CHALMERS
UNIVERSITY OF TECHNOLOGY

# Simulering av reparations-svetsning för rälshuvud

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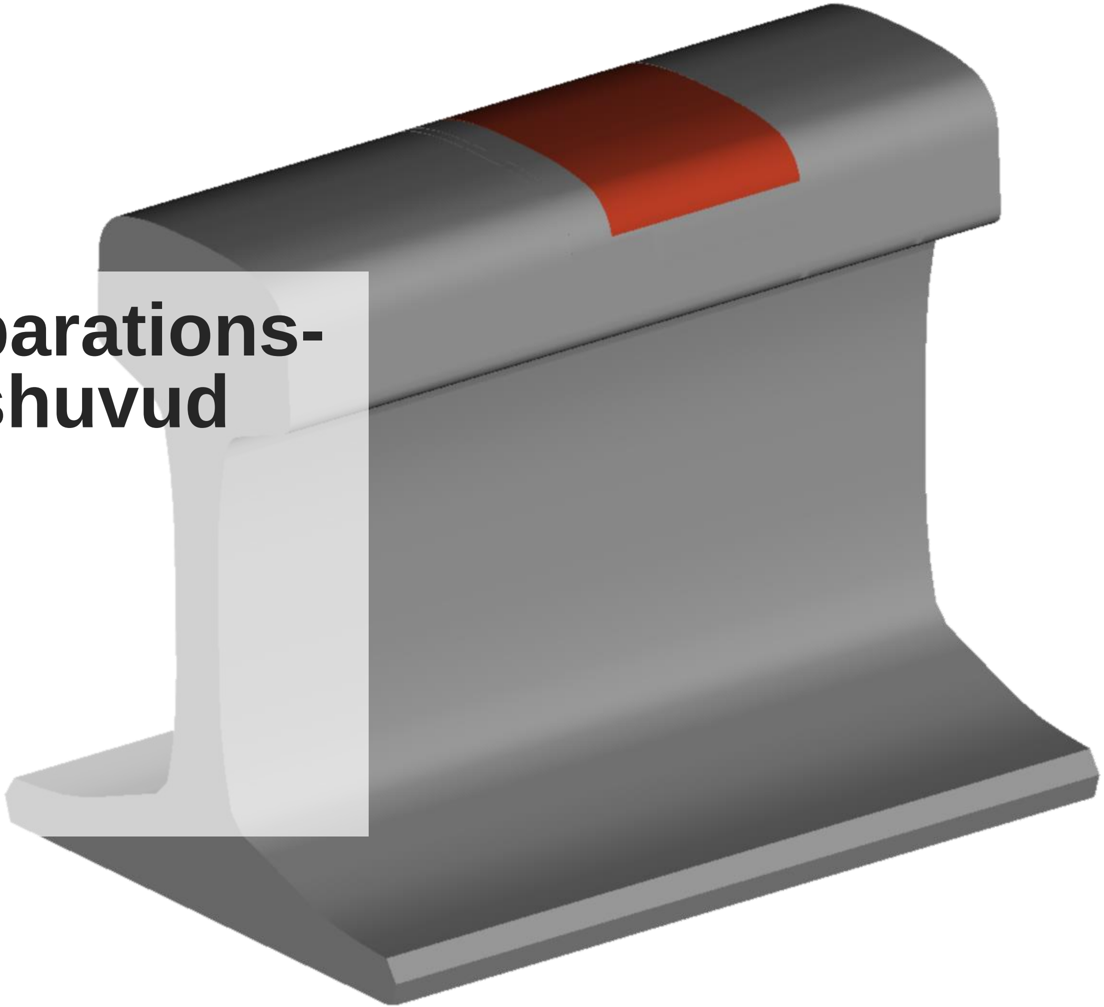
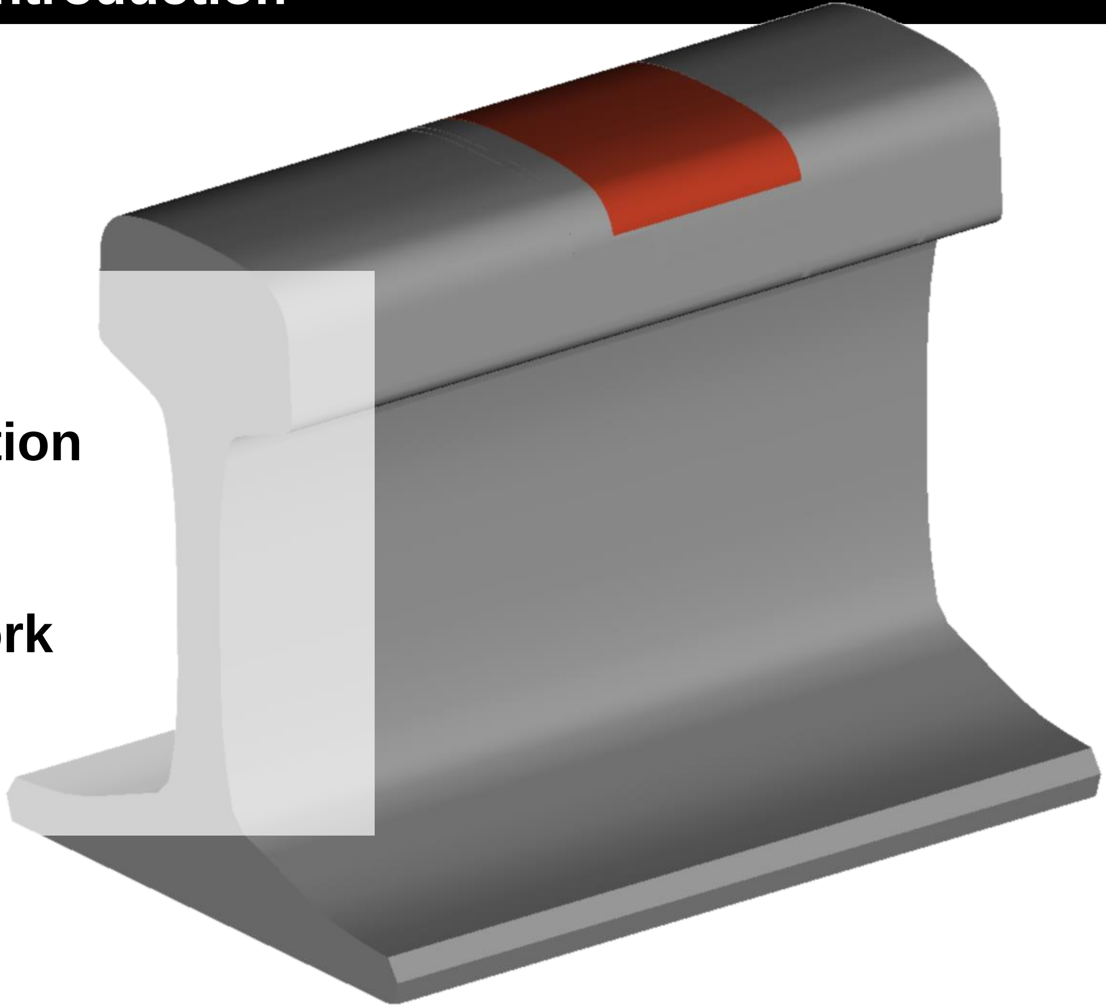


