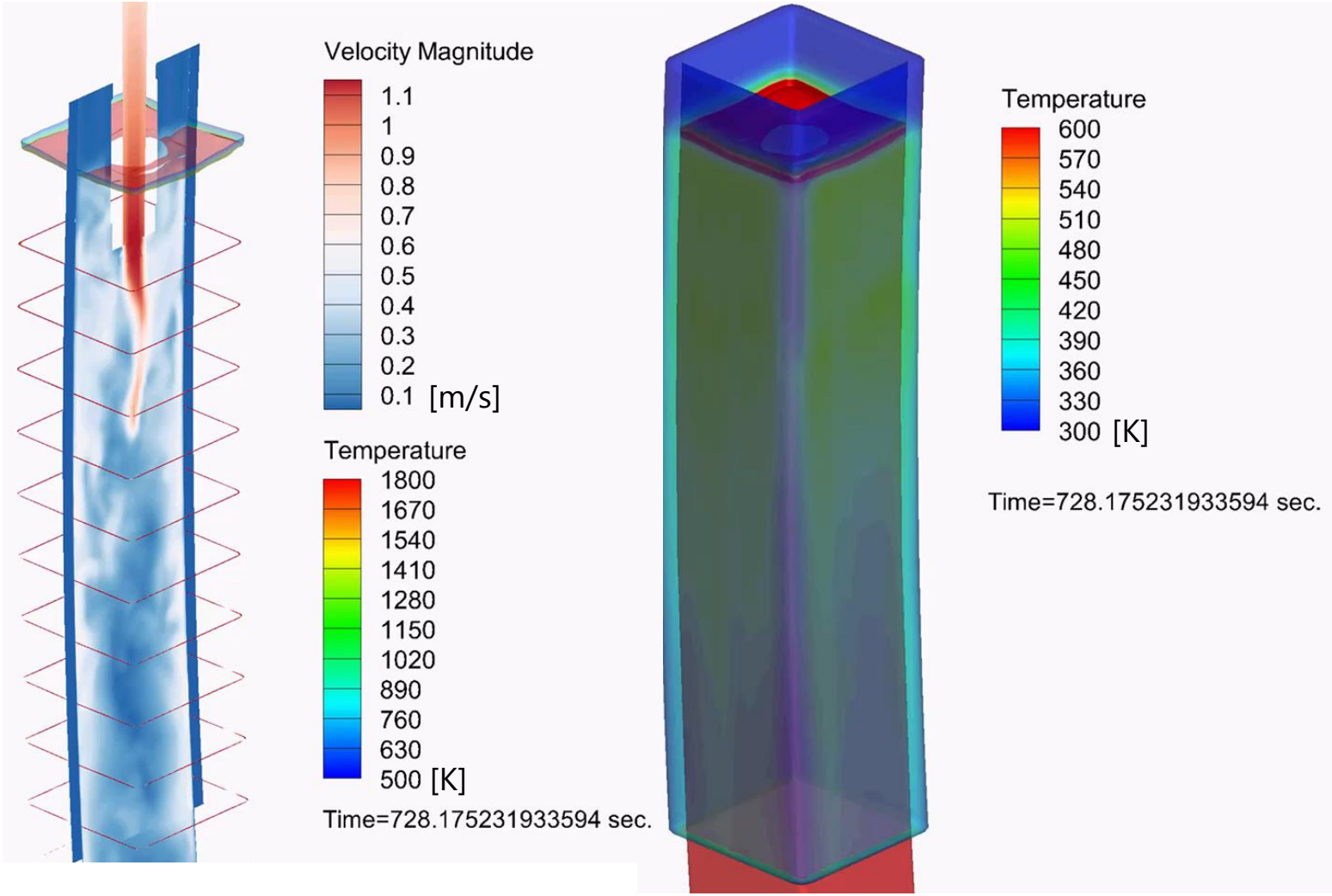
minimum cell size= 100 microns



Application examples

Slag infiltration in Billets under EMS effects

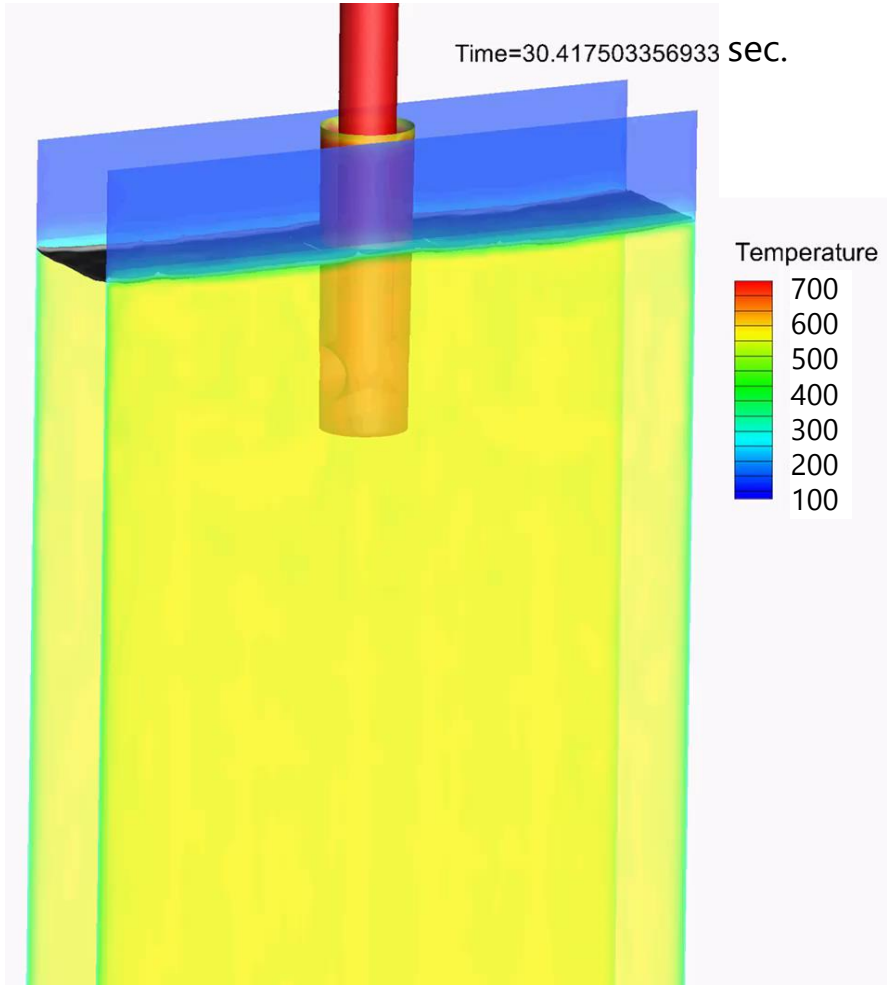
