Fogningsdagar - Svetskommissionens medlemsdagar

Processoptimering av reparationssvetsning av järnvägsräls med hjälp av simulering

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2022-04-07

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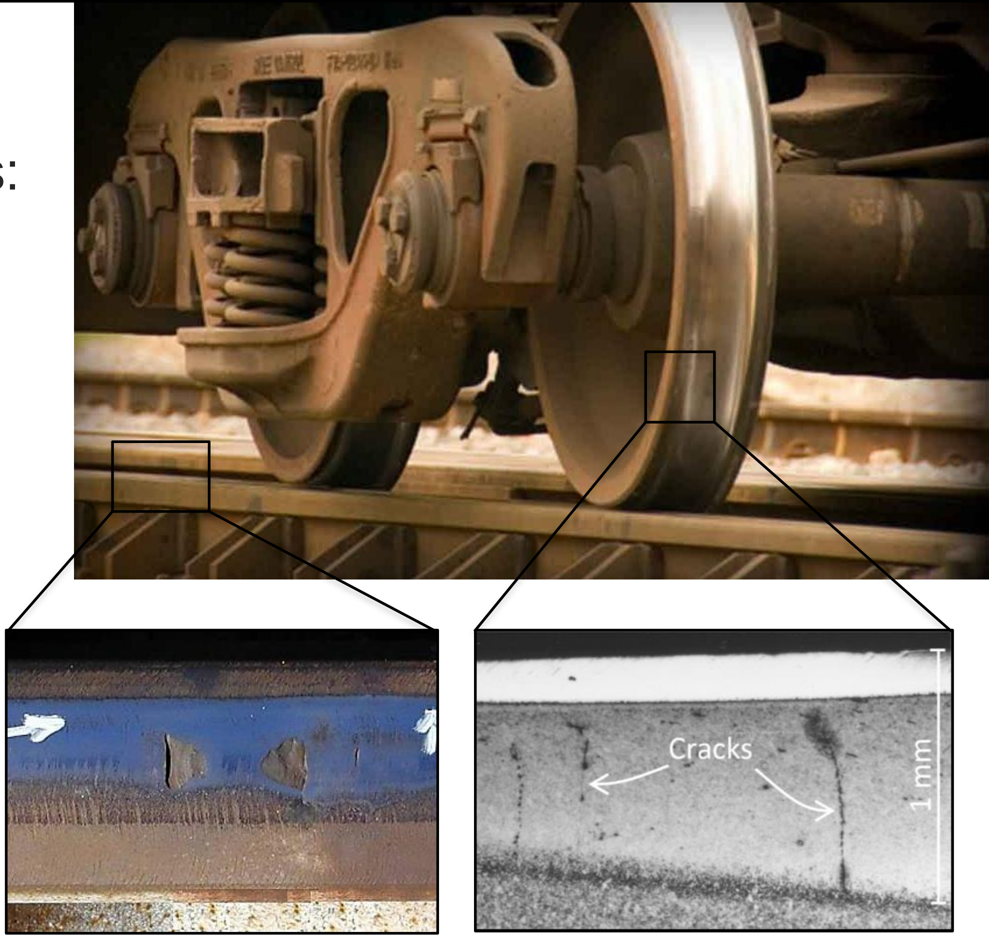
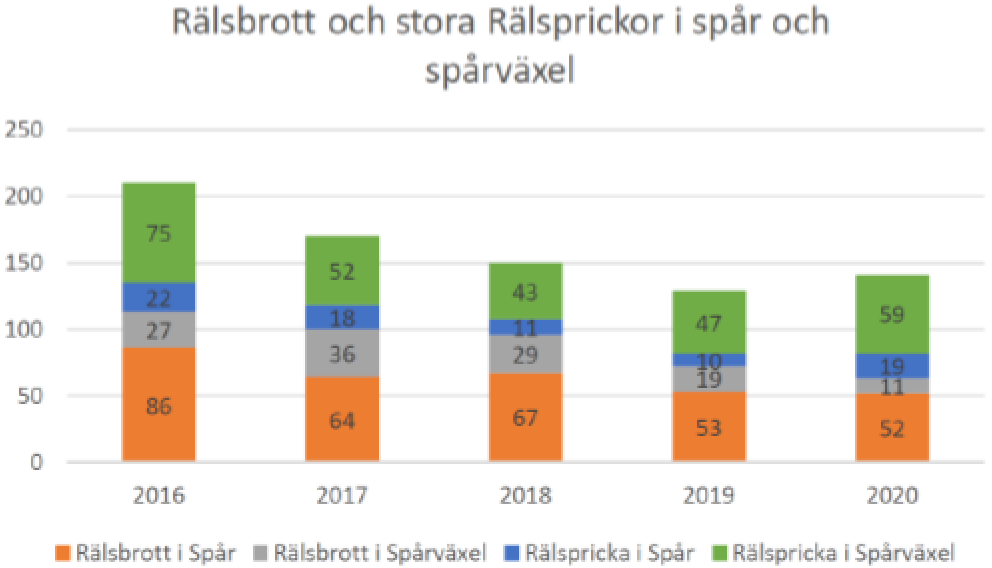
UNIVERSITY OF TECHNOLOGY

Background and motivation

- High temperature railway processes:
  - Welding
  - Grinding
  - Train wheel braking (rail and wheel)
- What happens:
  - Phase transformations
  - Inhomogeneous material properties
- Practical consequences:
  - Residual stresses, interaction with operational loads
  - Initiation of cracks

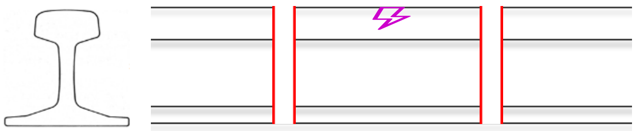




- Decreasing number of rail fractures
- Increasing number of rail cracks
- 33-50% of the fractures in welds
- More cracks and fractures during colder periods

