Crack initiation caused by repeated local heating – Modelling of possible mechanisms

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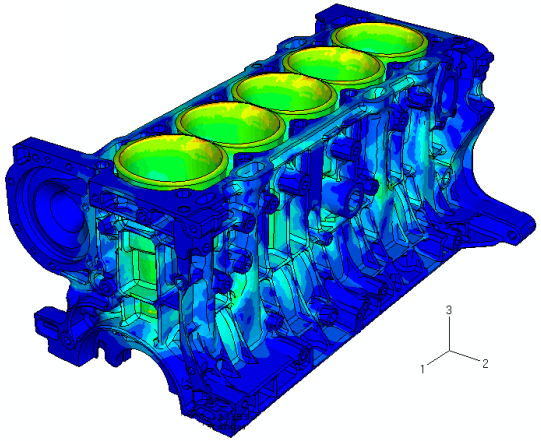
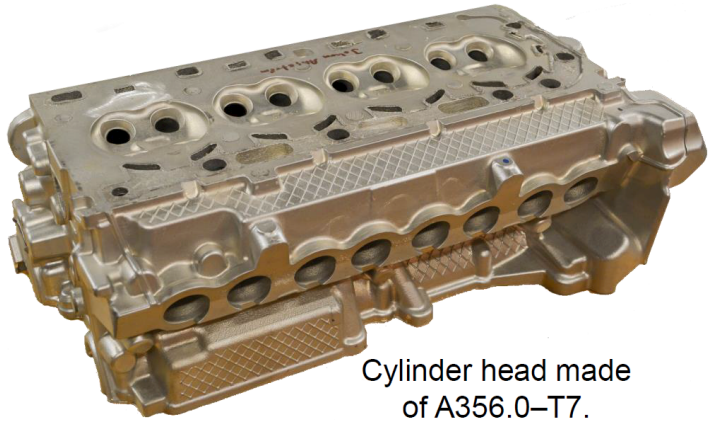
Research interests

Main research fields:

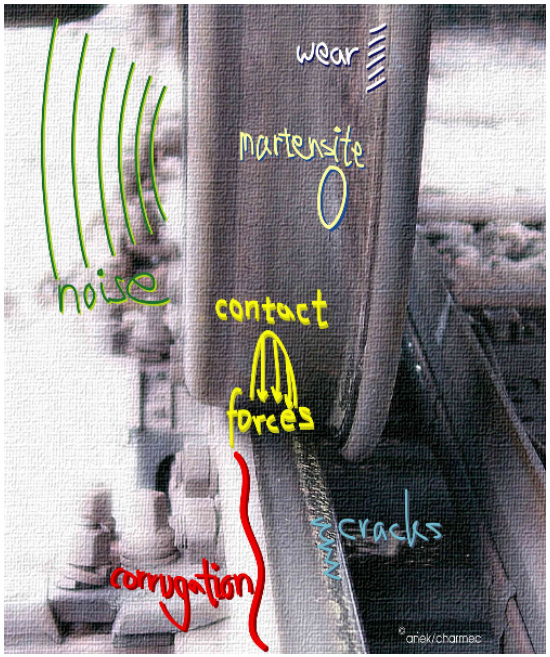
- Experimental studies of monotonic and cyclic deformation behaviour and its relation to microstructure, temperature and strain rate.
  - LCF stress-strain loop analysis - interpretation of material mechanical response
  - Input for numerical modelling of mechanical property development
- Numerical computation of phase transformations, residual stresses.

Applications:





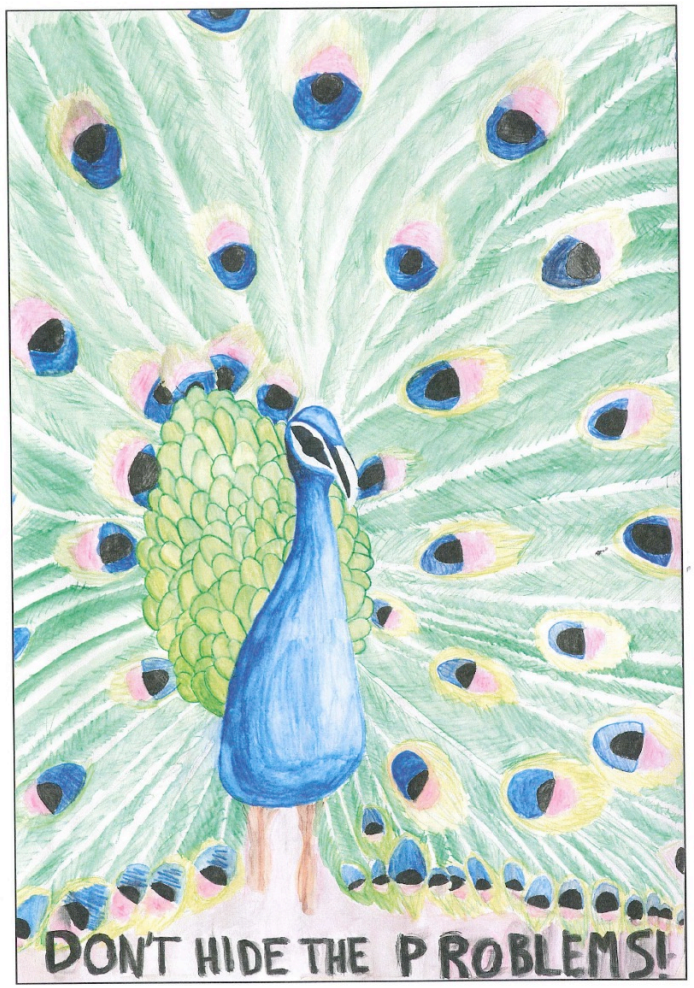
Cylinder head made of A356.0–T7.