Flow velocity contour with solidified shell formation



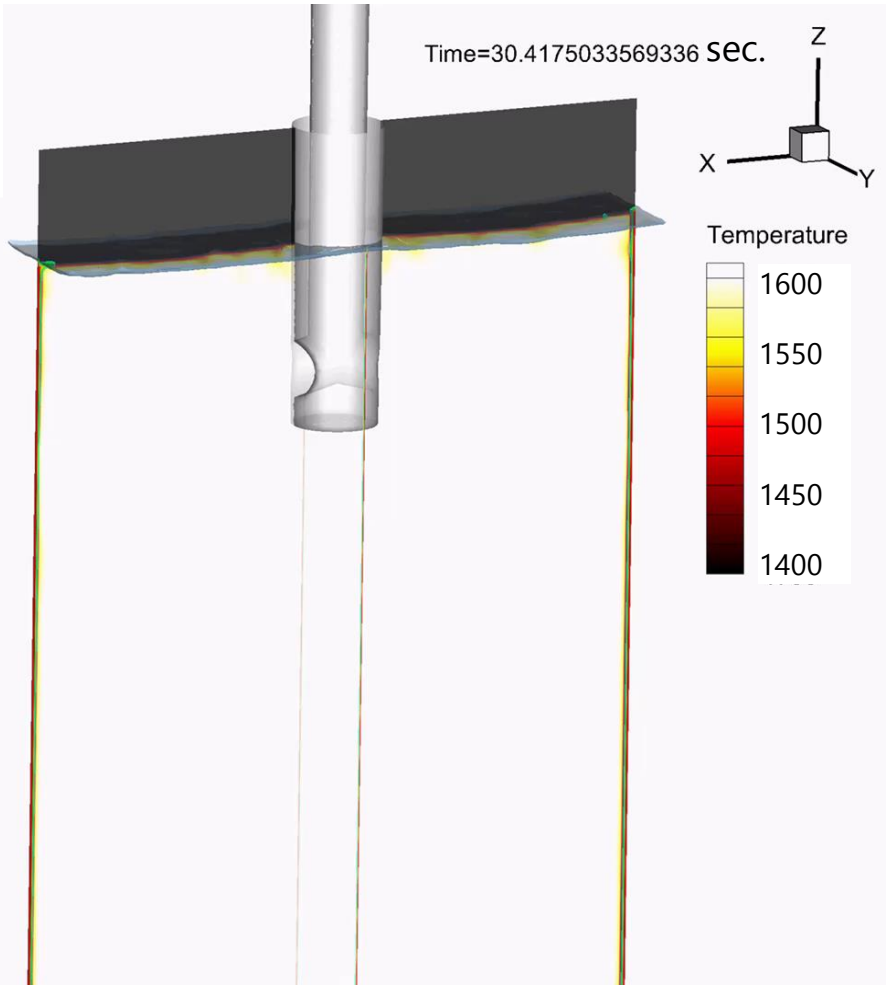
Mold hot-face temperature contour with slag infiltration