# Introduction





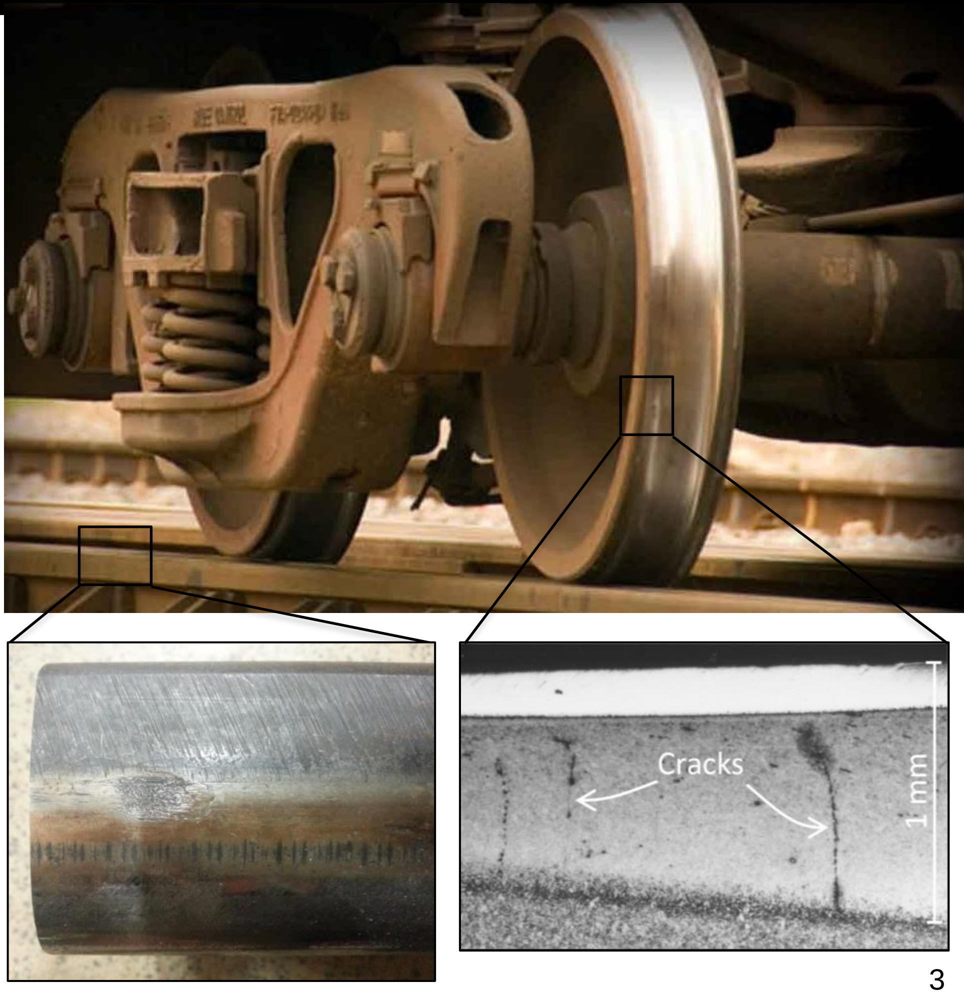
**Agenda**

- **Background / Motivation**
- **Simulation setup**
- **Simulation results**
- **Summary / Future work**

# Introduction

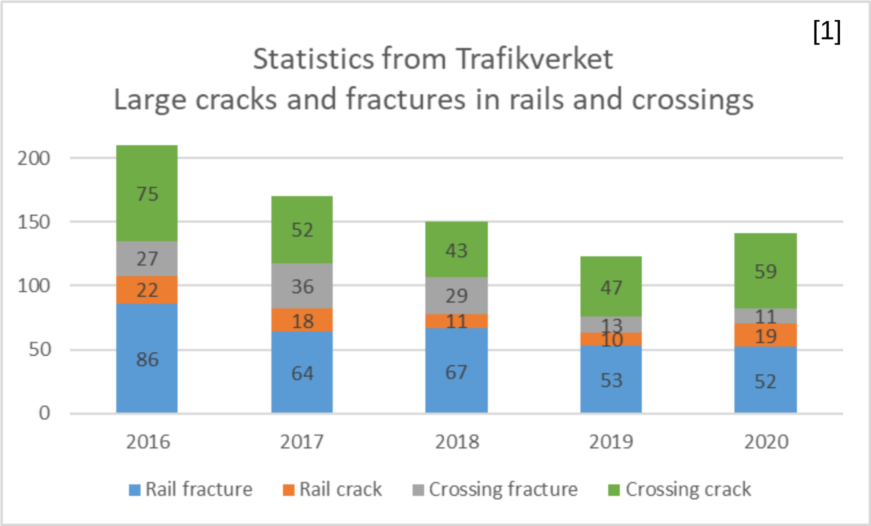


- Examples of high temperature processes:
  - Welding
  - Grinding
  - Train wheel braking (rail and wheel)
- What happens:
  - Phase transformations
  - Inhomogeneous material properties
- Practical consequences:
  - Residual stresses
  - Unfavorable microstructure
  - Initiation of cracks



# Background and motivation








Decreasing number of rail fractures

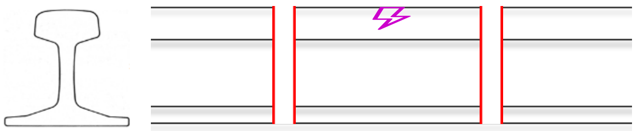
Constant number of rail cracks

30-50% of rail fractures in welds

More cracks and fractures during colder periods

[1] communications Stefan Kallander, [2] B. L. Josefson, *Welding of rails and how it affects crack initiation and propagation*, (2014)

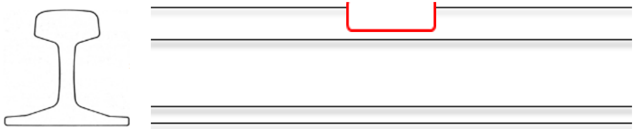
## Rail section repair - Thermite welding