Crack initiation caused by repeated local heating – Modelling of possible mechanisms

Outline

- Pros and Cons of railway traffic; an unqualified, simplified SWOT
- Rolling contact, typical R&D topics
- Charmec Materials research
  - Mechanical properties
  - Damage mechanisms
- Crack initiation from thermal damage
- Future work
- Acknowledgements



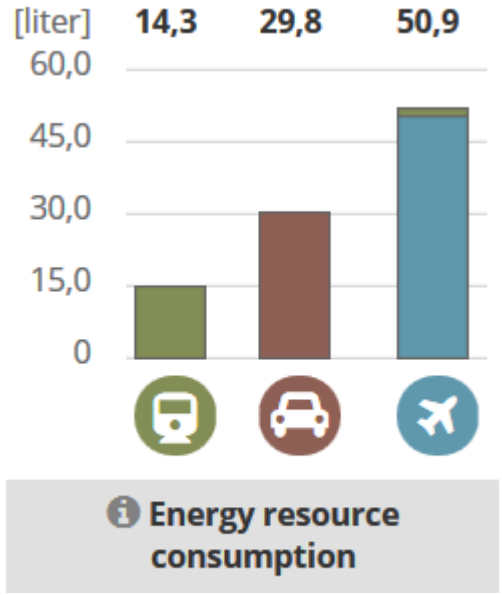
Strengths of Railway Traffic

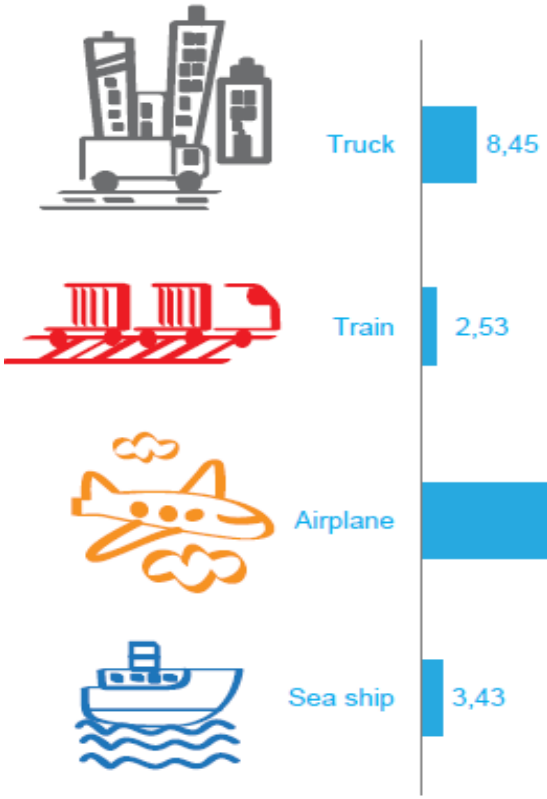
+ Lower rolling resistance than vehicles on rubber tires

+ Lower energy consumption than Car / Truck / Air

  Passenger journey example: Malmö-Stockholm

  Freight example: Beijing-Rotterdam





+ 50-100 times safer than Car transport

Sources:
http://www.ecopassenger.org
Charmec, Fact flash om järnvägssäkerhet. http://www.charmec.chalmers.se/ (2017-03-09)
Nationalencyklopedin, Järnvägens för- och nackdelar. http://www.ne.se/ (2017-03-09)
RAIL AND SUSTAINABLE DEVELOPMENT International Union of Railways (UIC) - Paris, April 2011, Authors: Alex Veitch, Henning Schwarz (UIC)

Weaknesses and ”Threats”

- Infrastructure costs/time/planning/needs
- Low flexibility, sensitive to disturbances
- From, To, When, With whom? – no free choice
- Transport to and from station often necessary

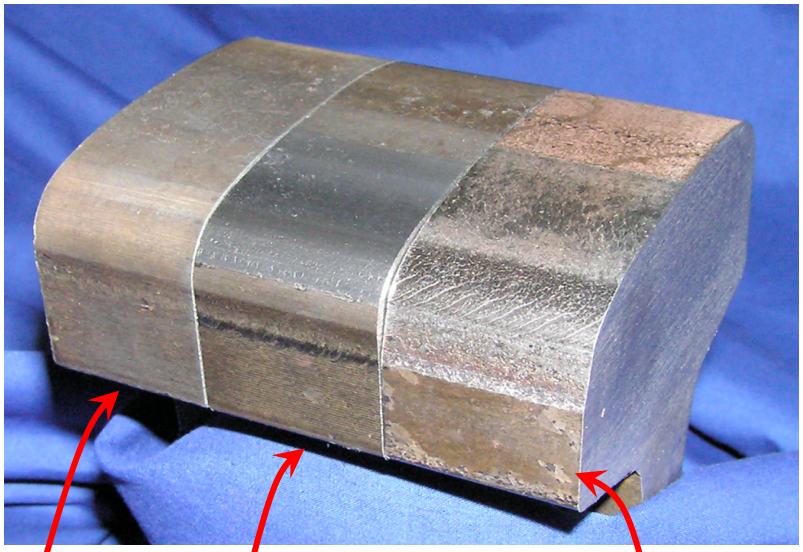
Threats to railways / Opportunities for society

- Electrified cars, trucks and buses
- Autonomous ”cars” (cabins?)
  - to appear outside your door
  - equipped for your needs that day
  - safer, increased capacity; no 3 s rule...
  - linking to reduce air resistance?

Opportunities

- Heavy, bulky freight where sea transport is not possible and electrified trucks are not competitive
- Passenger transport with high capacity on medium distances
  - Ride at 250-340 km/h with much lower energy consumption than air
  - Subways in densely populated areas should have higher capacity than linked cabins
  - the cheaper alternative?
  - autonoumous cabins can take you door - station
- ...

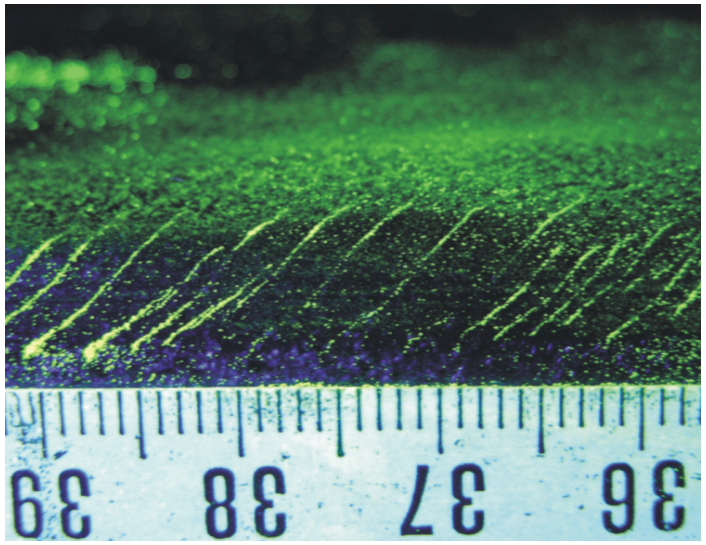
Wheel-Rail system development in general



New rail | Rail run with friction modifier ($\mu \approx 0.35$) | Rail run dry ($\mu > 0.6$) "Head check" cracks

Examples of R&D topics:

- *Higher strength wheel and rail materials*
- *Contact forces and profile distributions*
- *Wear and friction control*
- *Damage monitoring; maintenance strategies*
- *Traction and braking control*
- *Initiation and propagation of cracks*



Wheels and rail materials:

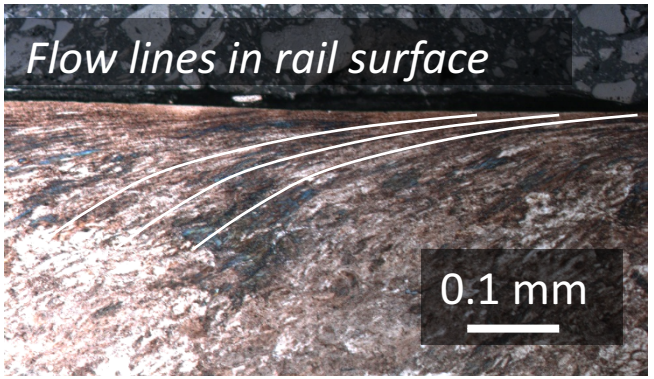
- *Pearlitic steels still dominate*
- *Heat treated pearlitic grades used in curves*
- *Martensitic, Bainitic, Austenitic steels used in switches/crossings*

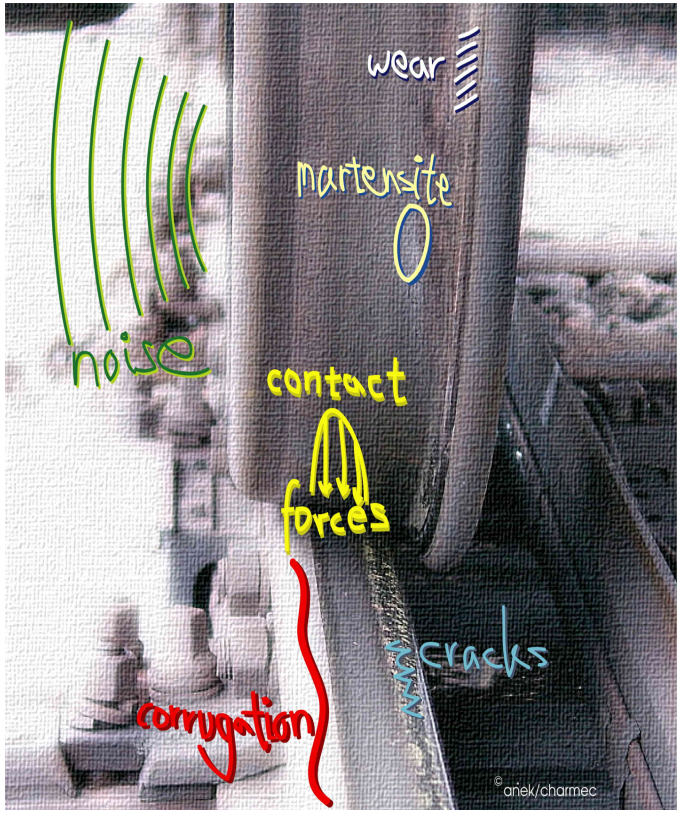
Pictures from Voestalpine Schienen GmbH

Wheel-Rail rolling contact

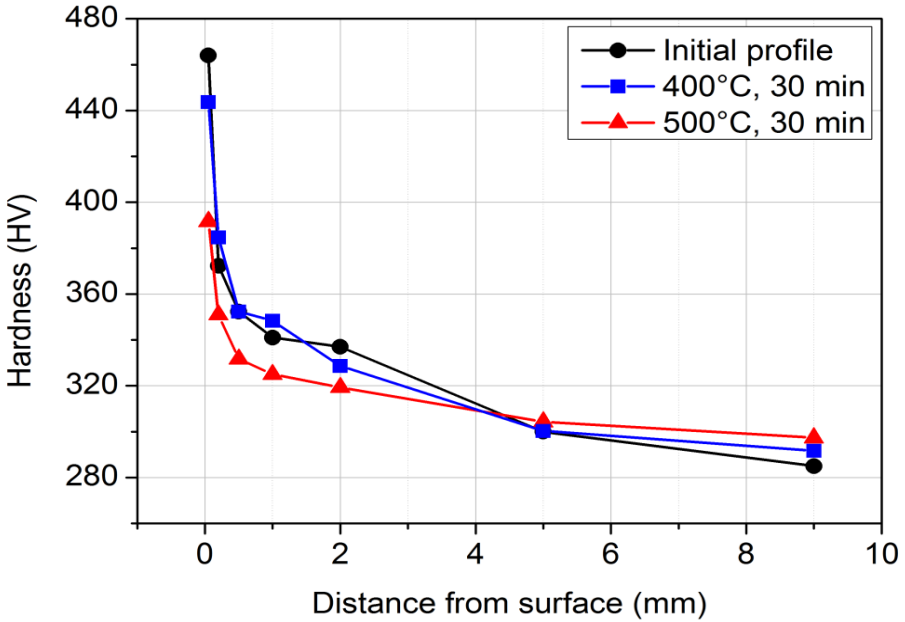
Characteristics:

- *7-15 tons load on a ϕ 10-15 mm contact patch*
- *Cyclic plastic deformation of surface layer*
- *Work hardening, Residual stresses, Anisotropy*