Slag infiltration on pilot Slab

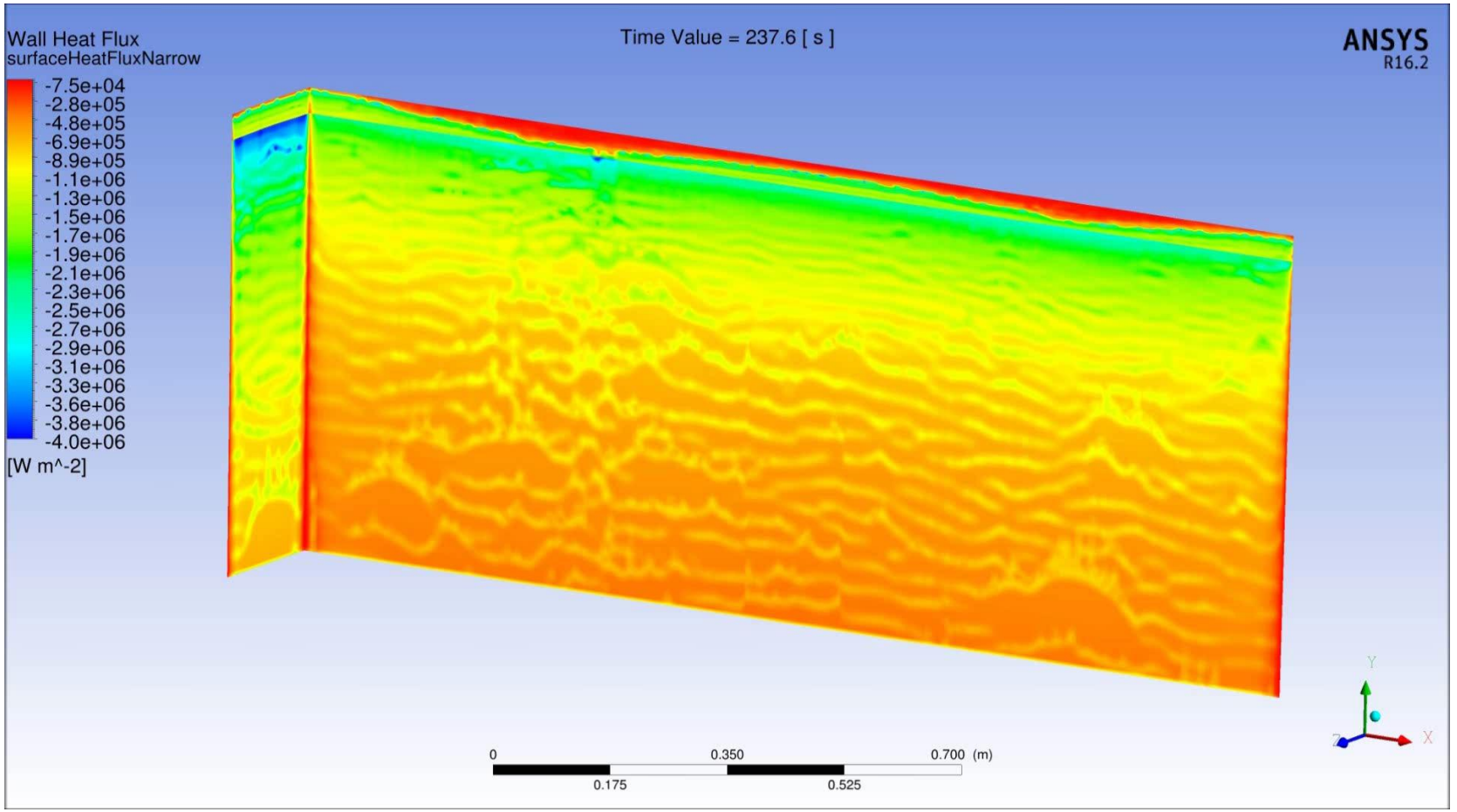
Mold hot-face temperature contour with slag infiltration