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

## Rail head repair – MIG/MMA welding



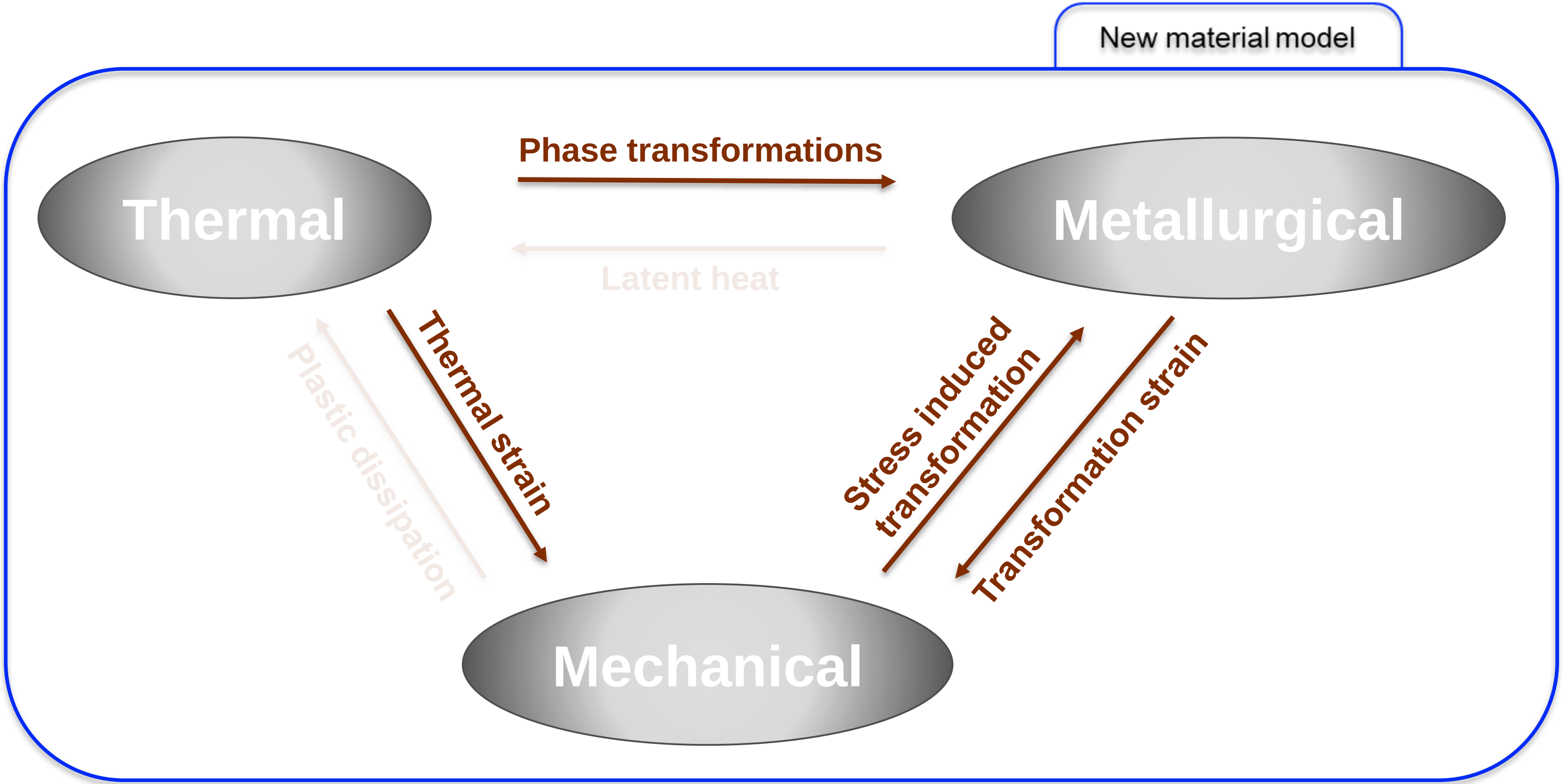


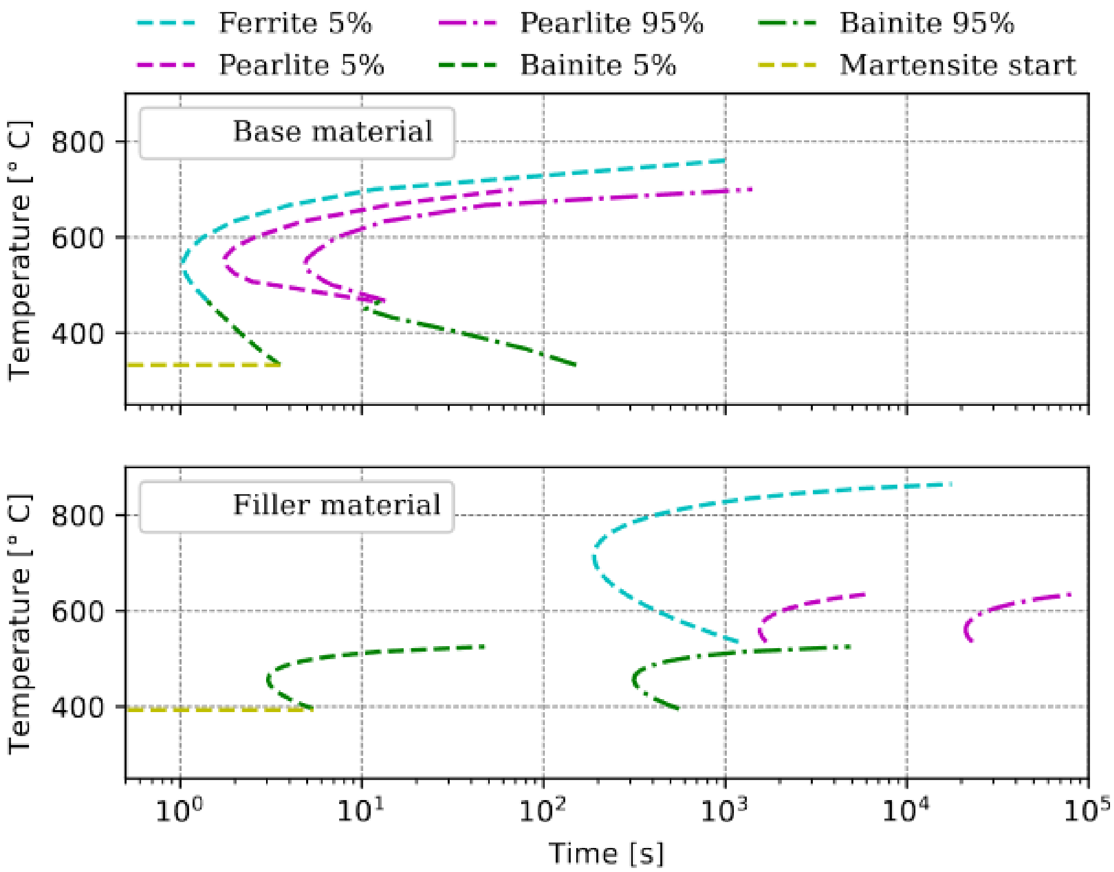
- Remove only railhead damage (or switches)
- Small, local heat input, several weld passes
- Rapid cooling, risk for martensite formation

New material model

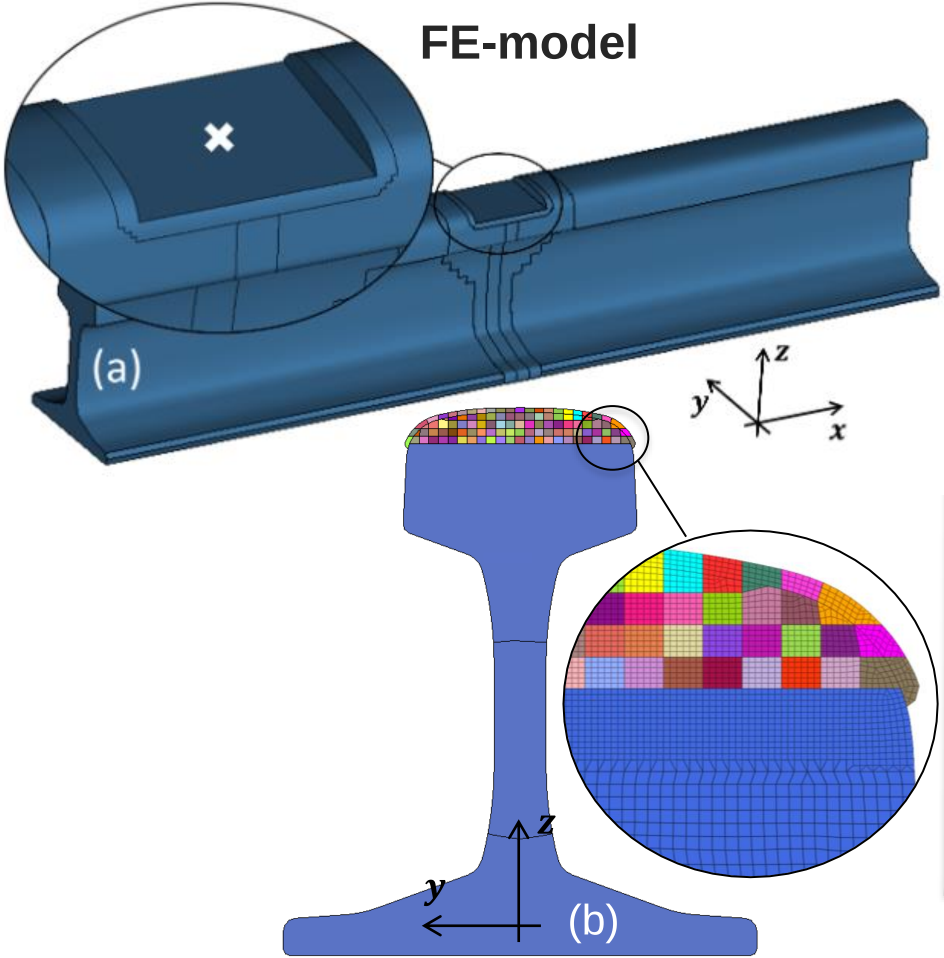
- Complex microstructure evolution
- Effects of phases and phase transformations

