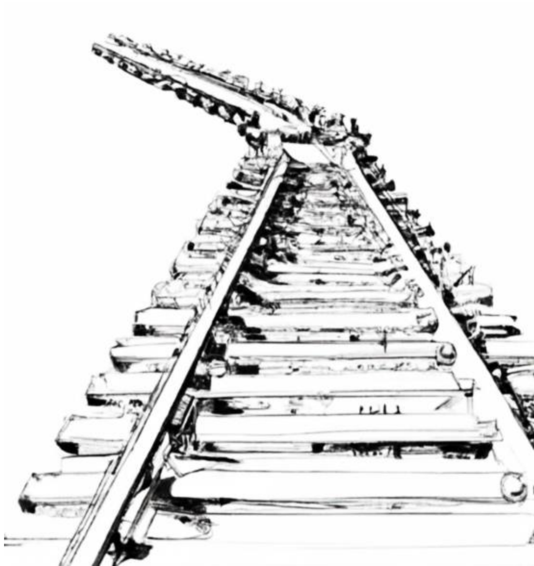
Simulering av Reparationssvetsning

Processparametrar och Reparationskvalitet

AG60, Borlänge, 2024-11-06

Björn Andersson, PhD
abjorn@chalmers.se
Division of Material and Computational Mechanics
Department of Industrial and Materials Science
Chalmers University of Technology



CHALMERS

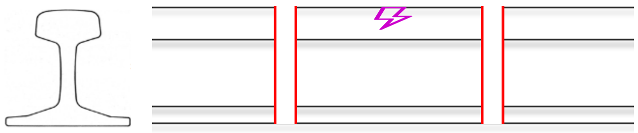
Background and motivation

Trafikverket 2022 rail defect statistics:

- 20-60% of all rail defects in weld regions
    - 60% most urgent (fix within a week)
    - 20% least urgent (wait until next inspection)
- ~ 450 defects in weld regions
- ~ 2100 defects in rail and switches

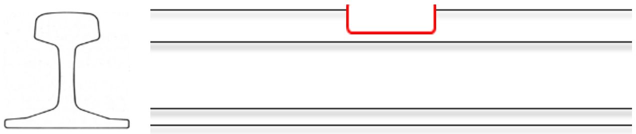
Background and motivation

Rail section repair - Thermite welding



- Remove entire damaged rail section
- Large heat input
- Slower cooling, pearlite formation, tensile stresses in web

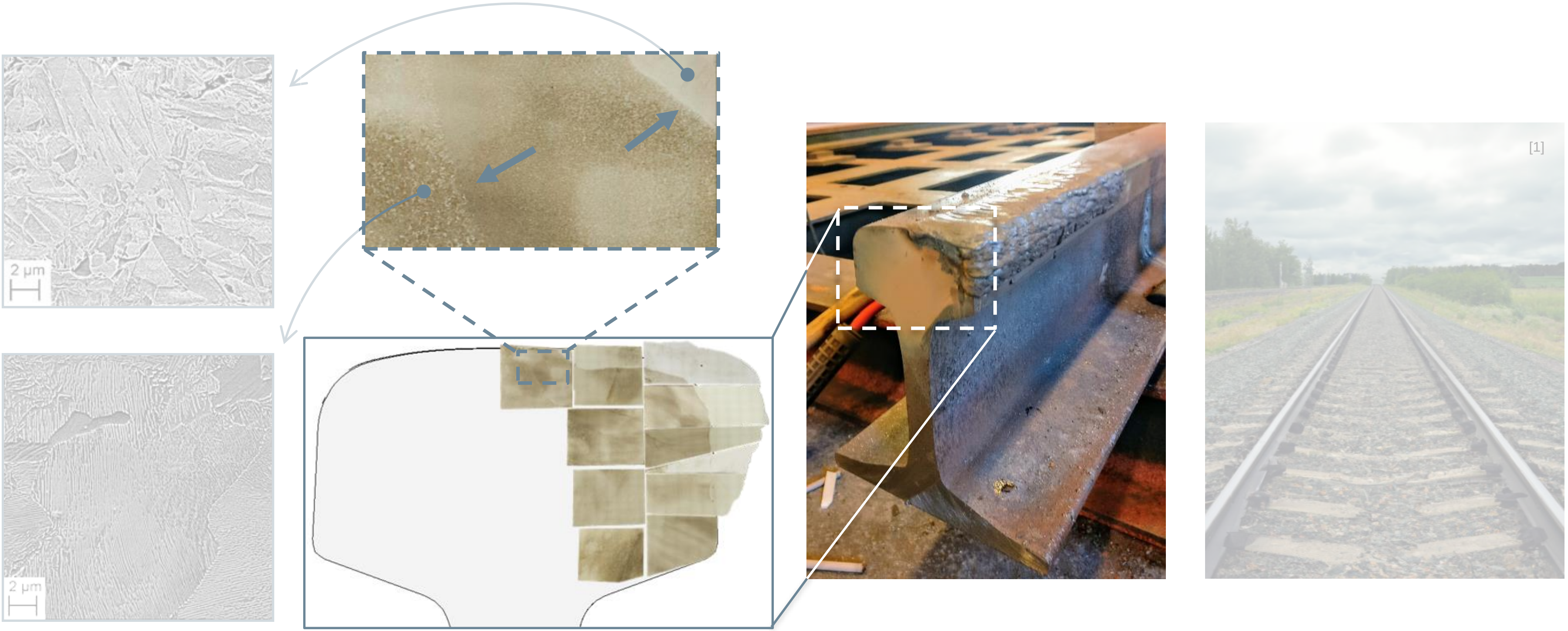
Rail head repair – MIG/MMA welding



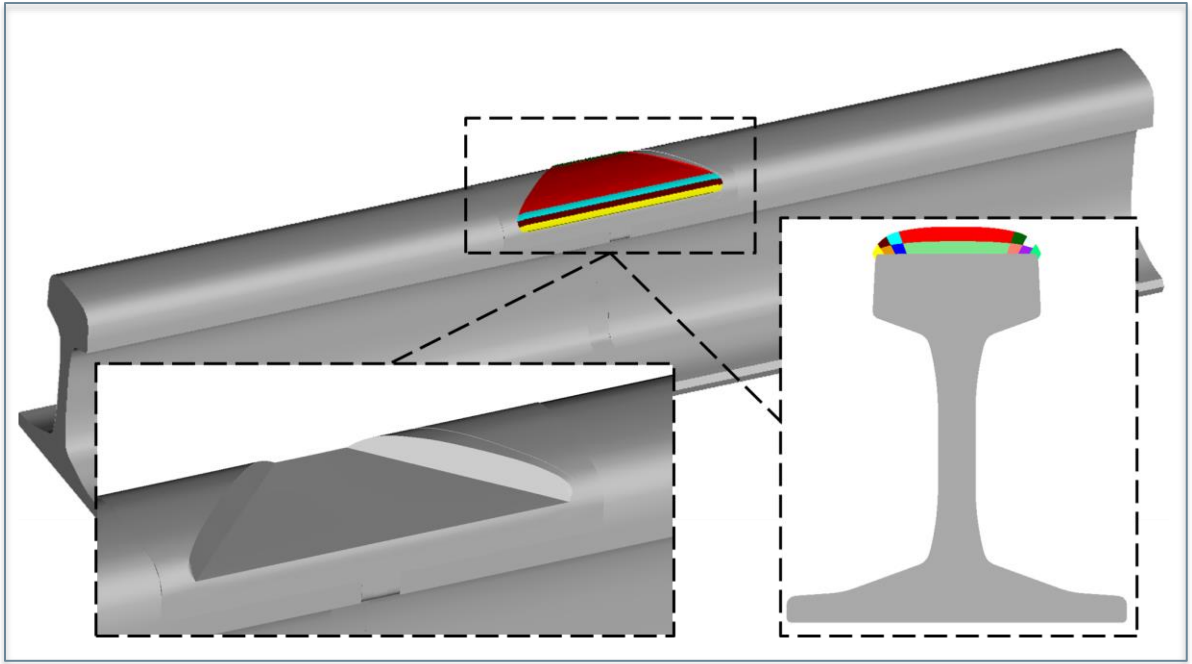
- Remove only railhead damage (or switches)
- Small, local heat input, several weld passes
- Rapid cooling, risk for martensite formation
- Complex microstructure evolution
- Effects of phases and phase transformations

