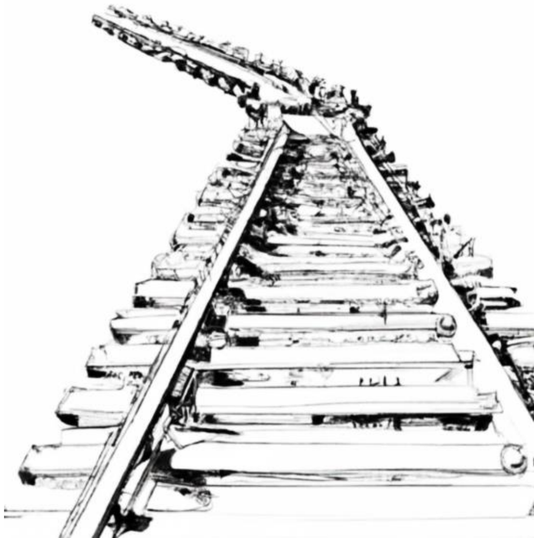
Simulering av Reparationssvetsning

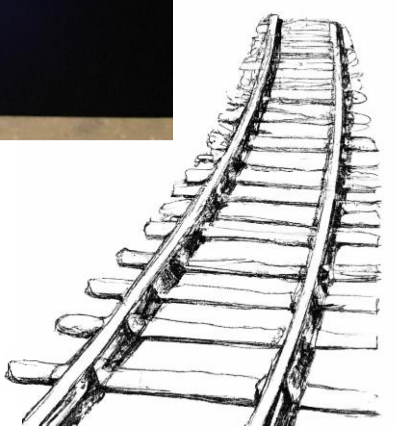
Evaluering av reparationskvalitet

AG60, Gävle, 2025-11-04

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



CHALMERS

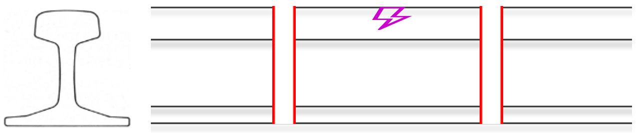


[1] https://mp.nl/en/solution/sound-measurements-board-train-detecting-rail-defects, [2] https://www.raildamage.com/

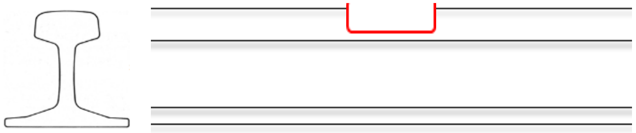
CHALMERS

Background and motivation – Rail repair

Rail section repair - Thermite welding



Rail head repair – Arc welding



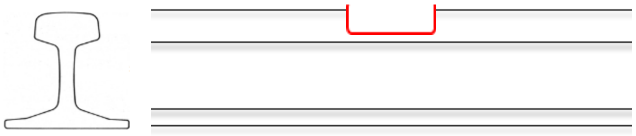
[1] modernrailways.com/article/faster-rail-welding, [2] thermit-welding.com/wp-content/uploads/2016, [3] pandrol.com/wp-content/uploads/2020/07/, [4] starkon.nl/project/sts-crane-trolley-rail-eld-repair/

Background and motivation – Rail repair

Research goal:
Improve using mechanical performance numerical simulations

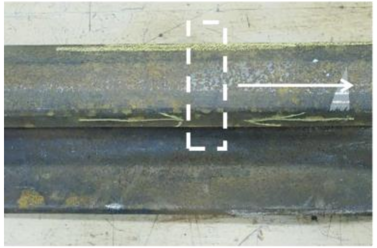
Rail Material R260
Fully Prearlitic (high carbon ~0.75%)
20-60% of all rail defects in weld regions

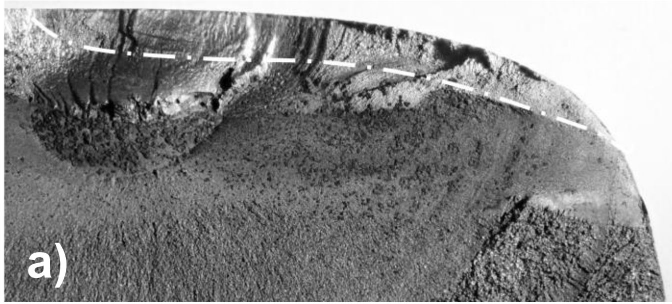
Rail head repair – Arc welding

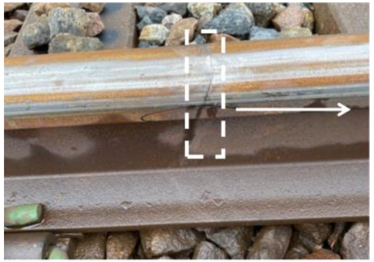


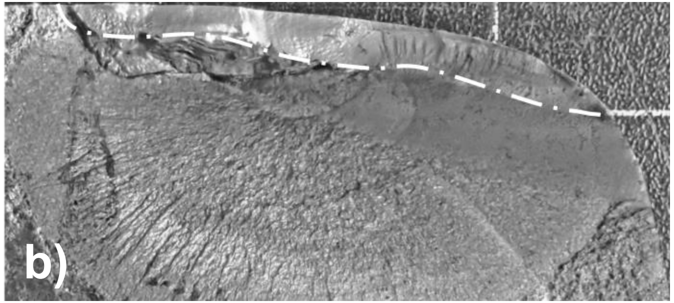
[1] modernrailways.com/article/faster-rail-welding, [2] thermit-welding.com/wp-content/uploads/2016, [3] pandrol.com/wp-content/uploads/2020/07/, [4] starkon.nl/project/sts-crane-trolley-rail-eld-repair/

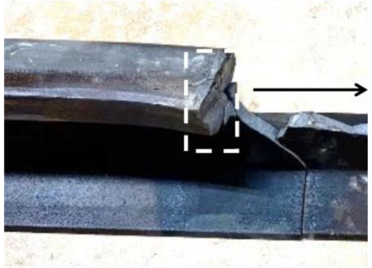
Background and motivation – Rail fracture











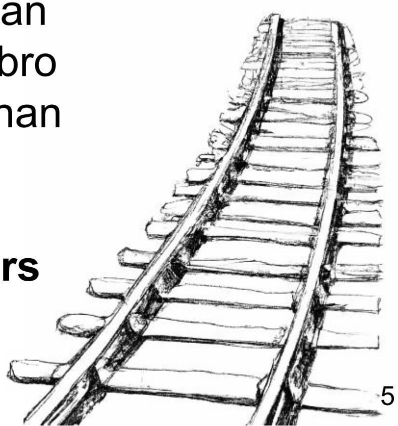
Trafikverket rail defect statistics:

- 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

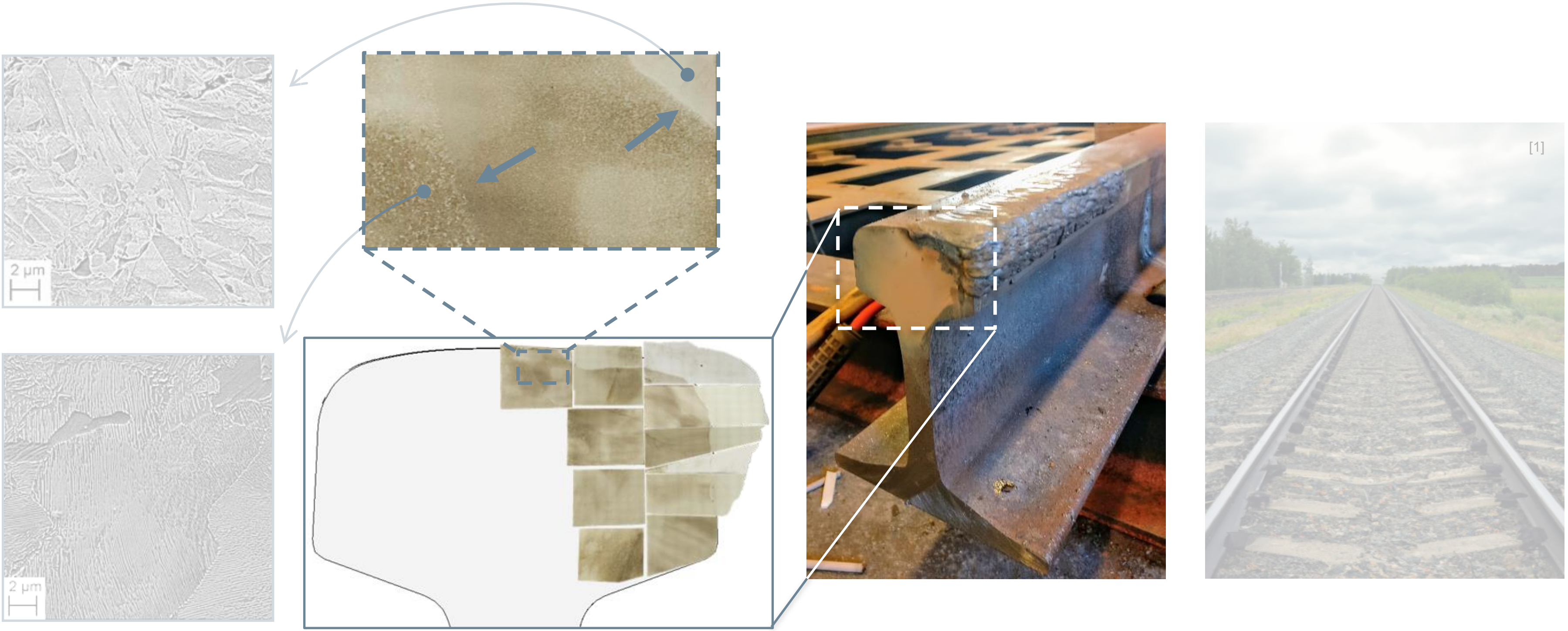
a) Rail crack Odenplan
b) Rail fracture Rotebro
c) Rail fracture Samnan

Fractured rail repairs



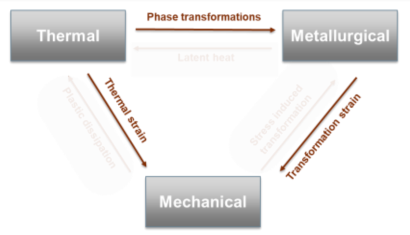
CHALMERS

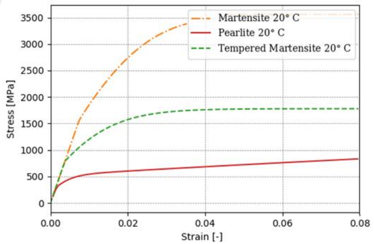
Research Overview

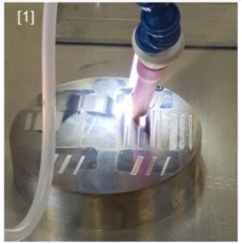


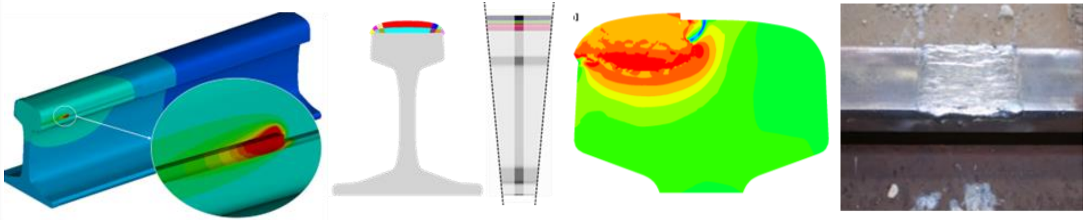
[1] Dall·E2 generated rail image

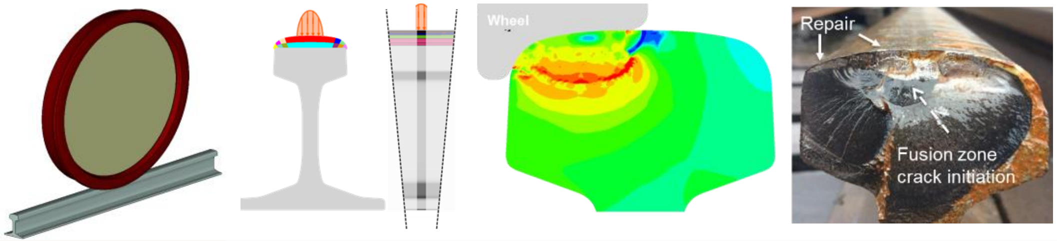
Rail repair welding simulation methodology