[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/

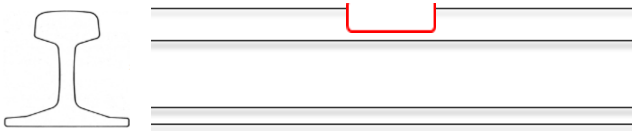

New material model
Thermal
Phase transformations
Latent heat
Metallurgical
Plastic dissipation
Thermal strain
Stress induced transformation
Transformation strain
Mechanical


Ferrite 5%
Pearlite 5%
Pearlite 95%
Bainite 5%
Bainite 95%
Martensite start
Base material
Filler material
Temperature [° C]
800
600
400
Time [s]
$10^0$
$10^1$
$10^2$
$10^3$
$10^4$
$10^5$

## FE-model




## Rail head repair – MIG/MMA welding





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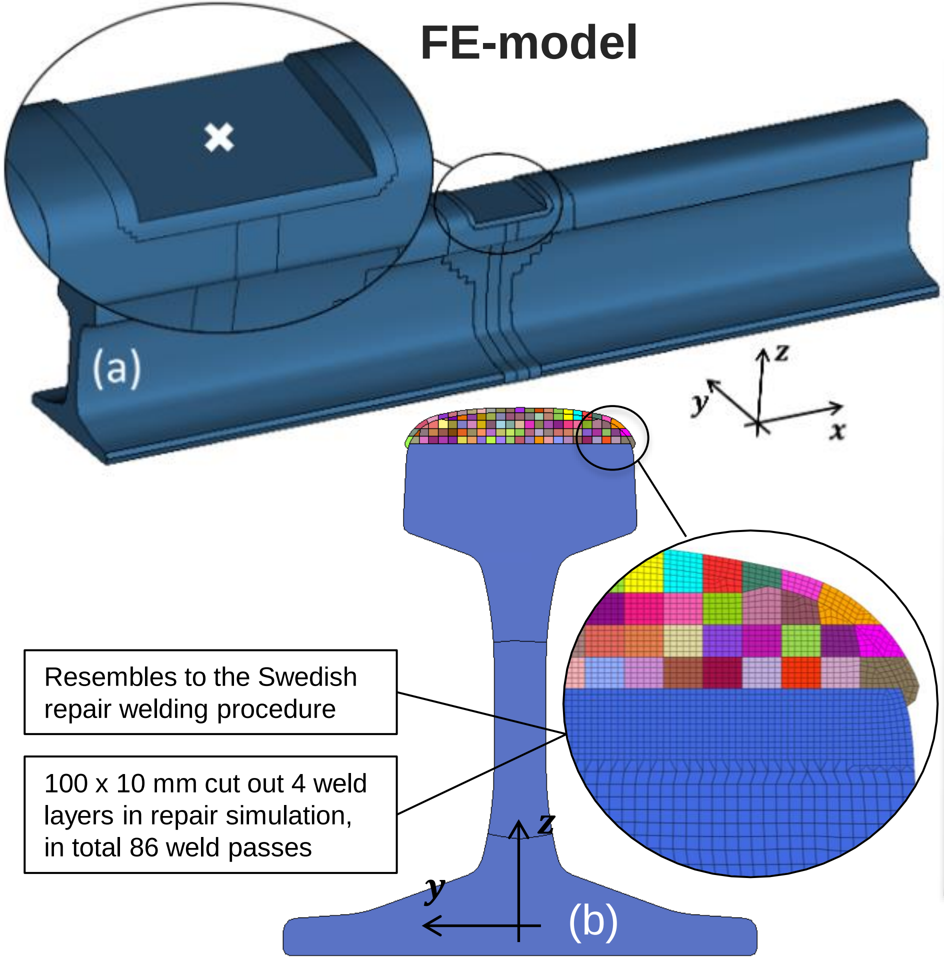
[1] pandrol.com/wp-content/uploads/2020/07/, [2] starkon.nl/project/sts-crane-trolley-rail-eld-repair/

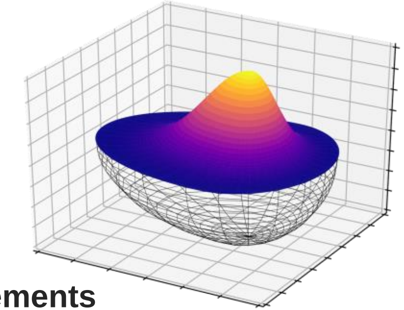
# FE-model




Resembles to the Swedish repair welding procedure

100 x 10 mm cut out 4 weld layers in repair simulation, in total 86 weld passes

## Moving heat source



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

## Continuous addition of filler elements

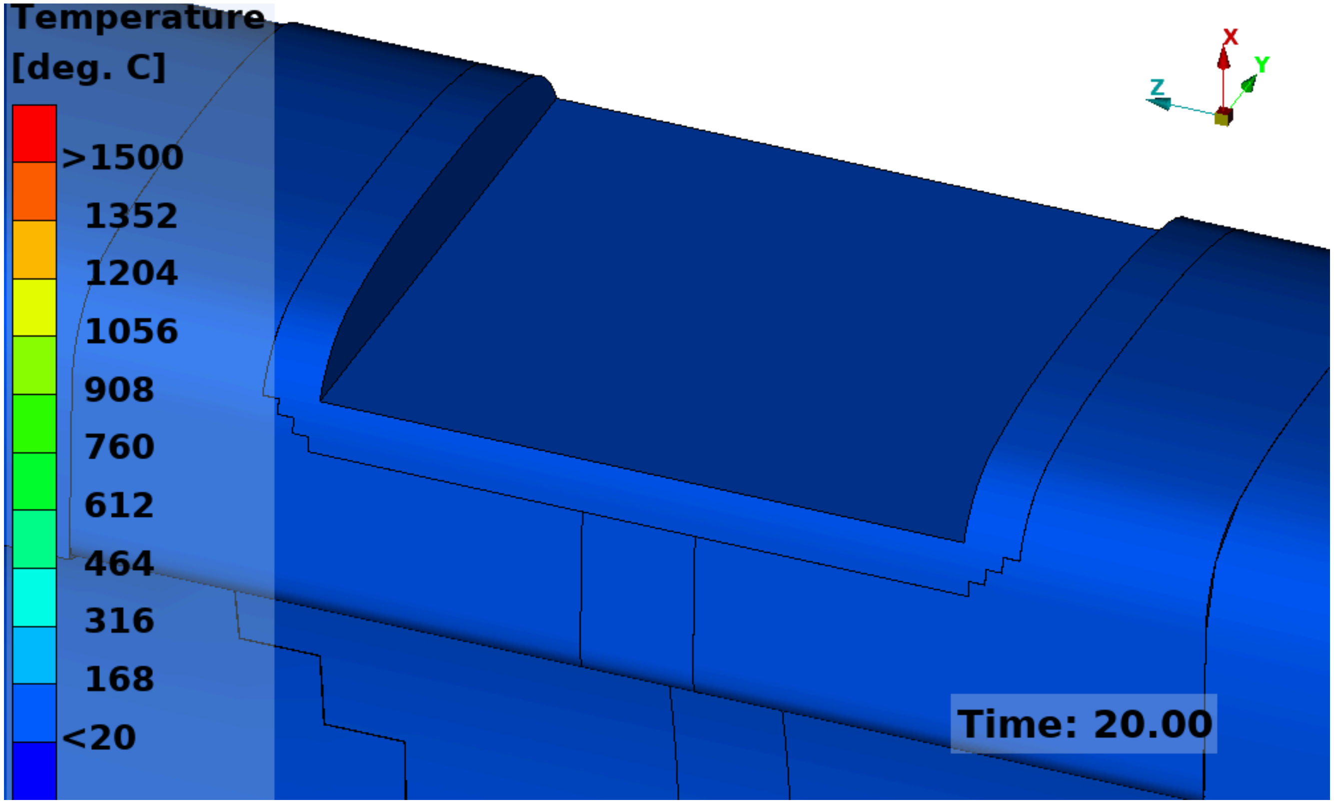
- "Silent" elements
- Activation moving with heat source
- Material properties, zero-strain temperature