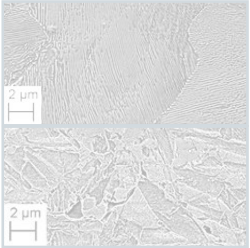
[1] modernrailways.com/article/faster-rail-welding, [2] thermit-welding.com/wp-content/uploads/2016, [3] pandrol.com/wp-content/uploads/2020/07/, [4] starkon.nl/project/sts-crane-trolley-rail-eld-repair/

Research Overview

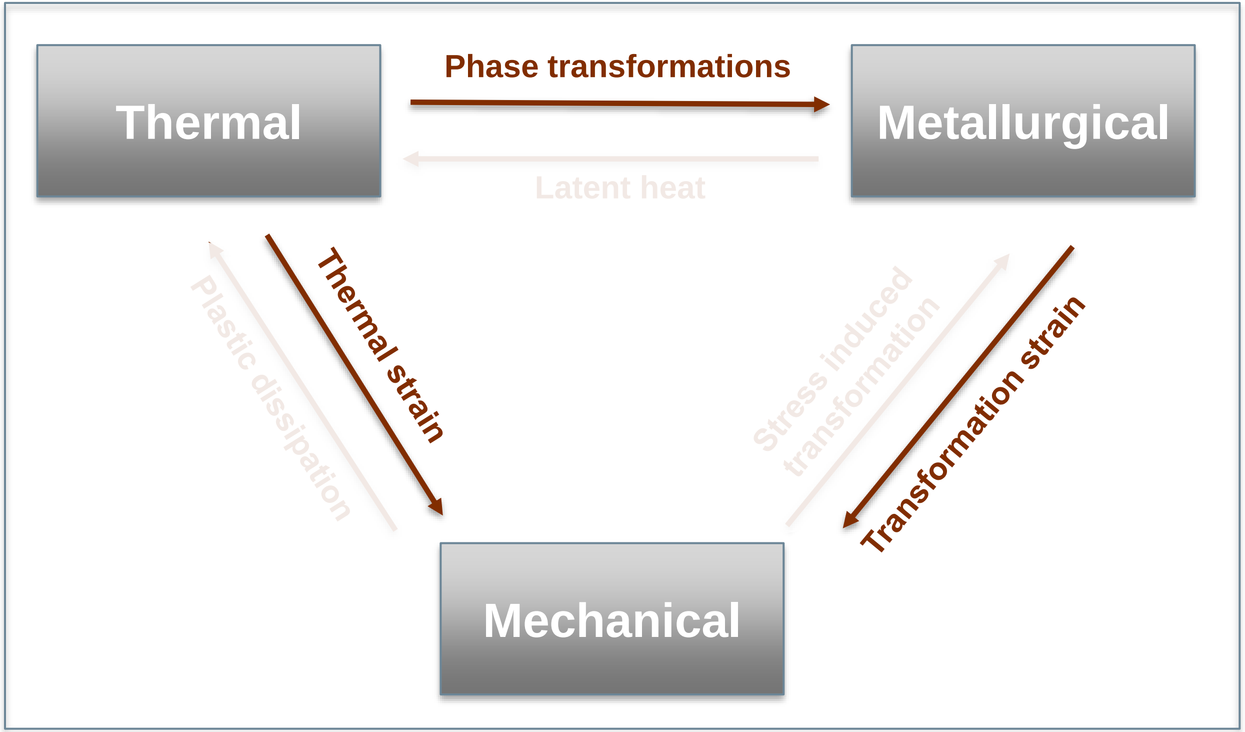


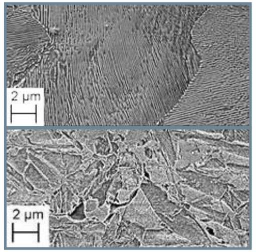
[1] Dall·E2 generated rail image

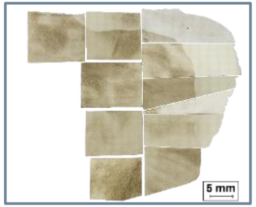



2 µm
2 µm

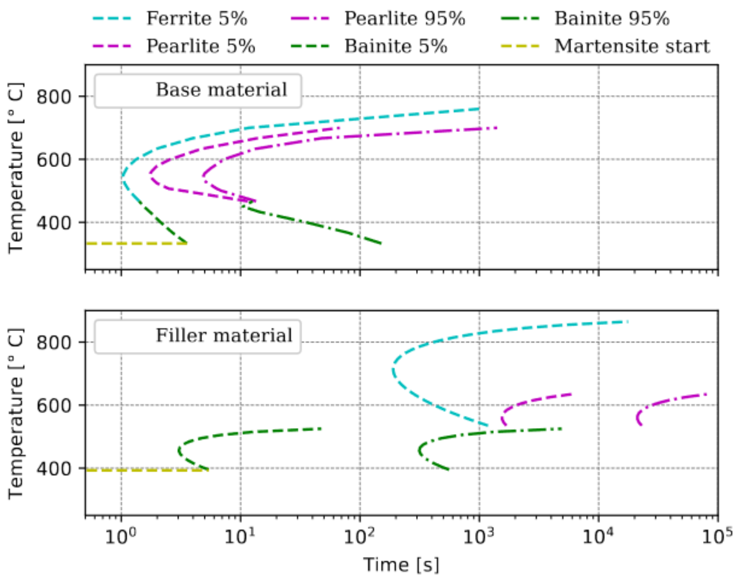

5 mm

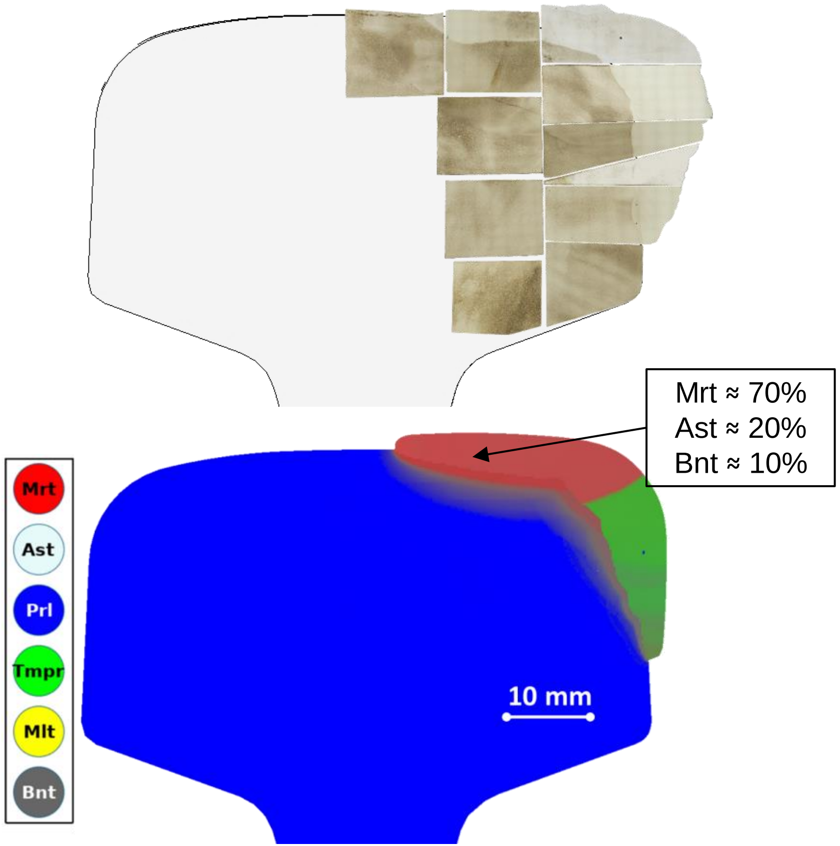

Thermal
Phase transformations
Metallurgical
Latent heat
Plastic dissipation
Thermal strain
Stress induced transformation
Transformation strain
Mechanical