Hardness near wheel surface



Charmec – Chalmers Railway Mechanics

Annual budget ca 25 MSEK

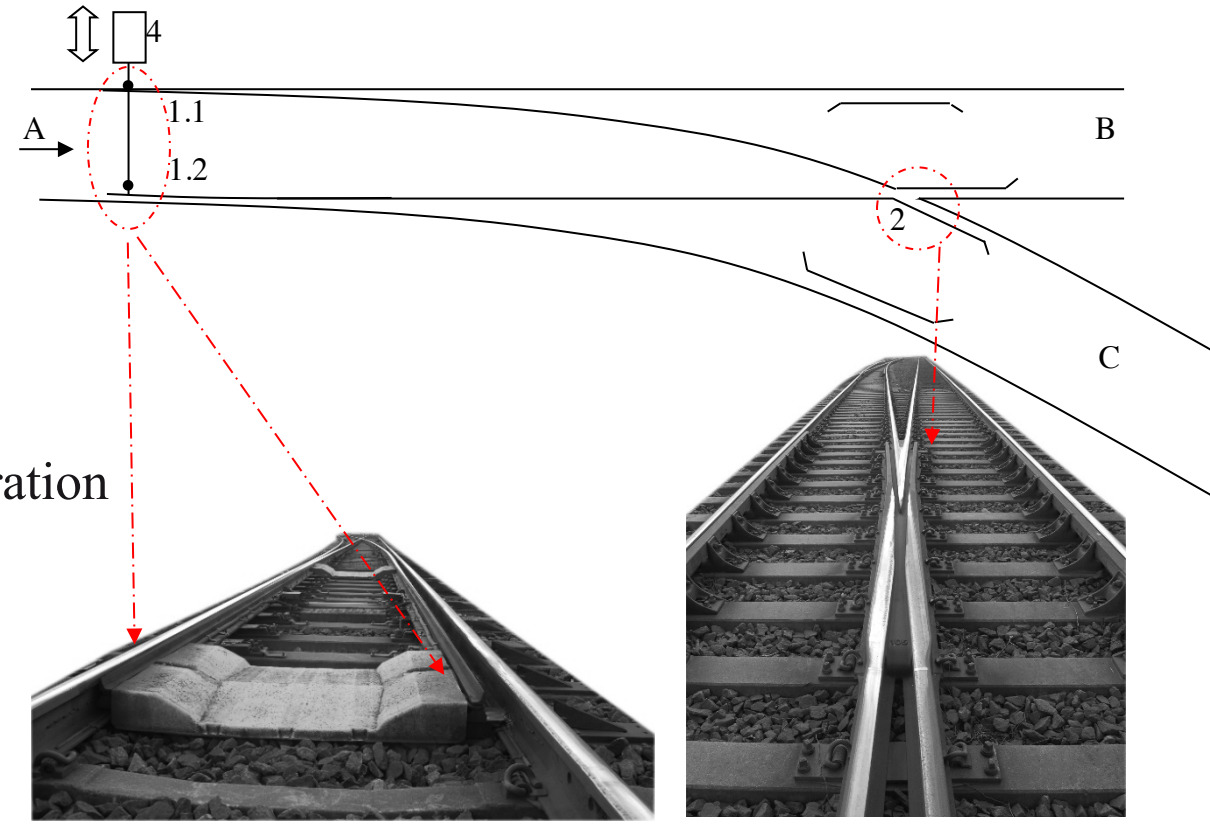
Started 1995, as competence center Nutek / Vinnova

Trafikverket largest sponsor, currently via EU project Shift2Rail

Charmec – Chalmers Railway Mechanics

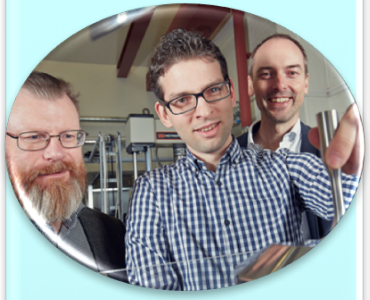
Programme areas:

1. Interaction of Train and Track
2. Vibrations and Noise
3. Materials and Maintenance
4. Systems for Monitoring and Operation
5. Parallel EU Projects
6. Parallel Special Projects



