TECHNISCHE UNIVERSITÄT BERGAKADEMIE FREIBERG
Die Ressourcenuniversität. Seit 1765.

technical THERMO DYNAMICS

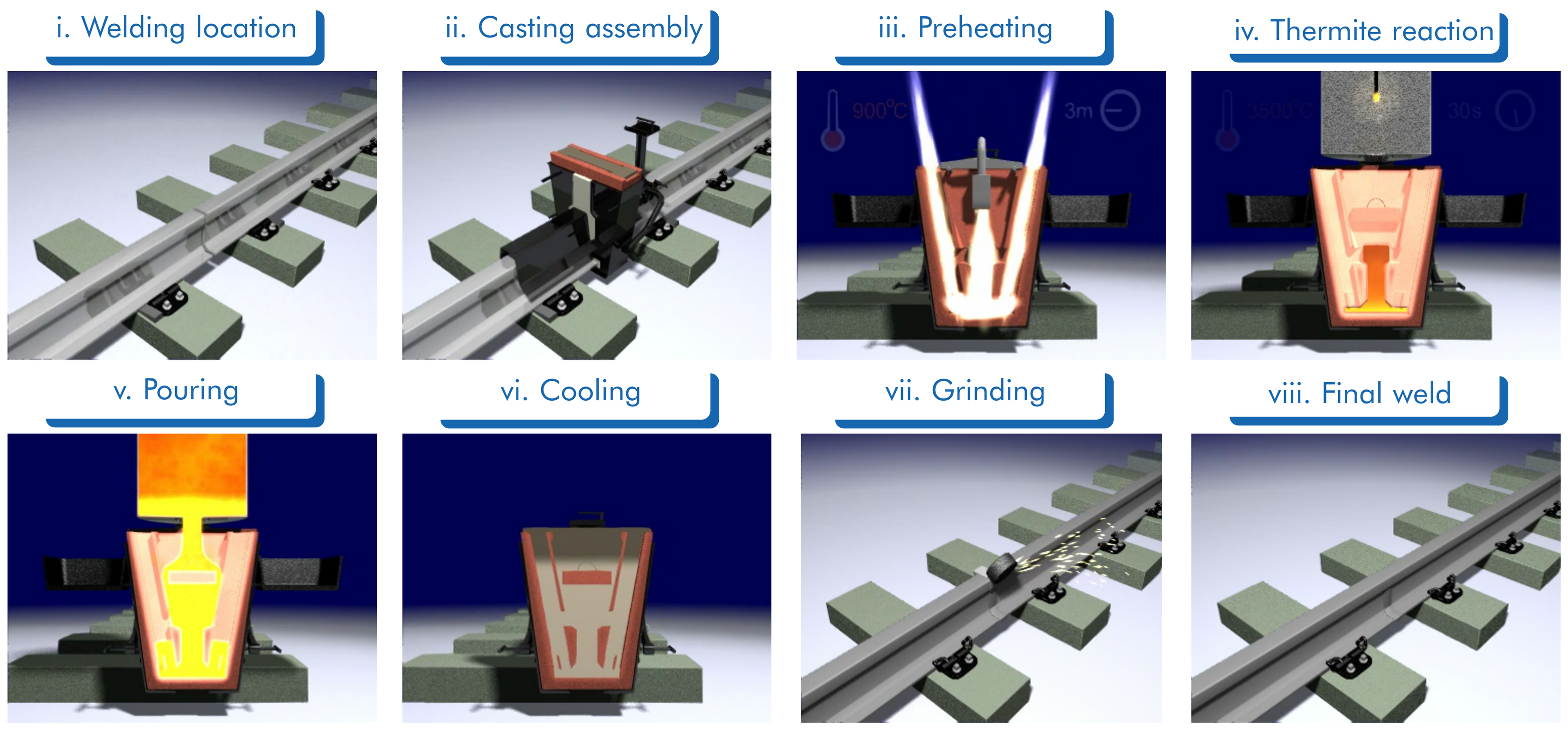
GOLDSCHMIDT Smart Rail Solutions

NUMERICAL MODELLING AND SIMULATION OF THE ALUMINOTHERMIC WELDING OF RAILS: HEAT TRANSFER AND SOLID-LIQUID PHASE CHANGE

R. G. Kewalramani[1,*], I. Riehl[1], J. Hantusch[2], J. Keichel[3], M. Niederkrueger[4], T. Fieback[1]

[1]Chair of Technical Thermodynamics, TU Bergakademie Freiberg, Gustav-Zeuner-Str. 7, 09599 Freiberg/Saxony, Germany
[2]Technology Innovation Center, Goldschmidt Holding GmbH, Am Schenkberg 20, 04349 Leipzig, Germany
[3]Elektro-Thermit GmbH & Co. KG., Chemiestr. 24, 06132 Halle (Saale), Germany
[4]Goldschmidt Holding GmbH, Hugo-Licht-Str. 3, 04109 Leipzig, Germany

1. Aluminothermic (AT) Welding Process



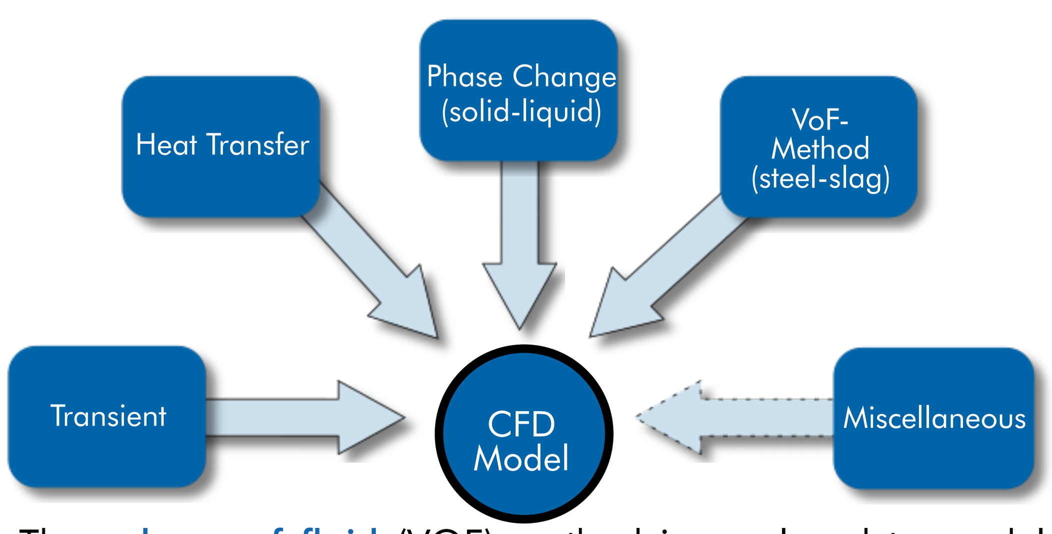
2. Motivation

- ➢ The aluminothermic welding process is well known for its simplicity, robustness, portability and economic usage for joining and repairing of rails.
- ➢ It is, in principle, a casting process in which the molten metal from the crucible is settled in a preheated mould and then allowed to solidify.
- ➢ For an efficient and high-quality weld, the knowledge of each stage involved during the rail joining process, such as preheating, thermite reaction, mould filling (pouring) and cooling (solidification) is significant.

3. Methodology

- ➢ As extremely high temperatures are involved during the process and the welding set-up being opaque, the flow field and phase change process inside the mould is notoriously difficult to observe in real time.
- ➢ Thus, a numerical multi-physics model is developed, which could be employed not only to observe the flow dynamics inside the mould, but also to investigate the influence of various process parameters on the Fusion Zone (FZ) and Heat Affected Zone (HAZ), i.e., the final weld.