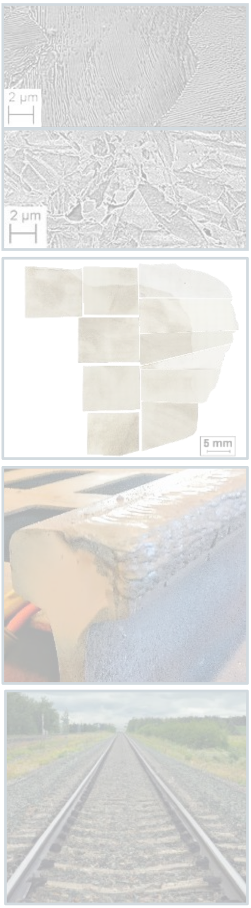


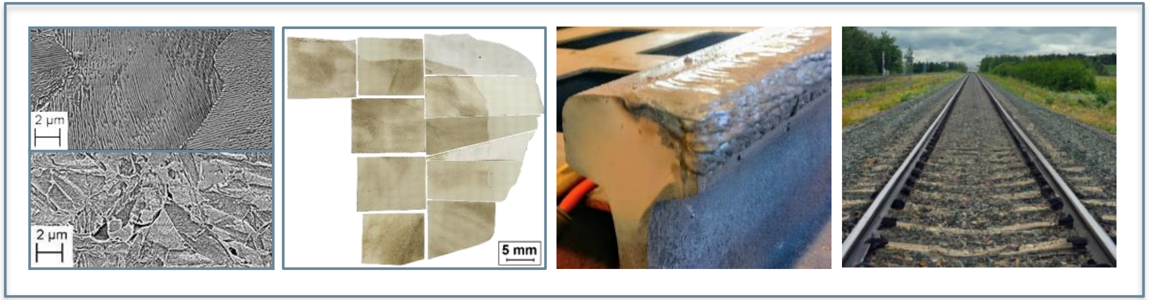


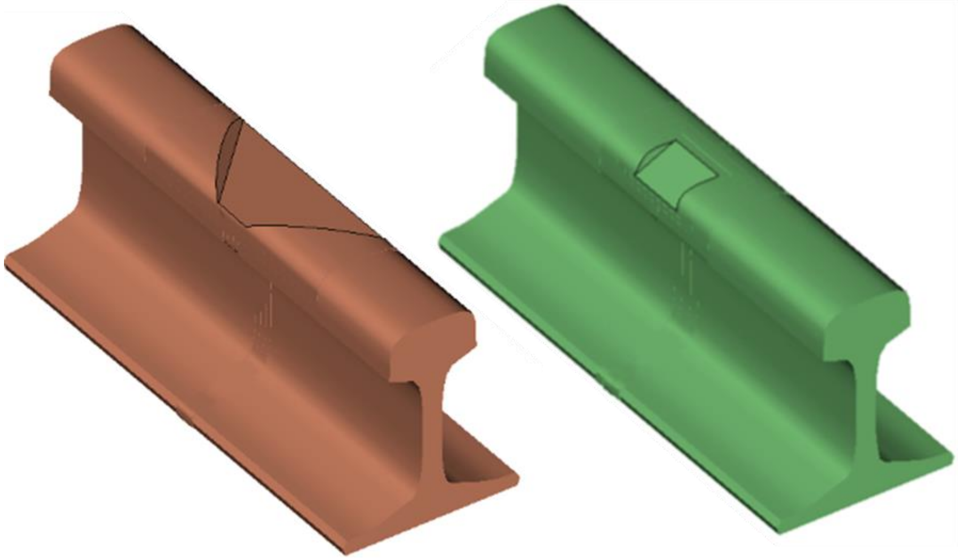






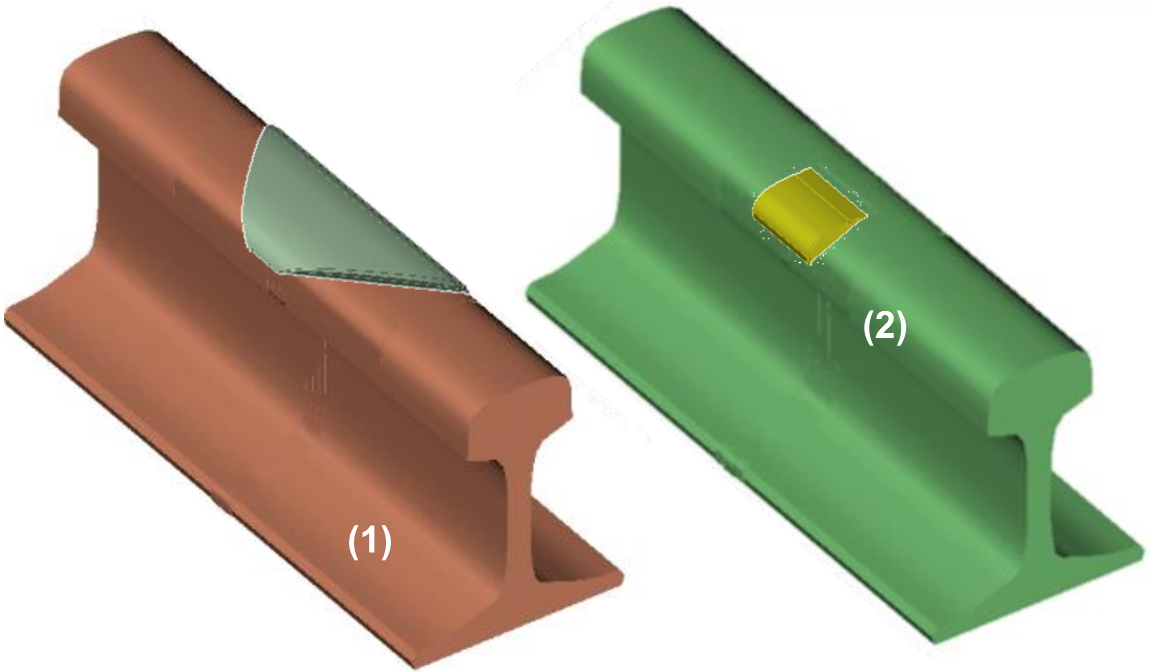



2 μm
2 μm
5 mm



CHALMERS

Railhead repair welding



Railhead repair welding procedure::

- 350°C preheat (and reheat)
- Manual Metal Arc Welding
- Filler material: Weartrode 30

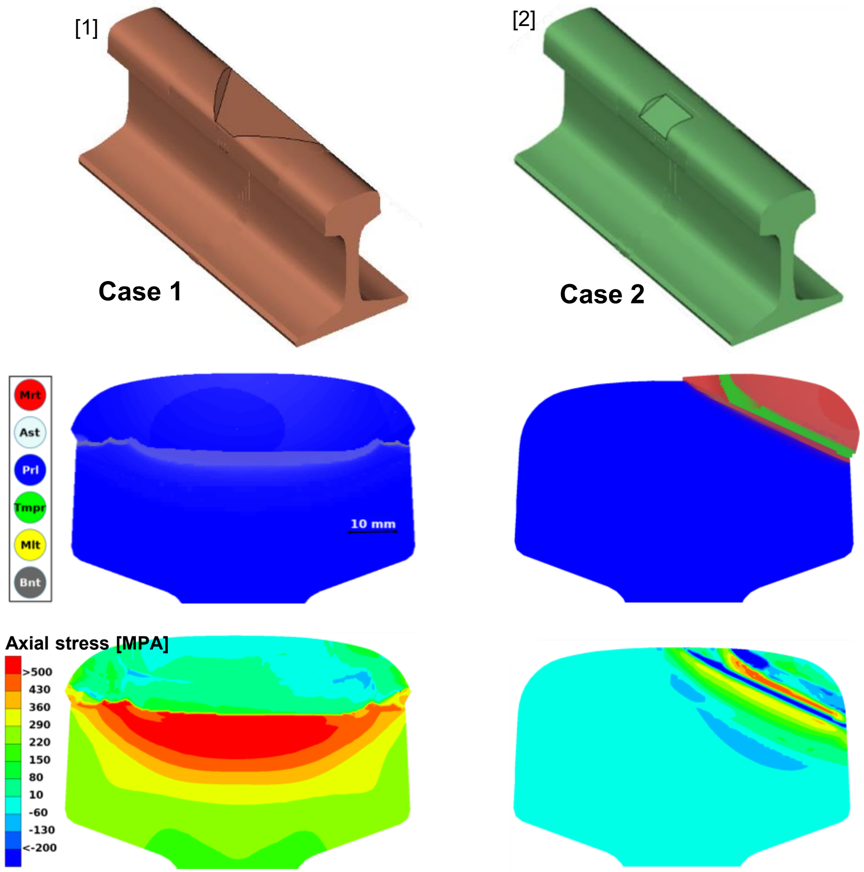
Case 1

- Following Swedish regulations
- 10 mm deep cut-out
- 45° chamfered cutouts
- Longitudinal support ridge weld passes
- Zig-zag weld passes between ridges

Case 2

- Typical faulty repair procedure
- Rail corner cut-out
- 10 mm deep cut-out (at max point)
- 50 mm long cut-out
- 25° slope

Simulation results: Case 1 & 2



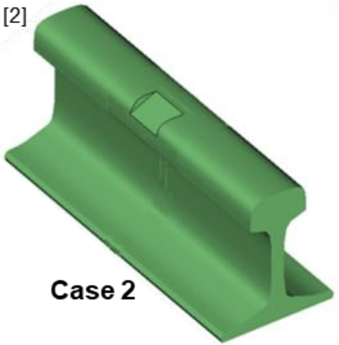
- Geometry significantly effects:
  Heat input
  Residual stress state
  Material phases
  Mechanical performance