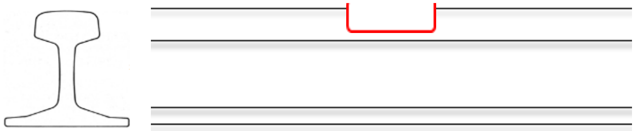
[1] B. L. Josefson, *Welding of rails and how it affects crack initiation and propagation*, (2014)

Rail section repair - Thermite welding



- Remove entire damaged rail section
- Large heat input
- Slower cooling, pearlite formation, tensile residual stresses in web
- Labor intensive, time consuming

Rail head repair – MIG/MMA welding

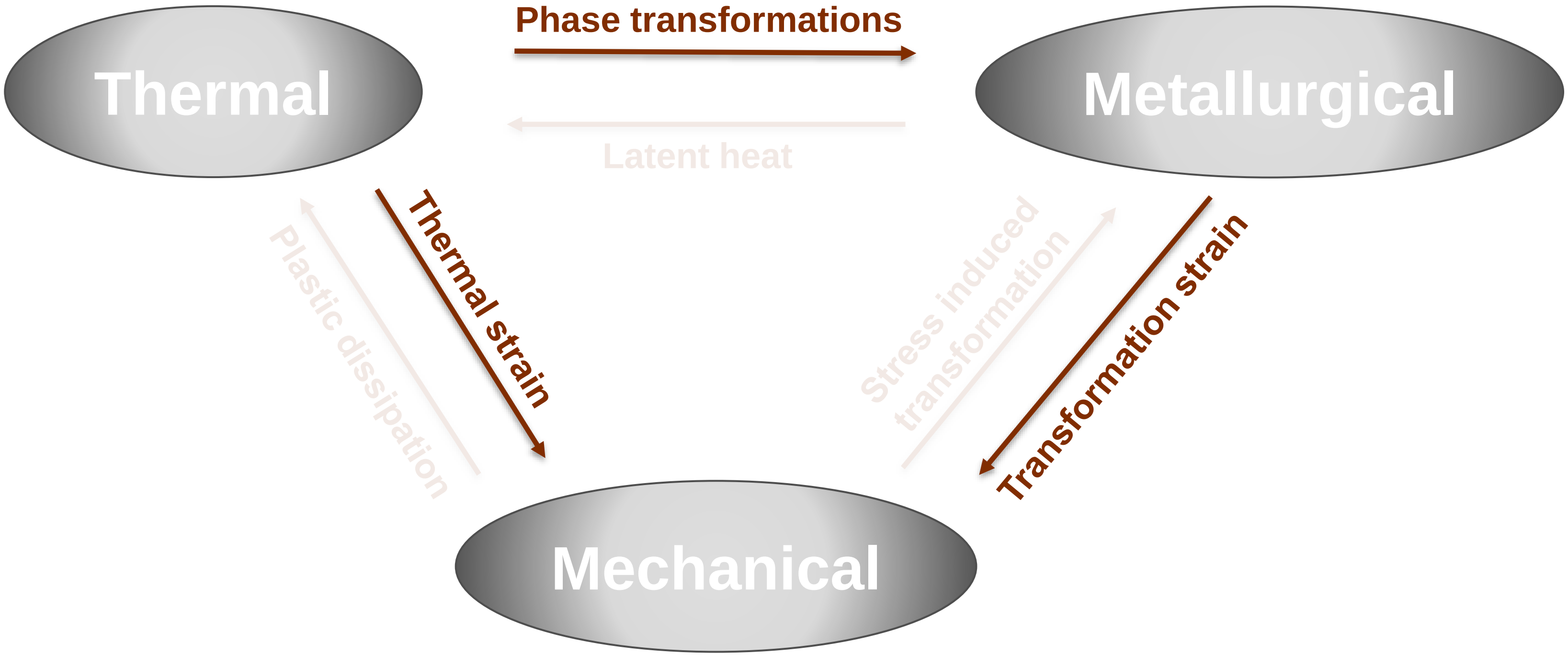


- Remove only railhead damage (or switches)
- Small, local heat input, several weld passes
- Rapid cooling, risk for martensite formation
- Quicker operation

