

Influence of electric-fossil combined heating on the total energy demand and the microstructure development in break down passes

The project has received funding from the European Union's Research Fund and Coal and Steel under grant agreement N. 101099118.

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Agenda

Motivation

Challenges

Hybrid Heating Technologies

Technological Challenge

Methodological Approach

Material and Properties

Technology Design Lab Scale

Roll Pass Simulation with PyRoLL

Conclusions

Motivation

2023:

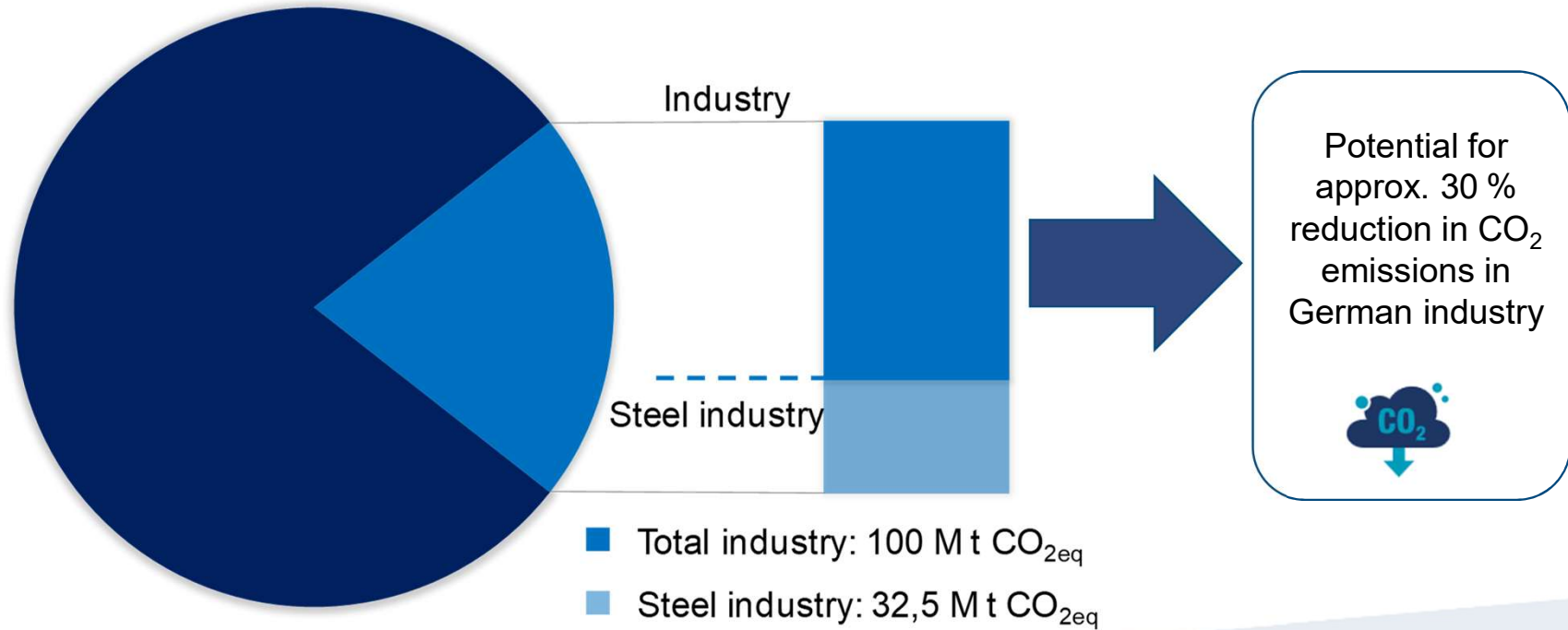
35,4 M t of crude steel



Natural gas consumption in the German steel industry
2.1 billion m³



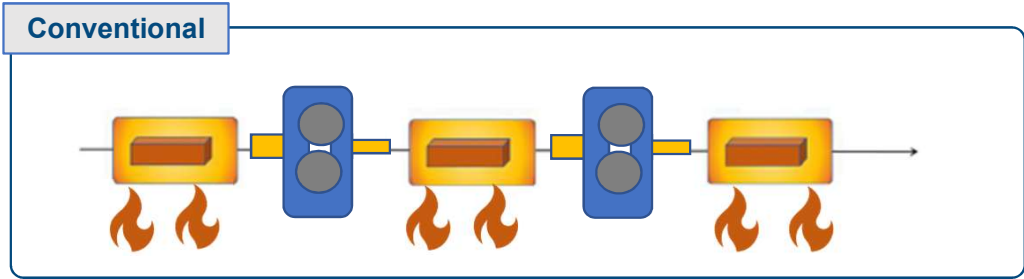
Greenhouse emissions in Germany in 2023: 674 M t of CO_{2eq}



statista

Implementation of renewable energy in steel production

Challenges



Heating by convection and radiation
 Furnace heated with fossil fuels
 Heat input only via the surface

↓

Poor CO₂ footprint

Goal → Material-optimised heating and forming route for groove rolling

 **Hybrid heating to reduce the use of fossil fuels**

Strong influence on Tc on dependence of the thermo-physical and magnetic material properties

↓

Loss of efficiency in energy input with different material dimensions and surface conditions

↓

Hybrid technologies reduce energy losses

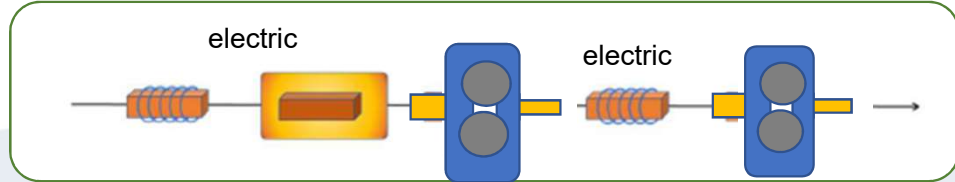
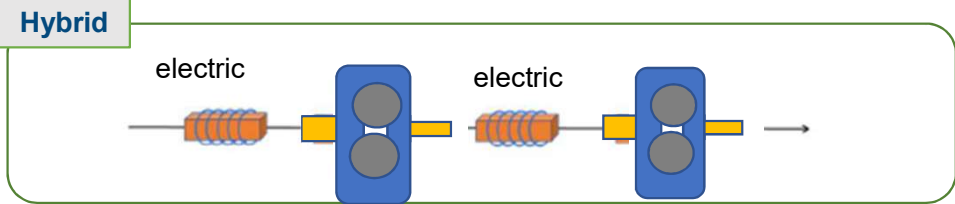
Rapid heating results in a changed initial state

↓

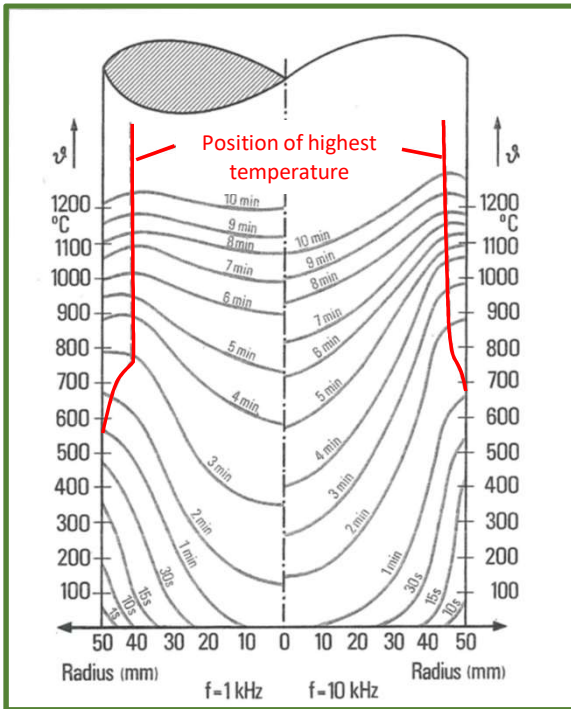
Inhomogeneous initial conditions in the material

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Technology adaptation required for hybrid heating



Technological Challenge



Source: Pfeifer, H: Taschenbuch industrielle Wärmtechnik, Vulkan-Verlag 2007

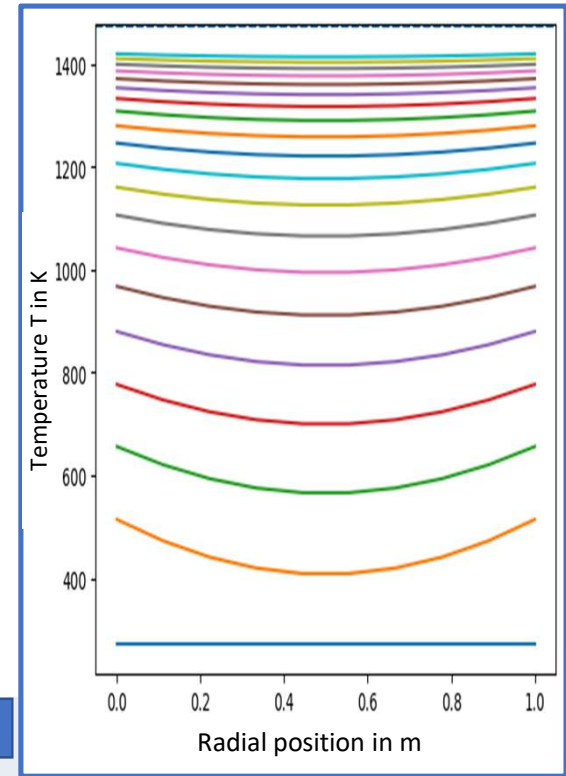
Inductive / conductive heating

- Electromagnetic properties and frequency determine the penetration depth of inductive and conductive heating
- Highest heating below the surface

Control of the heating rate and thus the phase transformation and precipitate formation through inductive-convective combined heating