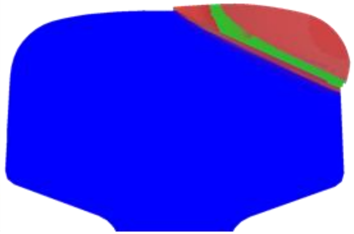
- Smaller repairs:
  → Less heat input
  → Rapid cooling
  → Unfavorable microstructure
  → Impaired performance

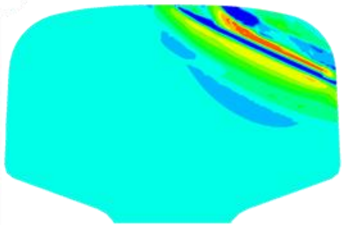
- Case 1 (Trapezoid shape):
  Large heat input with smooth ramp up and ramp down
  → Improved performance

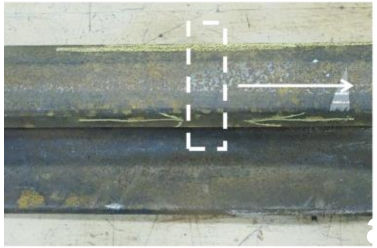
[1] Andersson, *et al*. Simulation-based assessment of railhead repair welding process parameters. Weld World 69, 177–197 (2025)
[2] Andersson & Josefson, Simulation-based failure analysis of faulty and regulatory railhead repair welding procedures, Engineering Failure Analysis, Volume 182 (2025)