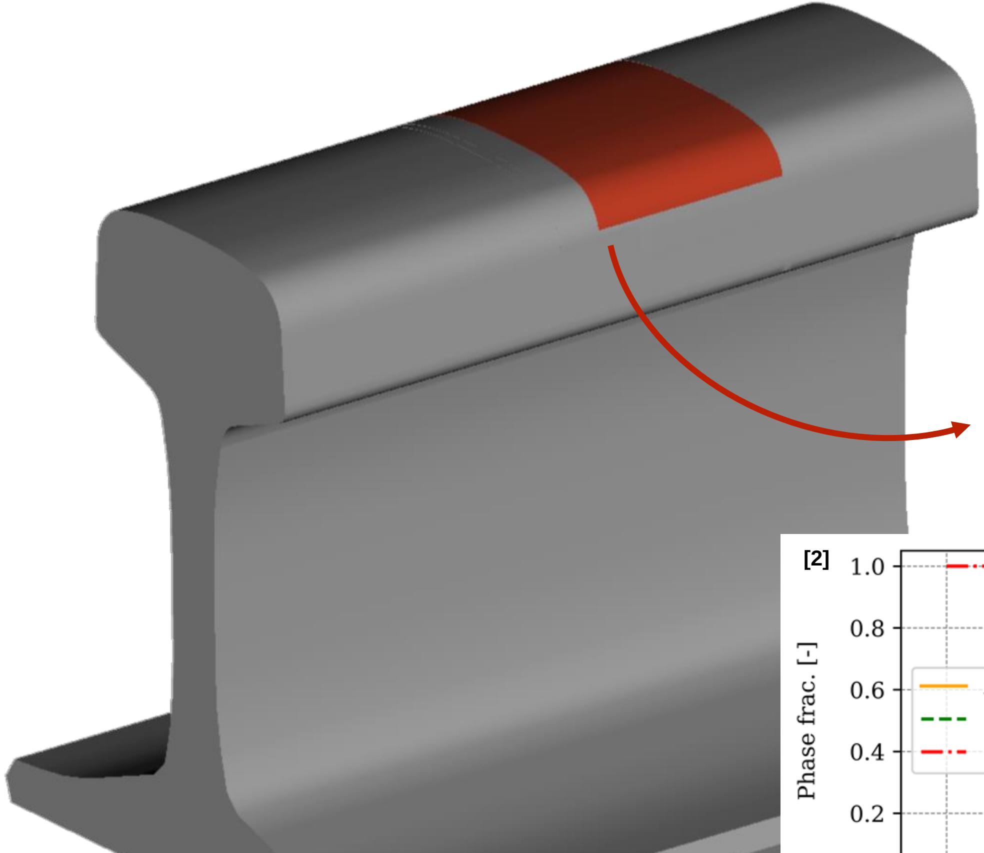
New material model

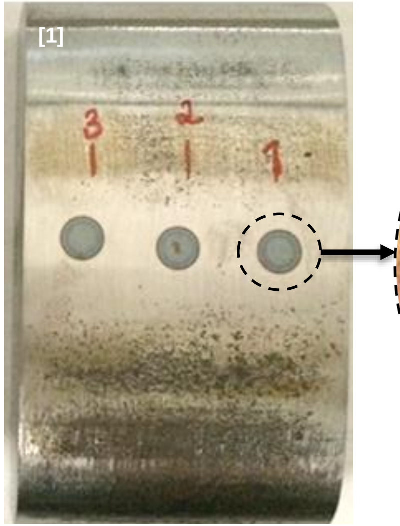
- Complex microstructure evolution
- Effects of phases and phase transformations

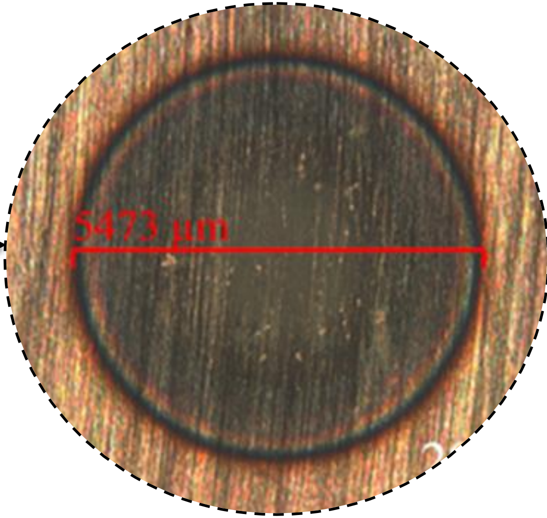
[1]modernrailways.com/article/faster-rail-welding, [2] thermit-welding.com/wp-content/uploads/2016, [3] pandrol.com/wp-content/uploads/2020/07/, [4] starkon.nl/project/sts-crane-trolley-rail-eld-repair/

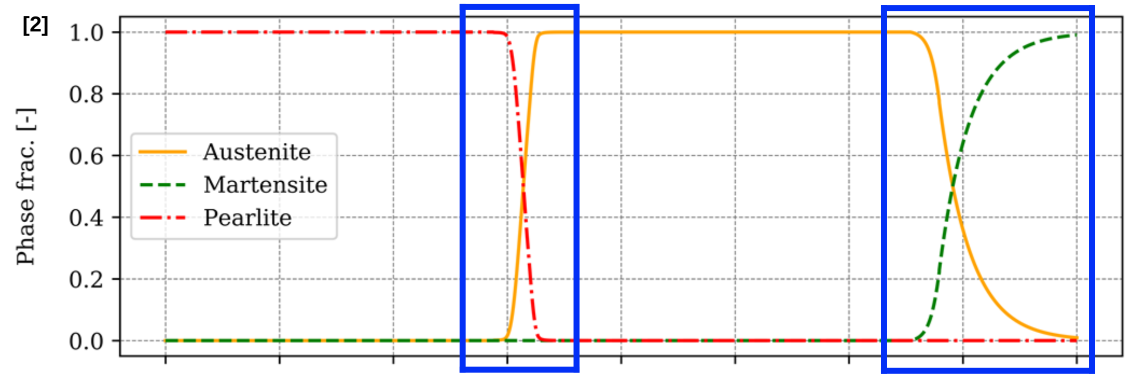

Thermal
Metallurgical
Mechanical
Phase transformations
Latent heat
Thermal strain
Plastic dissipation
Stress induced transformation
Transformation strain

extra









Multi-phase state

[1] Experiment photography: Jessop, Damage and defects in railway materials: influence of mechanical and thermal damage on crack initiation and propagation, Ph.D. thesis

[2] Simulation results: B. Andersson, J. Ahlström, M. Ekh, B. L. Josefson, Homogenization based macroscopic model of phase transformations and cyclic plasticity in pearlitic steel, International Journal of Thermal Stresses (Accepted 2022)

Homogenization methods

Voigt assumption

$$\epsilon_x = \bar{\epsilon}$$

$$\bar{\sigma} = \sum_x p_x \, \sigma_x$$

Reuss assumption:

$$\sigma_x = \bar{\sigma}$$

$$\bar{\epsilon} = \sum_x p_x \, \epsilon_x$$

Self-consistent

(Eshelby's inclusion 1957)

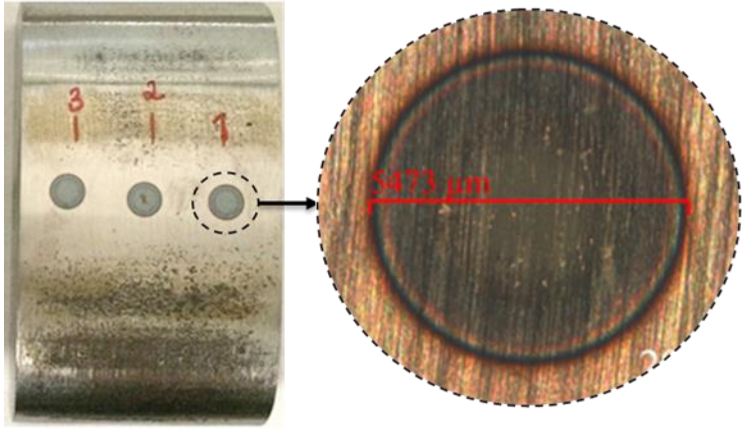
$$\epsilon_x = \mathbf{A}_x : \bar{\epsilon}$$