2 µm
2 µm


5 mm

Constitutive mechanical model – Metallurgical

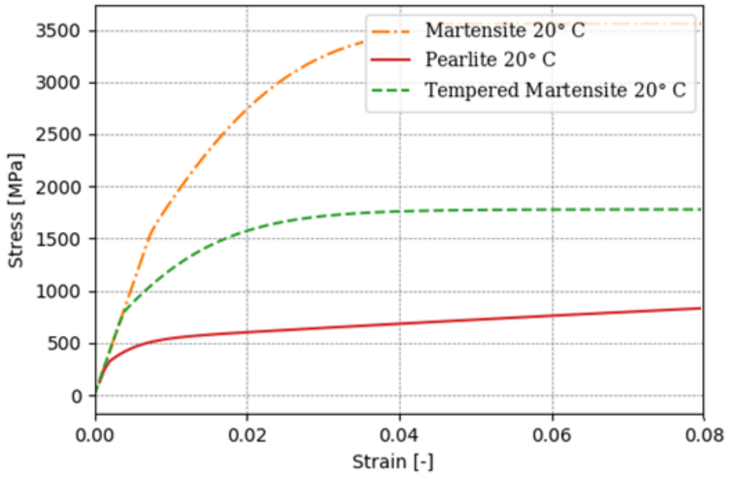




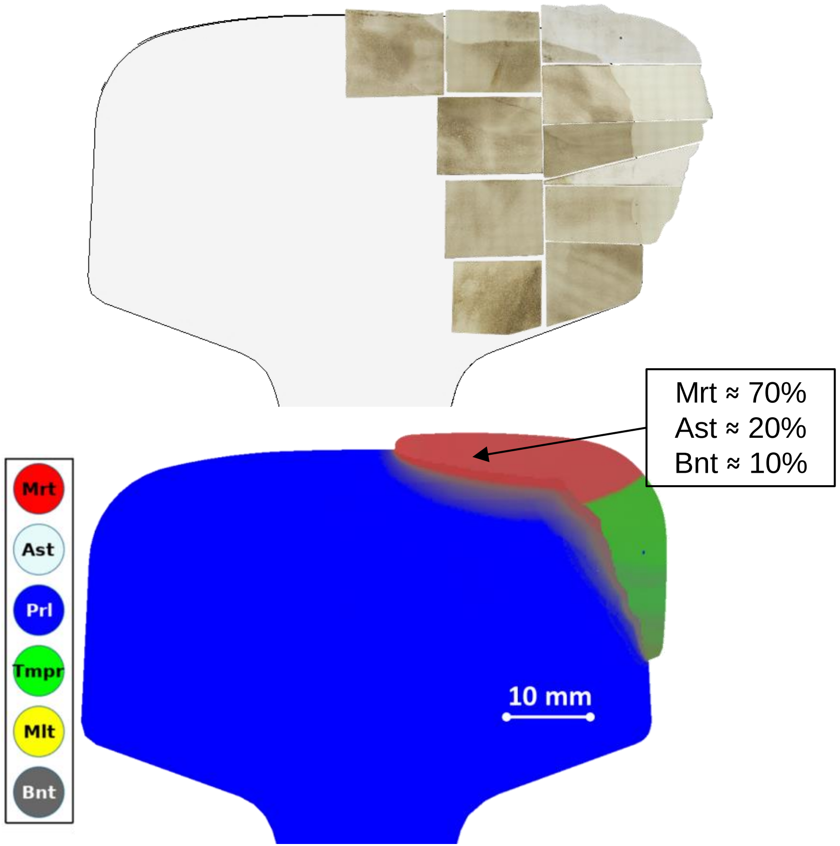
- Austenite, pearlite, bainite, martensite, tempered martensite and a liquid-like phase
- Diffusive transformations: JMAK and Scheil's additive rule
- Diffusionless martensite: Koistinen-Marburger
- Tempering: Temperature dependent
- Melting: Linear transformation

CHALMERS

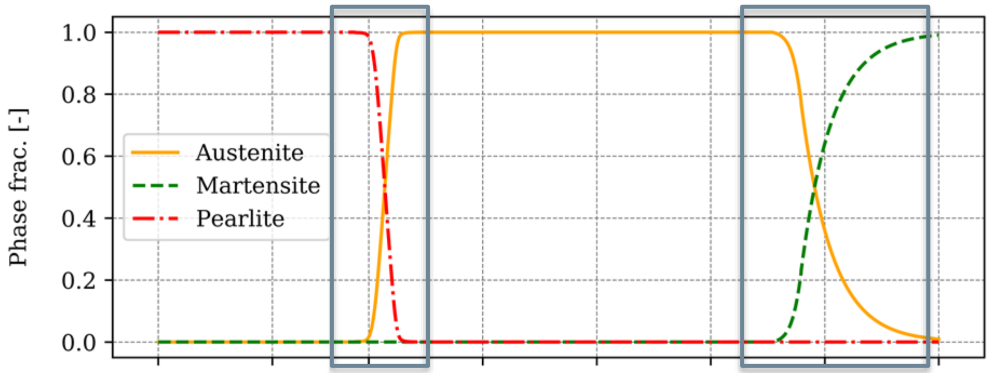
Constitutive mechanical model – Mechanical

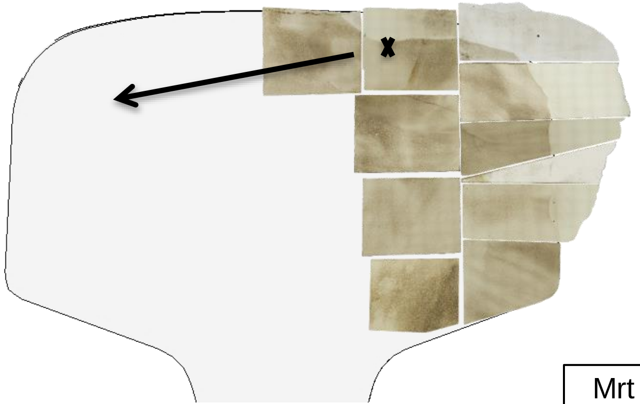


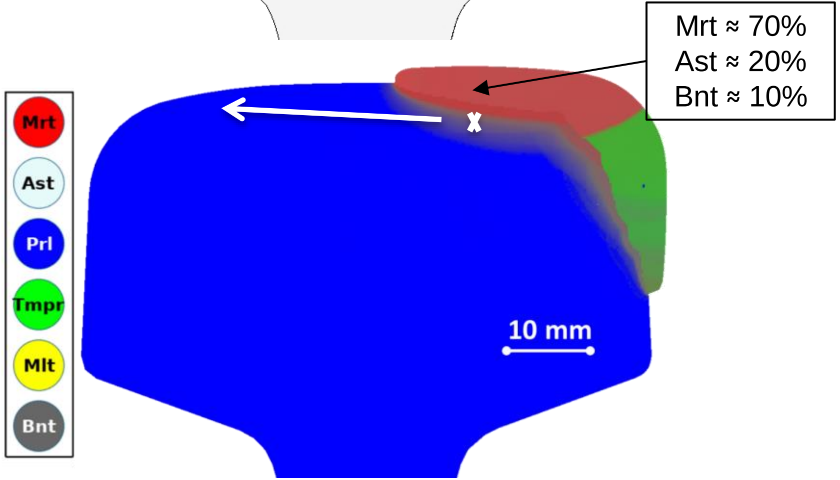
- Chaboche plasticity model
- Non-linear isotropic and kinematic hardening
- Volume changes, transformation strains
- Transformation induced plasticity (TRIP)
- Melting and re-melting virgin material state
- Multi-phase homogenization