## Multiple weld passes

- Preheat, weld prep, etc.
- Cooling time between passes
- Melting, remelting and virgin material state

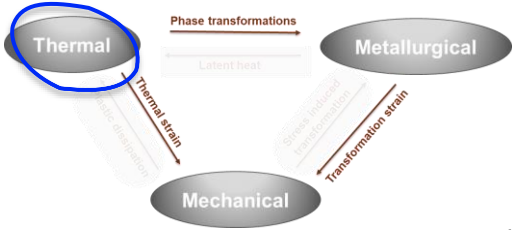
## Computationally efficient FE-model setup

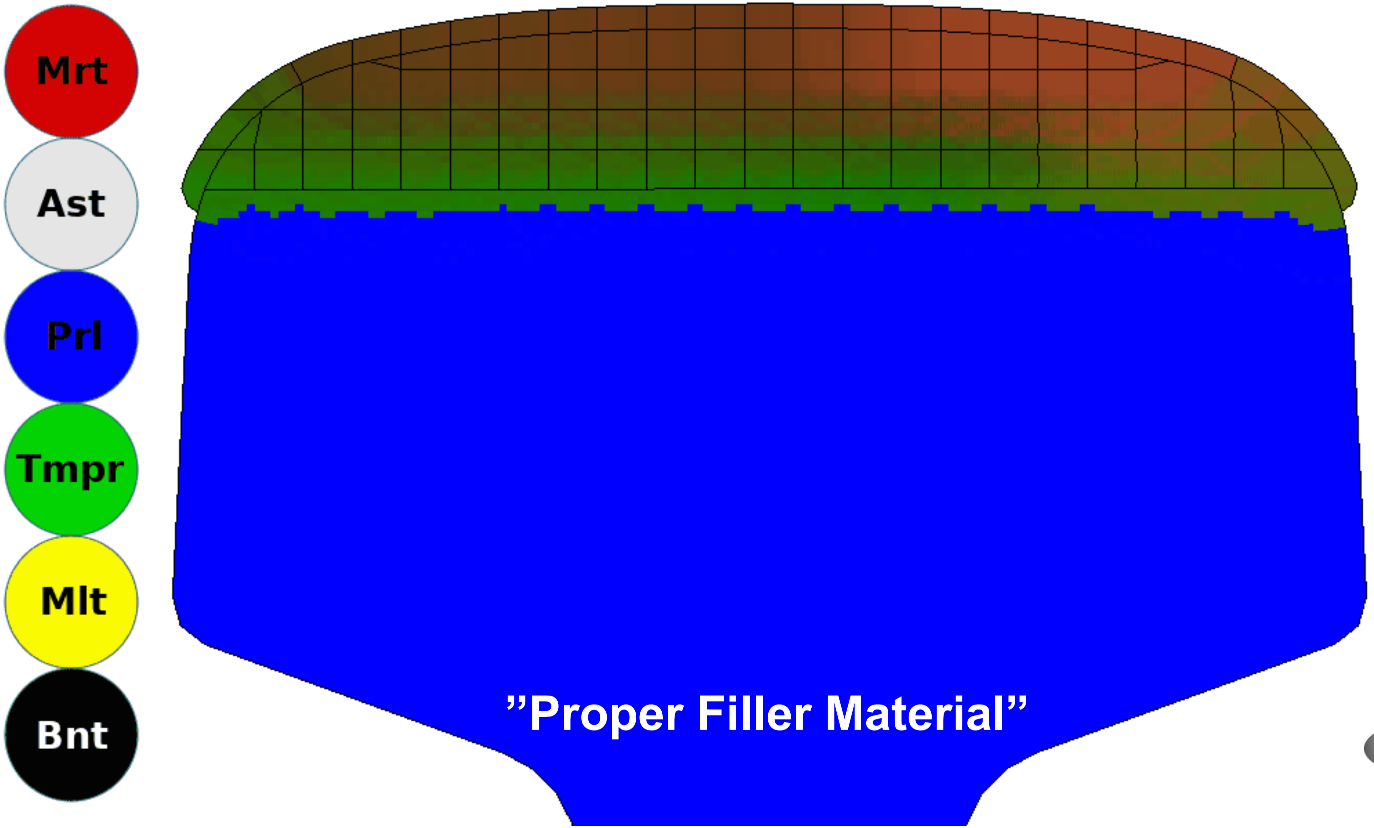
- 3D heat transfer simulation
- 2D mechanical simulation, generalized plane strain with out-of-plane stiffness
- Number of DOF's: 40k 2D mech, 530k 3D temp
- Computer: 32 CPUs, Intel Xeon Gold 6130 "Skylake"




2D cross-section
**Temperature field**

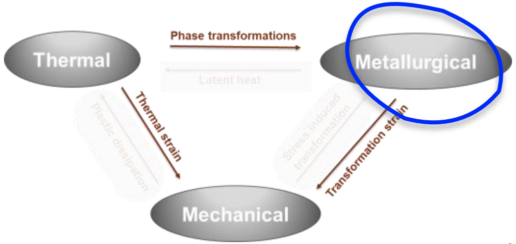
- 350°C preheat
- Operation temp. >300°C preheat
- 60 s inter-layer cooling
- Local heat input
- Strong temp. gradients