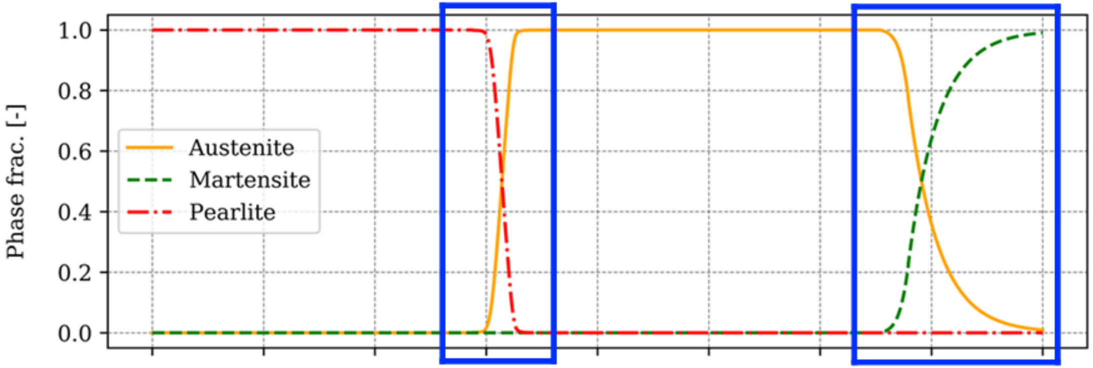
$$\bar{\sigma} = \sum_{x=1}^{n_x} p_x \mathbf{E}_x^{e} : \epsilon_x$$

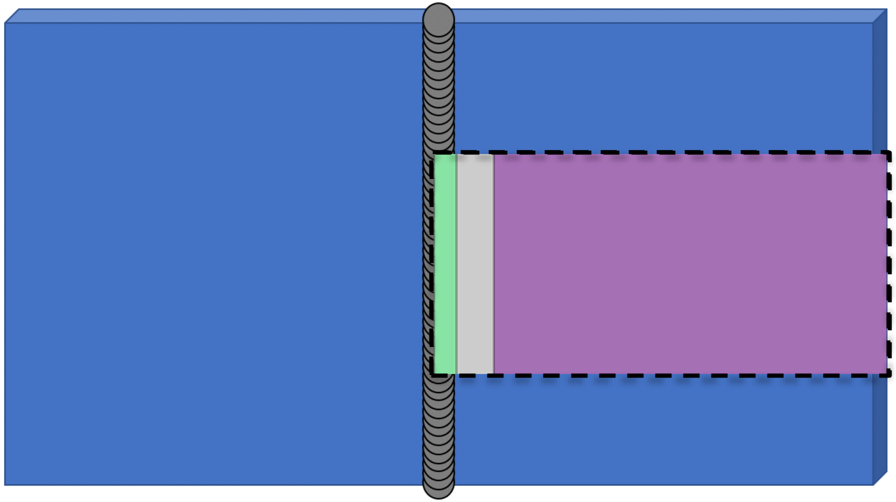
Linear mixture

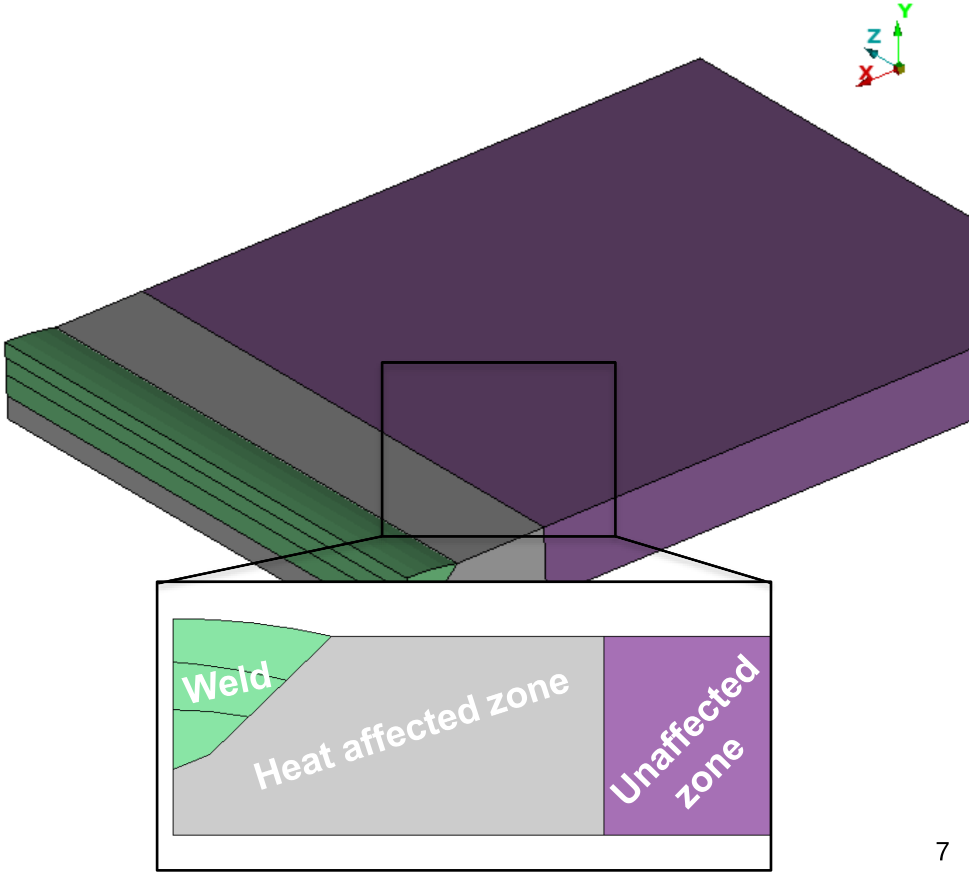
$$\mathbf{E}^e = \sum_{x=1}^{n_x} p_x \mathbf{E}_x^e$$