Flow temperature contour with solidified shell formation



Mould Wide Face Heat Flux

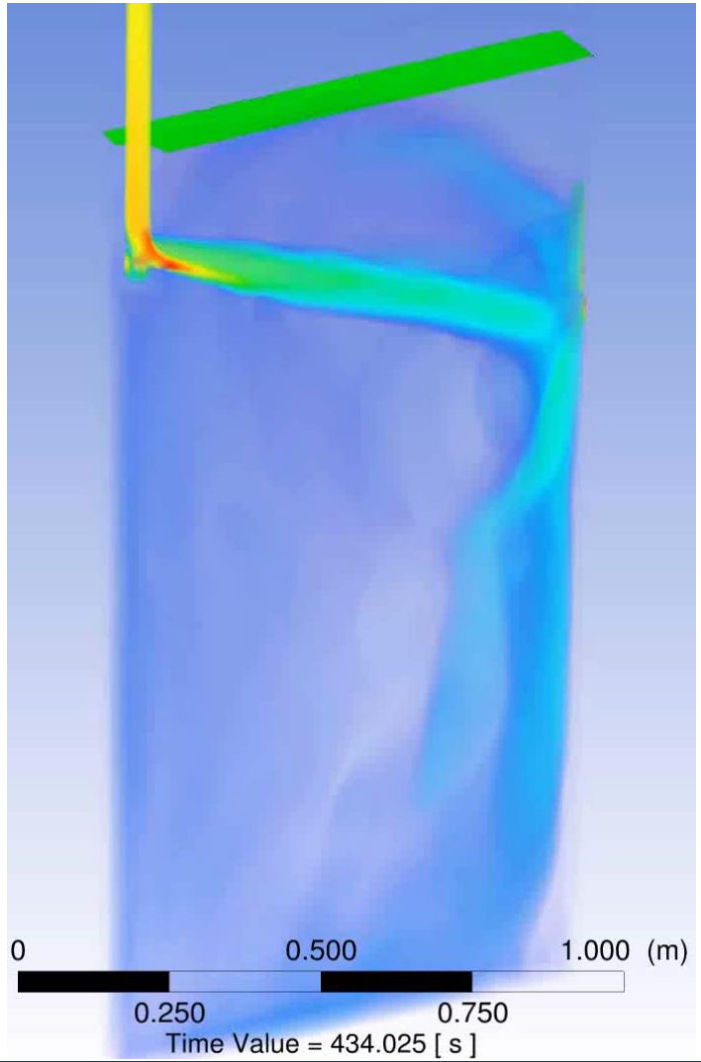


Effects on flow, heat transfer & solidification

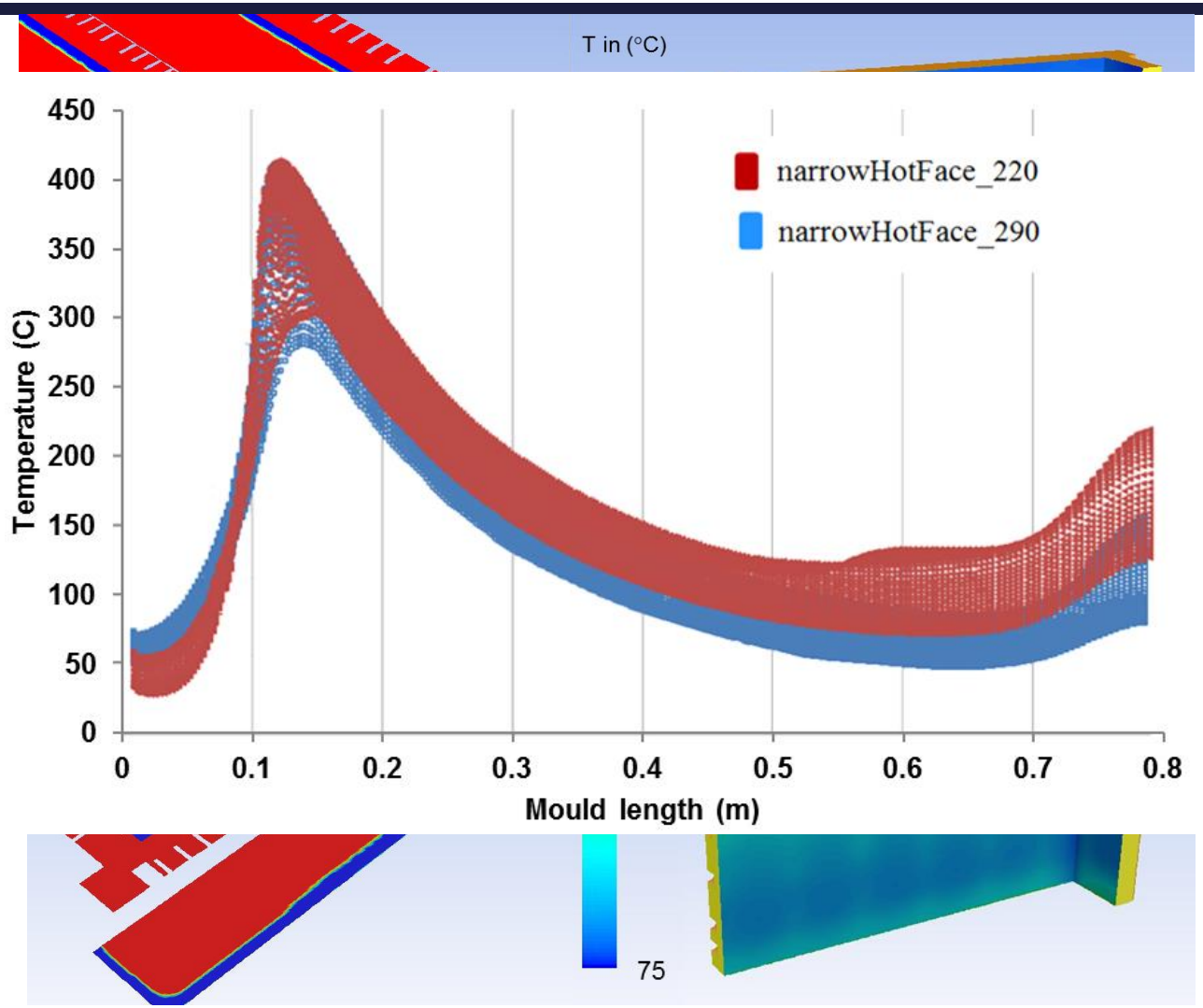
Parametric studies for different casting parameters with results discussed with companies for process optimization and reduction of defects

This includes effects of jet impingement:

- Mould size
- Nozzle performance
- Slag film development
- Shell solidification



Effects on flow, heat transfer & solidification



SUMMARY

Modelling of Slag infiltration during Continuous Casting (as advanced as it is) is far from complete and a variety of phenomena are yet to be included in the simulations which have a direct impact on the process; and thereby, in the quality of the predictions and industrial applicability.

- **DYNAMIC SLAG PROPERTIES!**
- **SLAG CRYSTALLISATION…**
- **SLAG-METAL REACTIONS combined with flow and solidification**
- **MODELLING VARIABLES IN THE REAL PROCESS (Operator praxis, Slag bed thickness, Powder feeding, etc.)**
- **MEASUREMENT TECHNIQUES for mould powders during CC**

RFCS Projects

The research leading to these results has received funding from the European Union's Research Programme of the Research Fund for Coal and Steel (RFCS) for the following projects:

RFCS DDT- Direct Defect Toolbox

RFCS SUPPORT-CAST

RFCS NNEWFLUX

SWERIM

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Thanks for the attention!

Stay informed

http://valcra.eu/

https://www.linkedin.com/company/european-continuous-casting-network

VALCRA linkedin group (linkedin.com/groups/13794289/)