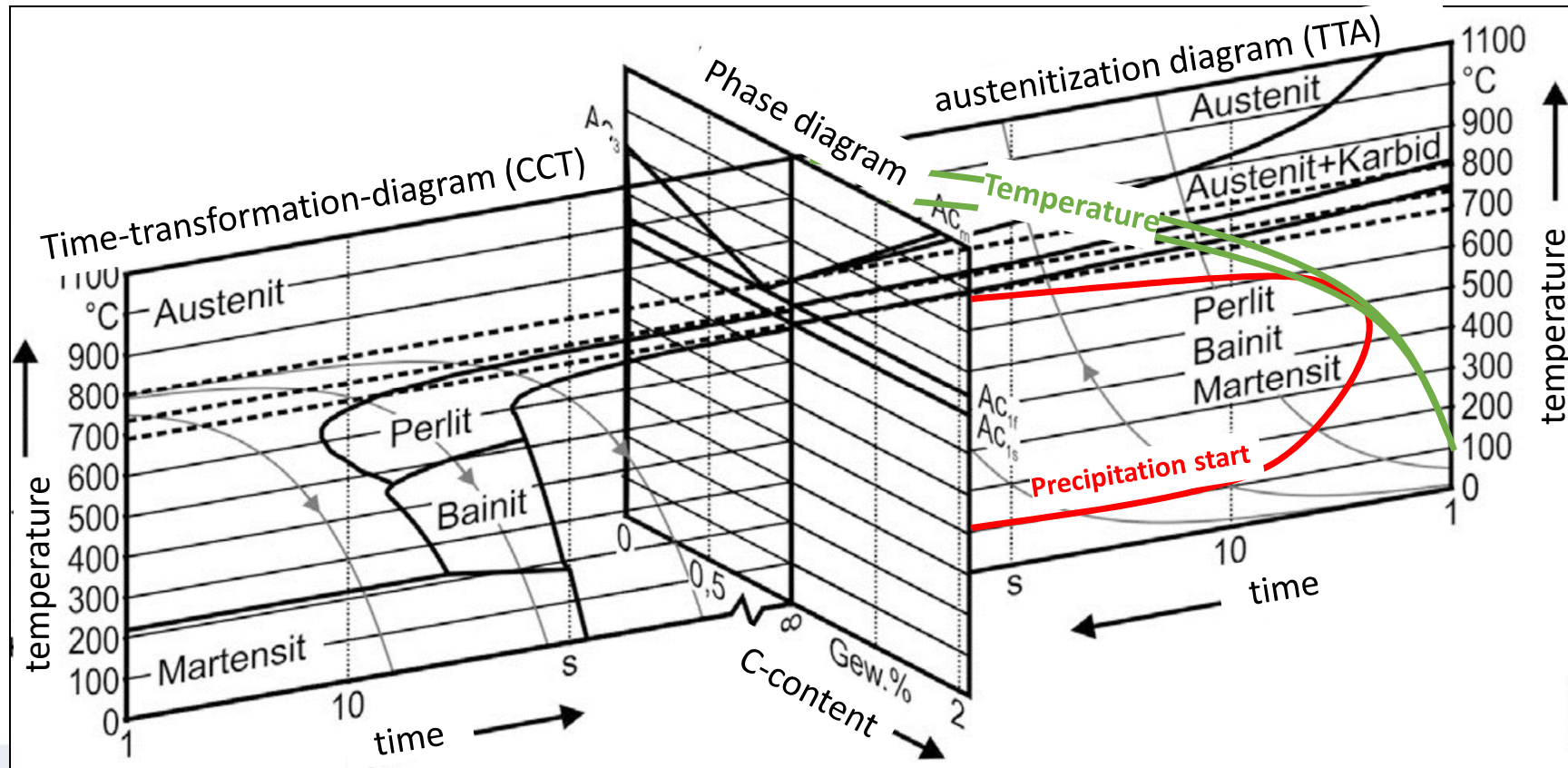
- Heat input depends on surface scaling, heat conduction and radiation
- Highest heating at the surface

Convective heating



Technological Challenge

Methodical approach: Control of the heating and cooling rate and thus the phase transformation and precipitate formation through inductive-conductive combined heating

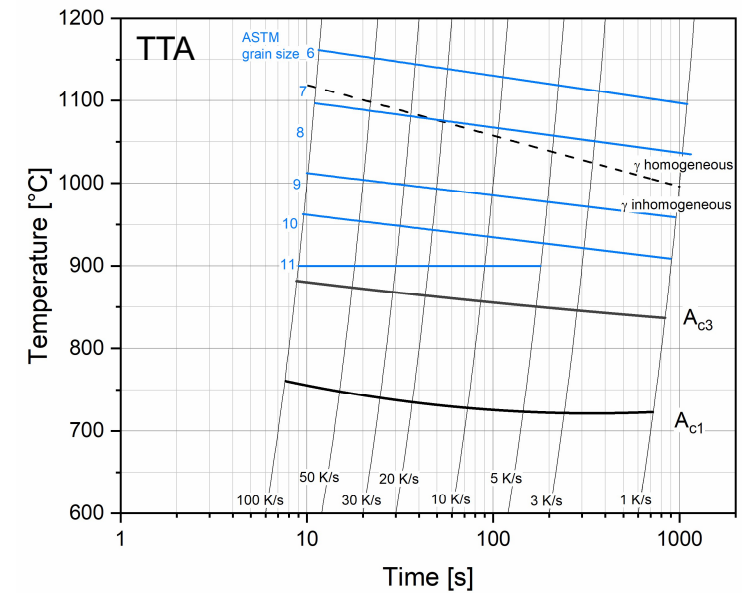
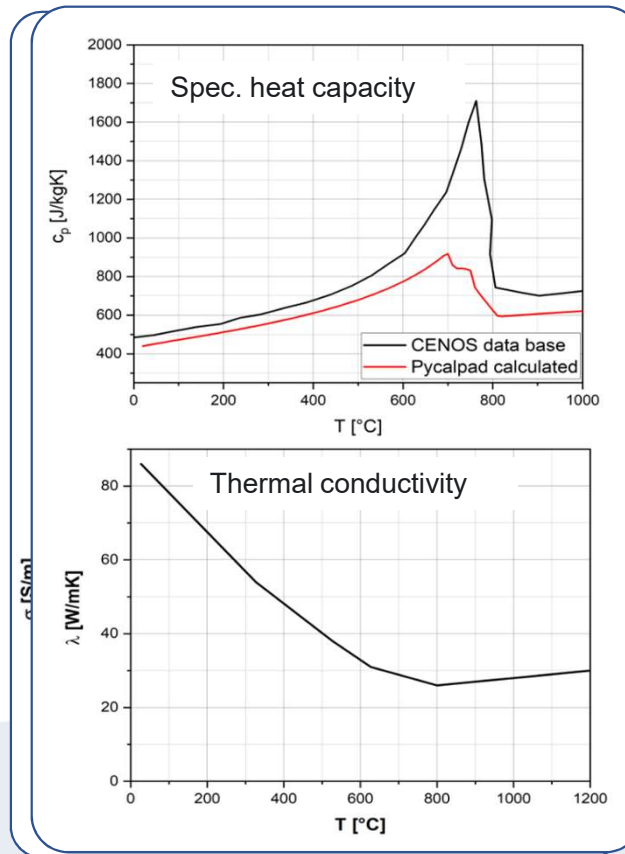
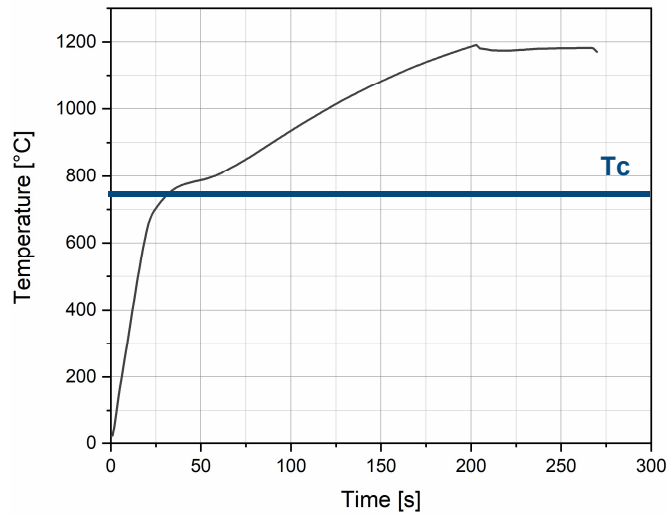


Material properties



Temperature Dependent Material Properties

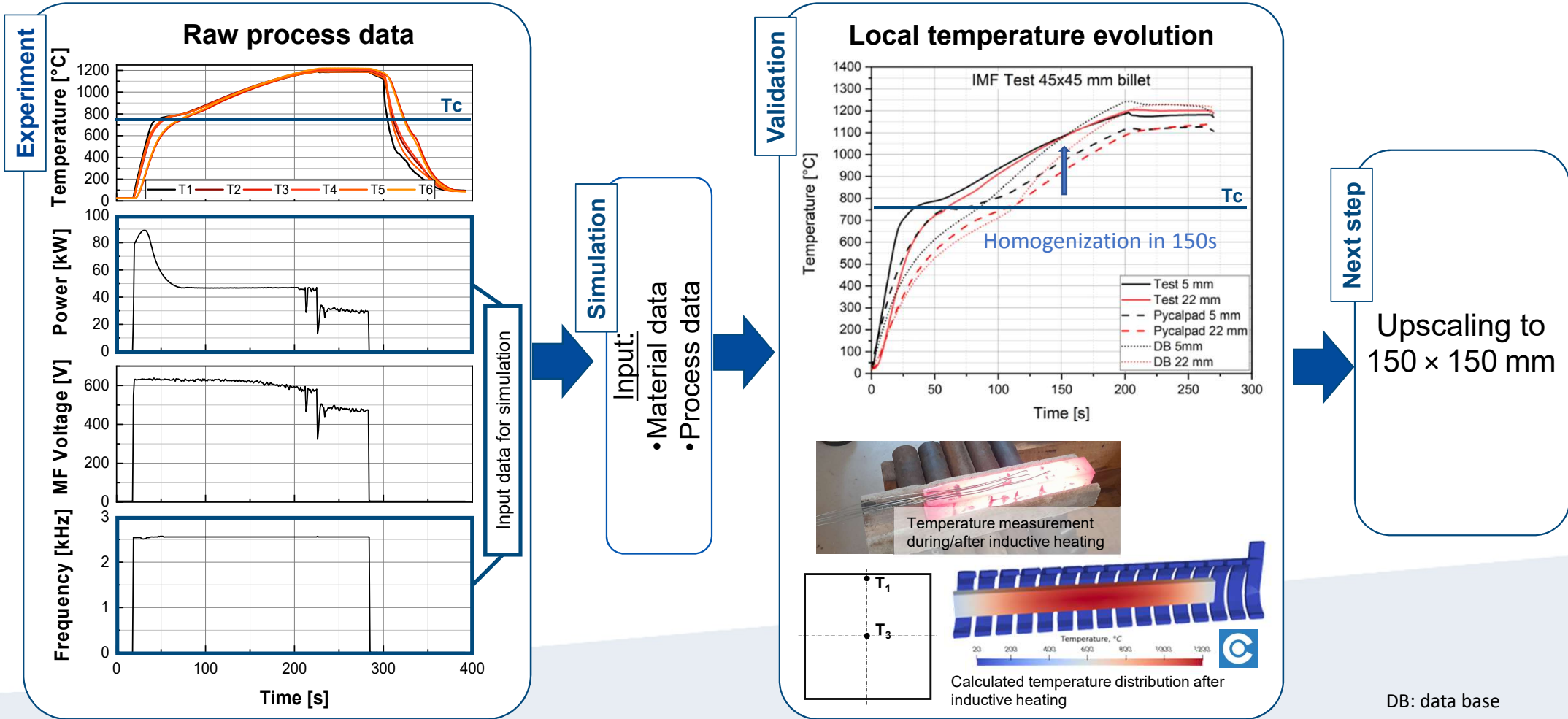
C	Mn	Si	P	S	N	Ni	Al	Cu	Sn	Fe
0.20	0.91	0.25	0.02	0.029	0.001	0.160	0.001	0.37	0.013	bal.



