Damage prediction in rail welds

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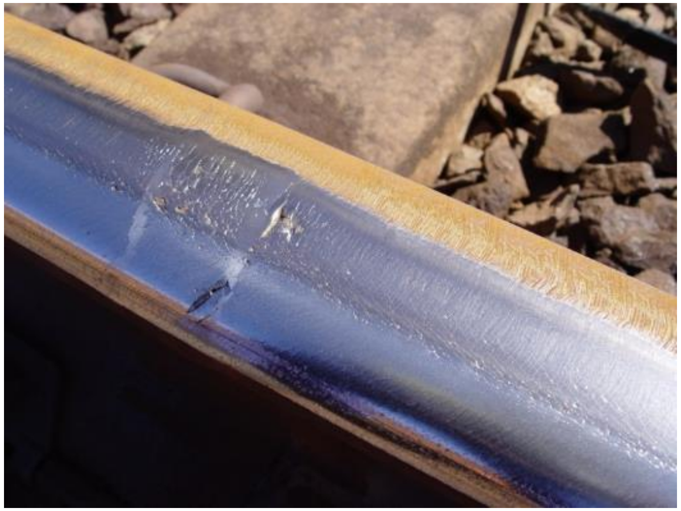
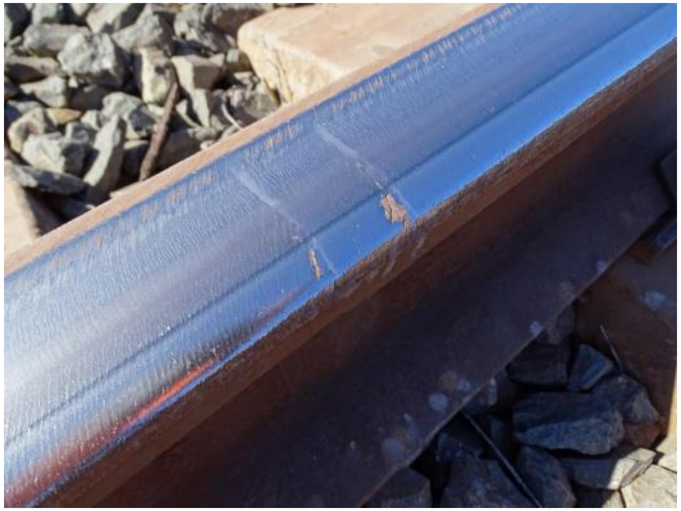
Outline

- Rolling contact fatigue damage at welds
  - What is it
  - Why is a problem
- Initiation and growth of RCF damage
- Options for addressing the RCF damage
- Research questions and proposed approach

Background

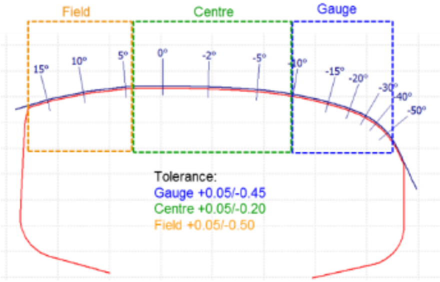
- Localised gauge corner damage in flashbutt welds in premium rail grades
  - More severe RCF damage in the heat-affected or softened zones
- Sensitivity to damage appears to vary between rail grades
- Observed under heavy haul conditions
  - Axle loads 35-40 tonnes
  - High adhesion locomotives



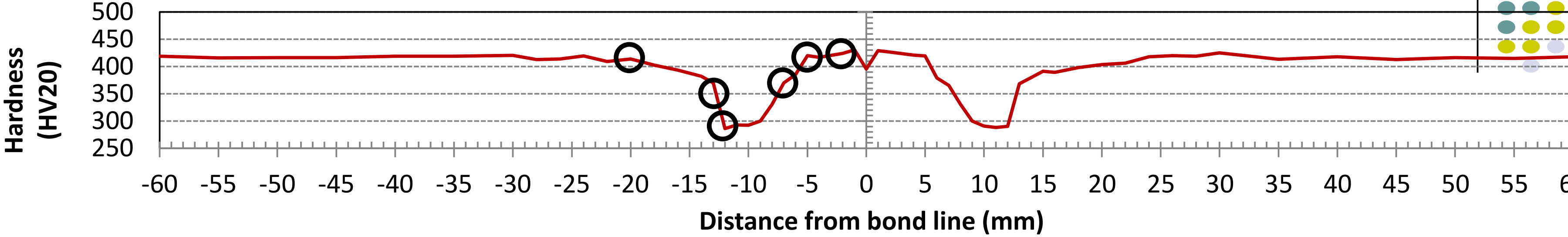


Why is it an issue?