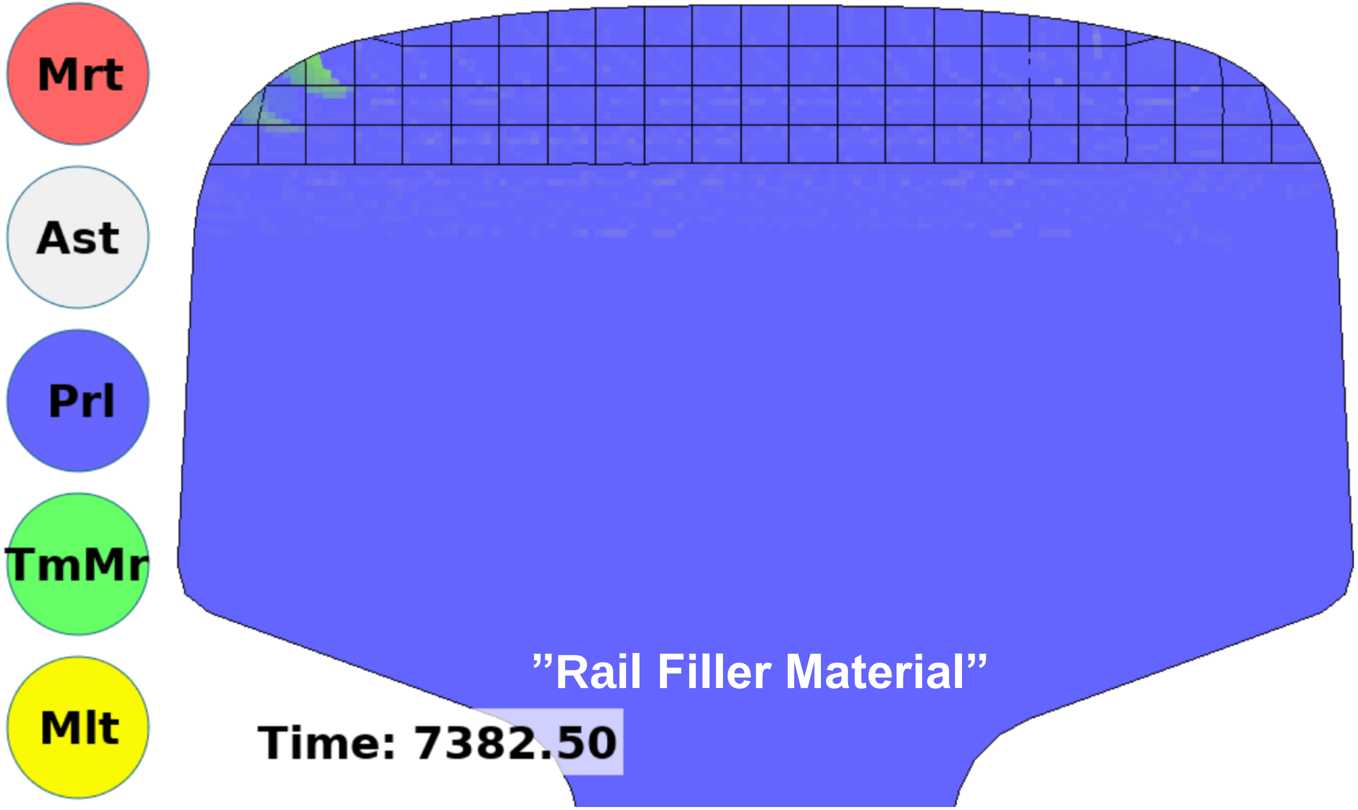



2D cross-section
**Volume fraction field**

- Pearlitic base material
- Ferrite/cementite repair
- Multiple remelting
- Decreasing operation temp
  → More rapid cooling
  → Some martensite at the surface




Mrt = Martensite
Ast = Austenite
Prl = Pearlite or Ferrite/Cementite
TmMr = Tempered Martensite/Bainite
Mlt=Melted state

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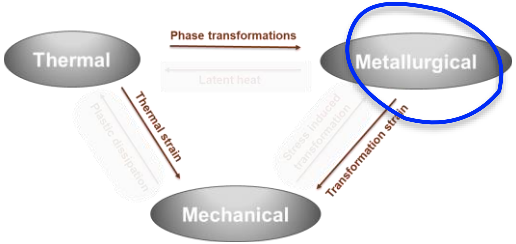
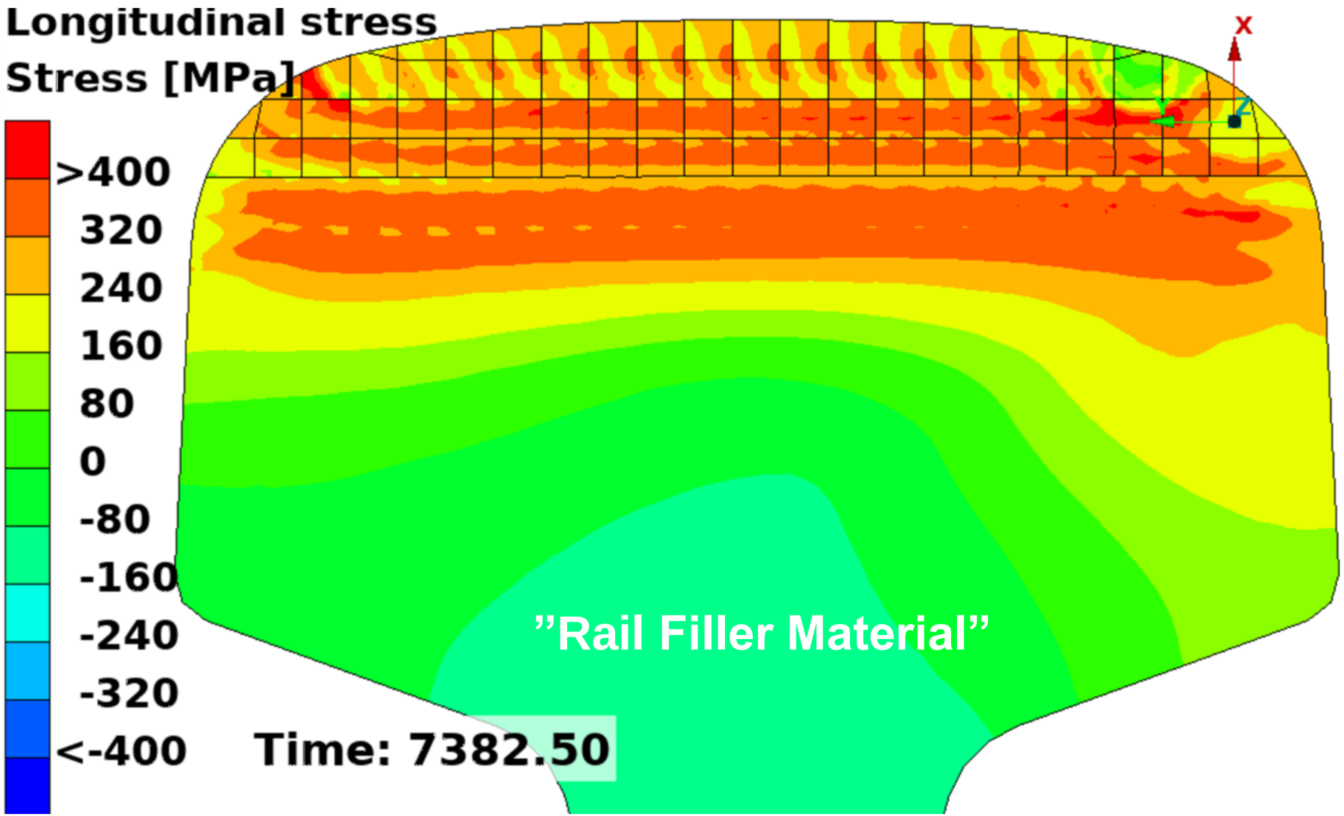
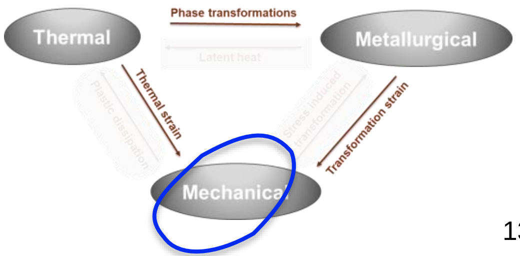