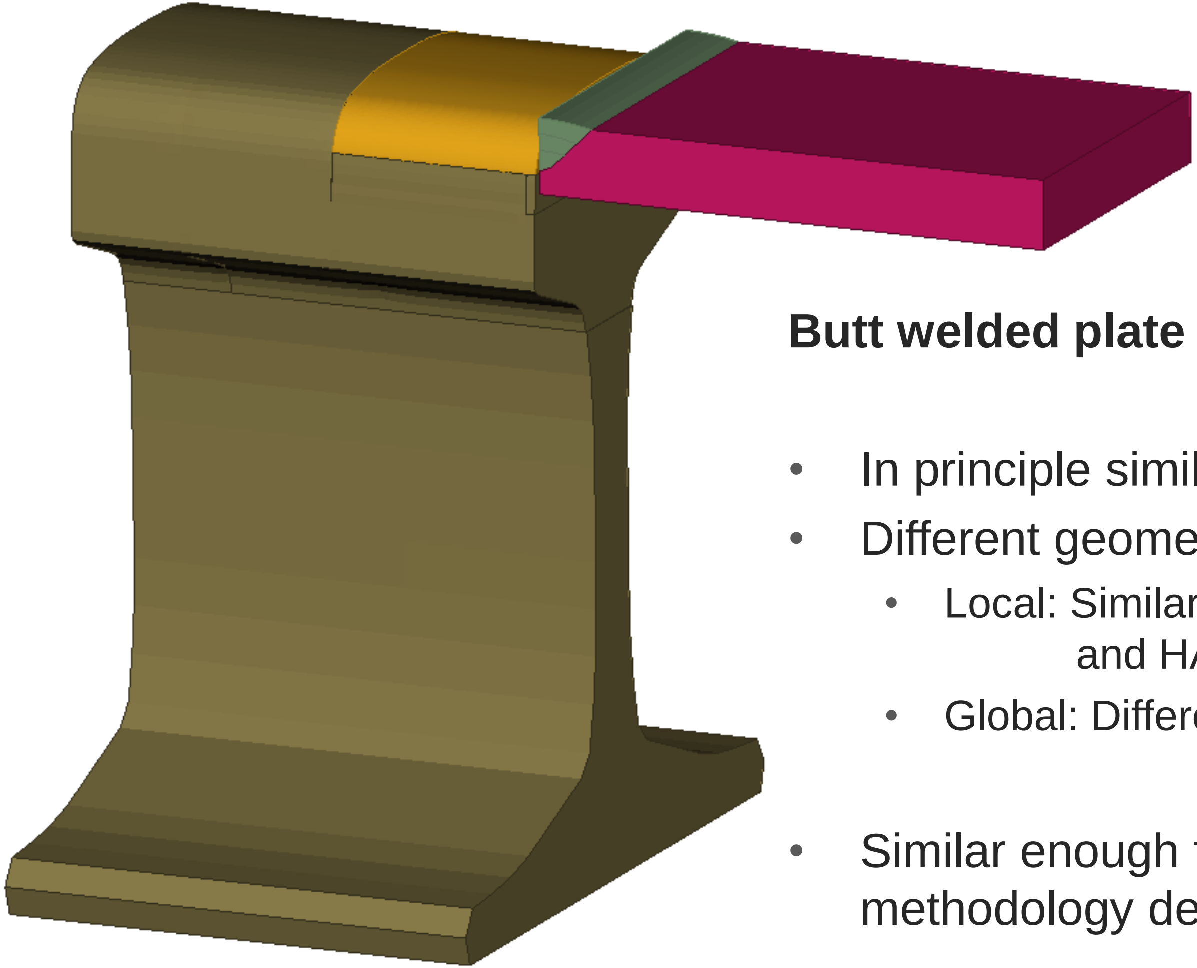
$$\bar{\sigma} = \mathbf{E}^{e} : \bar{\epsilon}$$








Y
Z
X
Weld
Heat affected zone
Unaffected zone



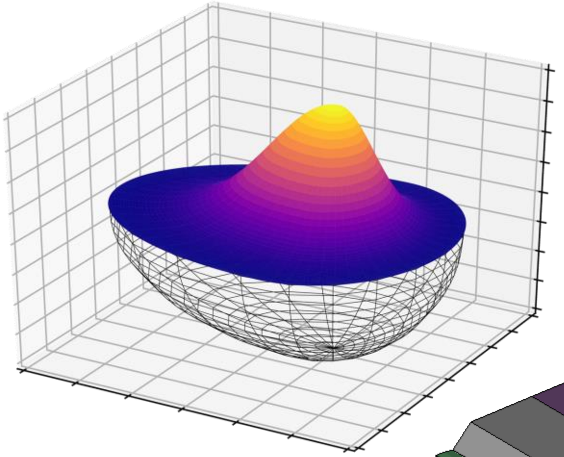
Butt welded plate – Rail head repair weld

- In principle similar
- Different geometry effects:
  - Local: Similar microstructure in weld and HAZ
  - Global: Different residual stress field