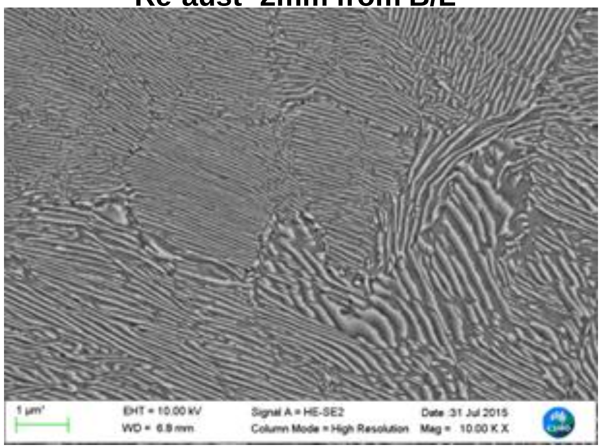
- Potential for development of transverse defects, particularly in high head loss rails
  - May restrict rail wear limits
- Additional or modified rail grinding procedures required to minimise or limit the extent of damage
- Limits the potential advantages of using premium rail grades



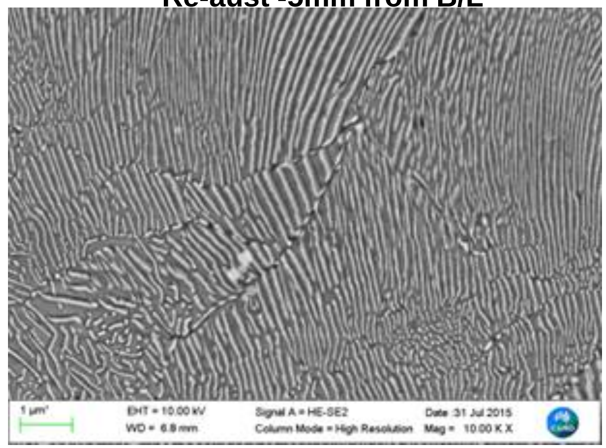
Hardness/microstructure distribution



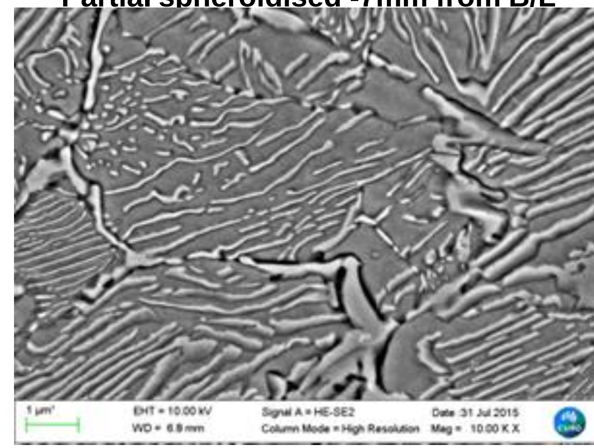