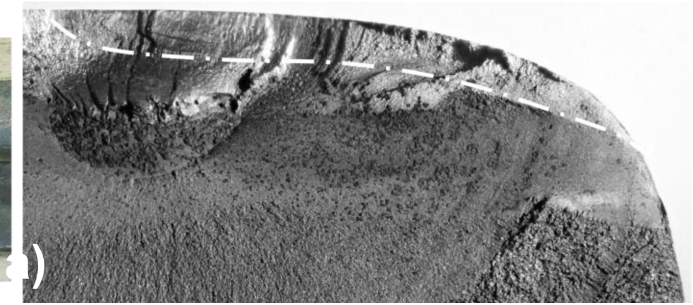
Simulation results vs Failure reports

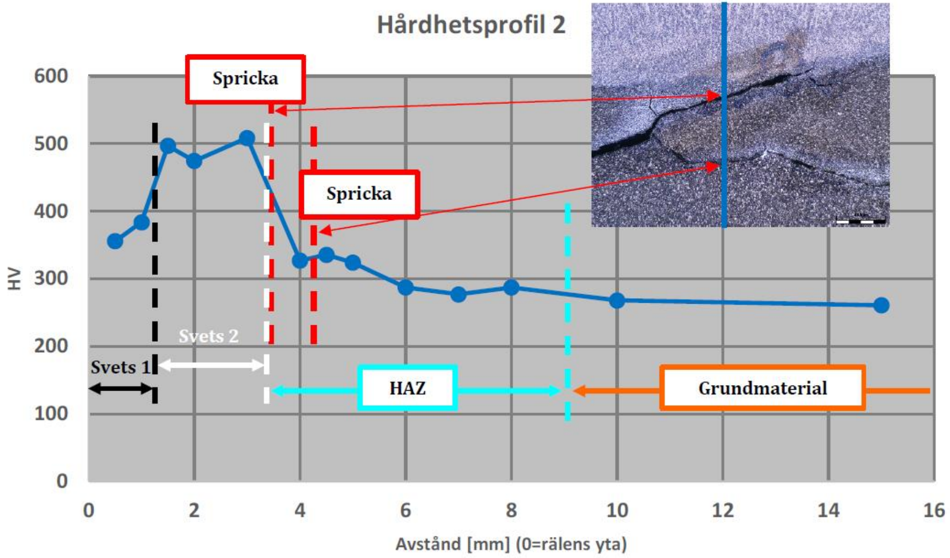


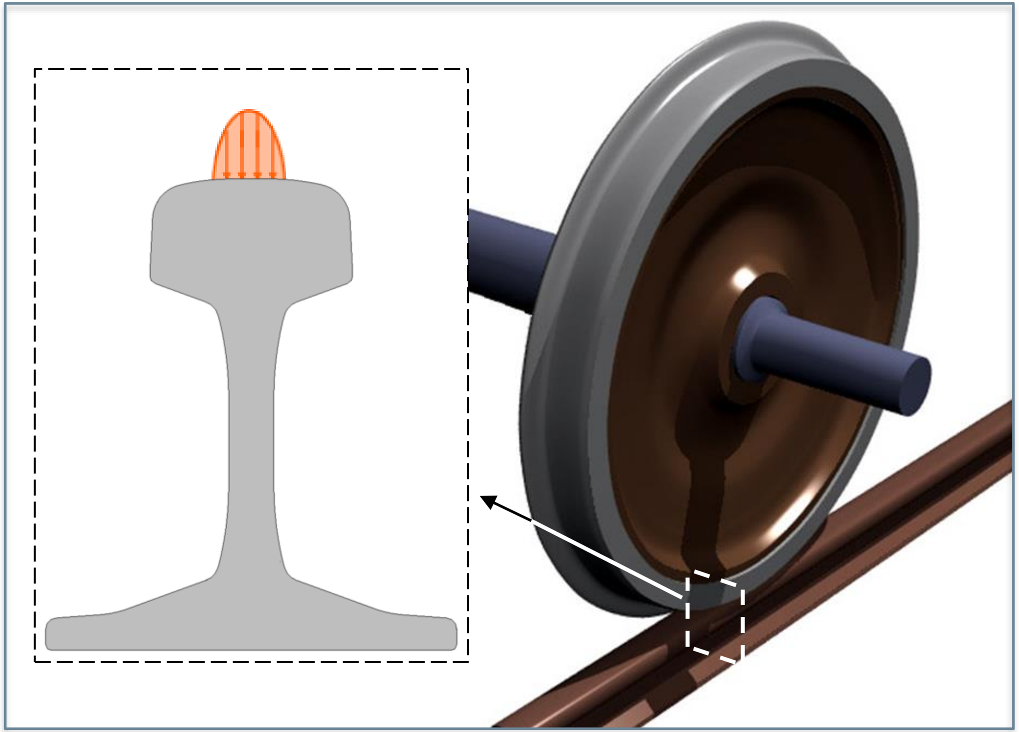


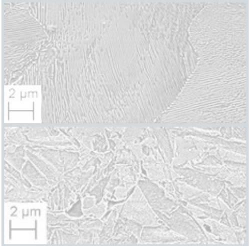






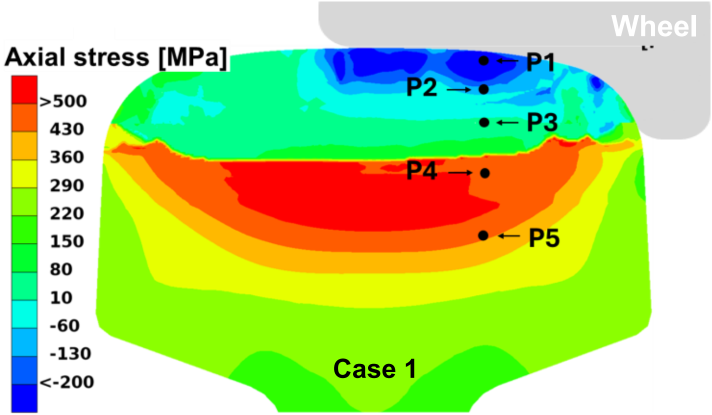


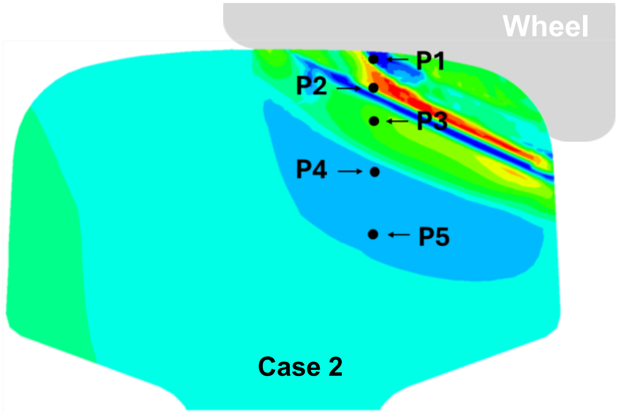


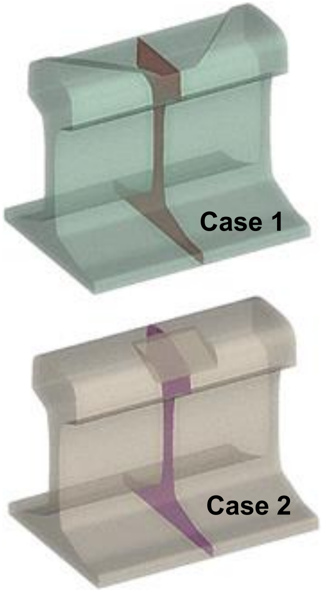

2 μm
2 μm


5 mm

Repair welding and over-rolling simulation







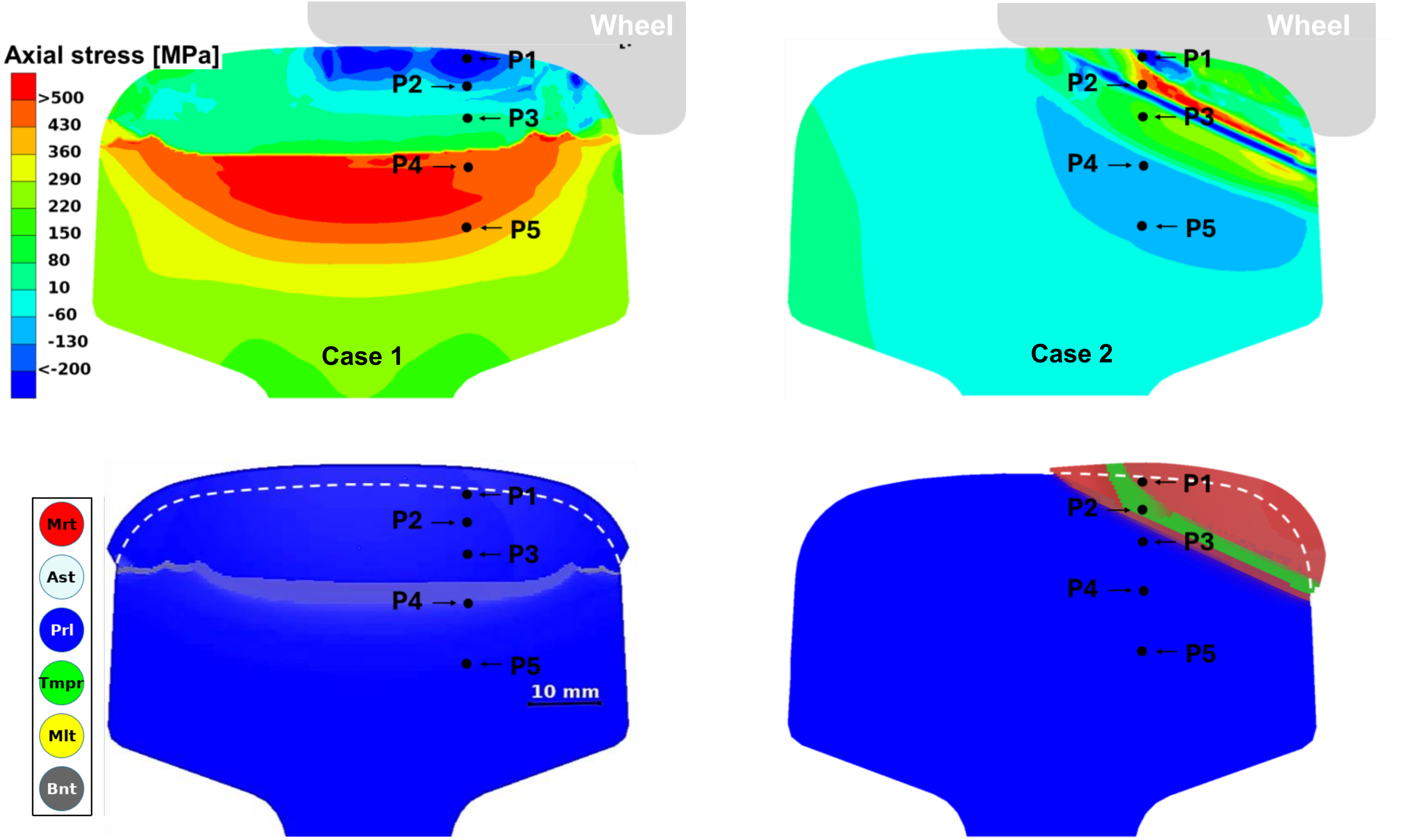
Post repair weld operational condition fatigue evaluation

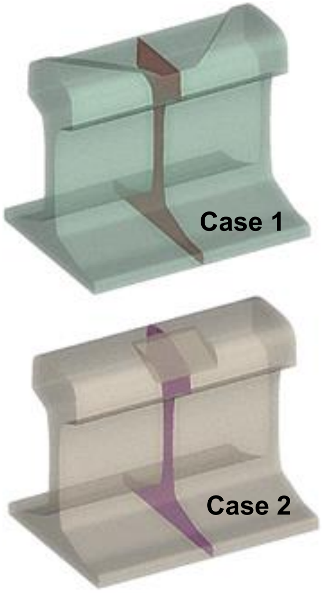
- Load 20 trains on Swedish western main line
- Load repeated 4 times: **2000 over-rollings**
- Residual stress weld + over-rollings
- Fatigue evaluation (crack initiation) using Dang Van method

$$\sigma_{eq,DV}(t) = \tau_{Tr,a}(t) + \langle c_{DV}\sigma_h(t) \rangle < \tau_{e,i}$$

[1] Andersson & Josefson, Simulation-based failure analysis of faulty and regulatory railhead repair welding procedures, Engineering Failure Analysis, Volume 182 (2025)