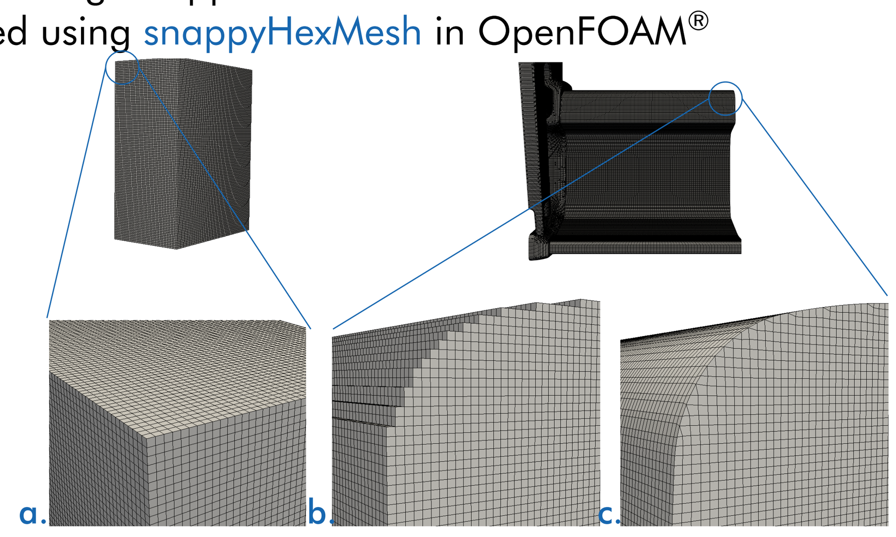
4. Numerical Modelling



- ➢ The volume of fluid (VOF) method is employed to model the steel-slag system [1,2].
- ➢ The enthalpy-porosity technique is adopted for the solid-liquid phase change [3].
- ➢ The multi-physics model has been implemented in OpenFOAM® and rigorously validated in our previous study [4].

5. Grid Generation

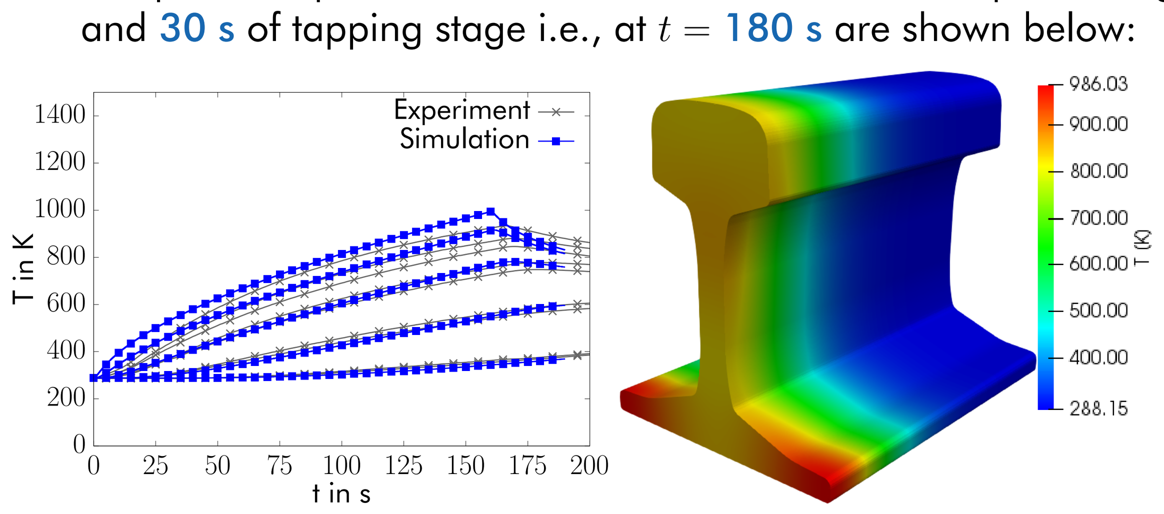
- ➢ Because of symmetry, only a quarter of the computational grid consisting of approx. 1.75 million cells is considered and generated using snappyHexMesh in OpenFOAM®



a. `blockMesh:` A base mesh with hexahedral cells is created that encloses the entire computational domain.
b. `Castellation:` The cells that are outside the computational domain are deleted.
c. `Snapping:` The surface is smoothed and adapted to the domain.