Re-aust -2mm from B/L



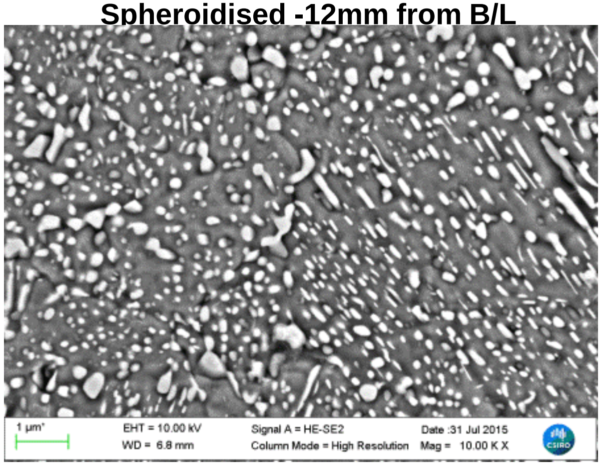
Re-aust -5mm from B/L



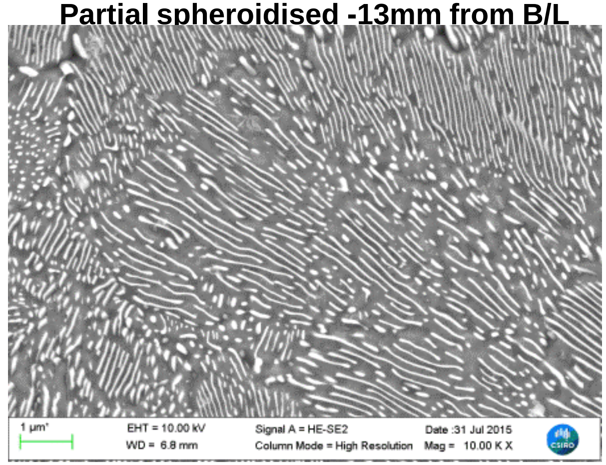
Partial spheroidised -7mm from B/L



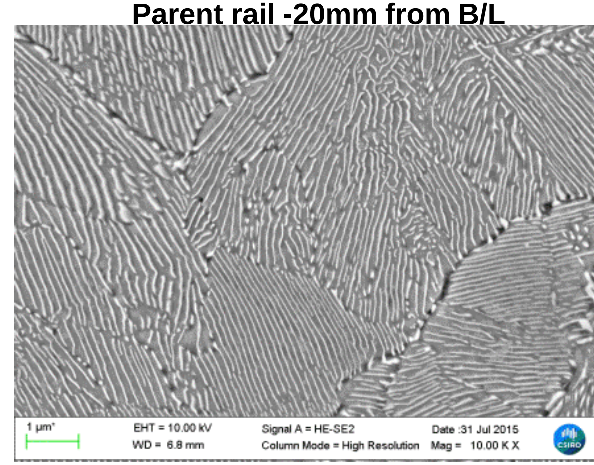
Spheroidised -12mm from B/L



Partial spheroidised -13mm from B/L



Parent rail -20mm from B/L



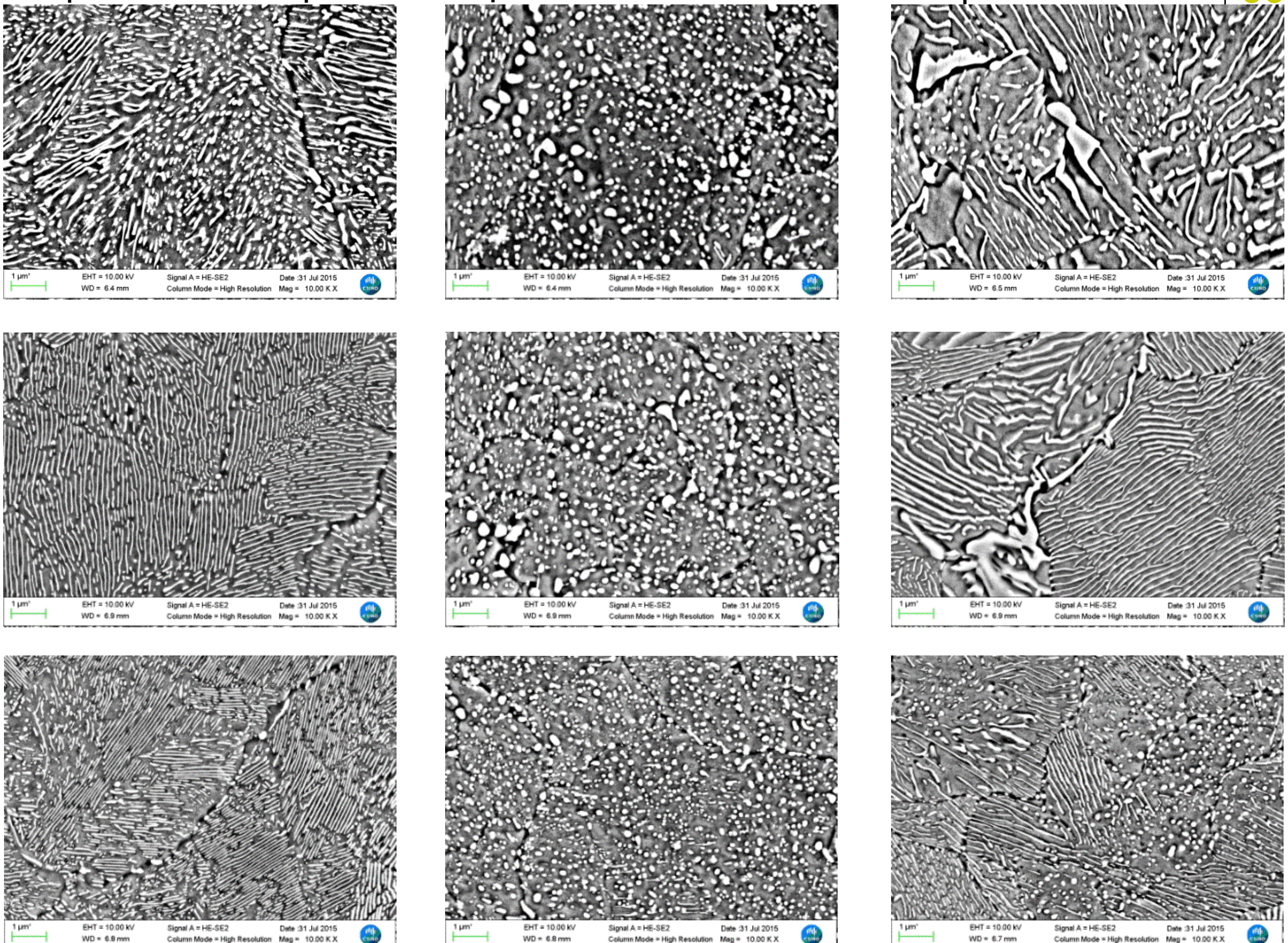
New welds

Partial spheroidised towards parent rail | Spheroidised -12mm from B/L | Partial spheroidised towards bond line