Constitutive mechanical model – Multi phase homogenization

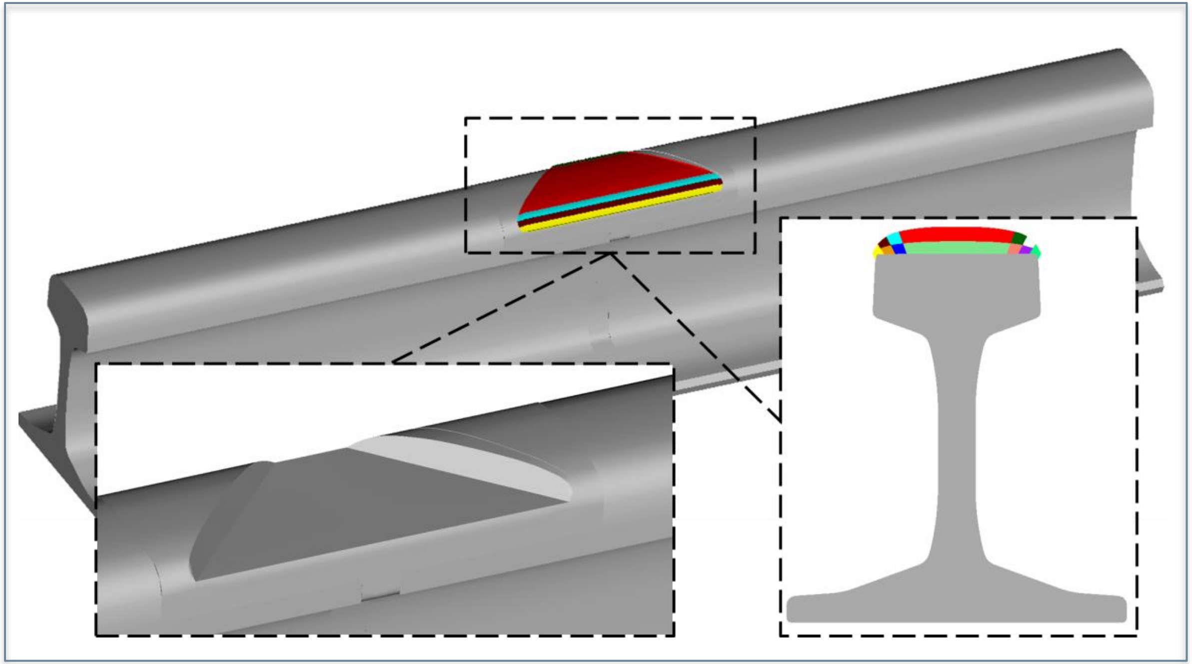


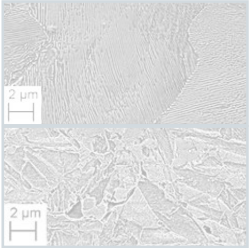




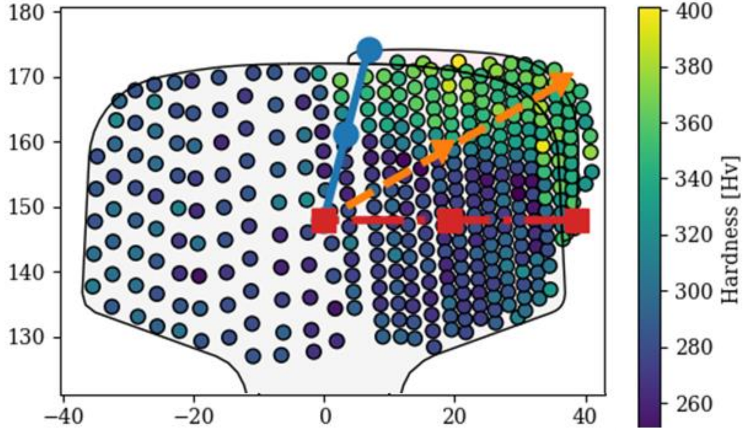
Multi-phase states

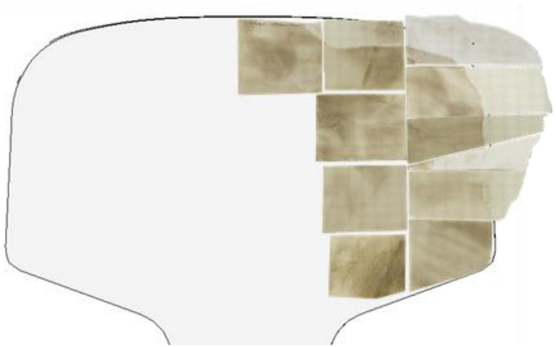
- Analytically based multi-phase homogenization
- Four homogenization methods studied
  - Isostrain (Voigt)
  - Isostress (Reuss)
  - Self-consistent method
  - Linear mixture rule
- Significant effect on the simulation output

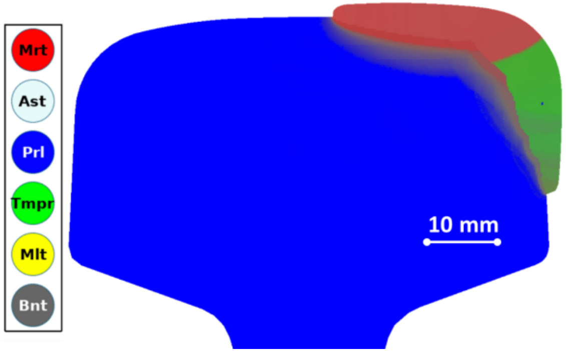


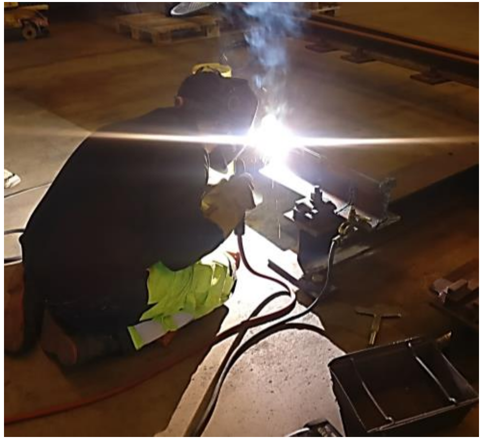

2 μm
2 μm


5 mm

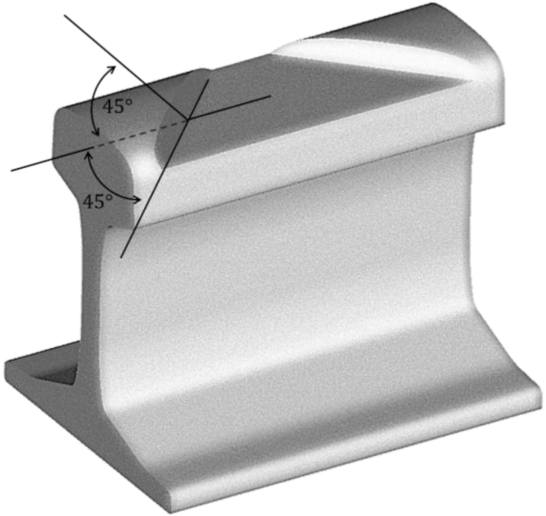

180
170
160
150
140
130
−40
−20
0
20
40
400
380
360
340
320
300
280
260
Hardness [Hv]




Mrt
Ast
Prl
Tmpr
Mlt
Bnt
10 mm



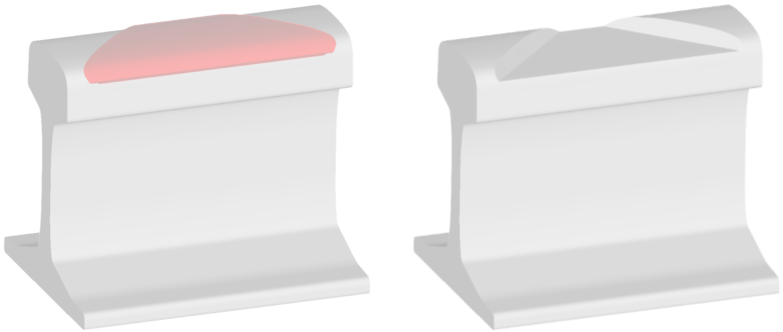
Repair welding simulation

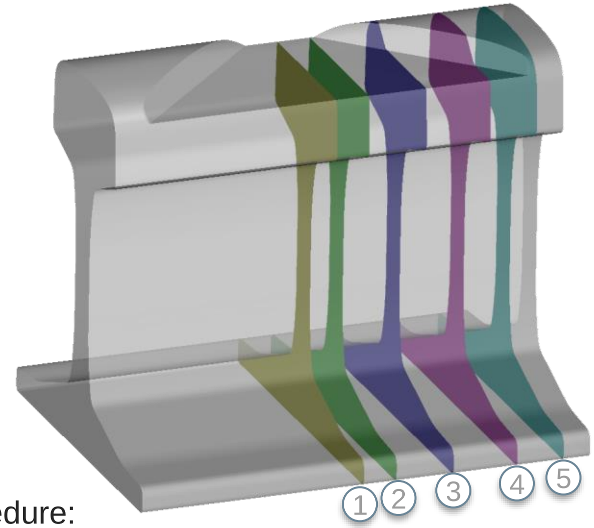


Railhead repair welding procedure:

- Following Swedish regulations
- 10 mm deep cut-out
- 45° chamfered cutouts
- Longitudinal support ridge weld passes
- Zig-zag weld passes between ridges
- 350°C preheat (and reheat)
- 12 weld passes (10 longitudinal, 2 zig-zag)

Repair welding simulation





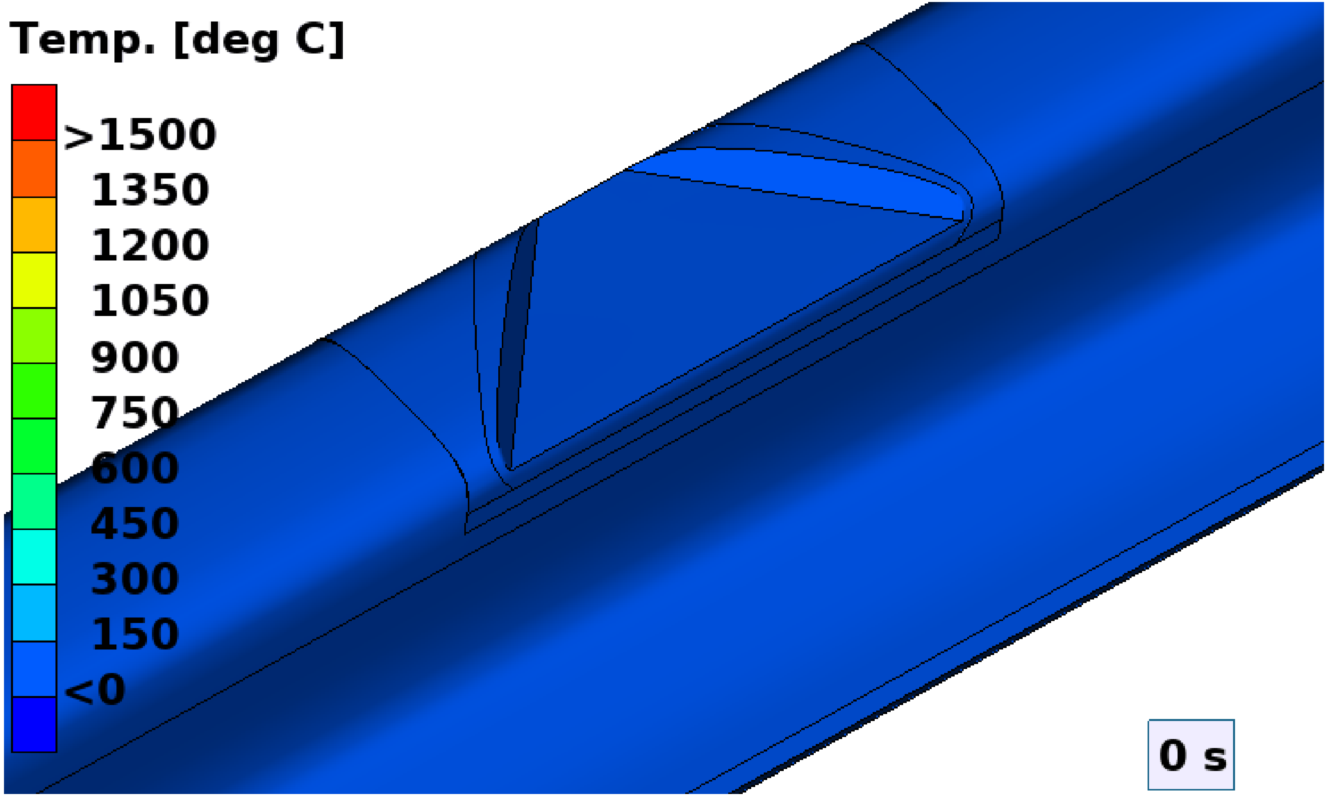
Railhead repair welding procedure:

- Following Swedish regulations
- 10 mm deep cut-out
- 45° chamfered cutouts
- Longitudinal support ridge weld passes
- Zig-zag weld passes between ridges
- 350°C preheat (and reheat)
- 12 weld passes (10 longitudinal, 2 zig-zag)

Weld simulation:

- Heat transfer: 3D model
- Mechanical: Multiple 2D cross sections

Heat source model tuning



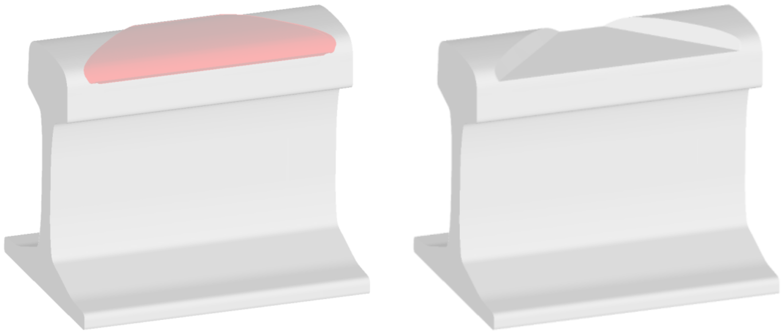
3D Heat transfer simulation

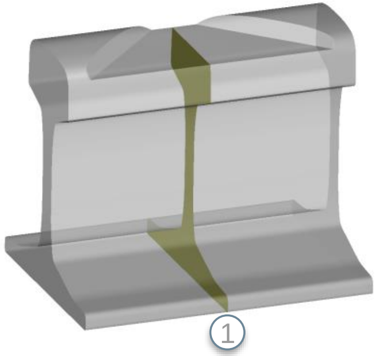
Temperature field

- Following Swedish regulations
- 10 mm deep cut-out
- 45° chamfered cutouts
- Longitudinal support ridge weld passes
- Zig-zag weld passes between ridges
- 350°C preheat (and reheat)
- 12 weld passes (10 longitudinal, 2 zig-zag)

CHALMERS

Repair welding simulation





Railhead repair welding procedure:

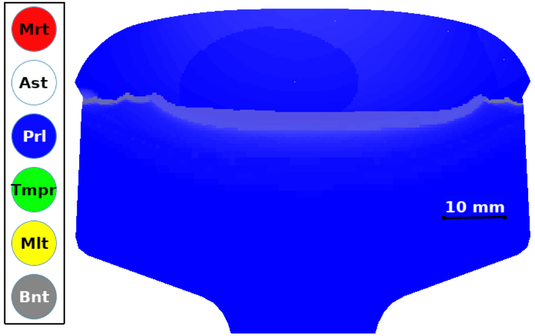
- Following Swedish regulations
- 10 mm deep cut-out
- 45° chamfered cutouts
- Longitudinal support ridge weld passes
- Zig-zag weld passes between ridges
- 350°C preheat (and reheat)

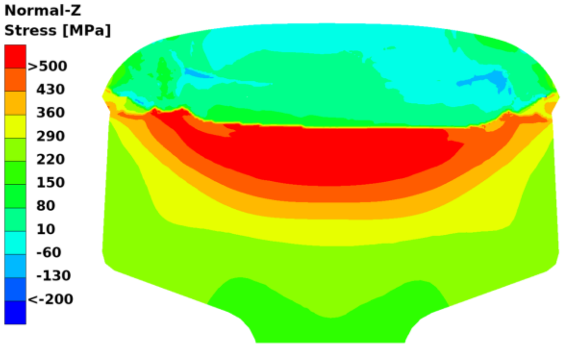
Weld simulation:

- Heat transfer: 3D model
- Mechanical: Multiple 2D cross sections

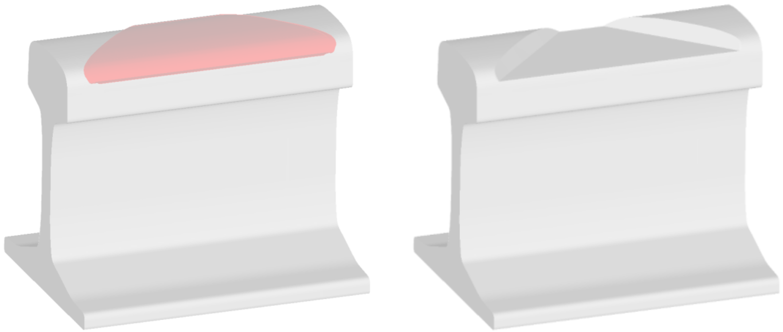
Simulation outcome:

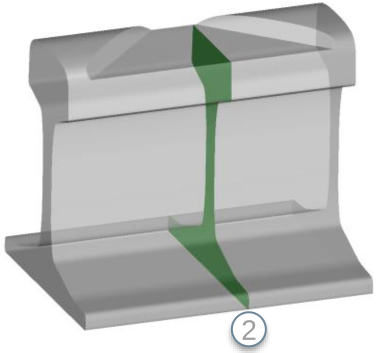
- Critical regions, material phases, stresses





Repair welding simulation





Railhead repair welding procedure:

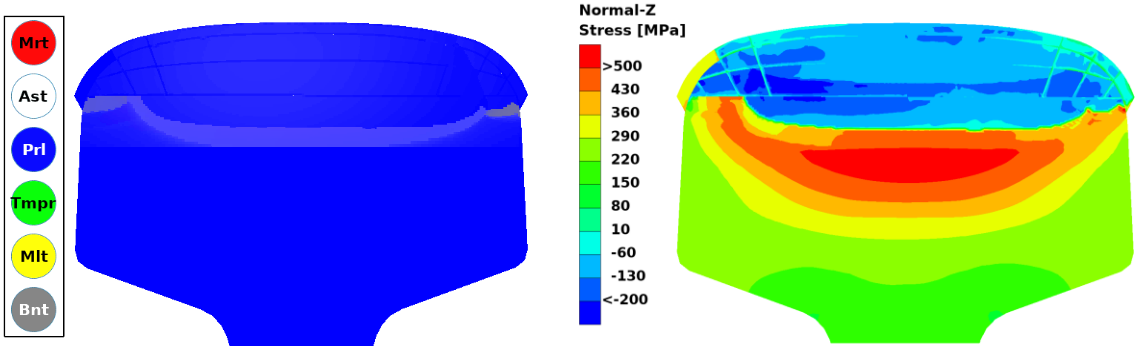
- Following Swedish regulations
- 10 mm deep cut-out
- 45° chamfered cutouts
- Longitudinal support ridge weld passes
- Zig-zag weld passes between ridges
- 350°C preheat (and reheat)

Weld simulation:

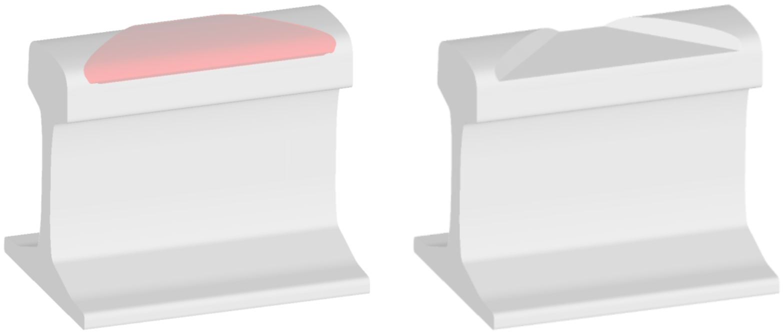
- Heat transfer: 3D model
- Mechanical: Multiple 2D cross sections

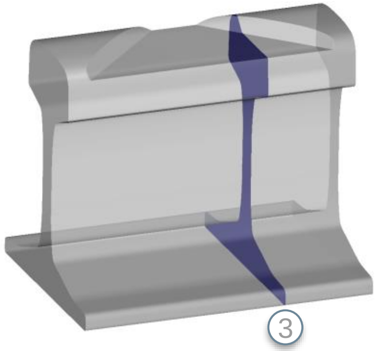
Simulation outcome:

- Critical regions, material phases, stresses



Repair welding simulation





Railhead repair welding procedure:

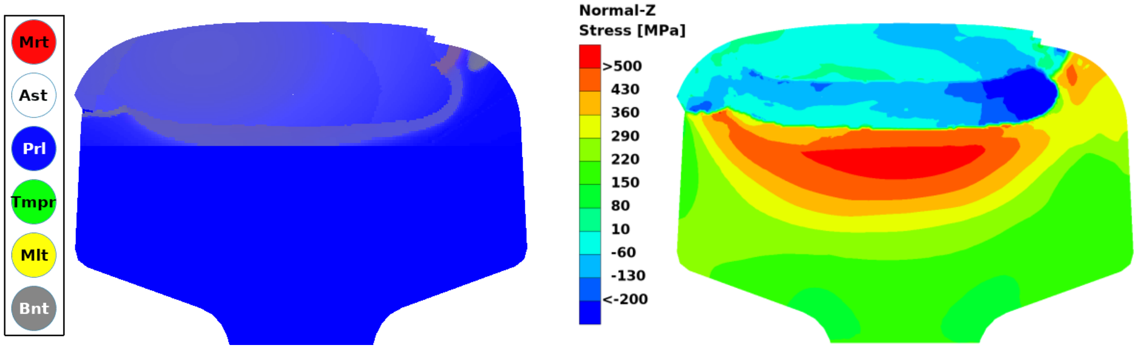
- Following Swedish regulations
- 10 mm deep cut-out
- 45° chamfered cutouts
- Longitudinal support ridge weld passes
- Zig-zag weld passes between ridges
- 350°C preheat (and reheat)

Weld simulation:

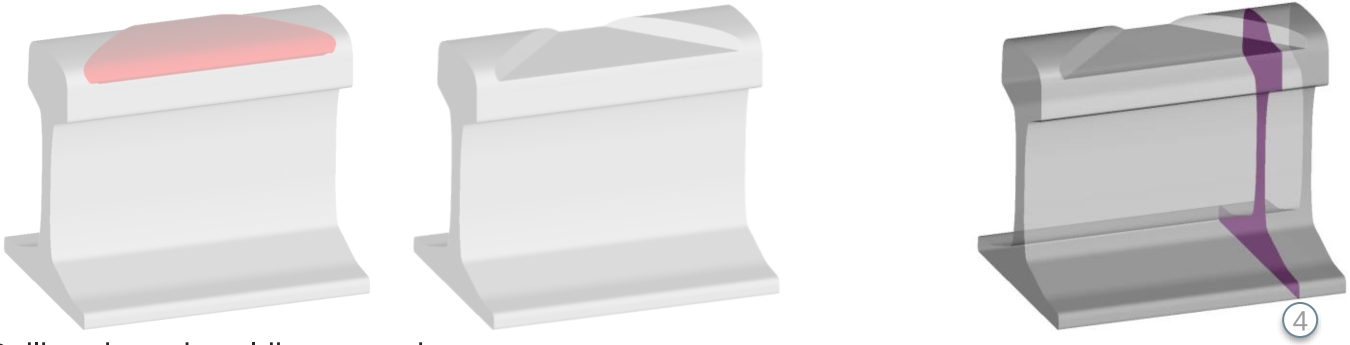
- Heat transfer: 3D model
- Mechanical: Multiple 2D cross sections

Simulation outcome:

- Critical regions, material phases, stresses



Repair welding simulation



Railhead repair welding procedure:

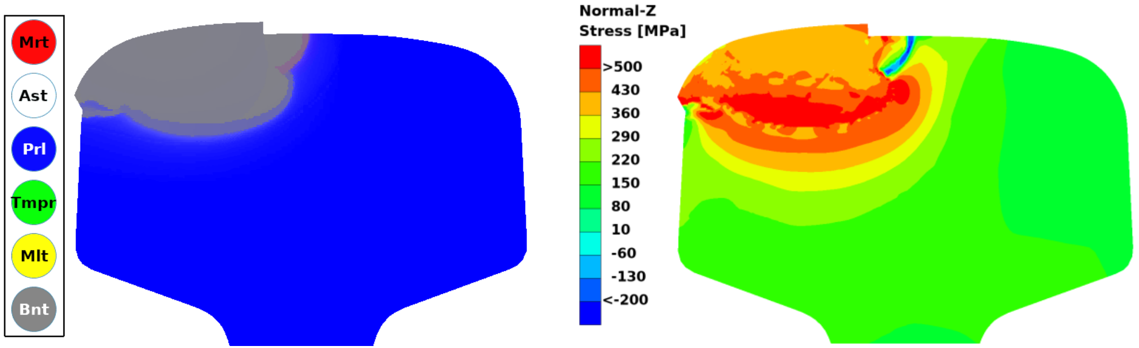
- Following Swedish regulations
- 10 mm deep cut-out
- 45° chamfered cutouts
- Longitudinal support ridge weld passes
- Zig-zag weld passes between ridges
- 350°C preheat (and reheat)