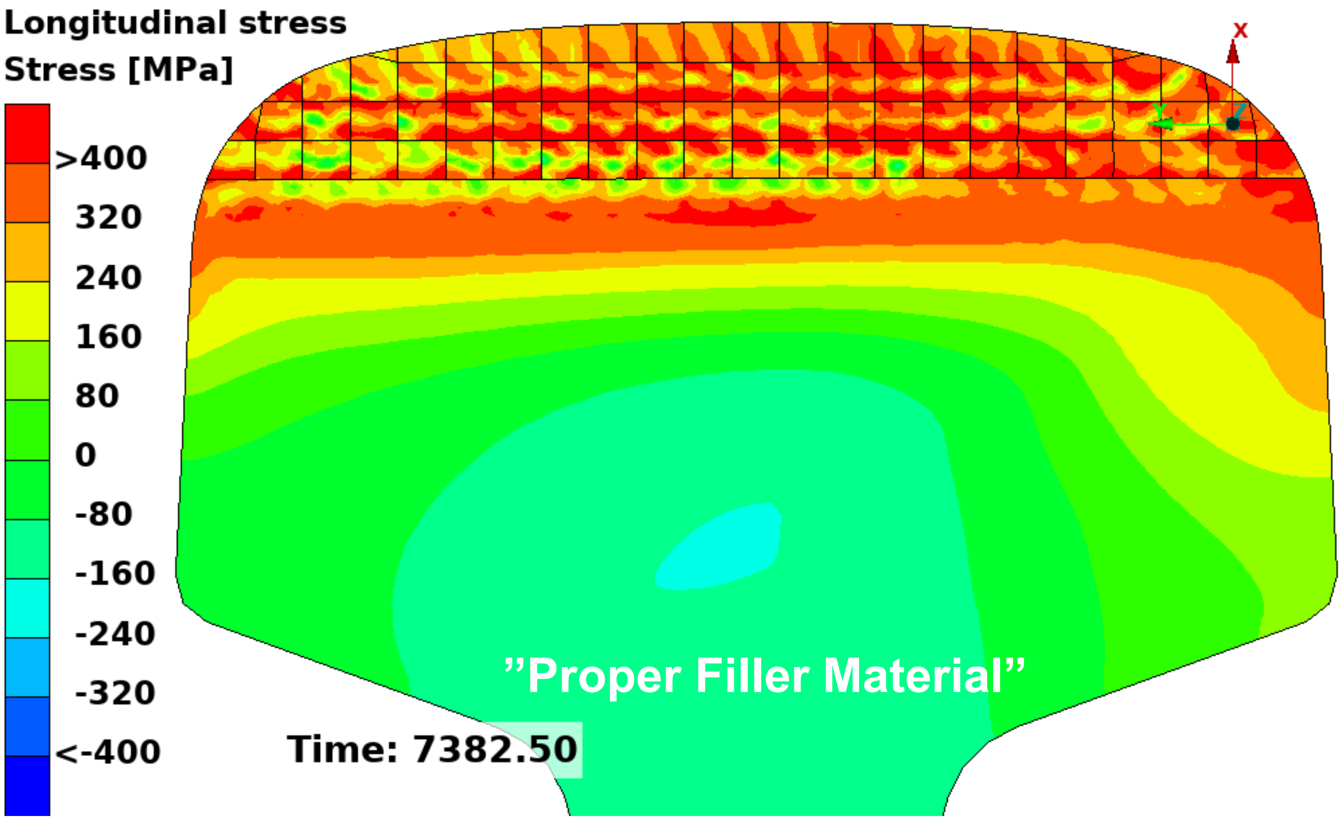



2D cross-section

**Longitudinal stress**

- Typical HAZ stress distribution:
  - Very low stress in melt
  - Compressive stress surrounding melt
  - Tensile residual stress
- Cyclic loading



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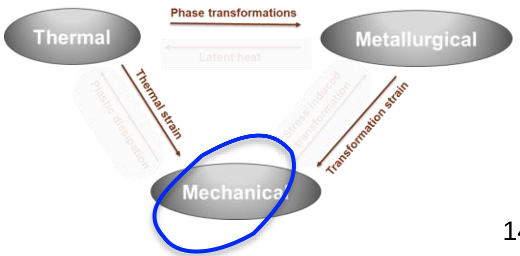
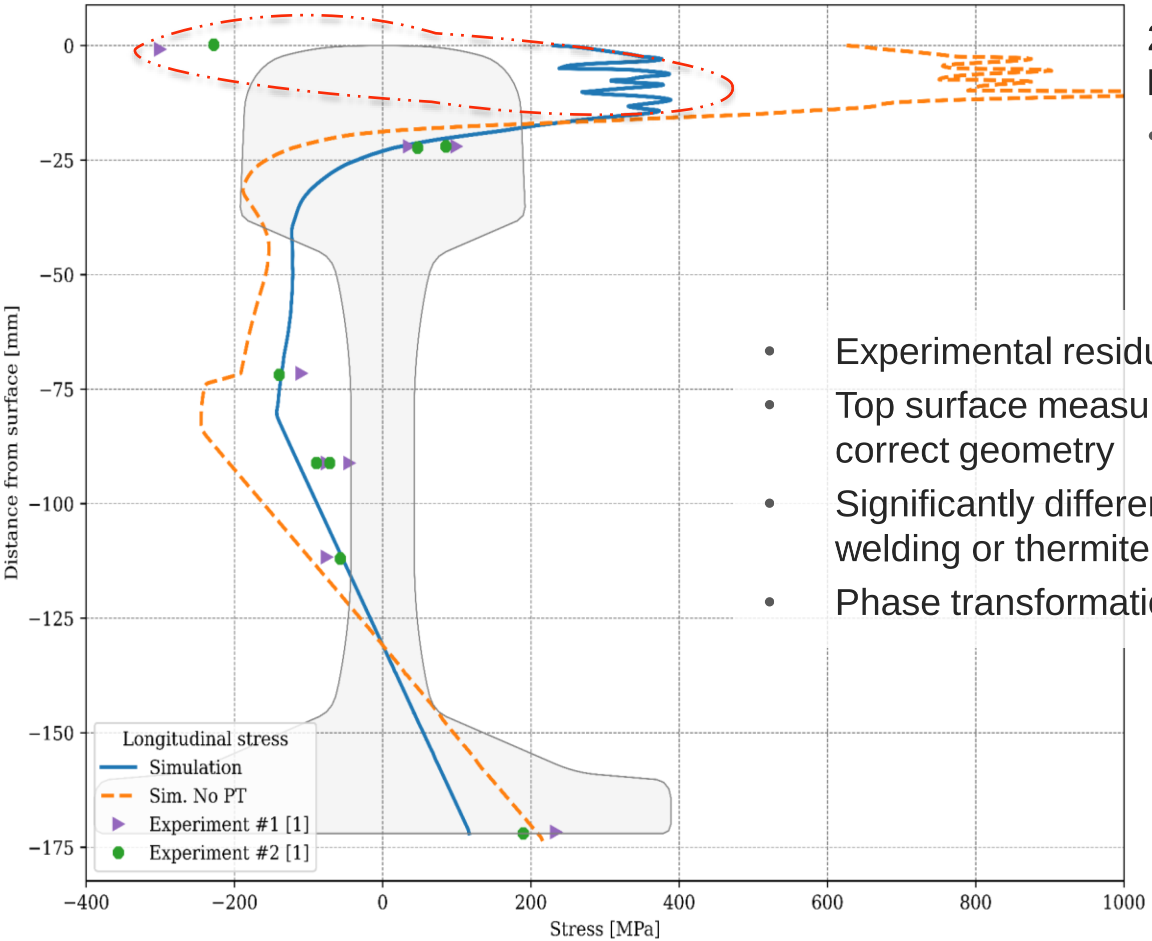
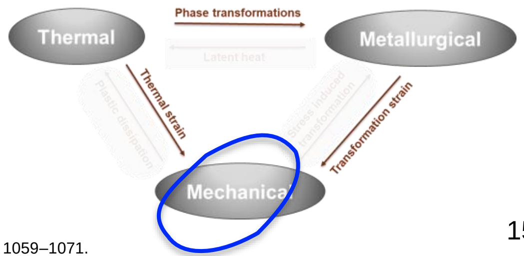