Evaluation of thermal model - Induction -



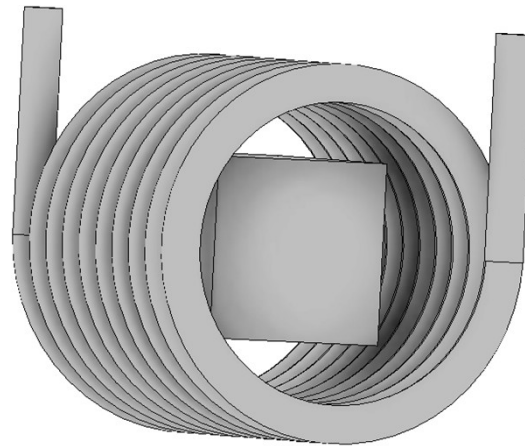
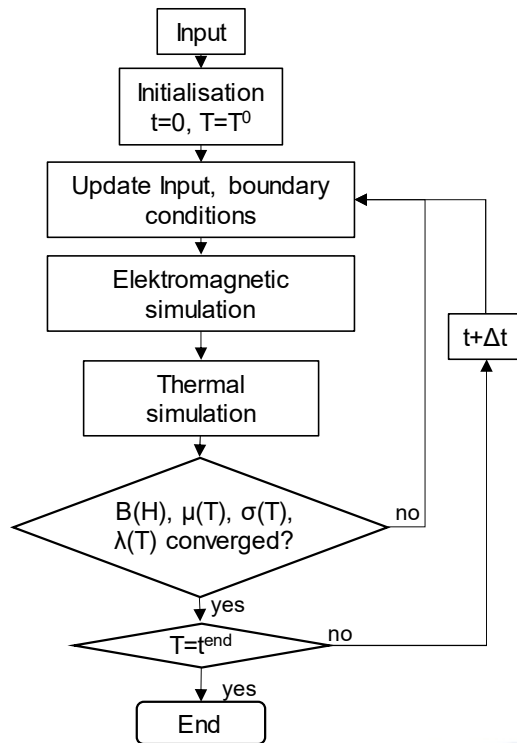
Technology Design Lab Scale – 45 × 45 mm Billet



DB: data base

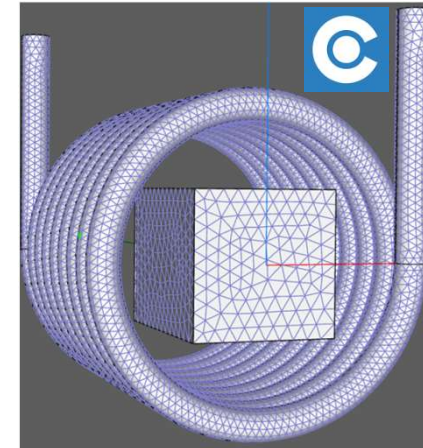
Simulation of inductive heating of 150×150 mm billet

Accurate algorithm uses two-way coupling: the electromagnetic source is converted depending on temperature field until convergence is reached



Technical data of the VIM12 Coil

Inner diameter [mm]	320
Outer diameter [mm]	365
Coil length [mm]	420
Number of windings	8



Input data for the simulation

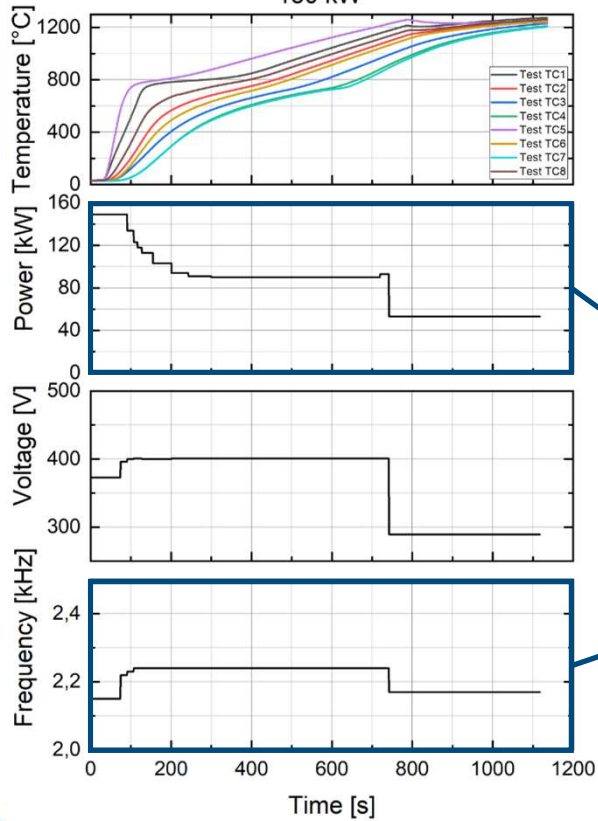
- Initial and room temperature 22 °C;
- Convection with heat transfer coefficient $h=15 \text{ W}/(\text{m}^2\text{K})$;
- Radiation with Emission coefficient $\epsilon=0,8$;
- Permeability $\mu=234$;
- Frequency 2500 Hz (from heating test);
- Power from heating test;
- No accounting for phase transformation during heating.