- Similar enough for simulation methodology development

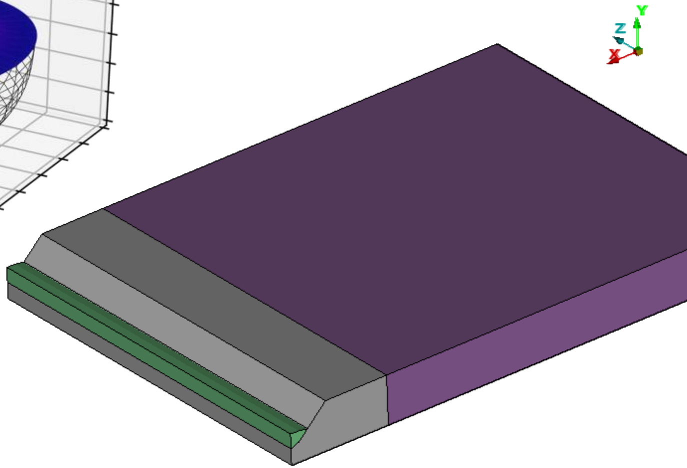
Moving heat source

- Power input
- Weld speed
- Heat distribution (Goldak et al. 1986)



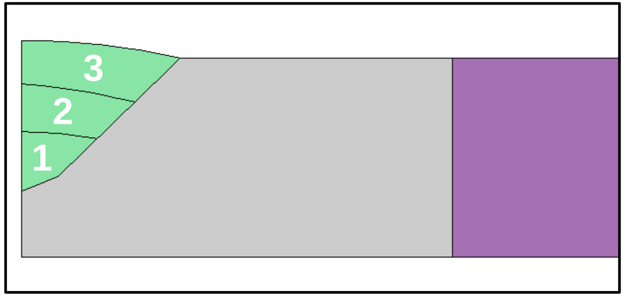
Continuous addition of filament elements

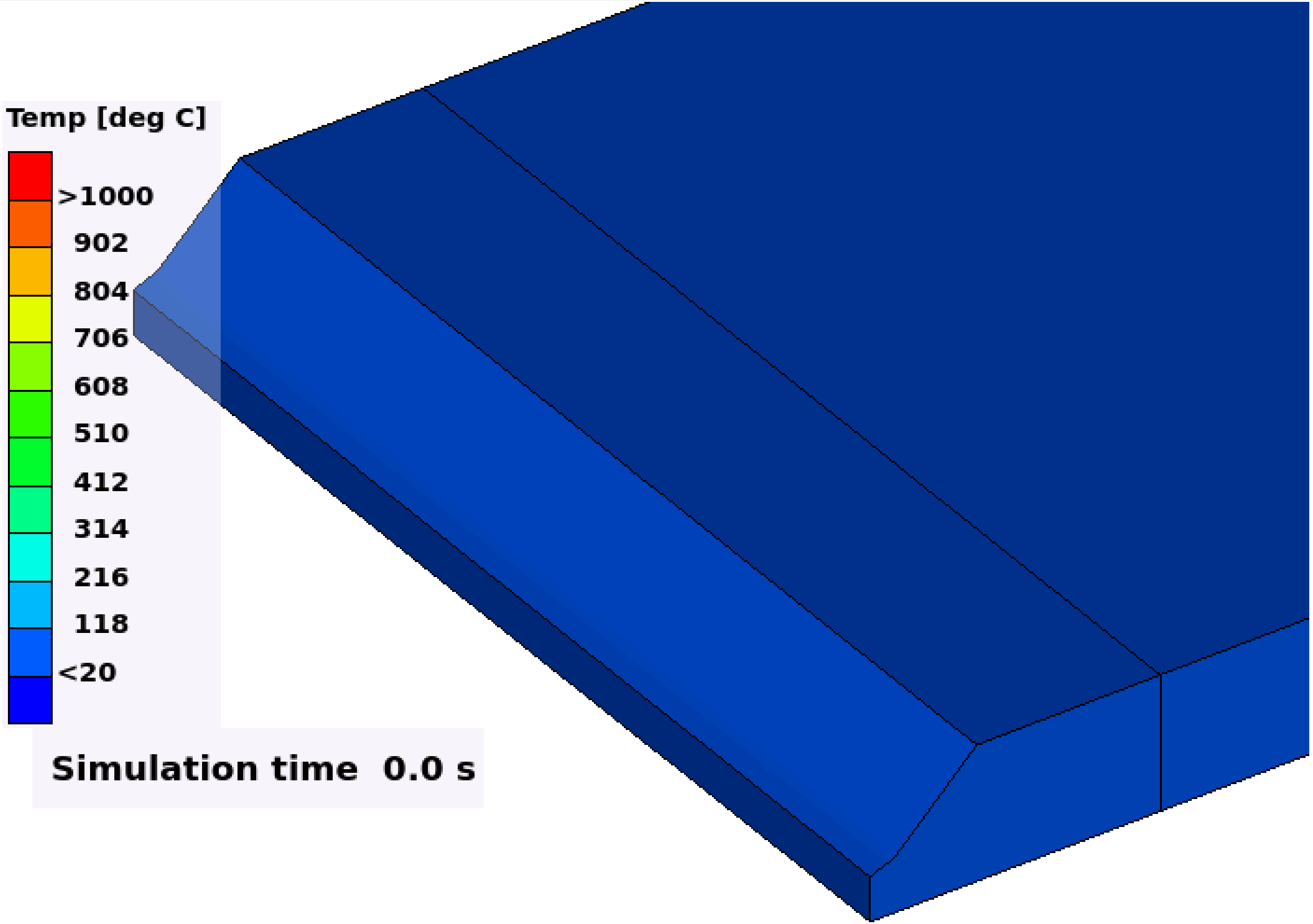
- “Silent” elements
- Activation moving with heat source
- Material properties, zero-strain temperature