http://www.charmec.chalmers.se

Ongoing CHARMEC collaborations

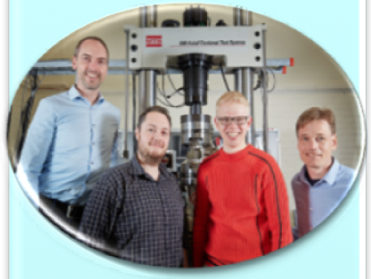


Dimitris
Material behaviour

Casey
Thermal damage

Robin
Thermal + Mechanical damage

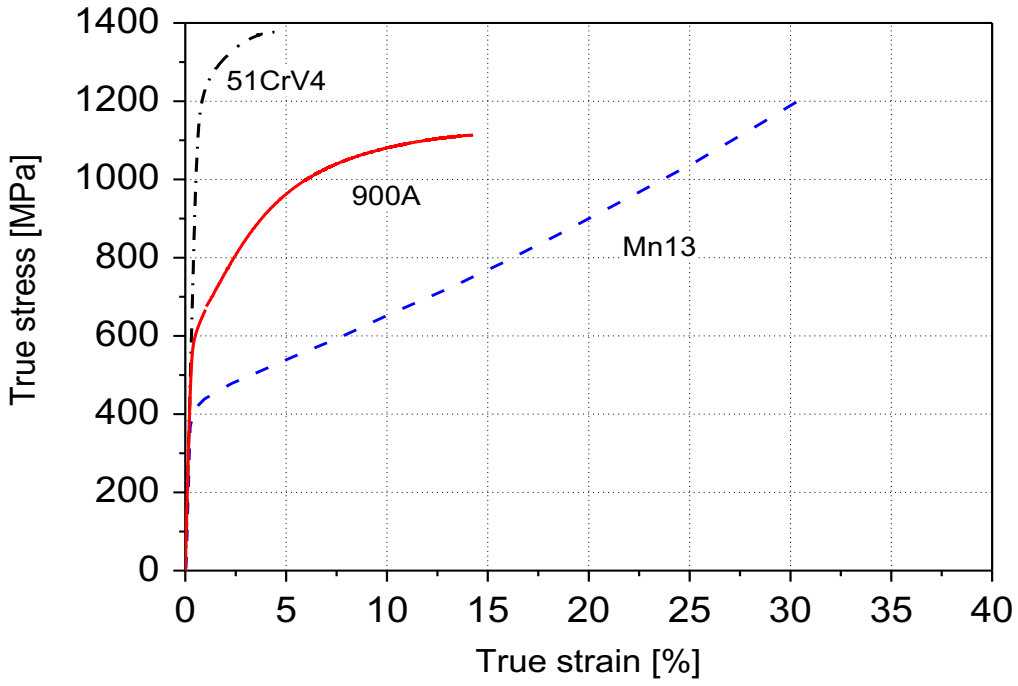
Ali
Material models

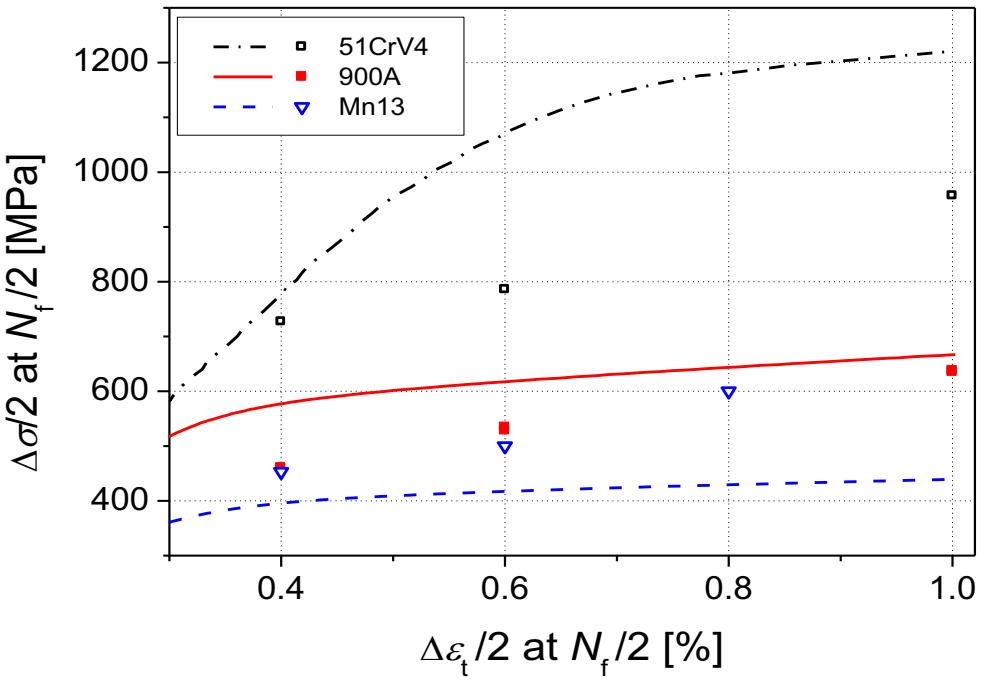


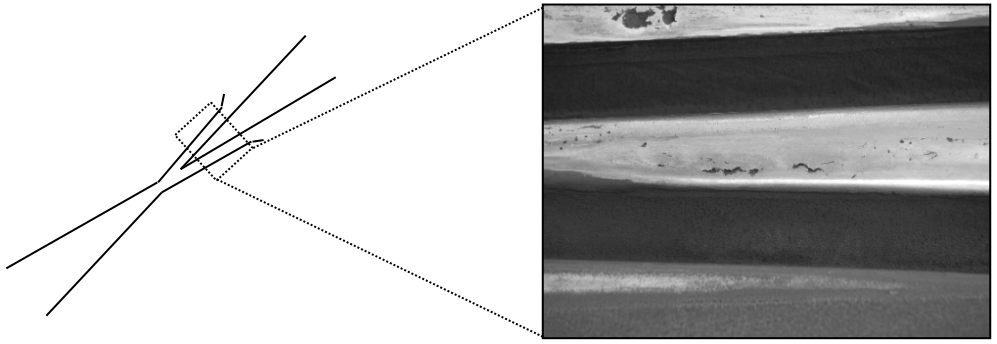
Knut Andreas
Biaxial testing and Anisotropy

Monotonic and cyclic stress-strain behaviour

Alternative steels for use in crossing noses (from EU project Innotrack)



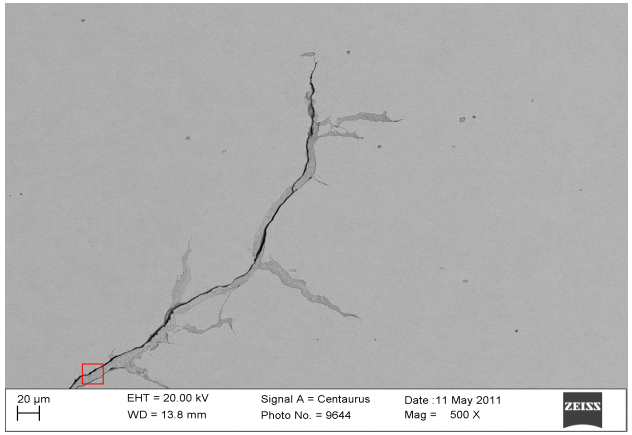


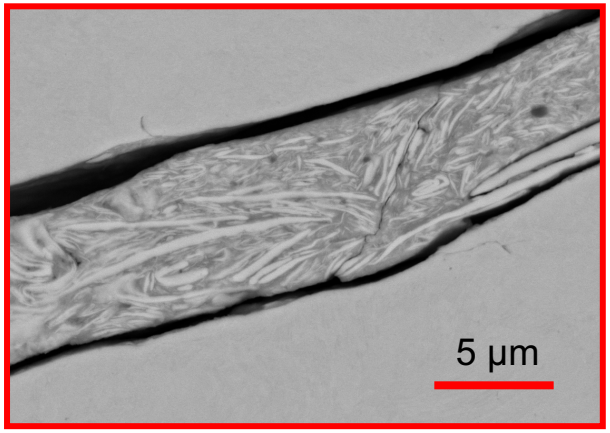


- Martensitic 51CrV4 – strong cyclic **softening**
- Pearlitic R260/900A – slight cyclic **softening**
- Austenitic Mn13 – strong cyclic **hardening**

Crack propagation mechanisms in mode II and III

Cracks in railway wheels, containing ≠ ”oxides”





Mechanism

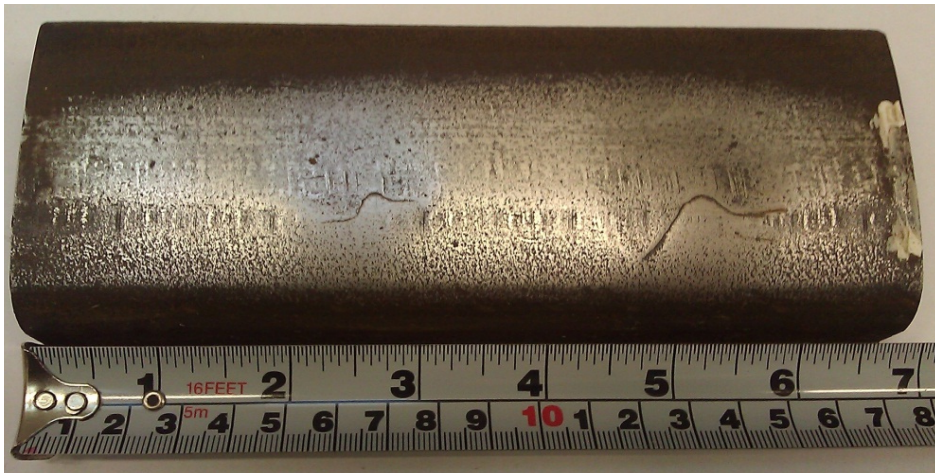
Rolling contact fatigue loading
=> crack surfaces are in contact
=> internal wear within cracks
=> residues build up , affect crack propagation?