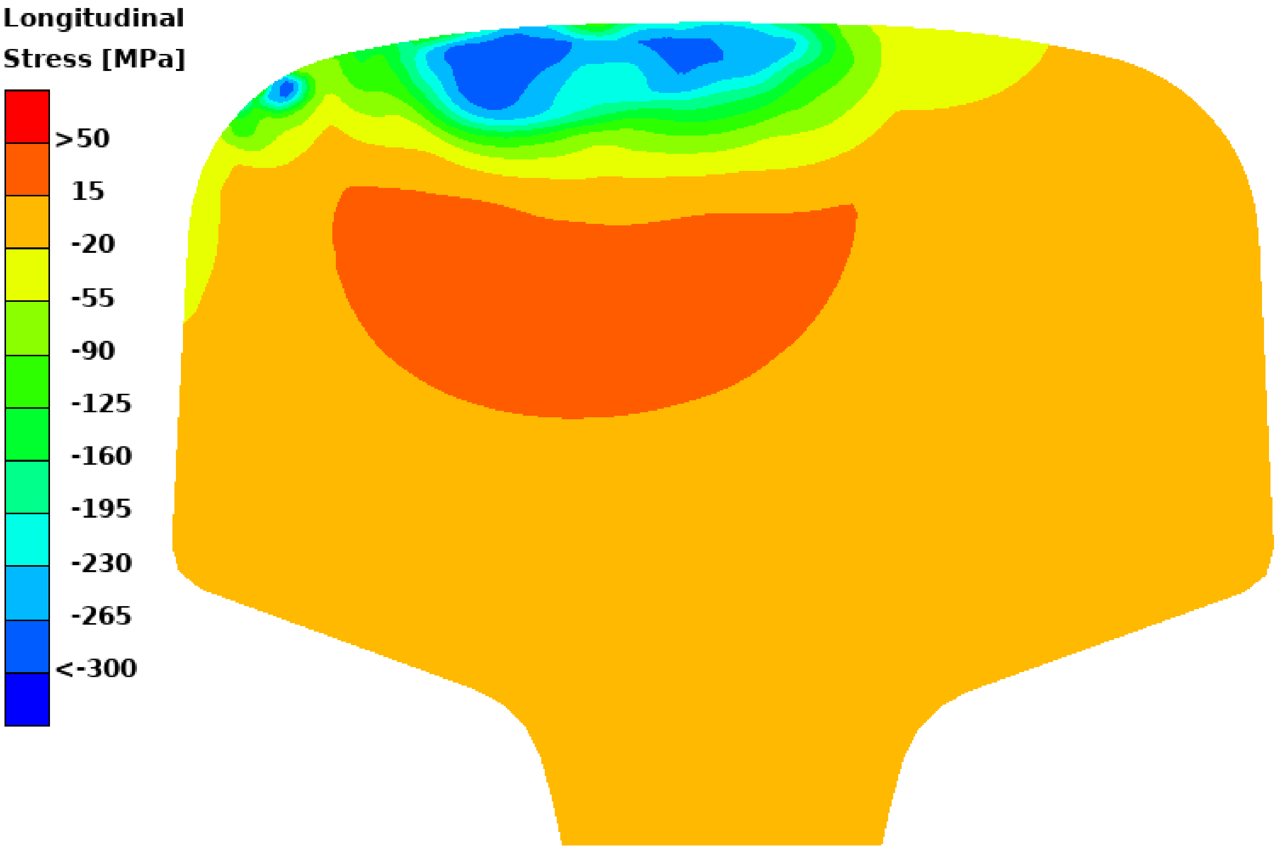

2D cross-section

**Longitudinal residual stress**

- Stress profile:
  - Tensile in rail foot
  - Compressive in rail web
  - Tensile in rail head
- Experimental residual stress measurements [1]
- Top surface measurement affected by grinding rail head to correct geometry
- Significantly different from residual stress after flash butt welding or thermite welding
- Phase transformation modeling is crucial for accurate results




[1] Jun et.al, Investigation of residual stresses in a repair-welded rail head considering solid-state phase transformation, Fatigue & Fracture of Engineering Materials & Structures 40 (7) (2017) 1059–1071.




2D cross-section

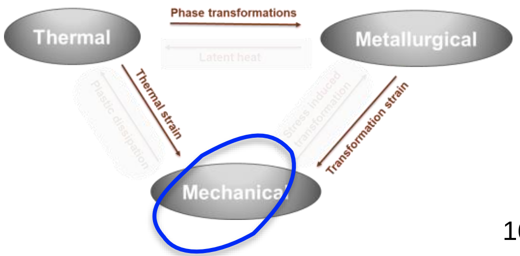
**Roll-over simulation**

***Non-repaired rail***

**Longitudinal stress**

Contact loads from 20 trains Västra Stambanan (Nyckelsjön-Sparreholmen)

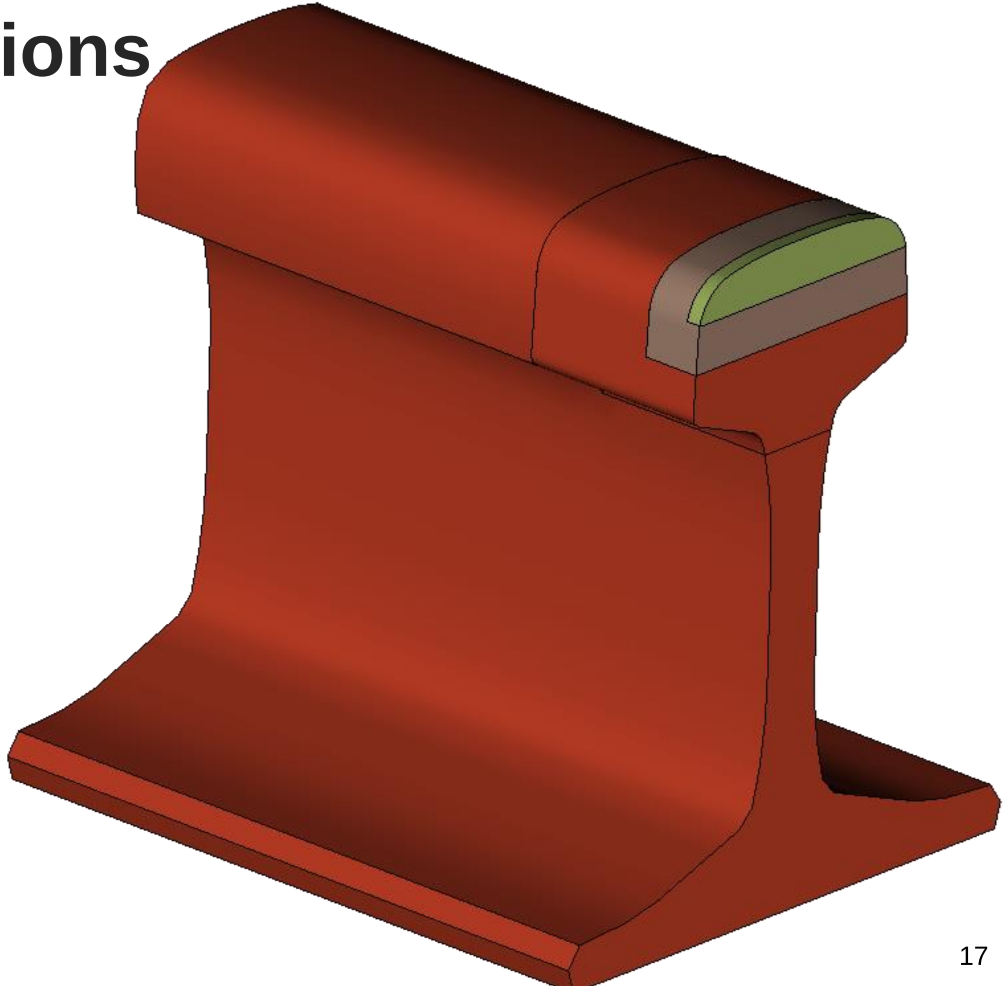
Compressive residual stresses at surface, tensile beneath the surface



# Summary and conclusions

- Thermo-mechanical-metallurgical model:
  - Phase / microstructure evolution
  - Homogenization of phase mechanical behavior
  - Transformation induced plasticity (TRIP)
  - Effect of phase transformation
- Welding simulation methodology:
  - Continuous addition of filler material
  - Moving heat source
  - Computationally efficient set-up
- Comparing homogenization methods:
  - Computational time and convergence issues
  - Residual stress states in heat affected zone

- Future Work
  - Tune and validate material model and methodology
  - Optimize repair welding process parameters:
    - Avoid martensite formation
    - Avoid unfavorable residual stresses
    - Controlled operation temperature and cooling
  - Investigate fatigue properties of repaired weld



# Thank you for listening

## CHARMEC MU37 - NUMERICAL SIMULATIONS OF WELDING AND OTHER HIGH TEMPERATURE PROCESSES

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