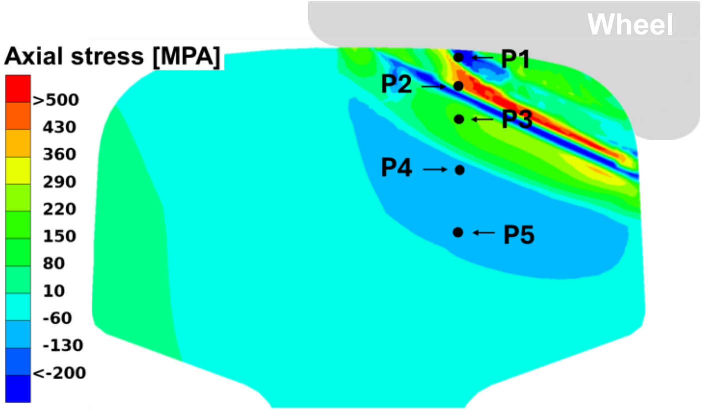
Repair welding and over-rolling simulation

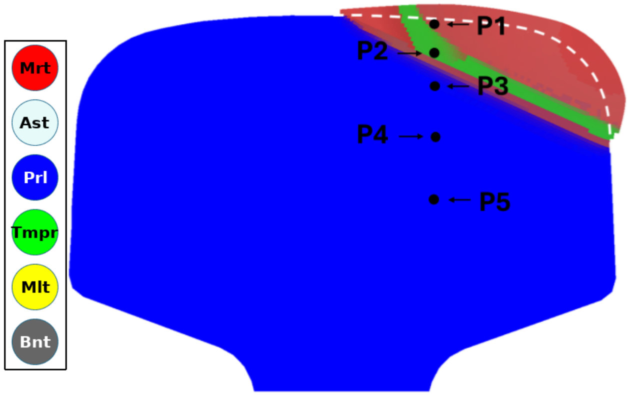




[1] Andersson & Josefson, Simulation-based failure analysis of faulty and regulatory railhead repair welding procedures, Engineering Failure Analysis, Volume 182 (2025)

Repair welding and over-rolling simulation





Dang Van fatigue stress

$$\sigma_{\mathrm{DV}}(t) = \tau_{\mathrm{Tr,a}}(t) + \langle c_{\mathrm{DV},i}\,\sigma_{\mathrm{h}}(t)\rangle > \tau_{\mathrm{e},i}$$

Shear stress fatigue limit and hydrostatic stress parameter

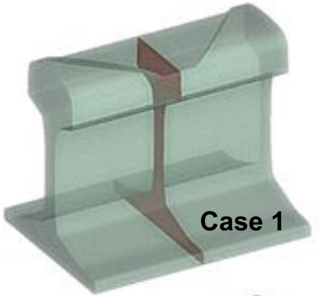
$$\tau_{\mathrm{e,i}} = \frac{H_{V,i}}{H_{V,\mathrm{p}}}\tau_{\mathrm{e,p}}$$

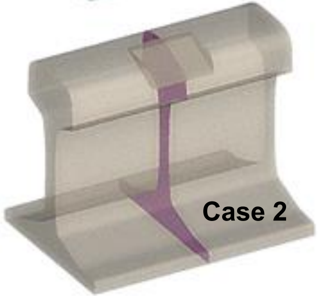
$$c_{\mathrm{DV},i} = 3\left(\frac{\tau_{\mathrm{e},i}}{\sigma_{\mathrm{ew},i}} - \frac{1}{2}\right)$$

Alternating bending shear stress (Murakami [2])

$$\sigma_{\mathrm{ew},i} = \frac{1.56(H_{V,i} + 120)}{(\sqrt{area})^{1/6}}$$

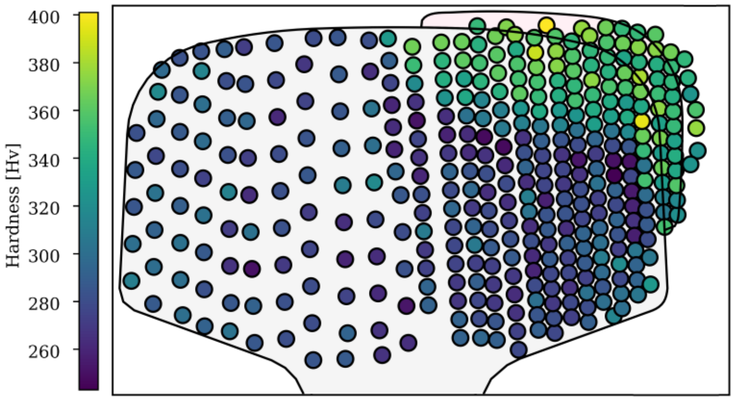
$\sqrt{area}$ inherent subsurface material defect [3]

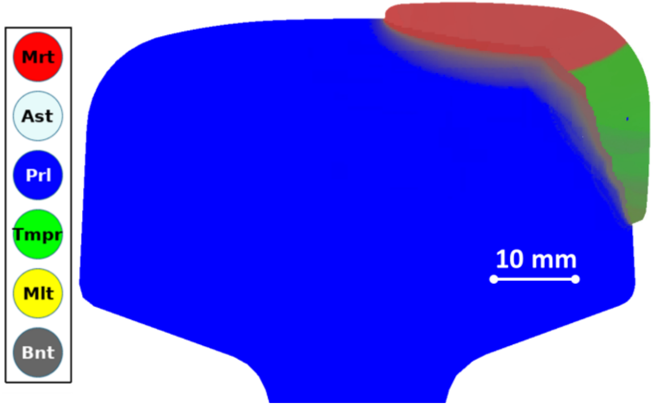


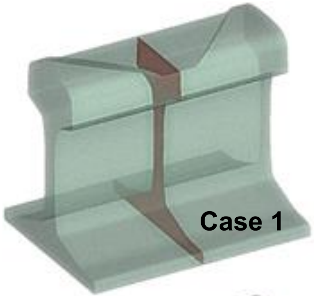


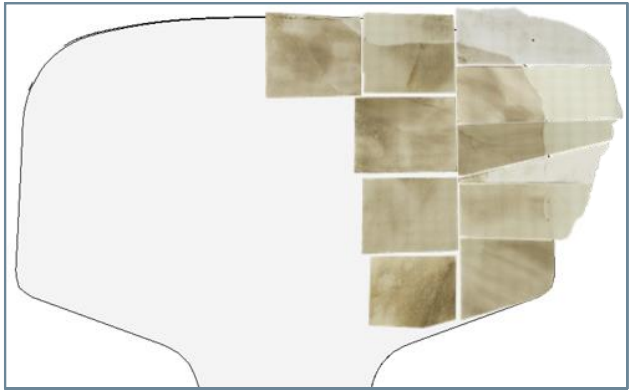
[1] Andersson & Josefson, Simulation-based failure analysis of faulty and regulatory railhead repair welding procedures, Engineering Failure Analysis, Volume 182 (2025)
[2] Y. Murakami, M. Endo, Effects of defects, inclusions and inhomogeneities on fatigue strength Int. J. Fatigue, 16 (3) (1994), pp. 163-182
[3] D. Franklin, A. Lundstjälk, LIVAR – Livslängsoptimering av räler: Tech. Rep., Swerim, Stockholm, Sweden (2021)

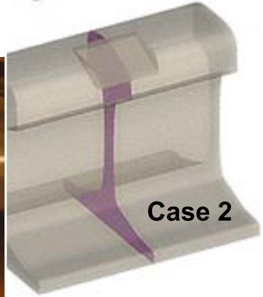
Repair welding and over-rolling simulation