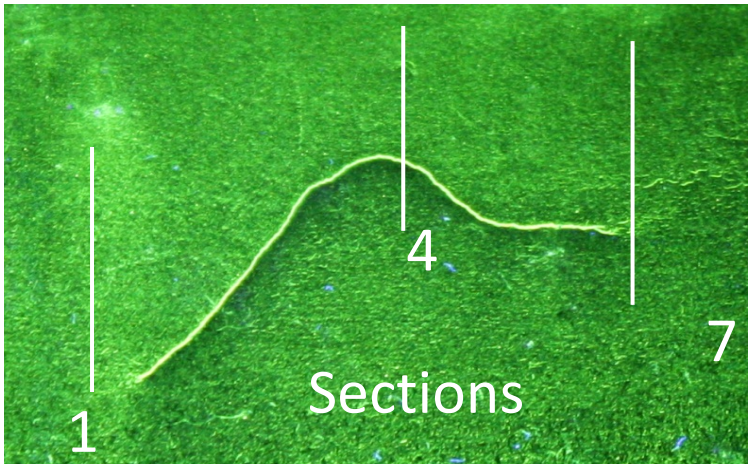
How to study?

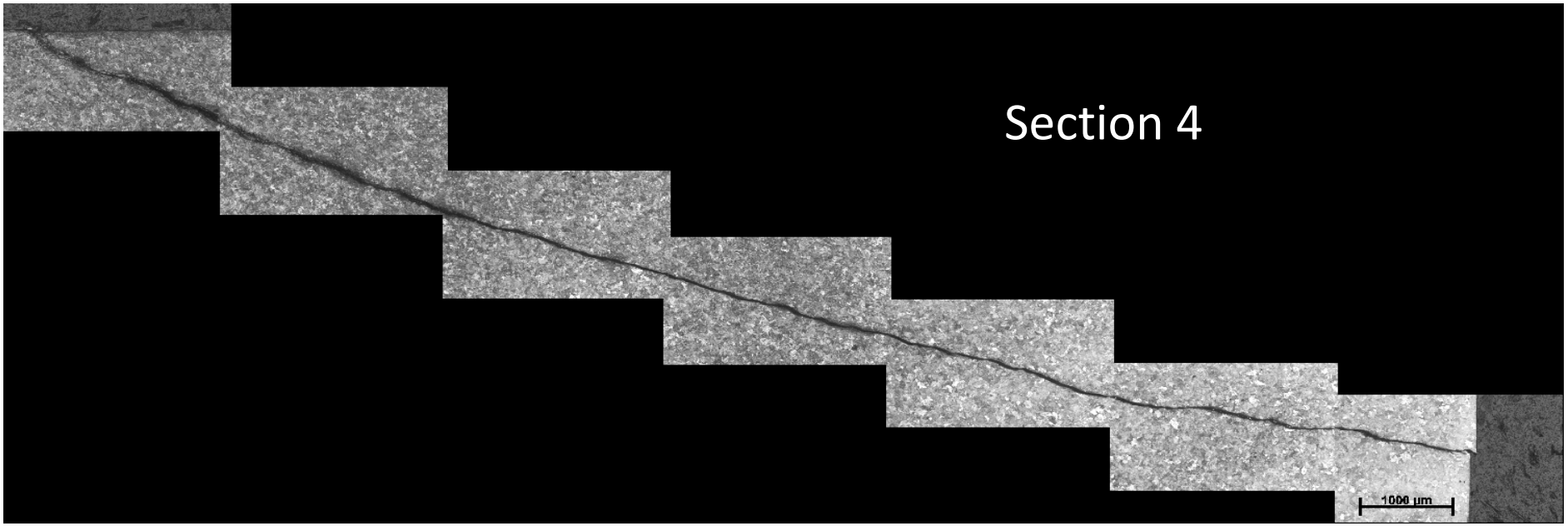
Axial torsion test machine with chamber providing controlled temperature and humidity

Also equipped with induction heating (elevated temp, TMF).