Multiple weld passes

- Preheat, weld prep, etc.
- Cooling time between passes





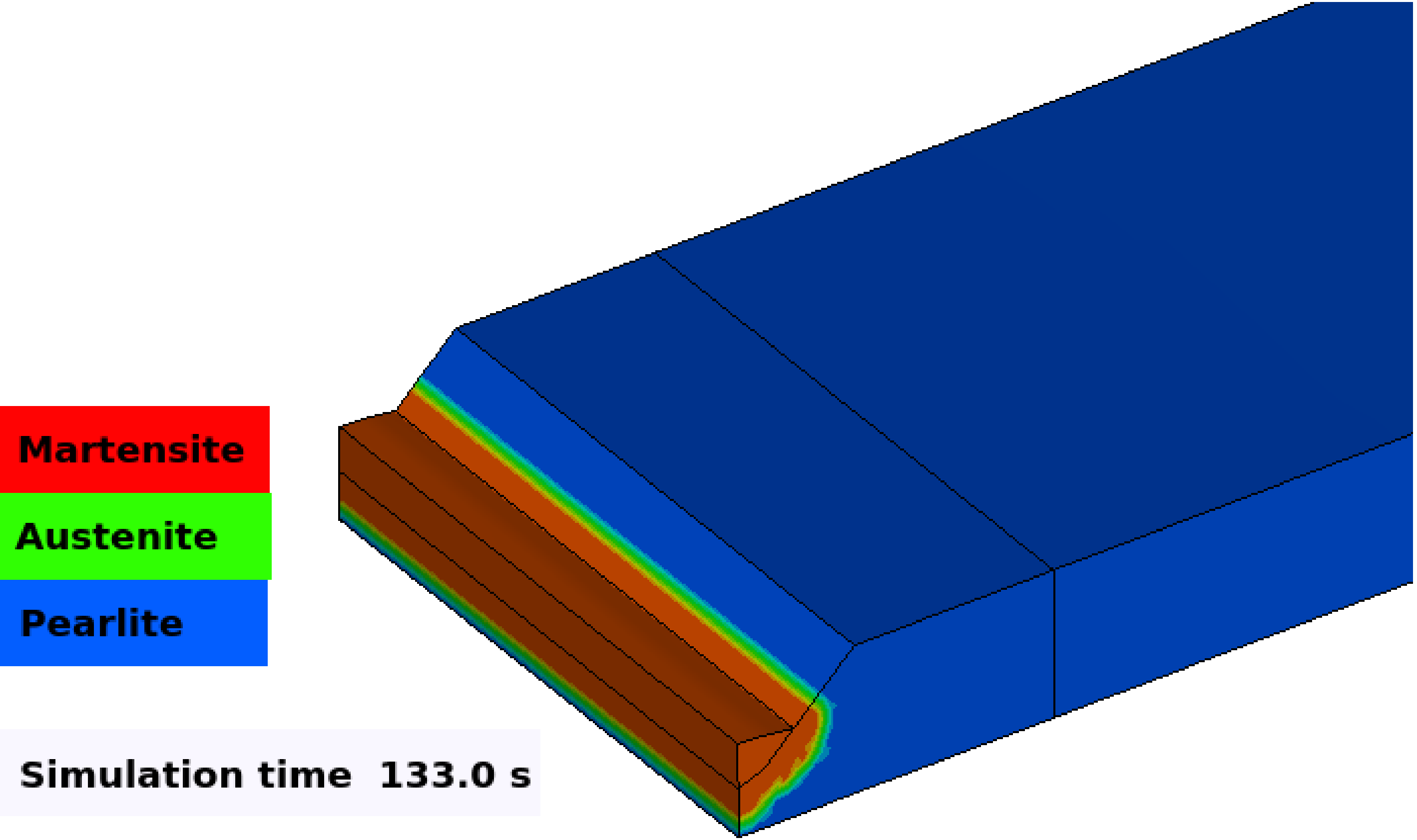
Temperature field

Moving heat source

Continuous addition of filament elements

FEM framework setup, parameter calibration needed

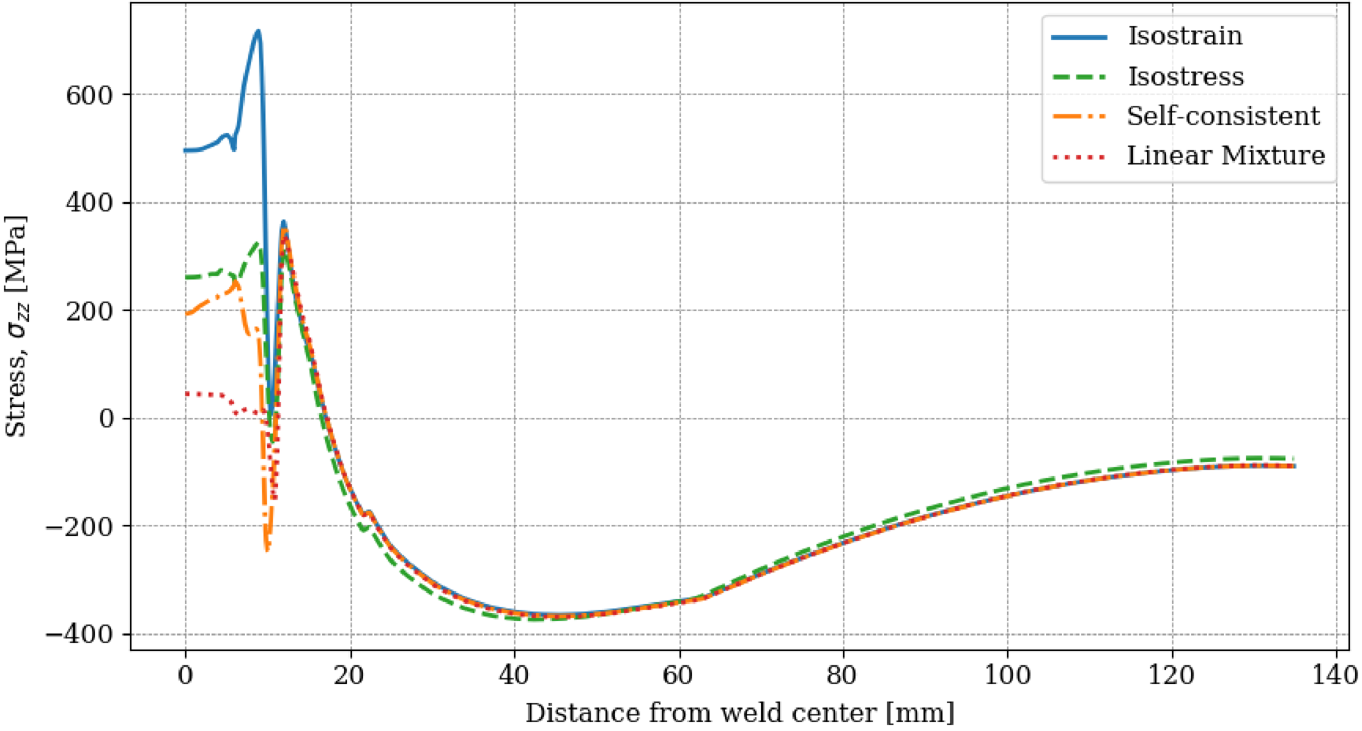
Phase field



Moving heat source

Continuous addition of filament elements

Rapid cooling
→ Martensite formation

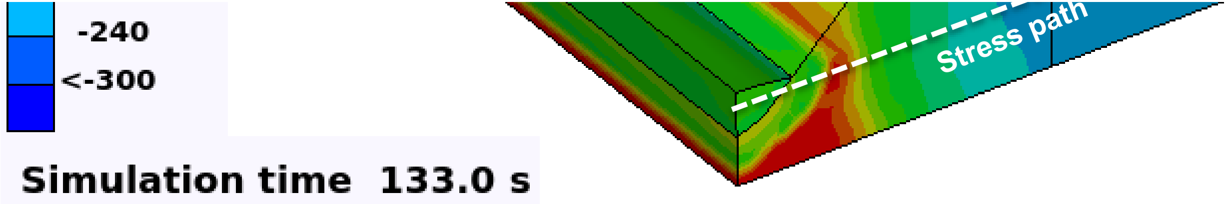


Residual stress field

Longitudinal stress

Basis for process parameter optimization together with phase evolution.

Optimization goal: Avoid both tensile stresses in certain regions and martensite formation

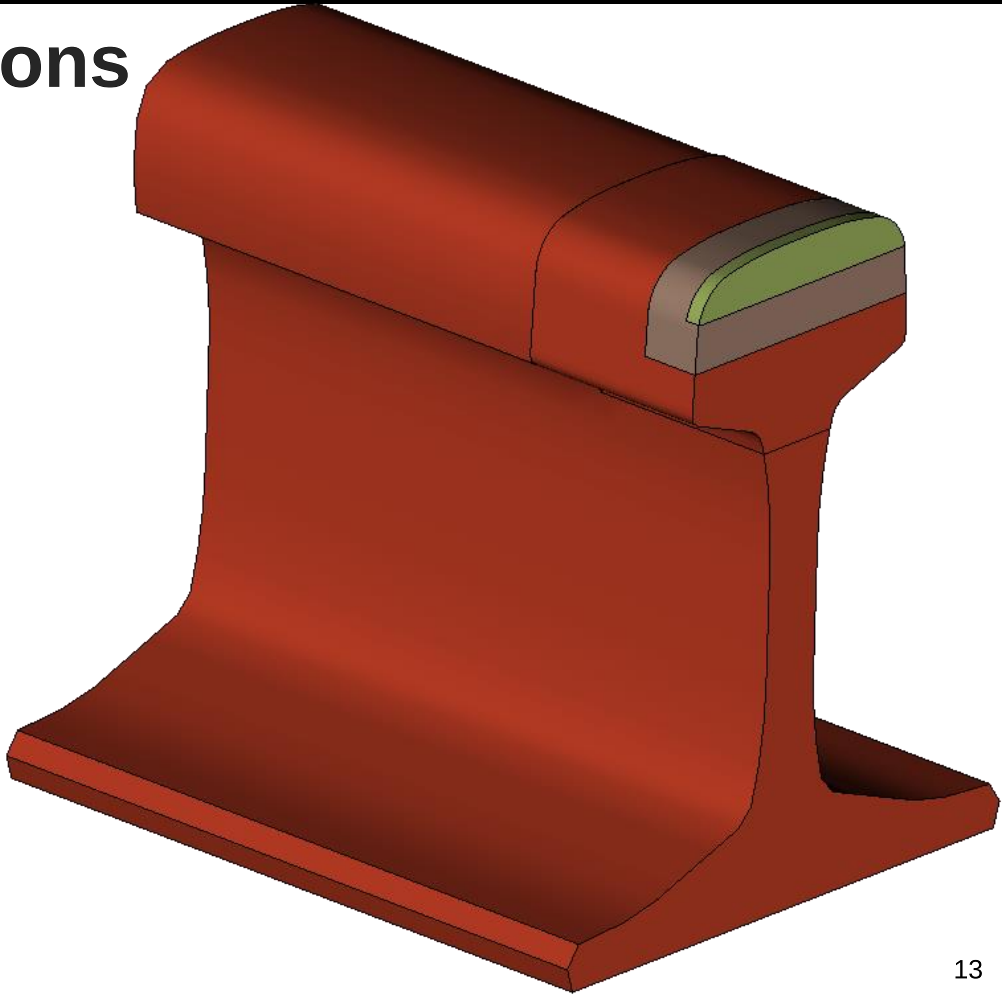


Summary and conclusions

- Thermo-mechanical-metallurgical model:
  - Phase / microstructure evolution
  - Homogenization of phase mechanical behavior
  - Transformation induced plasticity (TRIP)
  - Effect of phase transformation
- Advanced model for welding

- Comparing homogenization methods:
  - Computational time and convergence issues
  - Residual stress states in heat affected zone

- Future Work
  - Full scale simulation of repair welding process
  - Optimize process parameters and controlled pre-heating and operation temperature:
    - Avoid martensite formation
    - Avoid unfavorable residual stresses



Thank you

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CHARMEC Project MU37 – Numerical simulations of welding and other high temperature operations

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