Technology Design Lab Scale – 150 × 150 mm Bloom

Experiment

Raw process data

150 kW

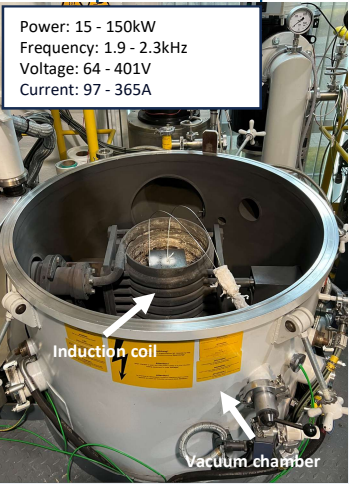


Input data for simulation

Simulation

- Input:
- Material data
 - Process data

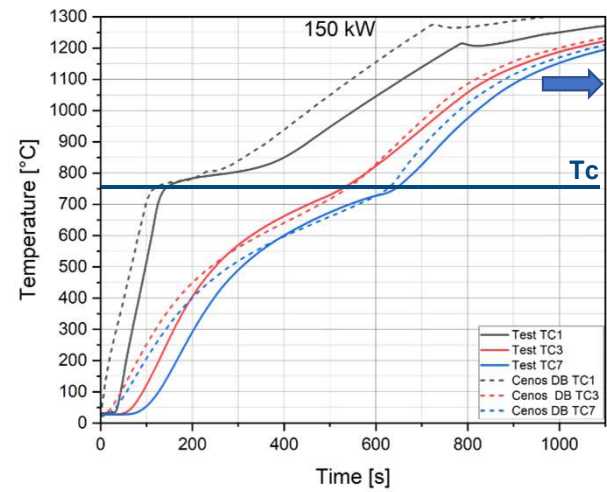
Validation



IEST Vacuum Induction Furnace

Local temperature evolution

150 kW

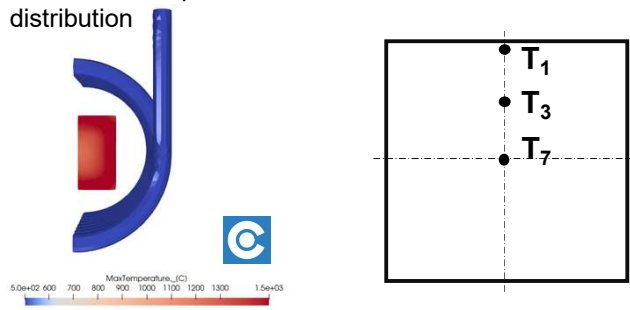


Homogenization in >1000s

Next step

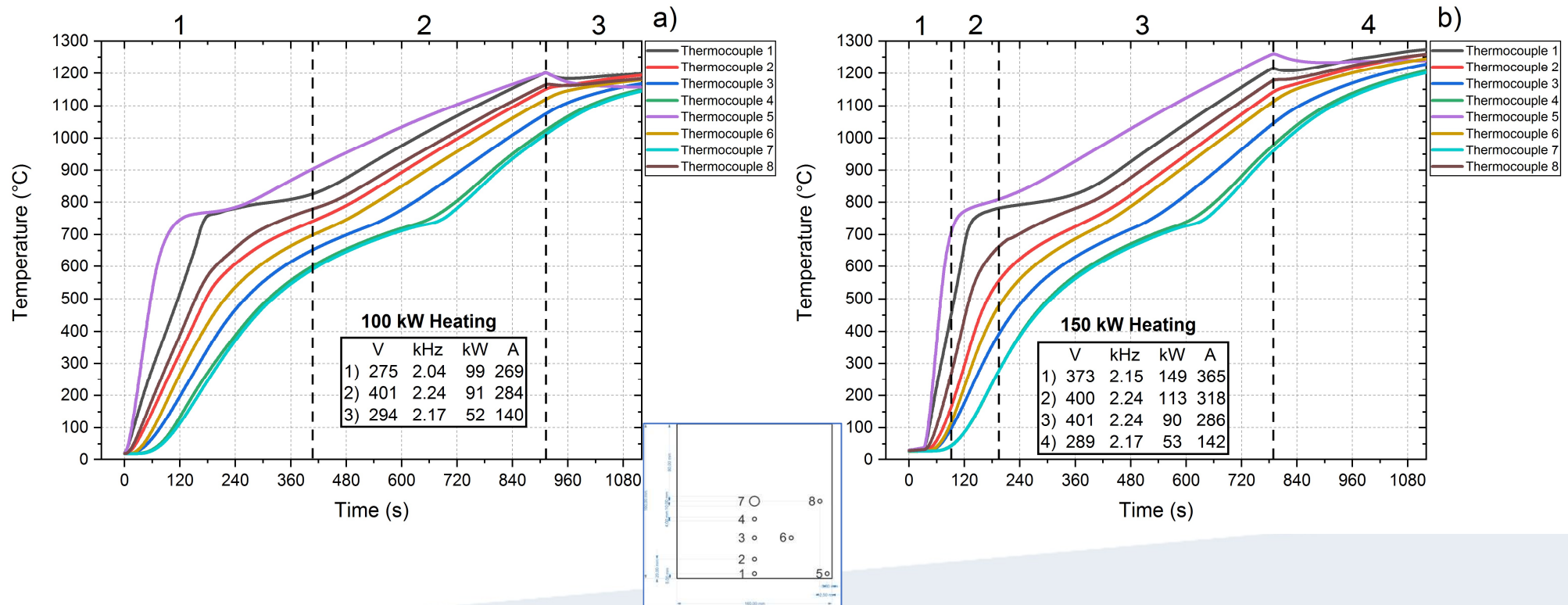
Industrial roll pass calculation

Calculated temperature distribution



Inductive heating in VIM

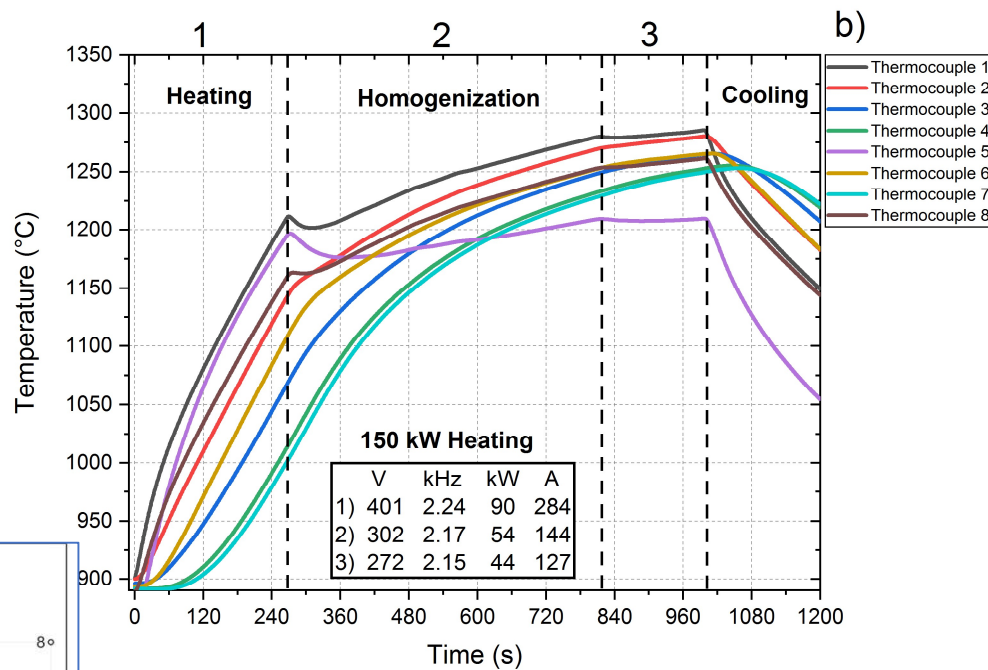
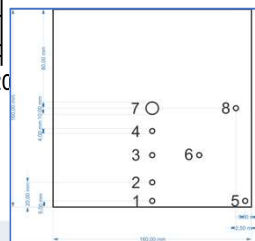
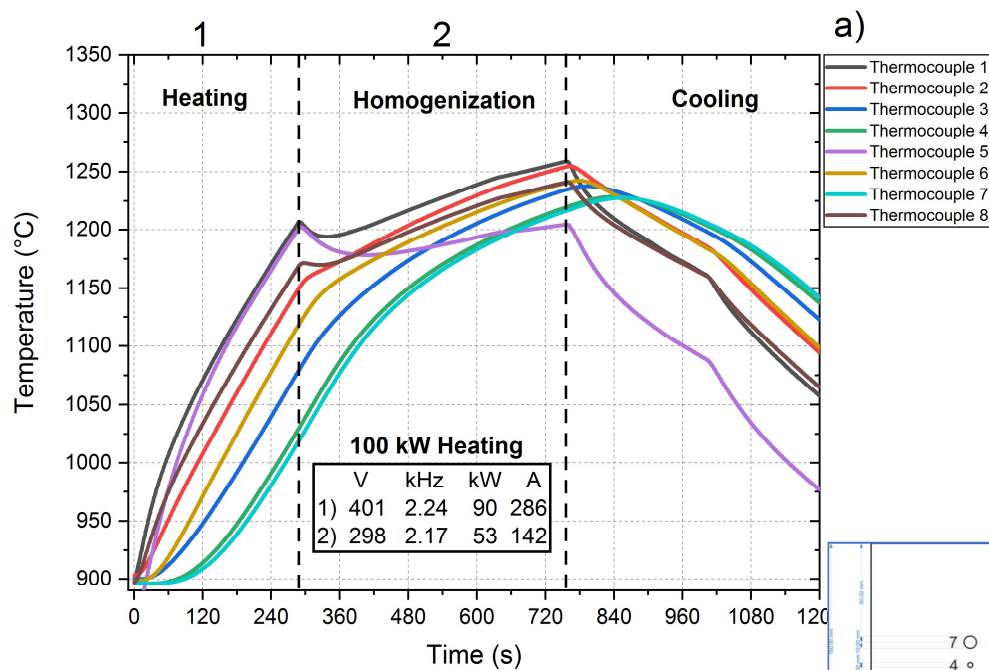
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Heating Test from Room Temperature up to 1200°C with Homogenization

Inductive heating in VIM

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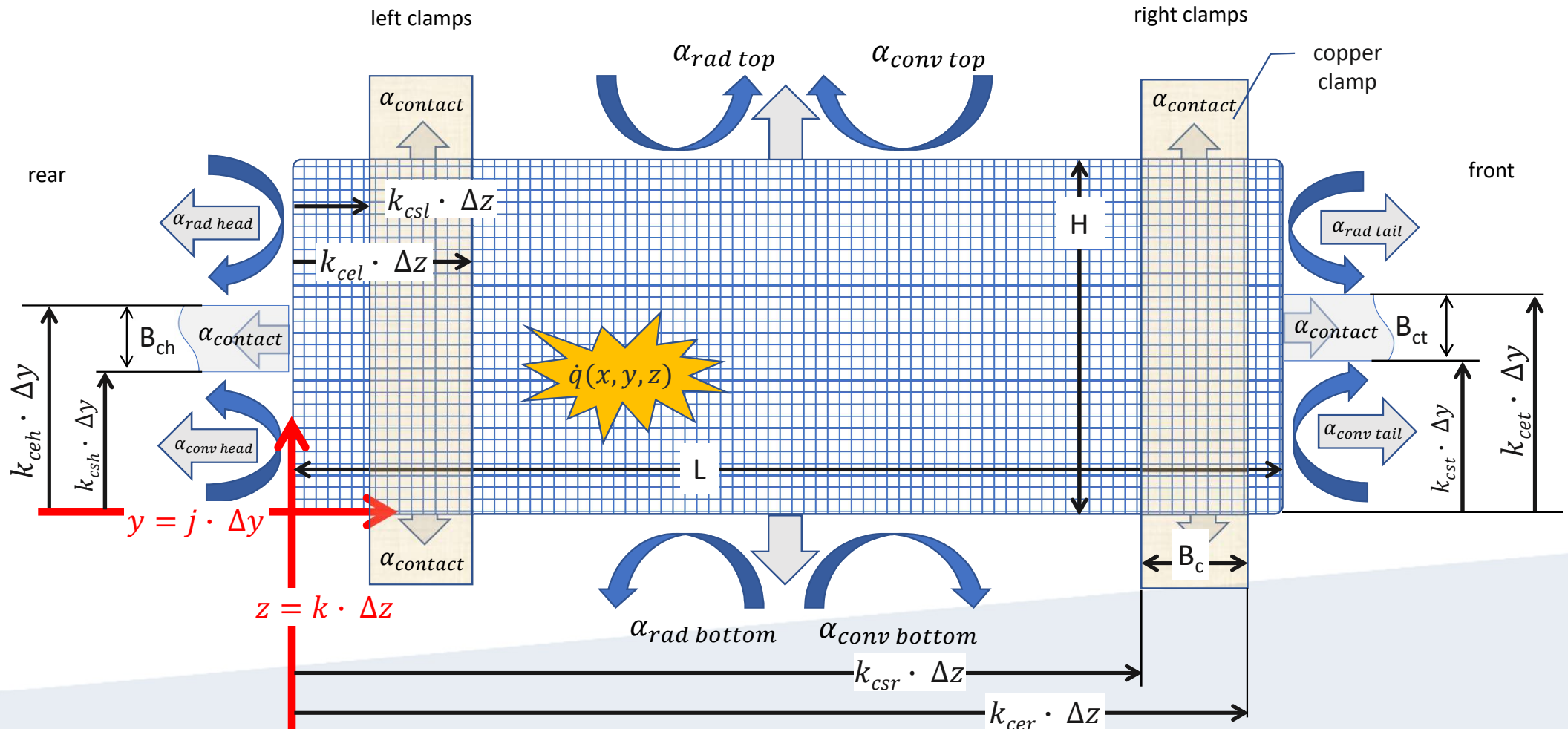


Heating Test from 900°C up to 1200°C with Homogenization

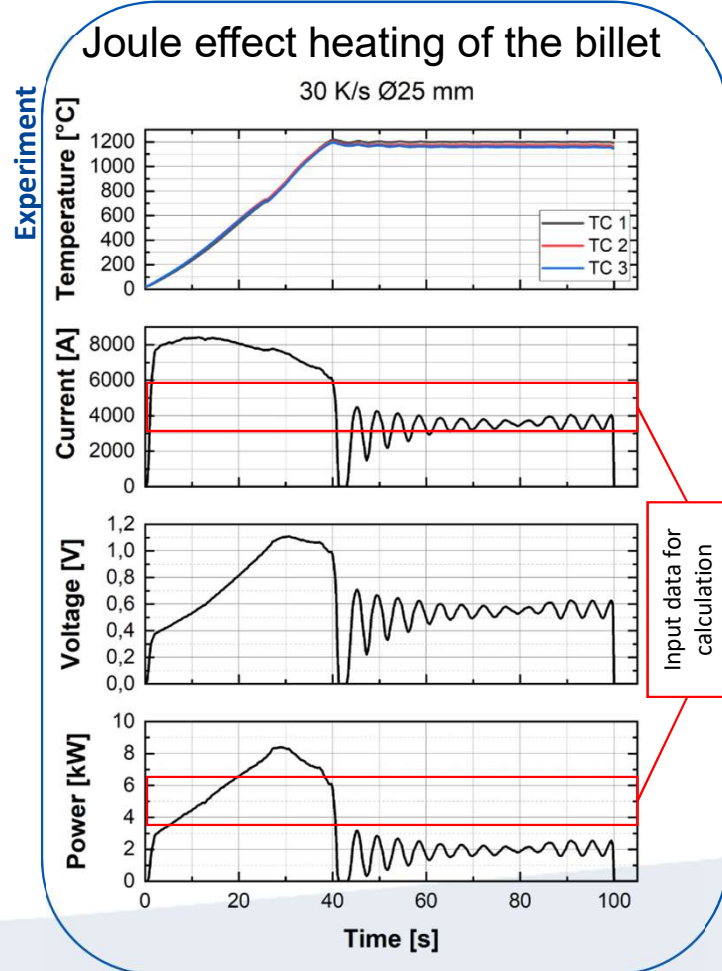
Evaluation of thermal model - Conduction -



Heating of a billet by conduction / induction – extended 2D approach



Technological design labscale

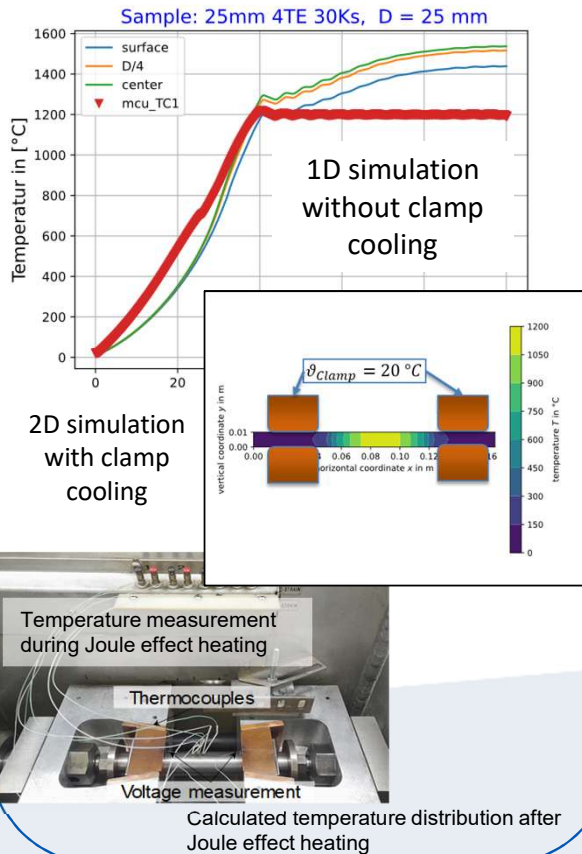


Simulation

- Input:**
- $T=22\text{ °C}$;
 - $h=15\frac{W}{m^2K}$
 - $\epsilon=0,8$;
 - Thermo-physical data = $f(T)$
 - Homogeneous electr. current distribution
 - No accounting of phase transformation during heating.