HEx Type C (mobile) 10mm below RS

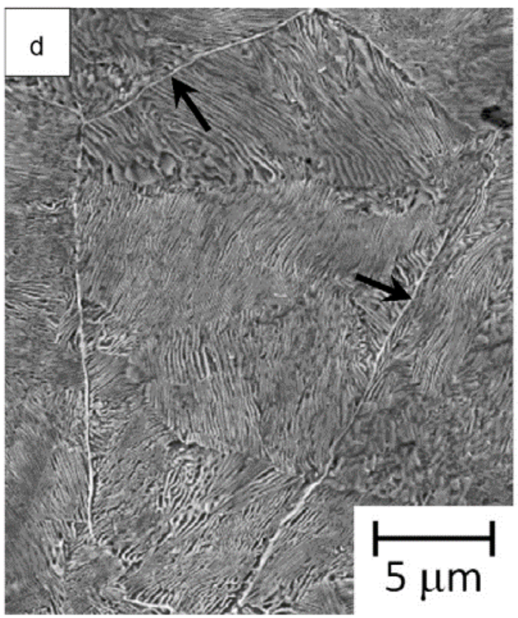
HEx Type A (fixed) 20mm below RS

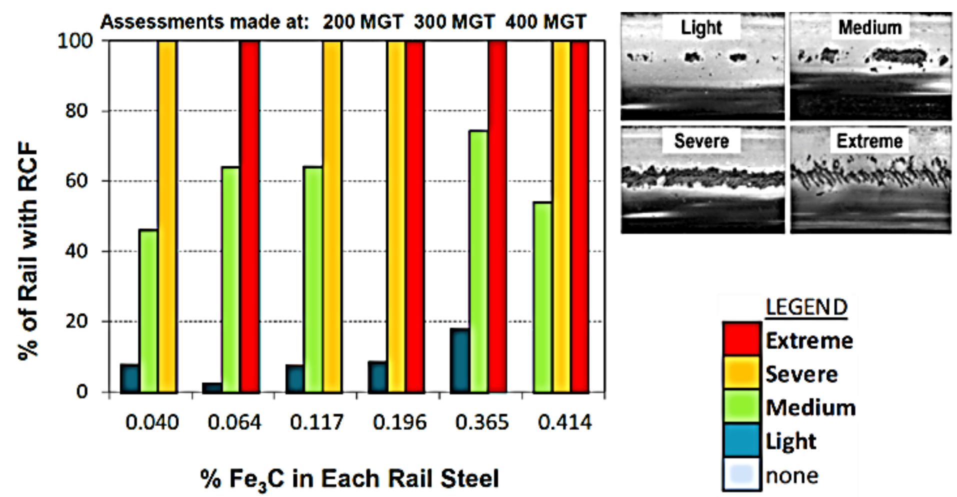
SP3 Type A (fixed) 20mm below RS



Pro-eutectoid cementite

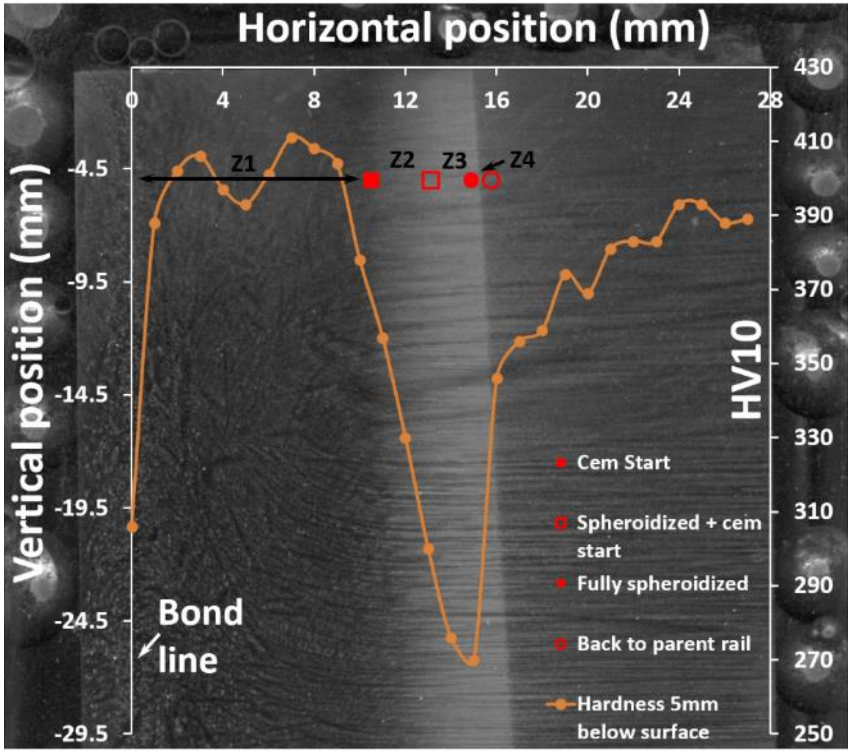
- A further consideration is the potential development of pro-eutectoid cementite (Fe_3C) networks in welds manufactured in hypereutectoid premium rails