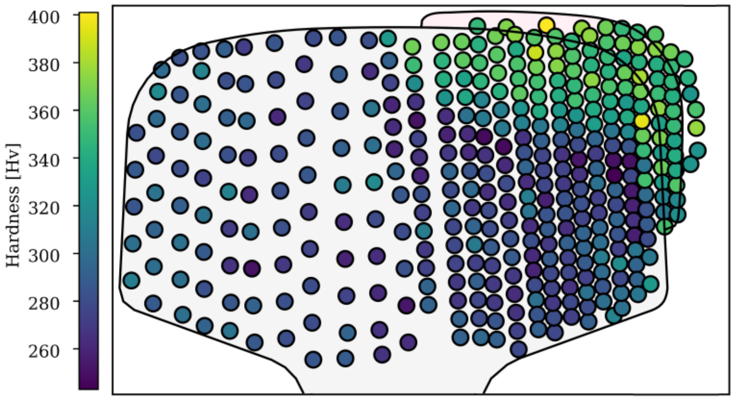


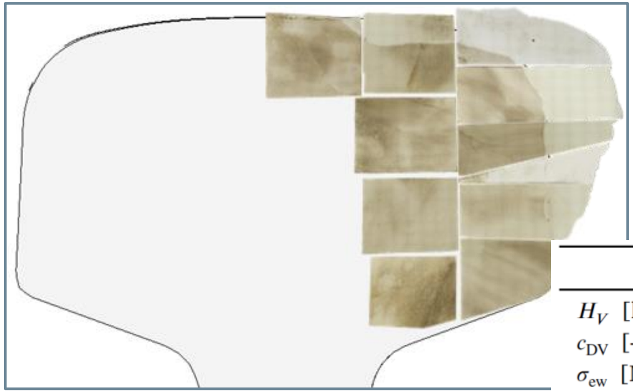




[1] Andersson, *et al*. Simulation-based assessment of railhead repair welding process parameters. Weld World 69, 177–197 (2025)
[2] Andersson & Josefson, Simulation-based failure analysis of faulty and regulatory railhead repair welding procedures, Engineering Failure Analysis, Volume 182 (2025)

Repair welding and over-rolling simulation





Dang Van fatigue stress

$$\sigma_{\mathrm{DV}}(t) = \tau_{\mathrm{Tr,a}}(t) + \langle c_{\mathrm{DV},i}\ \sigma_{\mathrm{h}}(t) \rangle > \tau_{\mathrm{e},i}$$

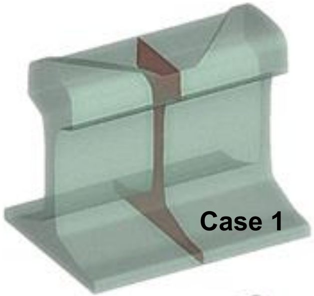
Shear stress fatigue limit and hydrostatic stress parameter

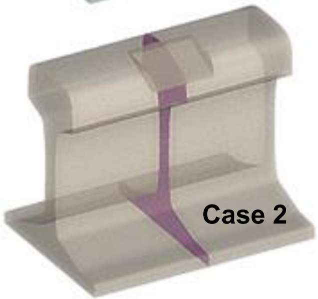
$$\tau_{\mathrm{e,i}} = \frac{H_{V,i}}{H_{V,\mathrm{p}}} \tau_{\mathrm{e,p}}$$

$$c_{\mathrm{DV},i} = 3\left(\frac{\tau_{\mathrm{e},i}}{\sigma_{\mathrm{ew},i}} - \frac{1}{2}\right)$$

Alternating bending shear stress (Murakami [2])

$$\sigma_{\mathrm{ew},i} = \frac{1.56(H_{V,i} + 120)}{(\sqrt{area})^{1/6}}$$

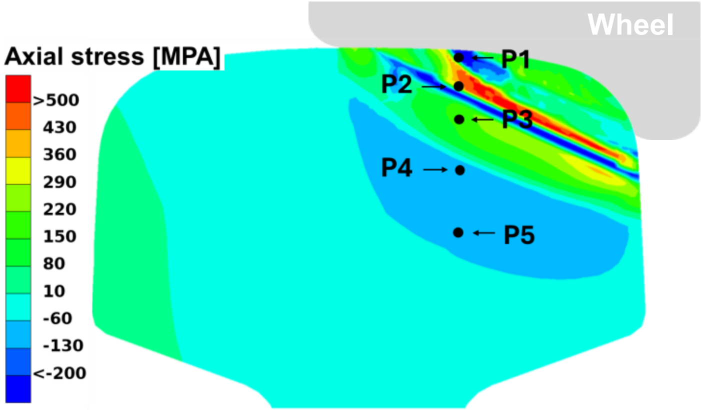


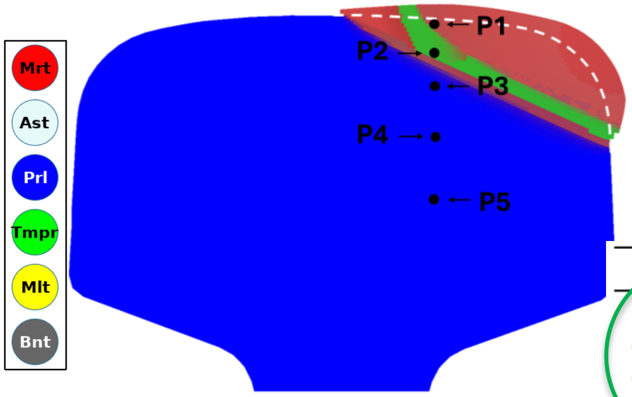


	Pearlite	Martensite	Bainite	Tempered
H_V [kgf/mm^2]	275	520	420	340
c_{DV} [–]	0.33	0.64	0.55	0.44
σ_{ew} [MPa]	275	446	376	320
τ_{e} [MPa]	168	318	257	208

[1] Andersson & Josefson, Simulation-based failure analysis of faulty and regulatory railhead repair welding procedures, Engineering Failure Analysis, Volume 182 (2025)

Repair welding and over-rolling simulation





Dang Van fatigue stress

$$\sigma_{\mathrm{DV}}(t) = \tau_{\mathrm{Tr,a}}(t) + \langle c_{\mathrm{DV},i}\,\sigma_{\mathrm{h}}(t)\rangle > \tau_{\mathrm{e},i}$$

Shear stress fatigue limit and hydrostatic stress parameter

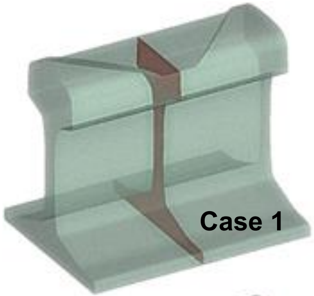
$$\tau_{\mathrm{e,i}} = \frac{H_{V,i}}{H_{V,\mathrm{p}}}\tau_{\mathrm{e,p}}$$

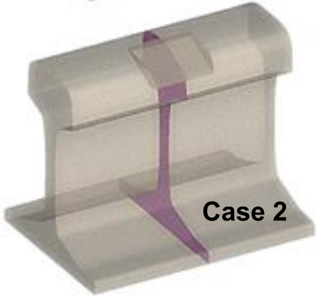
$$c_{\mathrm{DV},i} = 3\left(\frac{\tau_{\mathrm{e},i}}{\sigma_{\mathrm{ew},i}} - \frac{1}{2}\right)$$