Validation

Validation of the calculation results with experimental data



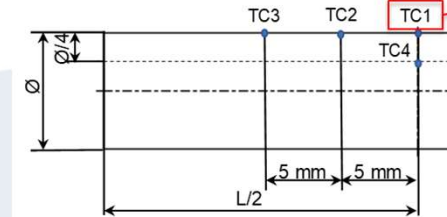
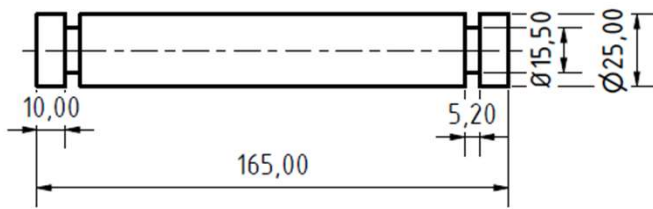
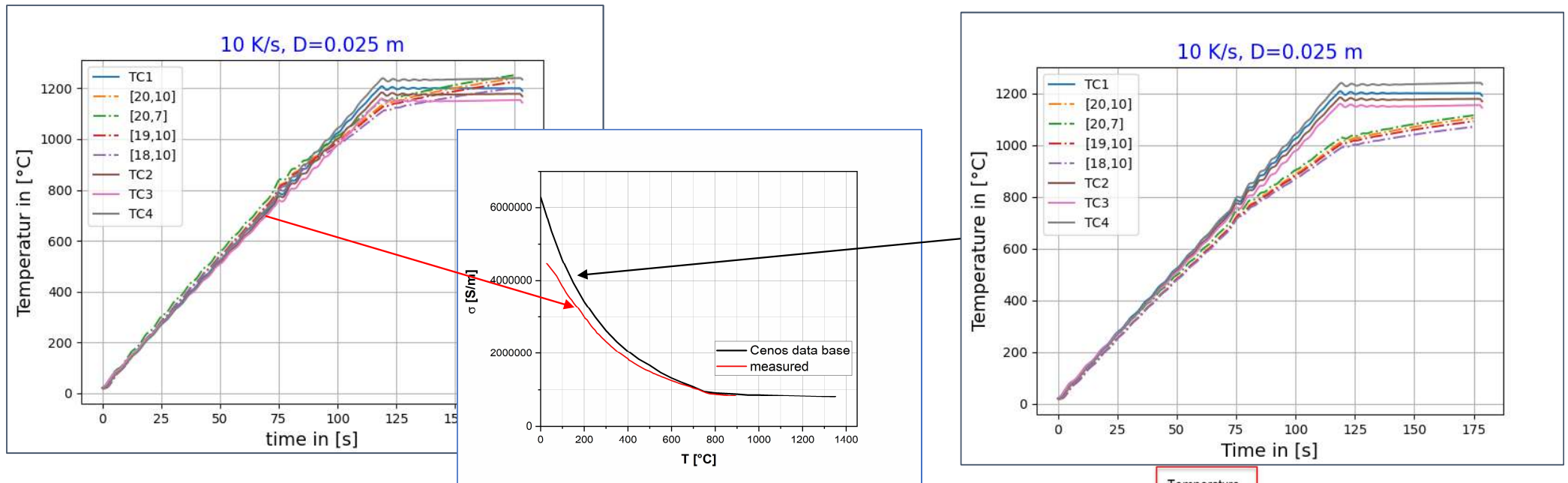
Outlook

Next steps

- improve material data;
- thermal influence of system design during conductive heating;
- calculate parameter variation with simulation tool;
- recalculation of industrial data

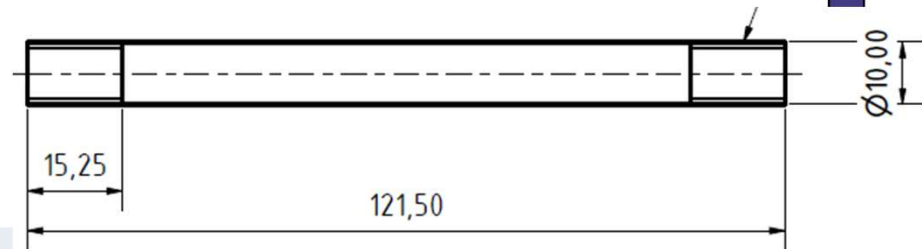
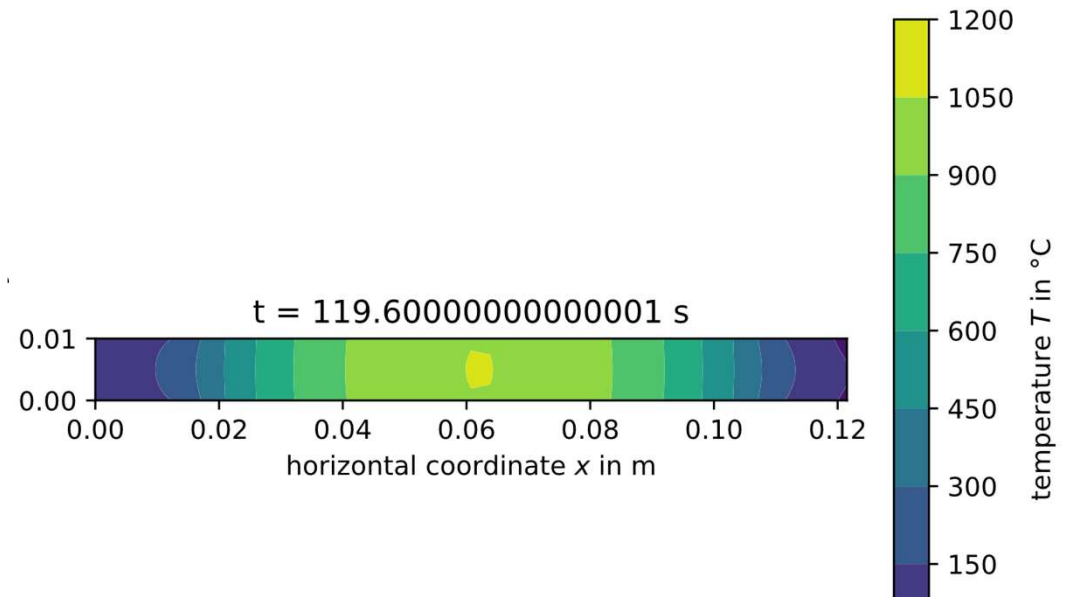
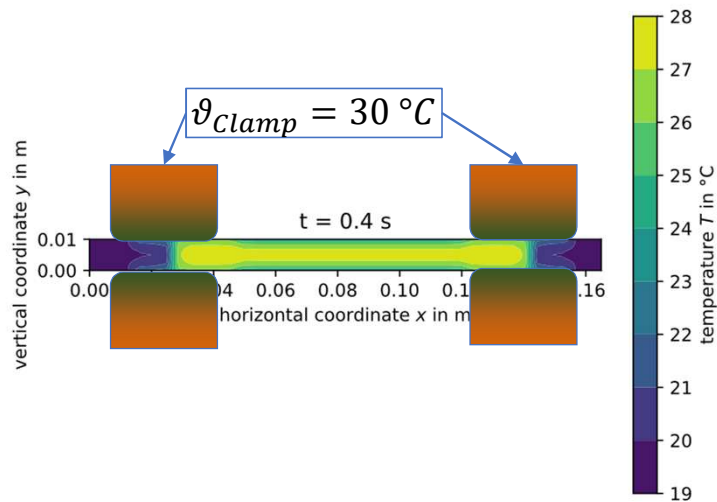
(1) Depending on the state of progress of the project, i.e. PR1 or PR2

Temperature distributions MCU 25 mm samples with clamp cooling heating rate 10K/s – effect of accuracy of material data



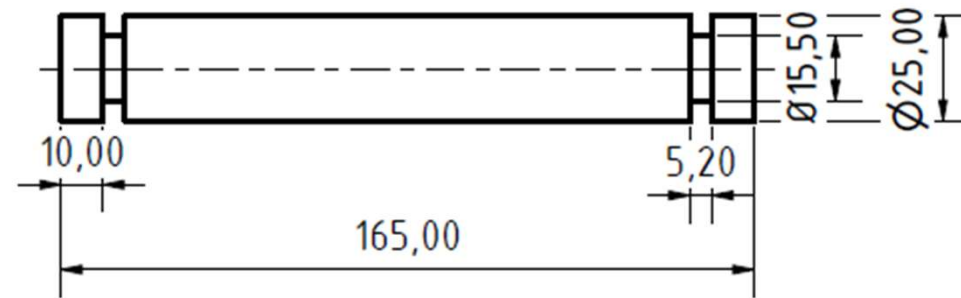
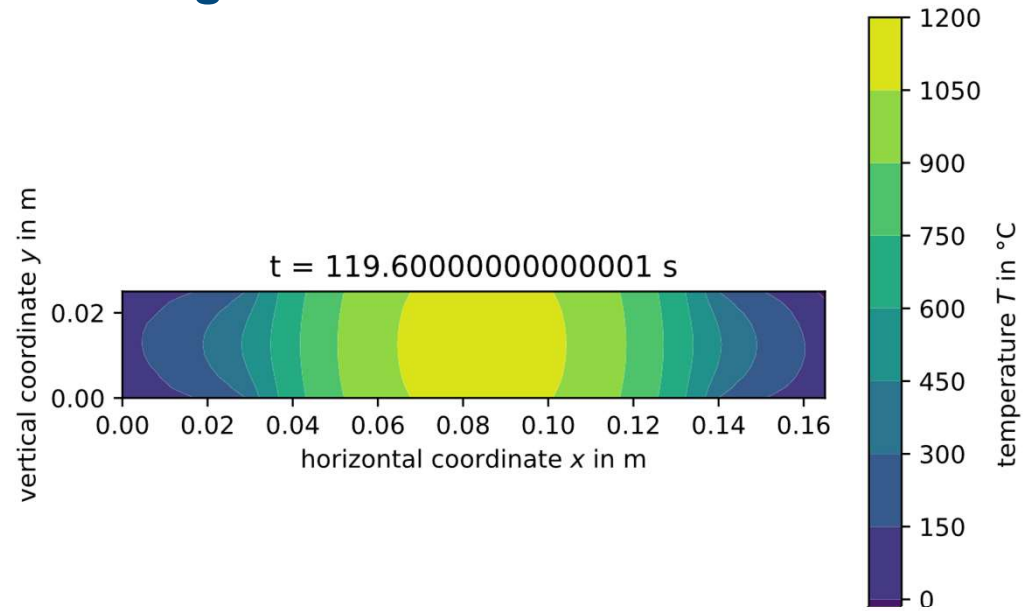
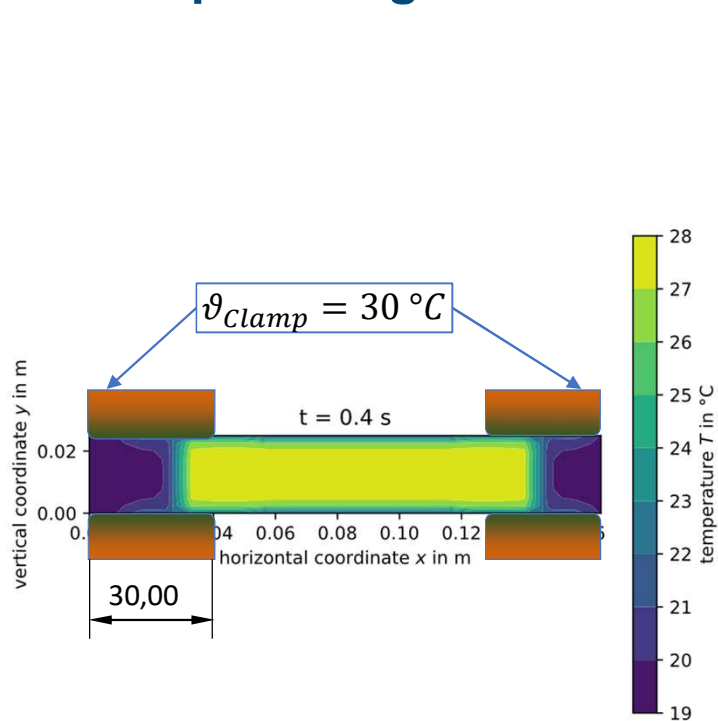
Temperature control during heating