Weld simulation:

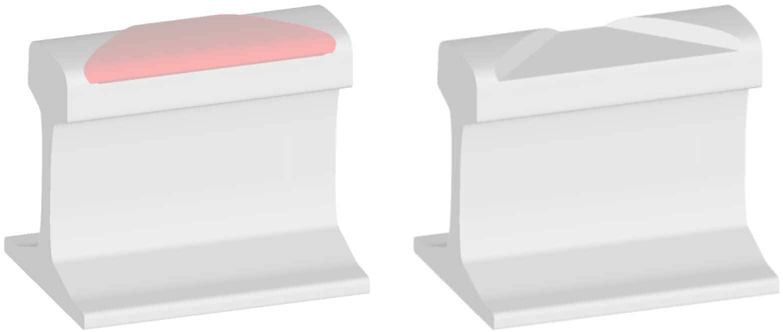
- Heat transfer: 3D model
- Mechanical: Multiple 2D cross sections

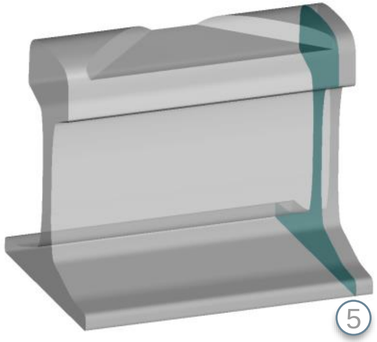
Simulation outcome:

- Critical regions, material phases, stresses



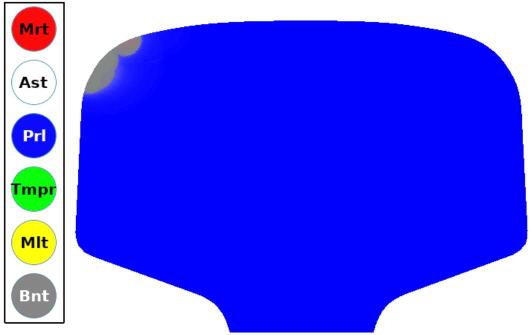
Repair welding simulation

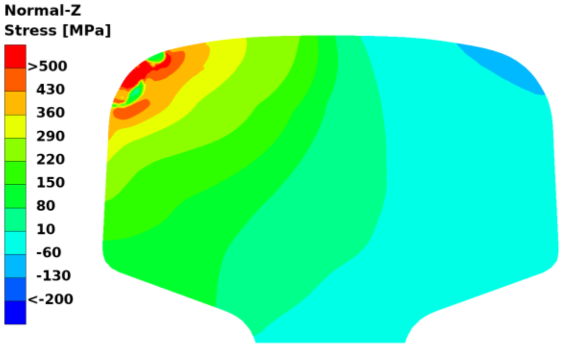




Railhead repair welding procedure:

- Following Swedish regulations
- 10 mm deep cut-out
- 45° chamfered cutouts
- Longitudinal support ridge weld passes
- Zig-zag weld passes between ridges
- 350°C preheat (and reheat)



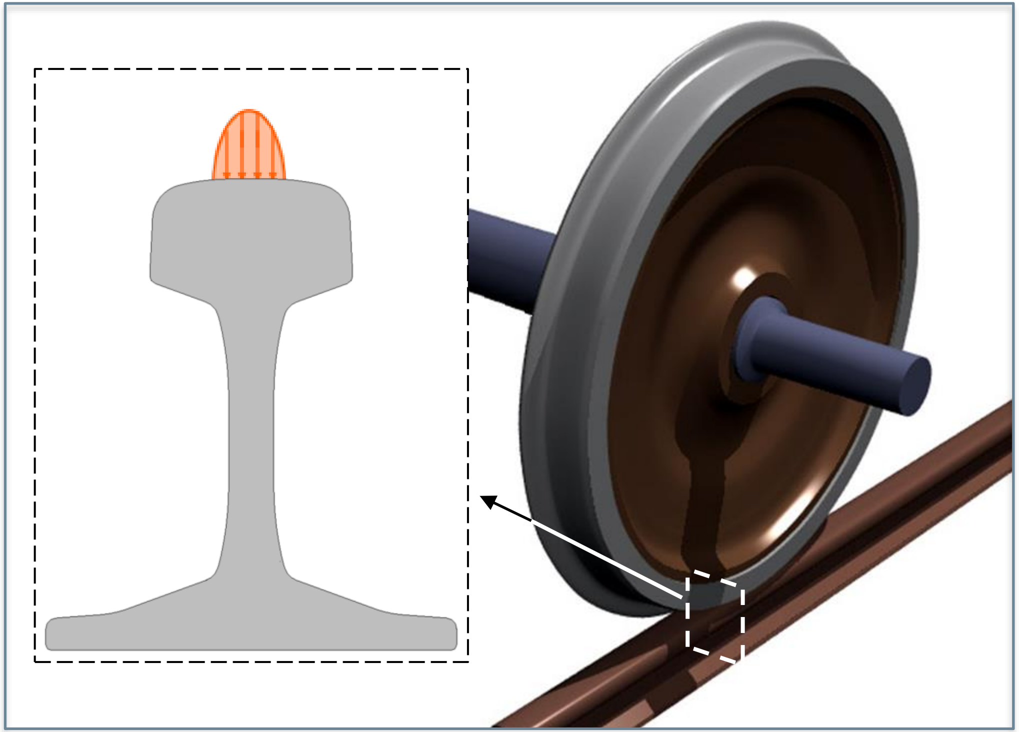


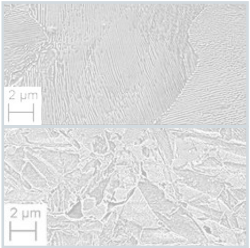
Weld simulation:

- Heat transfer: 3D model
- Mechanical: Multiple 2D cross sections

Simulation outcome:

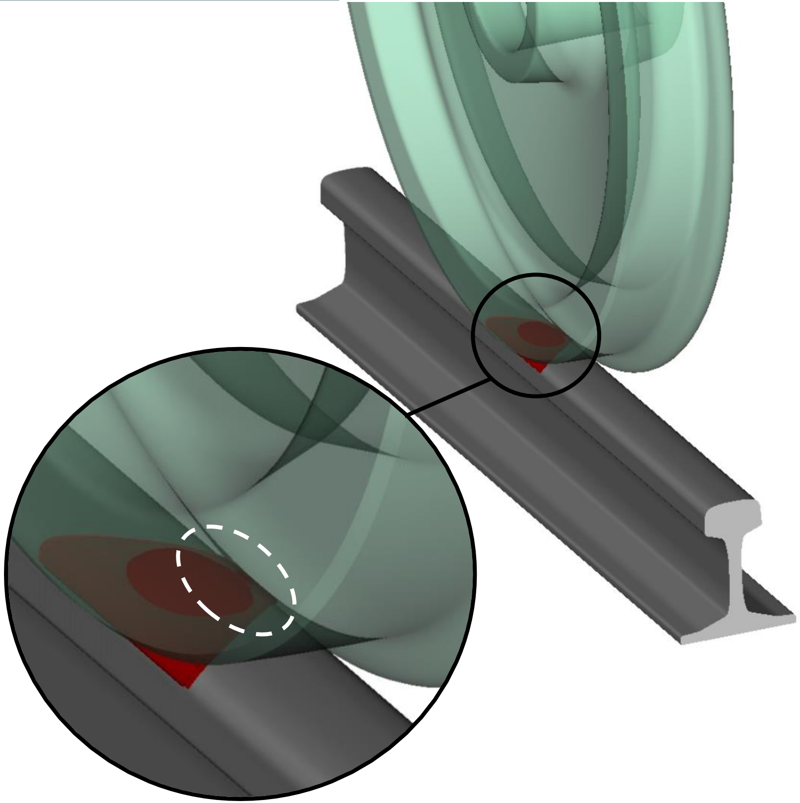
- Critical regions, material phases, stresses