6. Preheating Stage

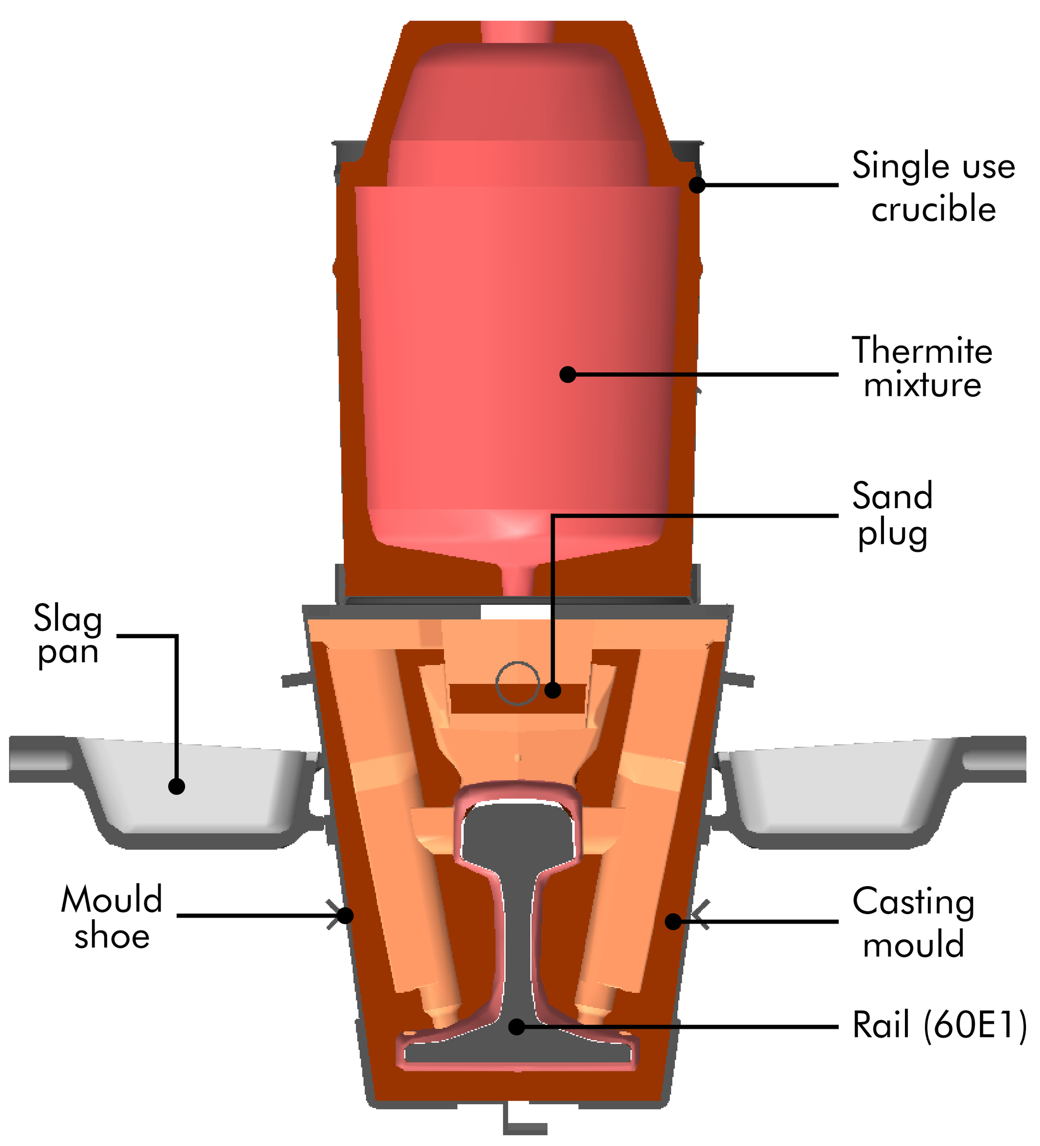
- ➢ The heat flux profile at the rail end inside the mould is calculated from the available experimental data and is imposed as boundary condition to obtain/predict the required temperature distribution (as discussed in [5]) in the rail for the CFD simulation of the cooling stage.
- ➢ The temperature history at the centre of the rail base and the complete temperature field in the rail after 150 s of preheating and 30 s of tapping stage i.e., at $t = 180$ s are shown below:



- ➢ The simulation results show a good agreement with the available experimental data.