Temperature distributions MCU 10 mm samples with clamp cooling no radiation and heating rate 10K/s



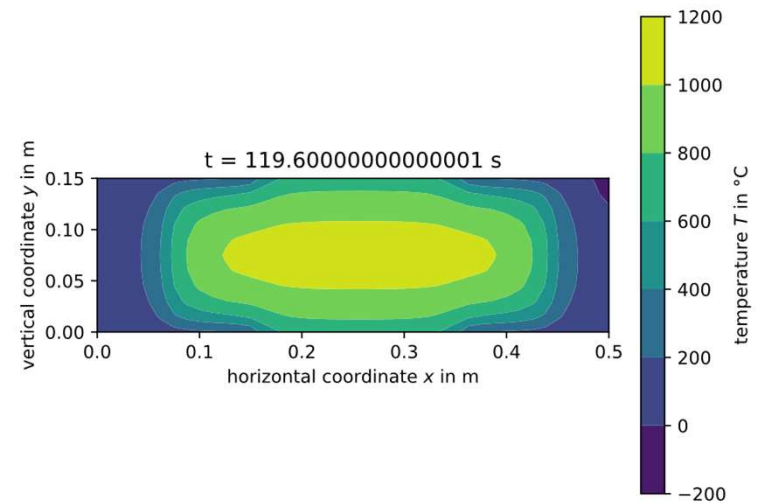
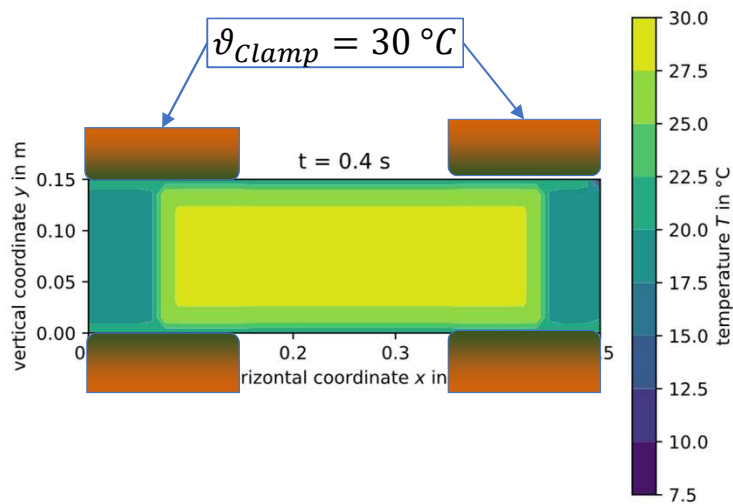
Current density: $1.1E07\text{ A/m}^2$

Temperature distributions MCU 25 mm samples with clamp cooling no radiation and heating rate 10K/s



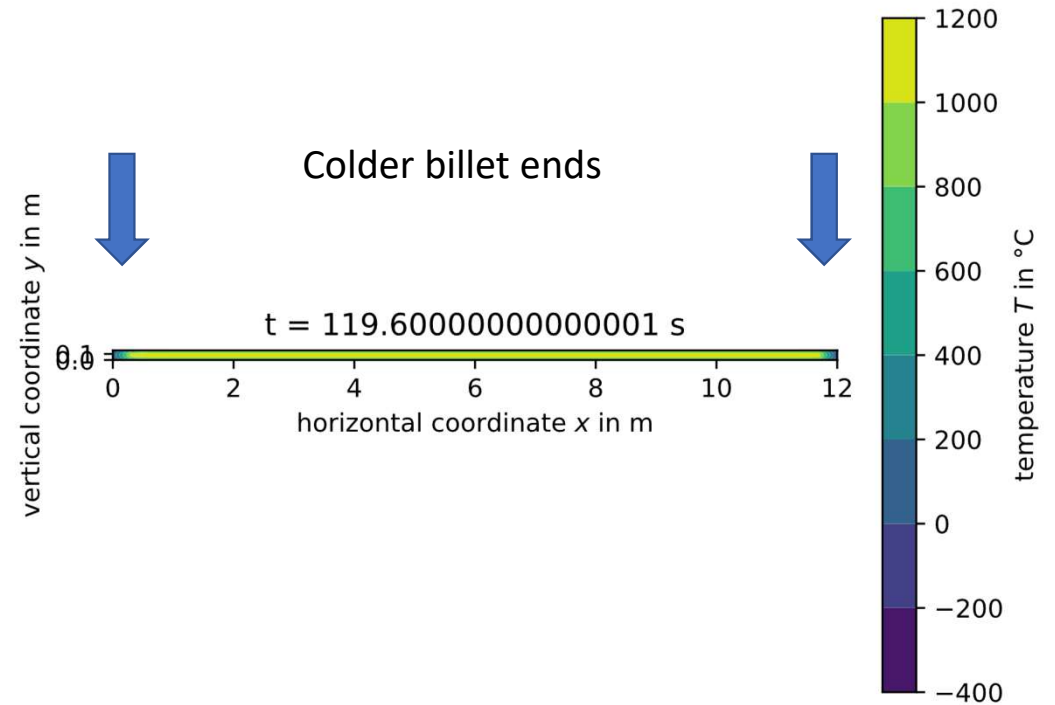
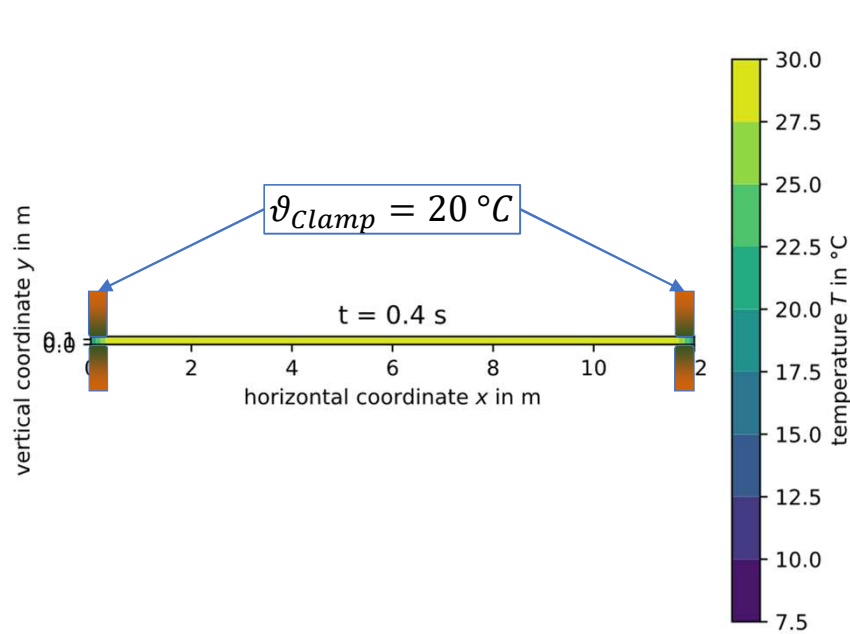
Current density: $1.05E07A/m^2$

Temperature distributions 150mm x 150mm samples with clamp cooling



Current density: $0.9E07 \text{ A/m}^2$

Temperature distributions Feralpi samples with clamp cooling – 2 clamp condition –