- The existence of pro-eutectoid Fe_3C at prior austenite grain boundaries has detrimental effects on fracture toughness and ductility, and may be linked to the development of RCF in rail steels [1]





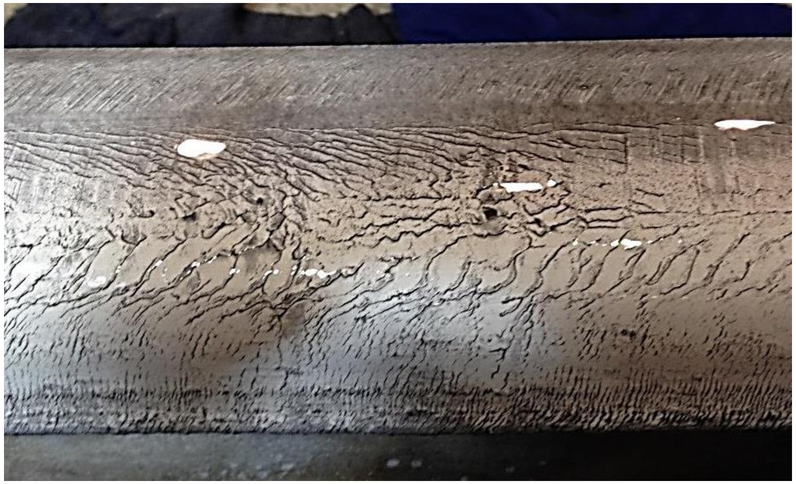
[1] Gutscher D, Baillargeon J, Li D: Railway Track & Structures, 2014, vol.110, pp. 11-13..