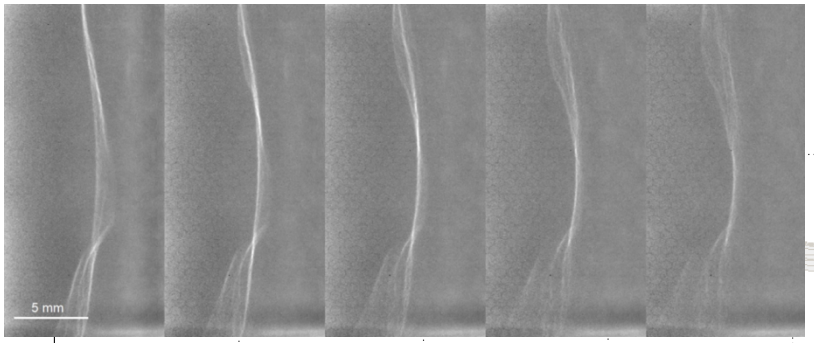
Squat cracks in rails



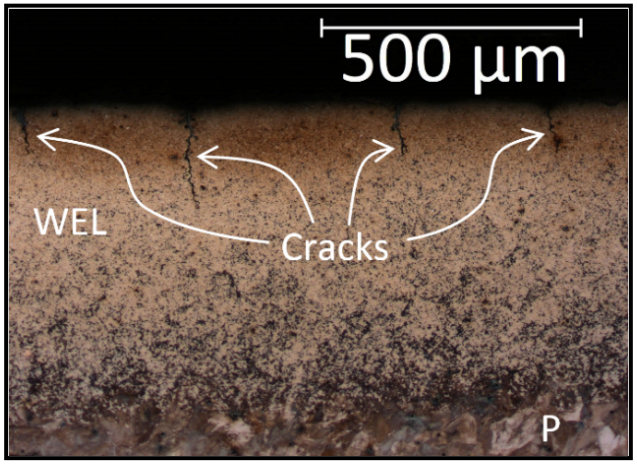


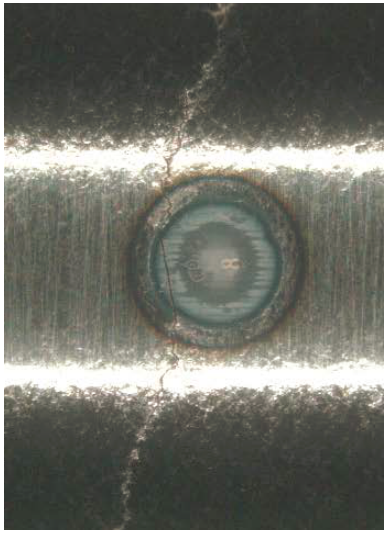


Determination of crack network geometry by X-ray reconstruction and sectioning

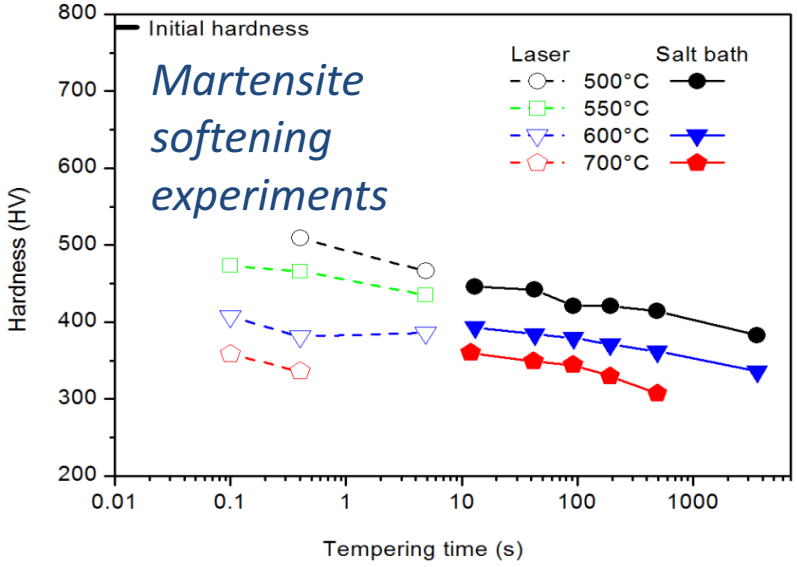


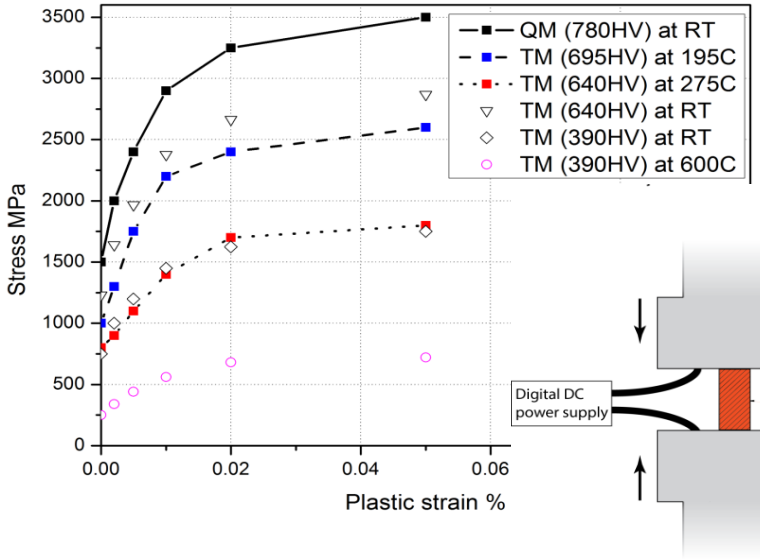
Thermal damage initiation of squat cracks, “studs”



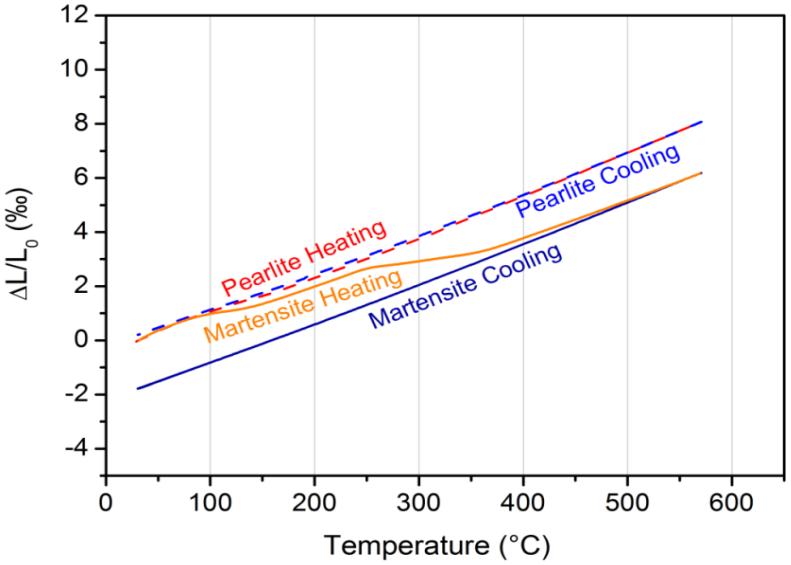


Experiments to support the residual stress modelling





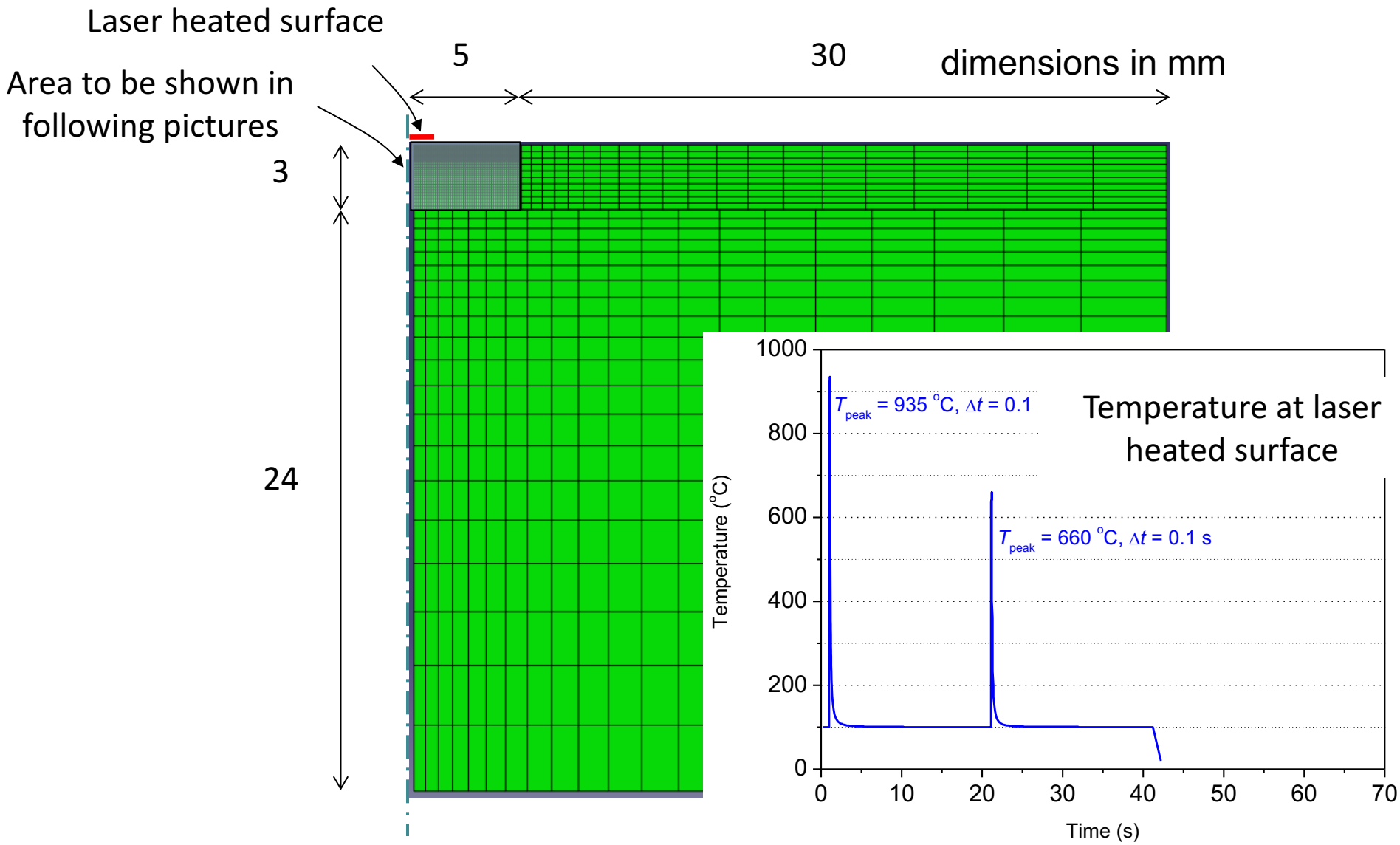
Stress-strain data f(annealing, temperature)