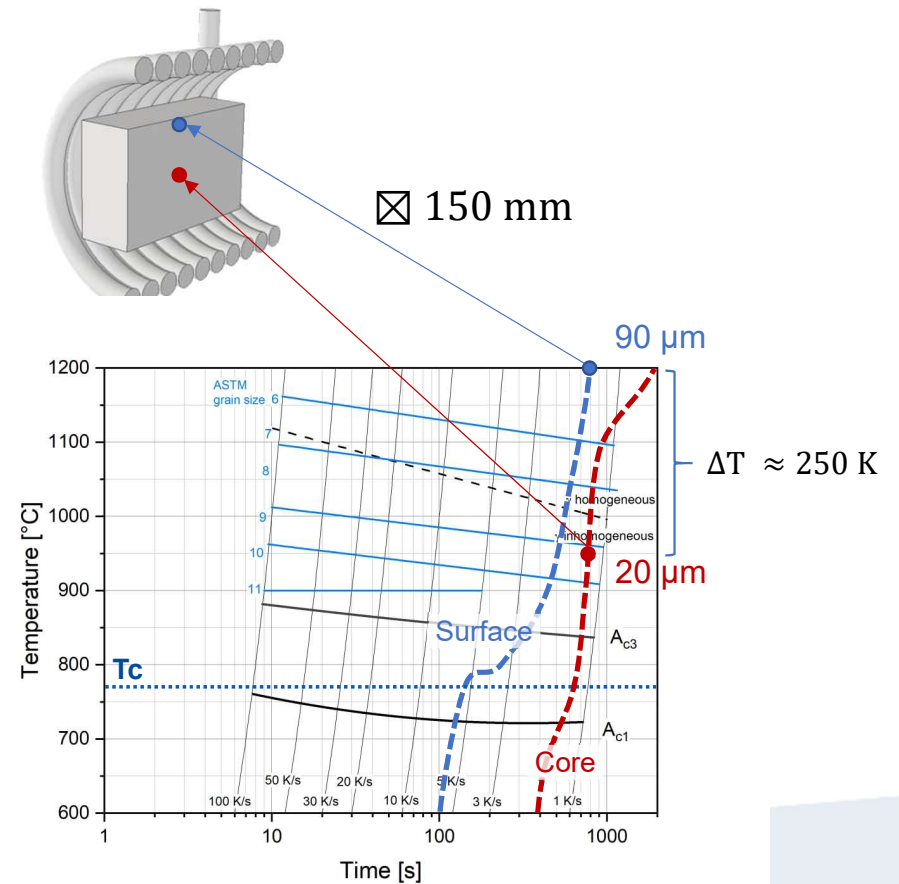
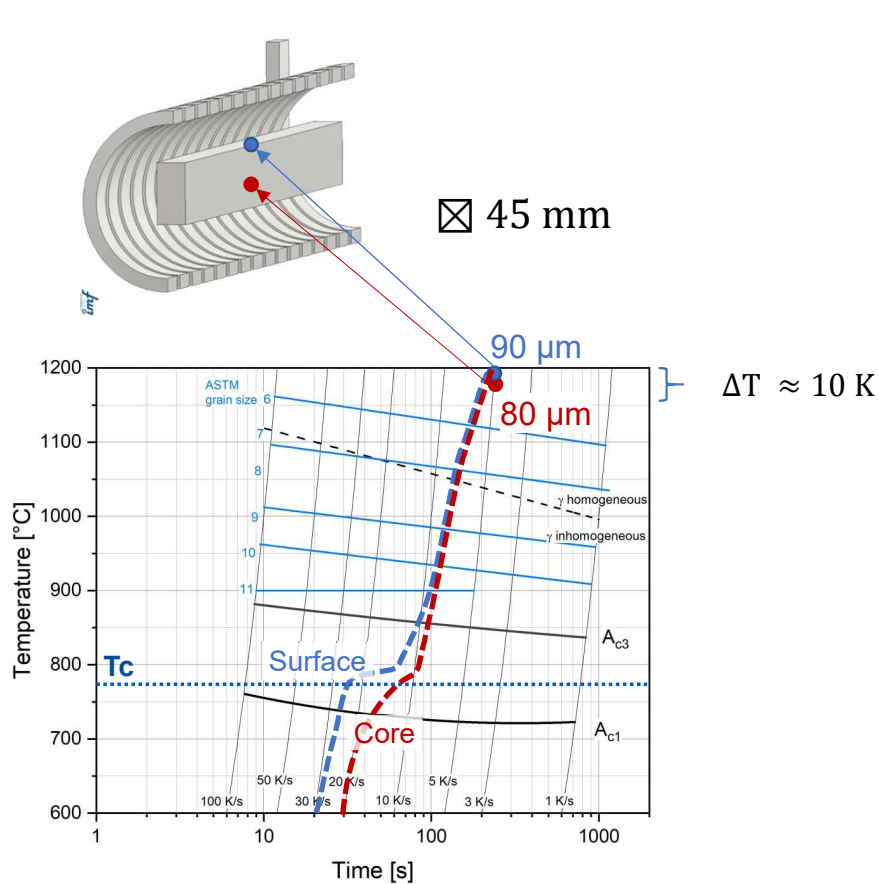
Application to Rolling



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lmf



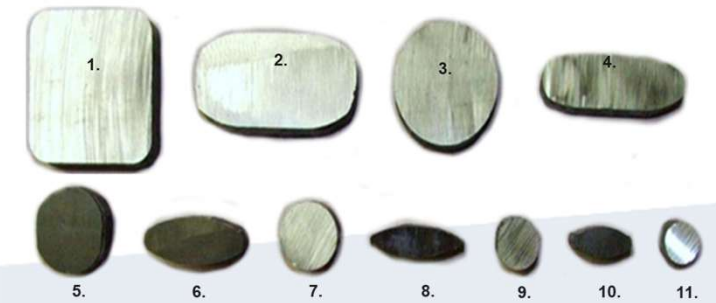
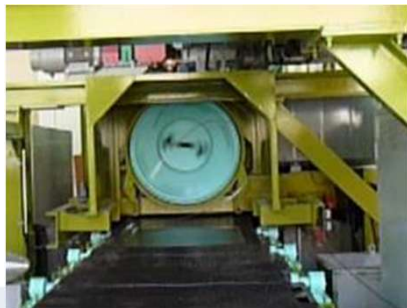
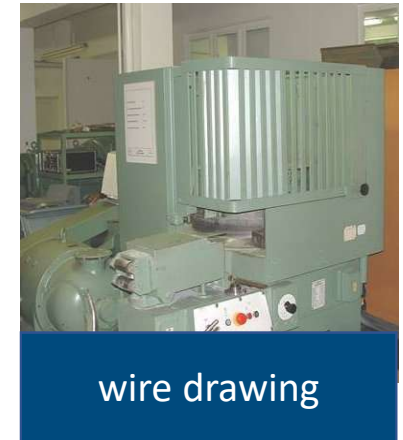
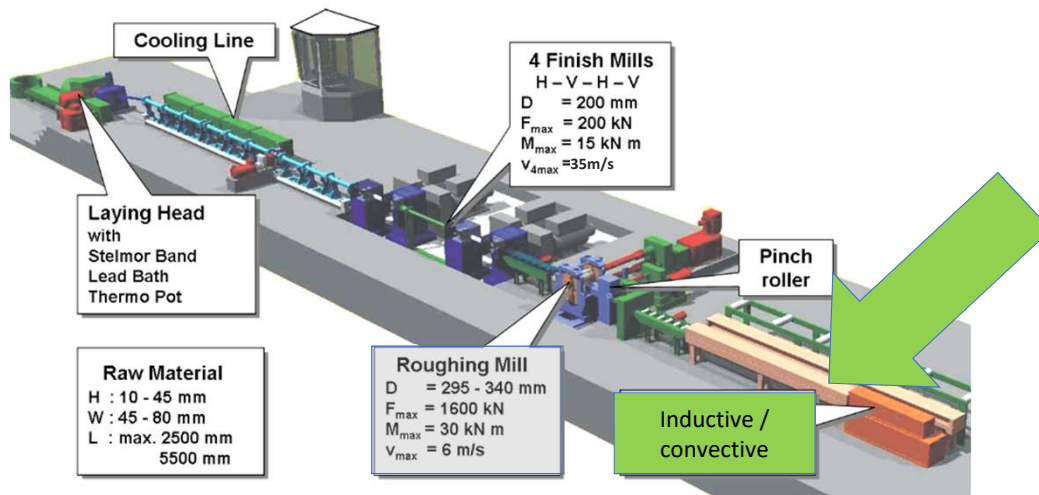
Initial State from Inductive Heating for Roll Pass Simulation with PyRoll



➤ With increasing billet size inhomogeneities more pronounced

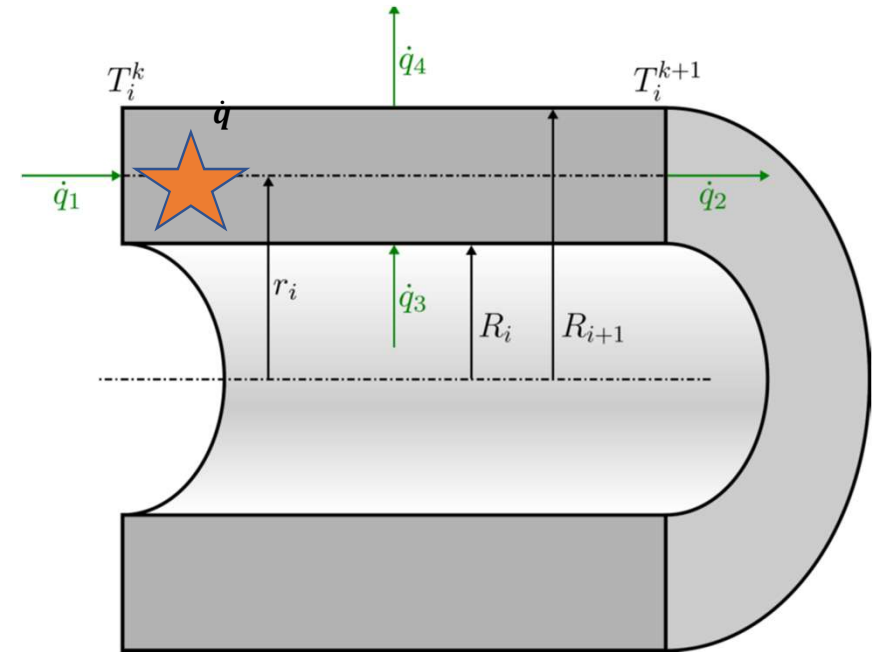
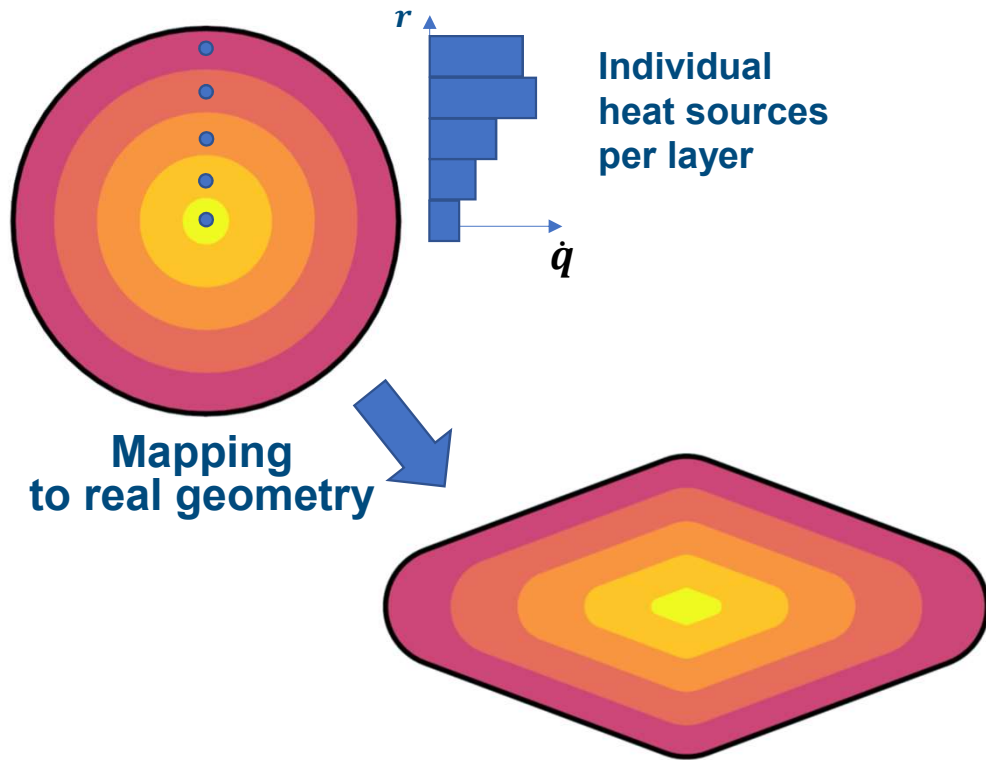
Rolling trials with different initial temperature distributions