Alternating bending shear stress (Murakami [2])

$$\sigma_{\mathrm{ew},i} = \frac{1.56(H_{V,i} + 120)}{(\sqrt{area})^{1/6}}$$

$\sqrt{area}$ inherent subsurface material defect [3]

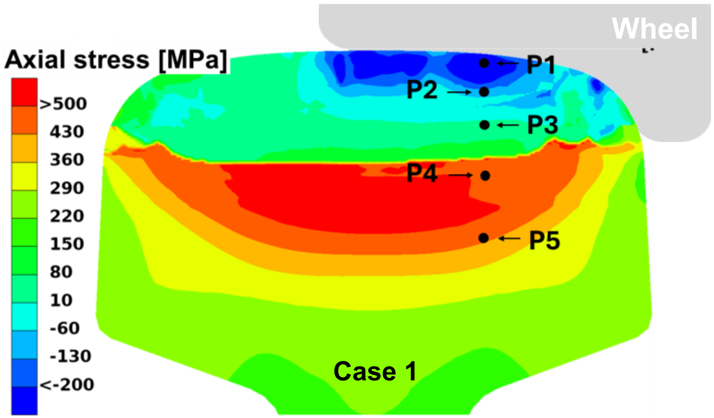


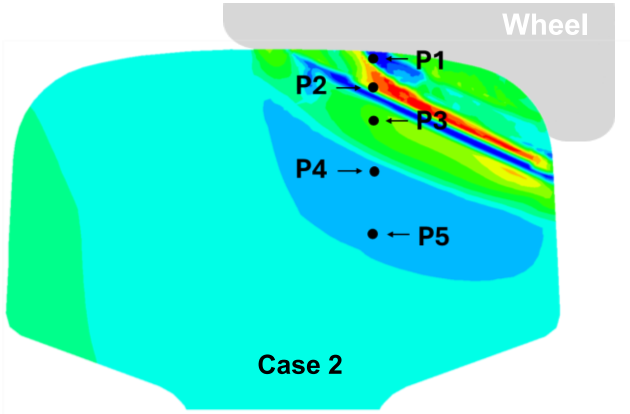


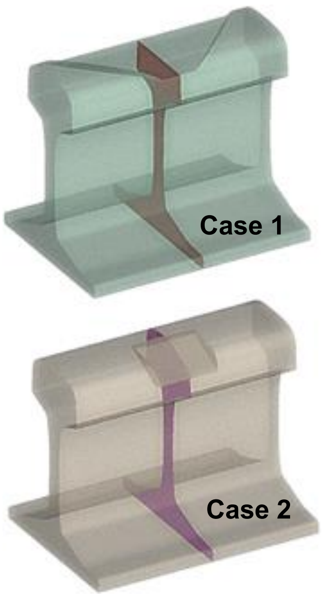
	Pearlite	Martensite	Bainite	Tempered
H_V [kgf/mm^2]	275	520	420	340
c_{DV} [–]	0.33	0.64	0.55	0.44
σ_{ew} [MPa]	275	446	376	320
τ_{e} [MPa]	168	318	257	208

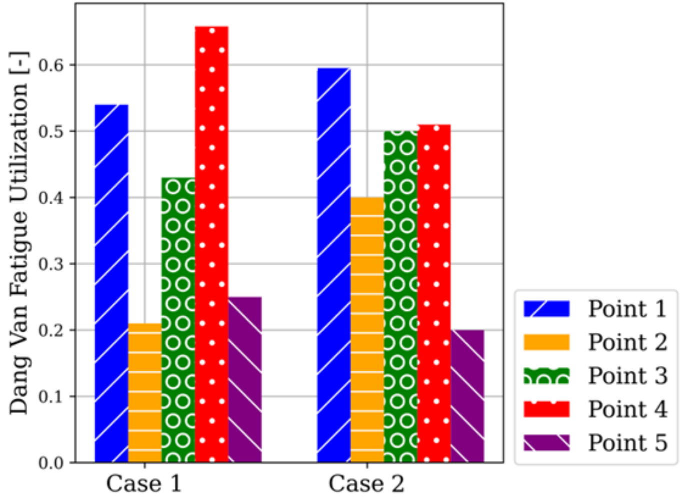
[1] Andersson & Josefson, Simulation-based failure analysis of faulty and regulatory railhead repair welding procedures, Engineering Failure Analysis, Volume 182 (2025)

Repair welding and over-rolling simulation









Post repair weld operational condition fatigue evaluation

- Load 20 trains on Swedish western main line
- Load repeated 4 times: **2000 over-rollings**
- Residual stress weld + over-rollings
- Fatigue evaluation (crack initiation) using Dang Van method
  $\sigma_{eq,DV}(t) = \tau_{Tr,a}(t) + \langle c_{DV}\sigma_h(t)\rangle < \tau_{e,i}$
- Critical point at fusion zone
- Better mechanical performance for Case 1

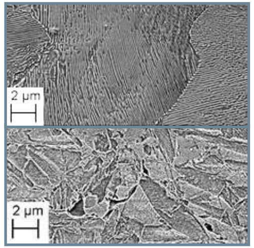
[1] Andersson & Josefson, Simulation-based failure analysis of faulty and regulatory railhead repair welding procedures, Engineering Failure Analysis, Volume 182 (2025)

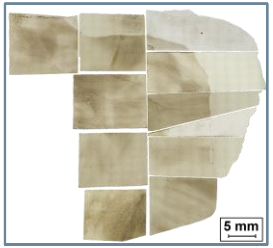
CHALMERS

Possibilities for Future Work

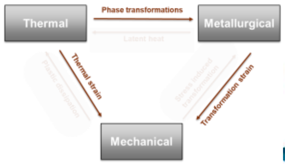
Using current simulation-based assessment tool to:

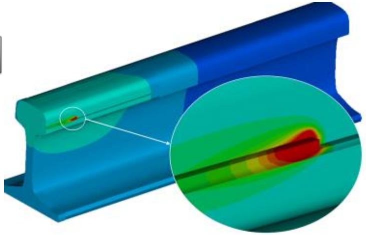
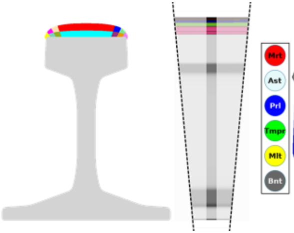
- Welding of other rail steel grades, e.g. Bainitic rails
- Rail Surface Cladding
- Investigate the surface effects of rail grinding
- **Open to suggestions!**

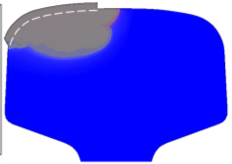
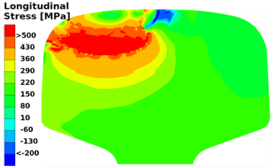








Thank you for listening!

Simulation-based Failure Analysis of Faulty and Regulatory Railhead Repair Welding Procedures

Dr. Björn Andersson (www.linkedin.com/in/björn-andersson-a0304a306)

Coauthors:
Prof. Lennart Josefson[1]
Prof. Magnus Ekh[1]
Prof. Johan Ahlström[1]
Dr Ali Esmaeili[1,2]
Dr Erika Steyn[1,7]
Lic Eng.Nasrin Talebi[1]

Support:
Prof. Jens Nielsen[3]
Prof. Ander Ekberg[3,4]
Lic Eng. Carolin Ansin[1]
Dr Michele Maglio[3,4]
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
[7]GKN Aerospace, Trollhättan