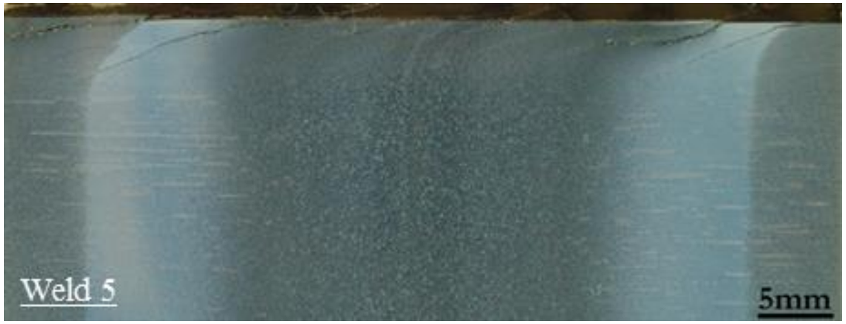
New welds

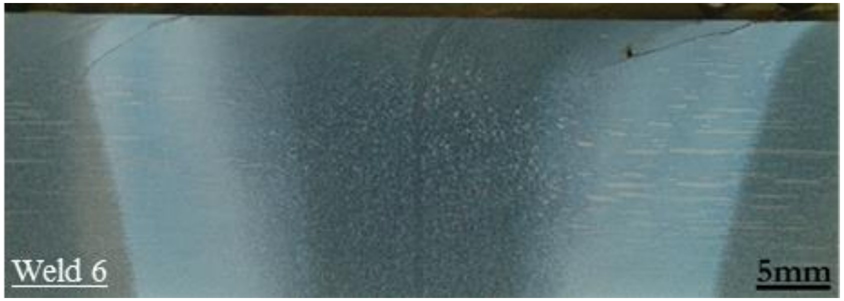


- Zone 1: no significant amount of grain boundary cementite observed.
- Zone 2: grain boundaries are heavily occupied by cementite
- Zone 3: grain boundary cementite and spheroidised microstructure are co-existing.
- Zone 4: fully spheroidised region