Semi continuous rolling line for long products



possible processing routes

PyRoIL – Ring Model with Heating Sources

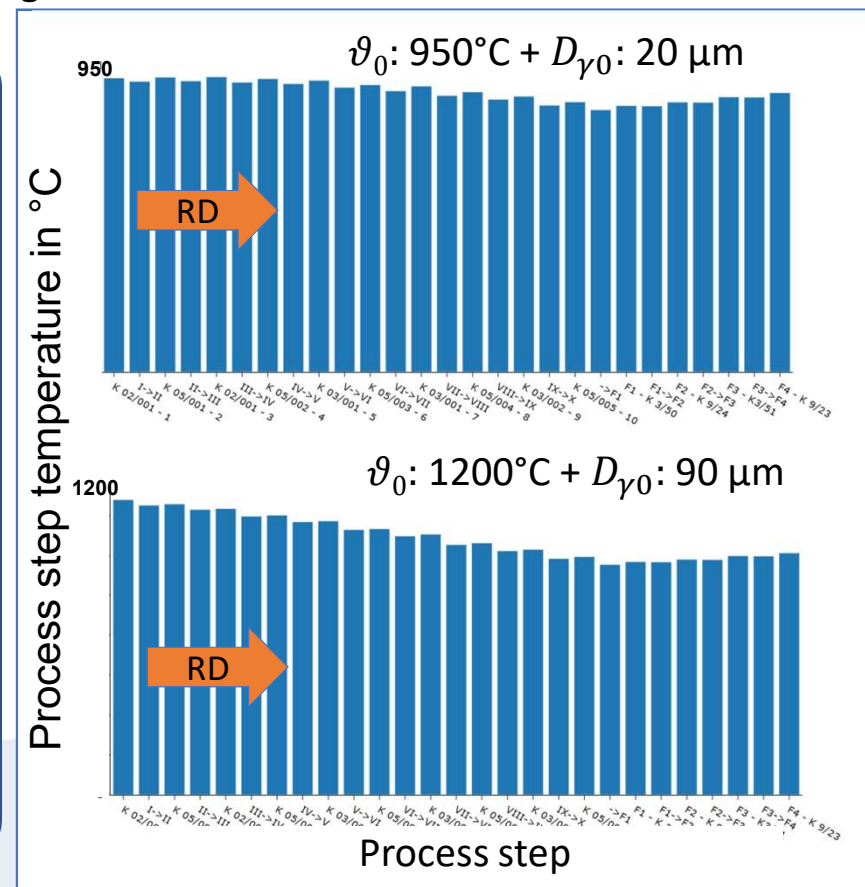
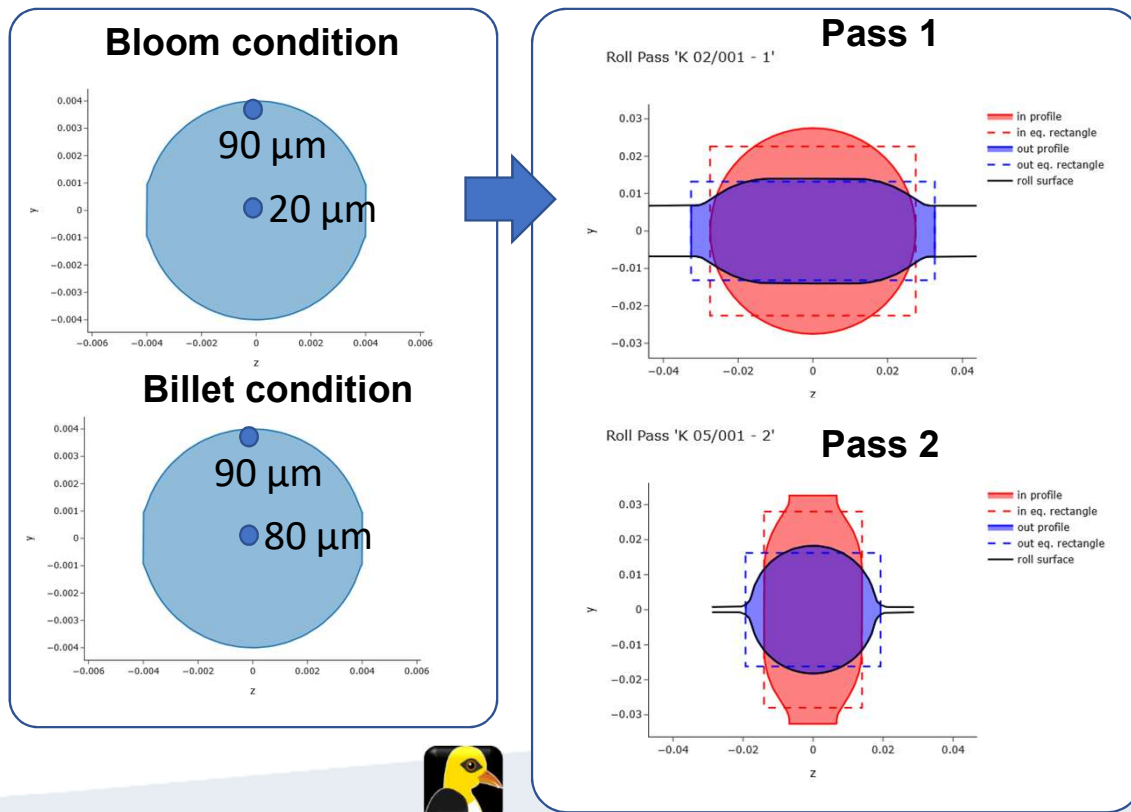


Advantage:
Temperature and microstructure gradients in thickness and rolling direction taken into account

Disadvantage:
Axial symmetry assumption

Coupling of Heating Simulator to Rolling Simulation with (PyRoll)

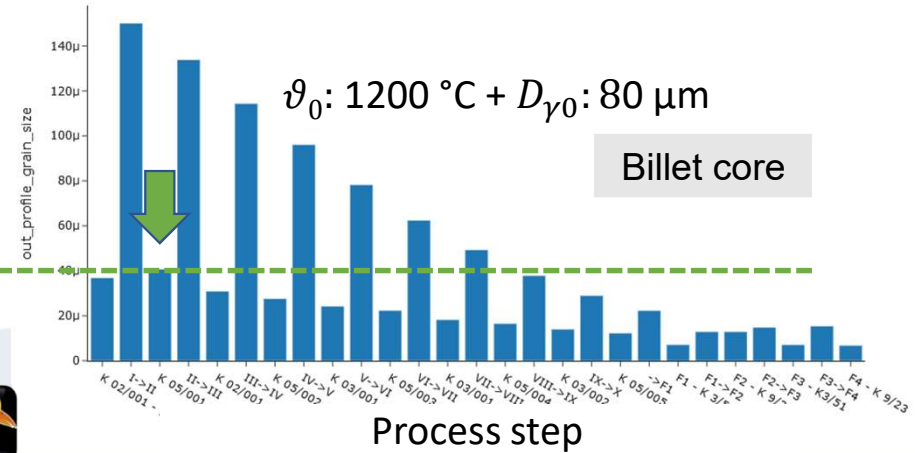
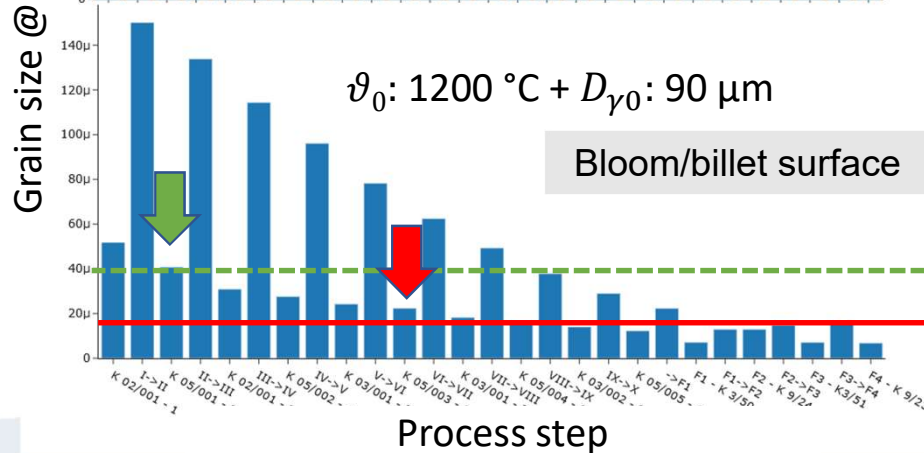
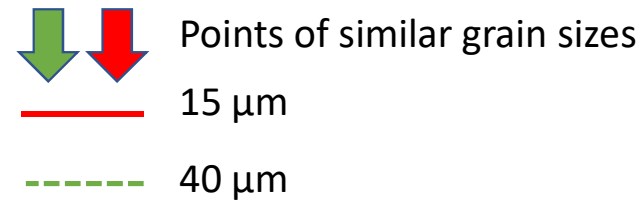
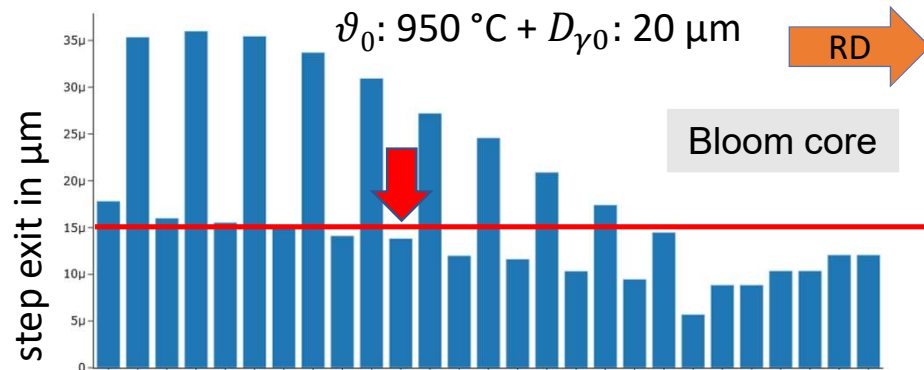
Understanding the influence of initial inhomogeneity on rolling behaviour



Coupling of Heating Simulator to Rolling Simulation with (PyRoIL)



Understanding the influence of initial inhomogeneity on rolling behaviour



Conclusions

- Accurate temperature dependent thermo-physical data needed
- Strong sensitivity of simulation results in the temperature range around Curie Point T_C
- Cenos simulation and IMF conduction simulation fits well to experimental investigated local temperatures
- Simulation can be used for upscaling to larger cross sections
- Inhomogeneous microstructure are important for rolling simulation of large cross sections
- In our example, inhomogeneous temperature and grain size distribution for 45 mm billet is released after 2 rolling passes, but for billet size 150 mm conditions 6 passes are necessary
- Inhomogeneous ingot due to hybrid heating technology effects only few first rolling passes but has no effect on final product properties if enough rolling steps are applied

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