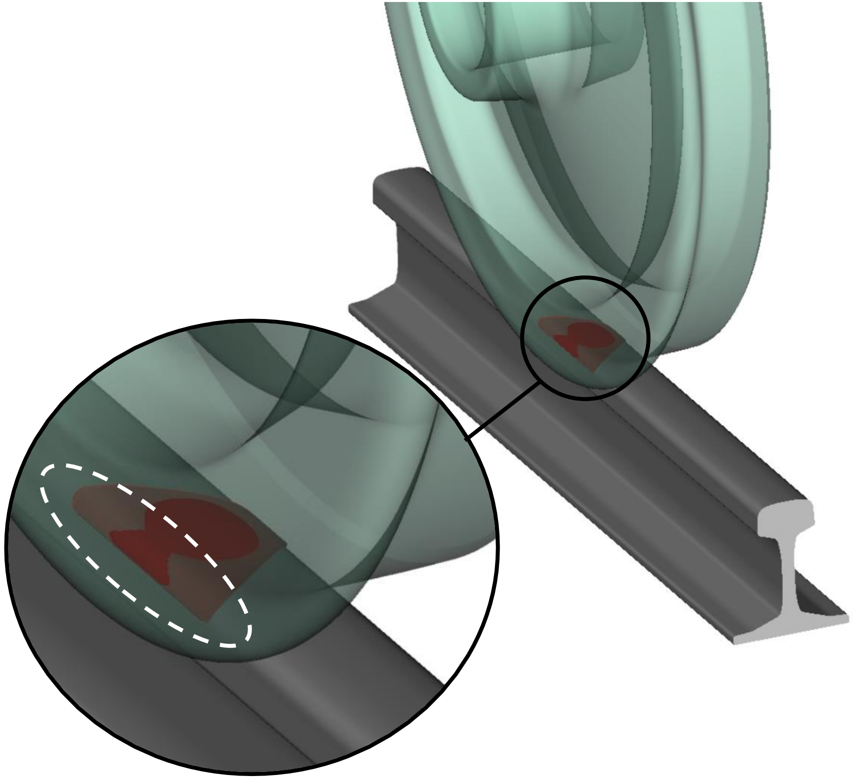

2 µm
2 µm


5 mm

Repair welding and over-rolling simulation

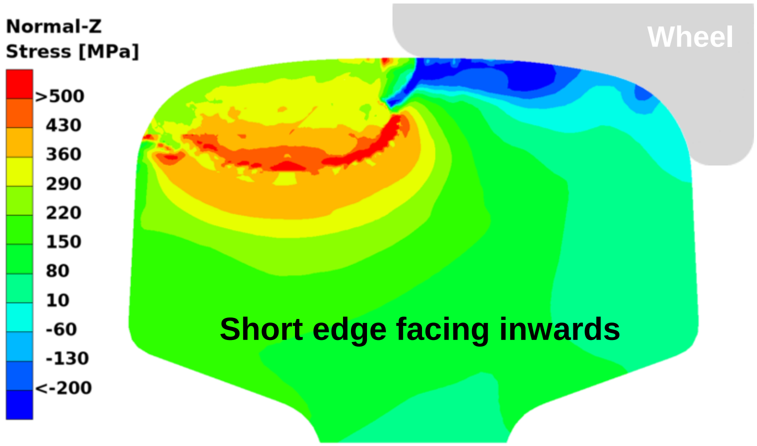


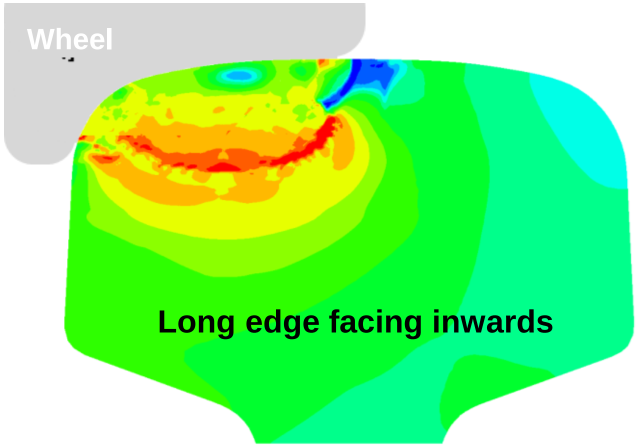
Short edge facing inwards



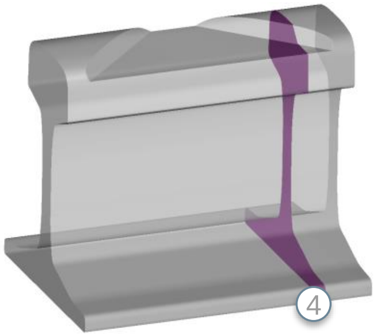
Long edge facing inwards

Repair welding and over-rolling simulation





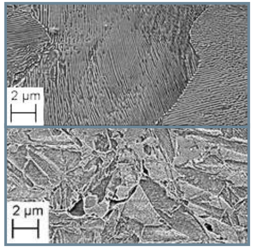
The orientation of the railhead cut-out has significant affect on mechanical performance

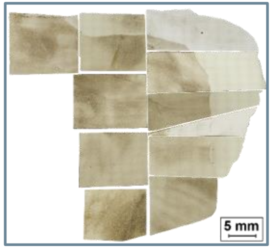


Summary

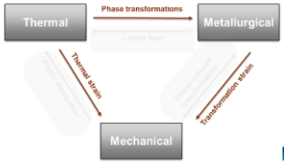
- Zick-zack “svetsbad” tillför mycket värme → långsam kylning
- 45° urkapningar ger up- och nedrampning av tillförd värme → långsam kylning
- Korta sidan av urkapning inåt i spar → hjulet åker på region med långsammare kylning
- Djupare urkapningar (mer tillfört material) → mer värme → långsam kylning

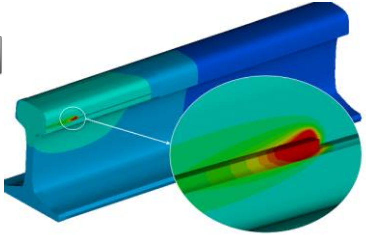
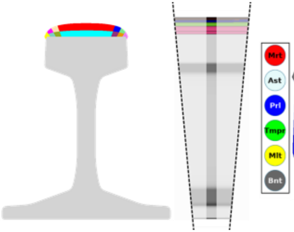
- Långsam kylning → mindre risk för spröd martensit

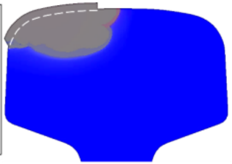
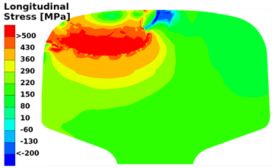








Future Work

Intressanta frågor att undersöka med simuleringar:

1. Hur påverkas tillståndet i den reparerade rälen om reparationssvetsningen sker med olika tillsatsmaterial i olika lager av uppbyggandet av material?
2. Hur påverkas rälen av en liten, minsta möjliga, reparationssvets?

Future Work

Hur går ni tillväga här:

- **I bästa fall?**
- **I värsta fall?**

Future Work

Hur går ni tillväga här:

- **I bästa fall?**
- **I värsta fall?**

Thank you for listening!

Simulering av Reparationssvetsning
Processparametrar och Reparationskvalitet

Dr. Björn Andersson

Supervisors:
Prof. Magnus Ekh[1]
Prof. Johan Ahlström[1]
Prof. Lennart Josefson[1]

Coauthors:
Dr Ali Esmaeili[1,2]
Dr Erika Steyn[1]

Support:
Prof. Jens Nielsen[3]
Lic Eng. Carolin Ansin[1]
Dr Michele Maglio[3,4]
Dr William Hearn[1]
Mr Stefan Kallander[4]
Mr David Heino[4]
Mr Anders Hegelmark[4]
Mr Ove Wahlbeck[5]
Mr Lennart Ericson[6]

[1]Chalmers University of Technology, Industrial and Materials Science
[2] Alleima, Gävle
[3]Chalmers University of Technology, Mechanics and Maritime Sciences
[4]Swedish Transport Administration (Trafikverket), Göteborg/Ängelholm/Luleå
[5]Alpha Laser, Göteborg
[6]Infranord AB, Karlstad