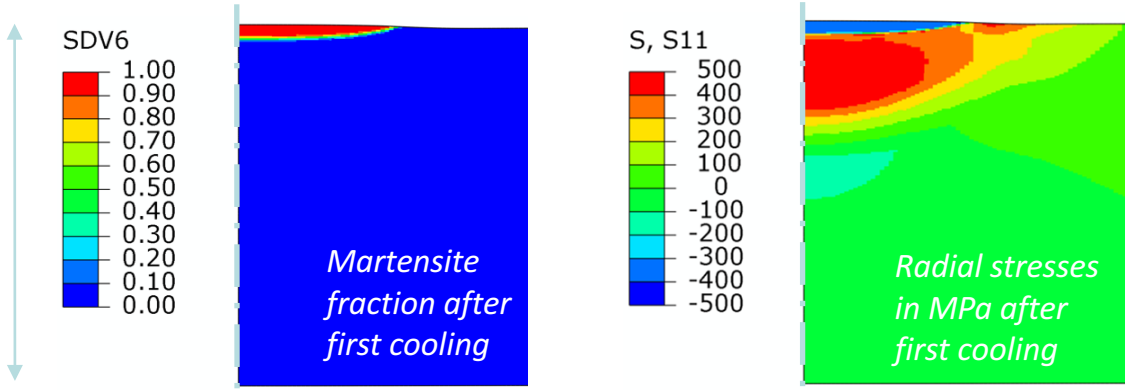
Dilatation on heating and cooling

1. The un-tempered martensite will decrease in volume after heating.
2. Pearlite and fully tempered martensite (>400°C) dilate similarly.

Axisymmetric FE model for ”squat/cluster initiation”



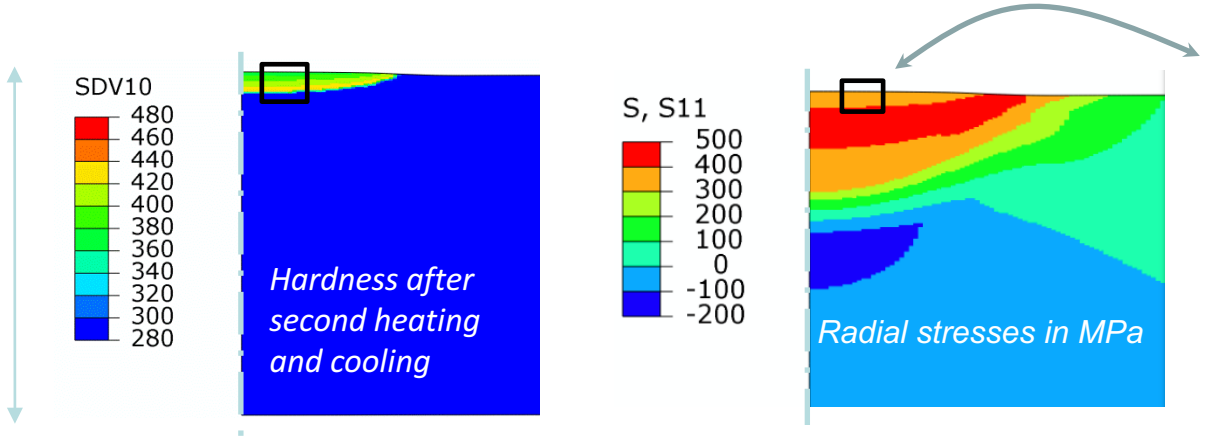
Thermal damage

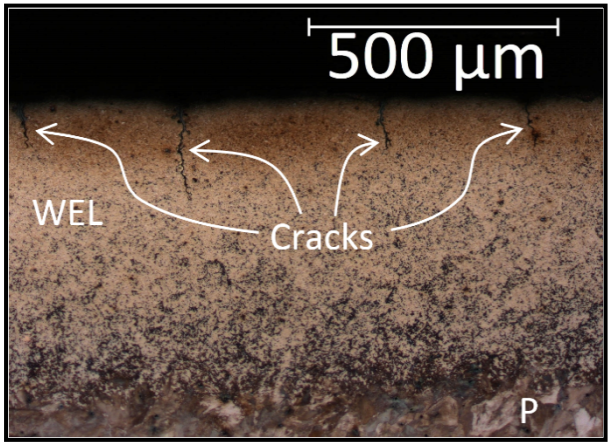


Local frictional heating of rail surface => martensite formation, volume expansion, compressive stresses

Repeated heating => martensite tempering, shrinkage, tensile stresses in brittle martensite, crack formation

4 mm





From: Residual stresses generated by repeated local heating events – Modelling of possible mechanisms for crack initiation
http://dx.doi.org/10.1016/j.wear.2016.05.029

Conclusions

- Road traffic developments; important to consider when planning for new railway lines
- Detailed models for phase transformation, tempering and thermal expansion are required for correct prediction of how stress and strength develop in thermal processes
- Proper models of thermal damage should be useful to help answering the questions: "Initiation of thermally induced cracks where, how and when? How to avoid?"
- Long term funding from Charmec has stimulated cross disciplinary research.
- Advanced tests and evaluation of data required for correct predictions of deformation and RCF. With the new bi-axial test machine and collaborations between disciplines this is now possible within Charmec.

THANK YOU