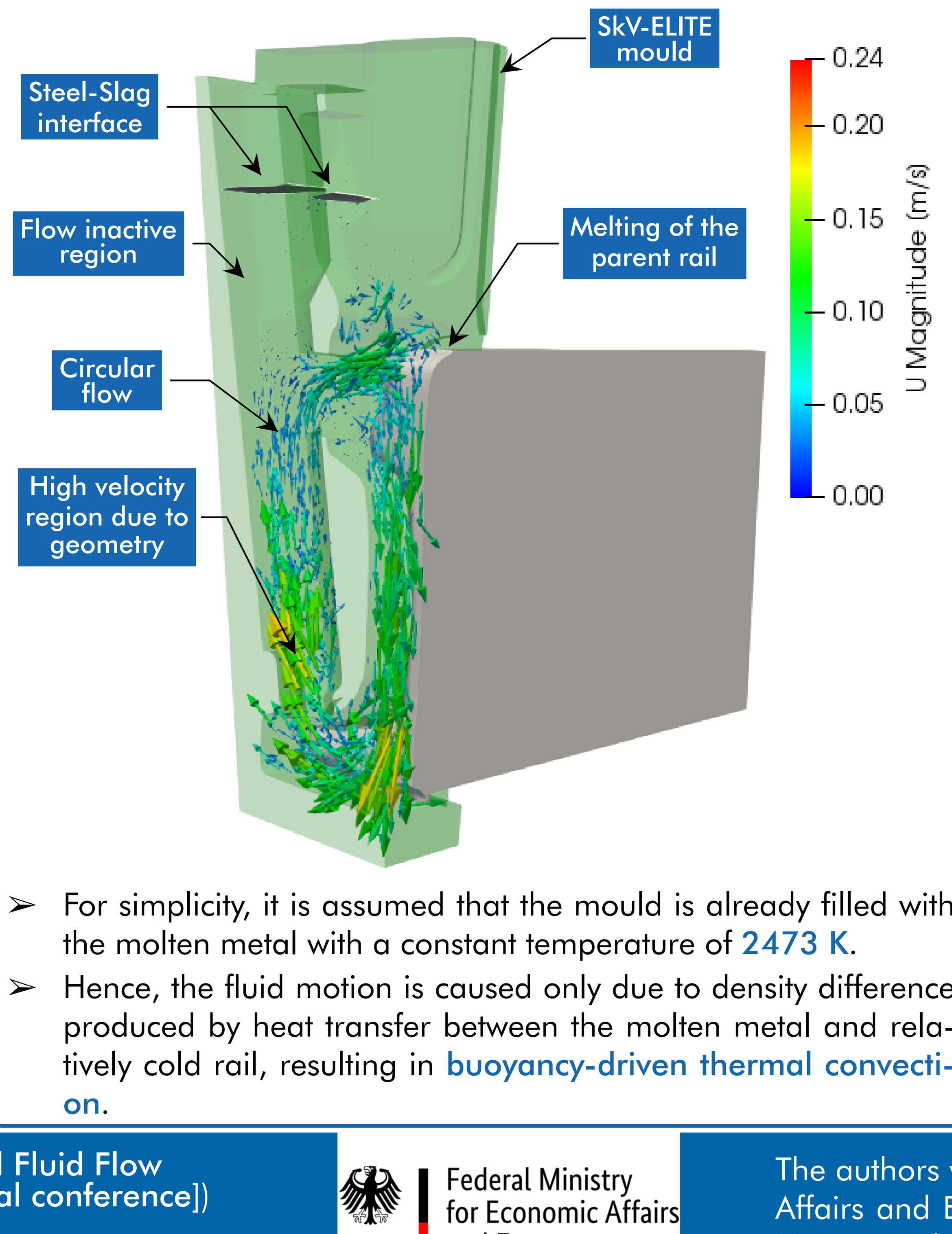
Welding Set-up

- ➢ The complete welding set-up is assembled around the railway track that is to be joined.
- ➢ The welding set-up consists of the following components:



7. Cooling Stage - I

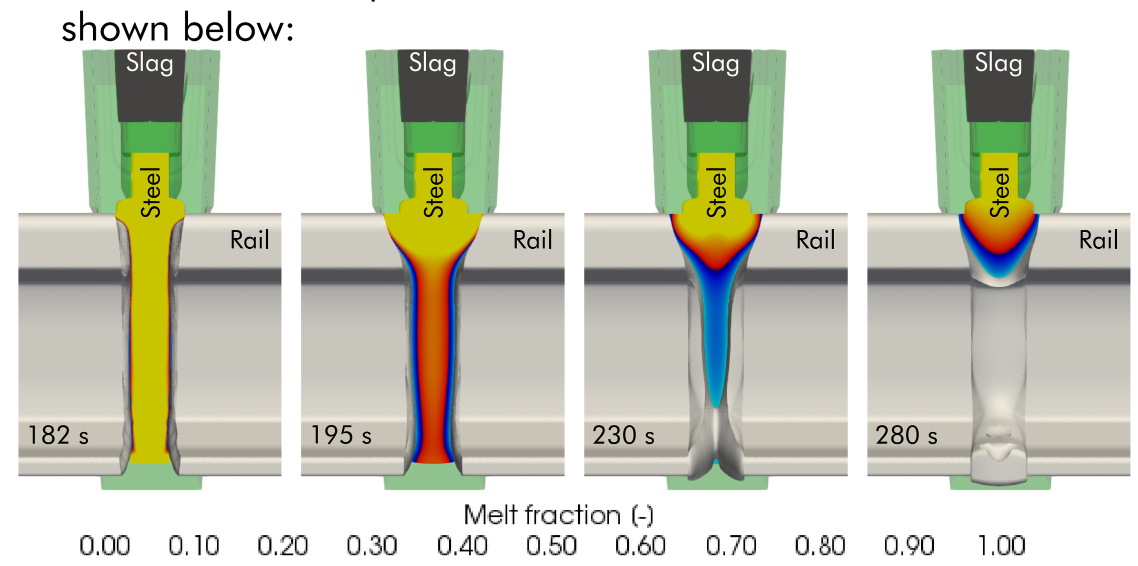
- ➢ Melt dynamics inside the mould 2 s after the preheating and tapping stage i.e., at $t = 182$ s is shown below:



- ➢ For simplicity, it is assumed that the mould is already filled with the molten metal with a constant temperature of 2473 K.
- ➢ Hence, the fluid motion is caused only due to density difference produced by heat transfer between the molten metal and relatively cold rail, resulting in buoyancy-driven thermal convection.

8. Cooling Stage - II

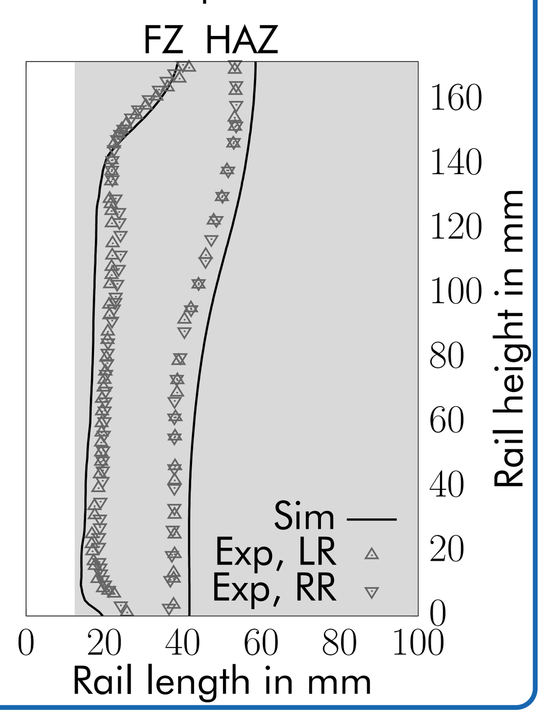
- ➢ The solidification process inside the mould at different times is shown below:



- ➢ For better visualisation the computational domain is mirrored to represent the solidification process on full rail geometry.
- ➢ Here, the melt fraction in steel ranges from 0 in the solid phase ($T \leq T_{\mathrm{solid}}$) to 1 in the liquid phase ($T \geq T_{\mathrm{liquid}}$) and the 3D solid-liquid phase front is evaluated at $T_{\mathrm{solid}} = 1653$ K.
- ➢ The spatial and temporal evolution of the solid-liquid phase front results in a V-shaped solidification.

9. Final Weld

- ➢ The predicted maximum width of the fusion zone (FZ) and heat affected zone (HAZ) are compared with the experiment.
- ➢ In the experiment the width of the FZ is wider in the rail web and rail base region than the simulation results. This is because the mould filling stage is completely skipped, moreover, the rail surface inside the mould is assumed to be flat.
- ➢ The width of the HAZ is overpredicted in the simulation. This is because the mould is not considered during the simulation and radiation heat transfer is neglected.



10. Closure

Conclusions:

- ➢ CFD simulation of AT welding of rails is carried out successfully with the proposed numerical model.
- ➢ The HAZ, FZ and the temperature distribution in the rail show a similar trend as observed in experiments.

Future Work:

- ➢ Sensitivity analysis → Numerical and process parameters
- ➢ Simulations including mould → Conjugate Heat Transfer (CHT)
- ➢ Mould filling with phase change → Extending the model
- ➢ Temperature dependent material properties

Bibliography:

[1] C. W. Hirt and B. D. Nichols, "Volume of Fluid (VOF) Method for the Dynamics of Free Boundaries," J. Comput. Phys., vol. 39, pp. 201-225, 1981.
[2] H. Rusche, "Computational fluid dynamics of dispersed two-phase flows at high phase fractions," Ph.D. dissertation, University of London, 2002.
[3] V. R. Voller and C. Prakash, "A fixed grid numerical modelling methodology for convection-diffusion mushy region phase change problems," Int. J. Heat Mass Transf., vol. 30(8), pp. 1709-1719, 1987.
[4] R. G. Kewalramani, S. Pose, I. Riehl and T. Fieback, "Solid-Liquid Phase Change in the Presence of Gas Phase: Numerical Modeling and Validation," Journal of Fluid Flow, Heat and Mass Transfer, vol. 7, pp. 1-11, 2020.
[5] Y. Chen, F. V. Lawrence, C. P. L. Barkan, and J. A. Dantzig, "Heat transfer modelling of rail thermite welding," Proc. IMechE, Part F: J. of Rail and Rapid Transit, vol. 220, pp. 207- 217, 2006.

HTFF 2021

8th International Conference on Heat Transfer and Fluid Flow
(2. - 4. August 2021, Prague, Czech Republic [Virtual conference])

*Corresponding author: M.Sc. Ravi Govindram Kewalramani
Gustav-Zeuner-Str. 7 | 09599 Freiberg/Saxony Germany |
+49 3731 / 39-2161 | Ravi.Kewalramani@ttd.tu-freiberg.de

Federal Ministry for Economic Affairs and Energy

The authors wish to acknowledge the Federal Ministry of Economic Affairs and Energy (BMWi), Germany, for the financial support of MOTEVAS bearing project no. 03ET1192B. Special thanks to the Computer Centre (URZ) of TU Bergakademie Freiberg for the HPC-Cluster support.