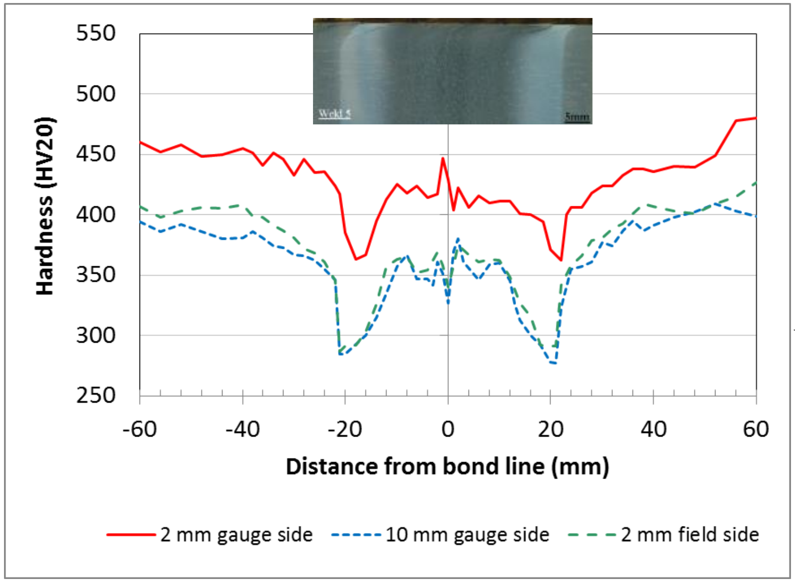
Damage appearance: Ex-service welds



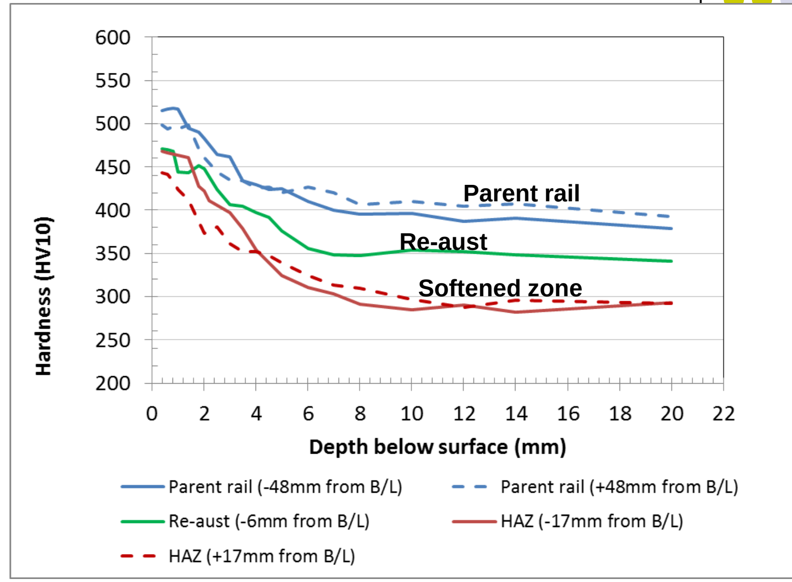


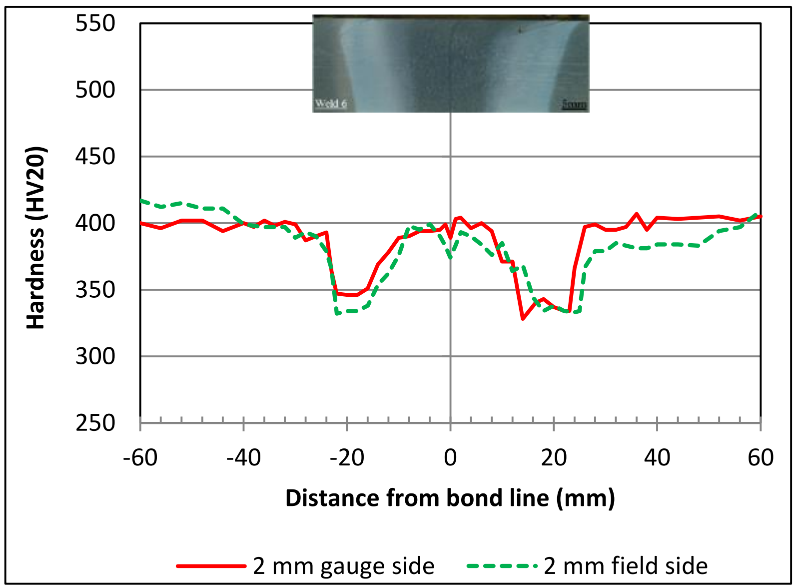


Hardness: Ex-service welds

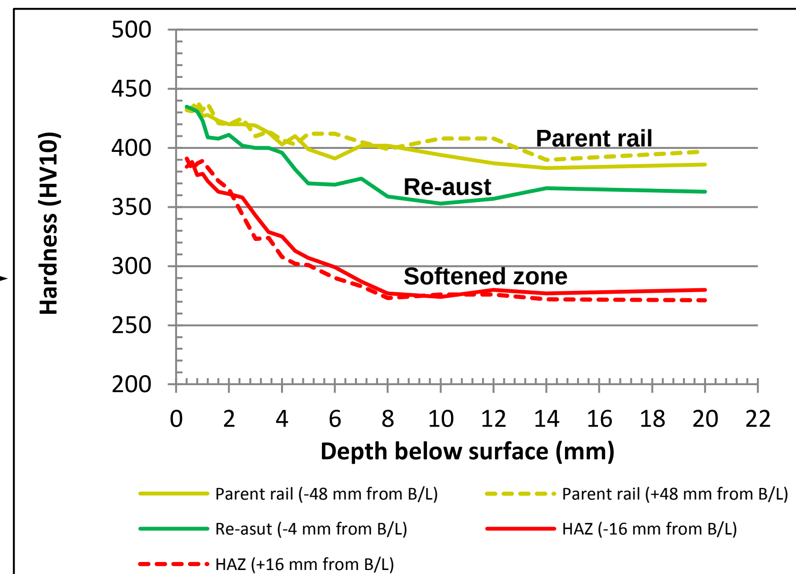


Weld 5

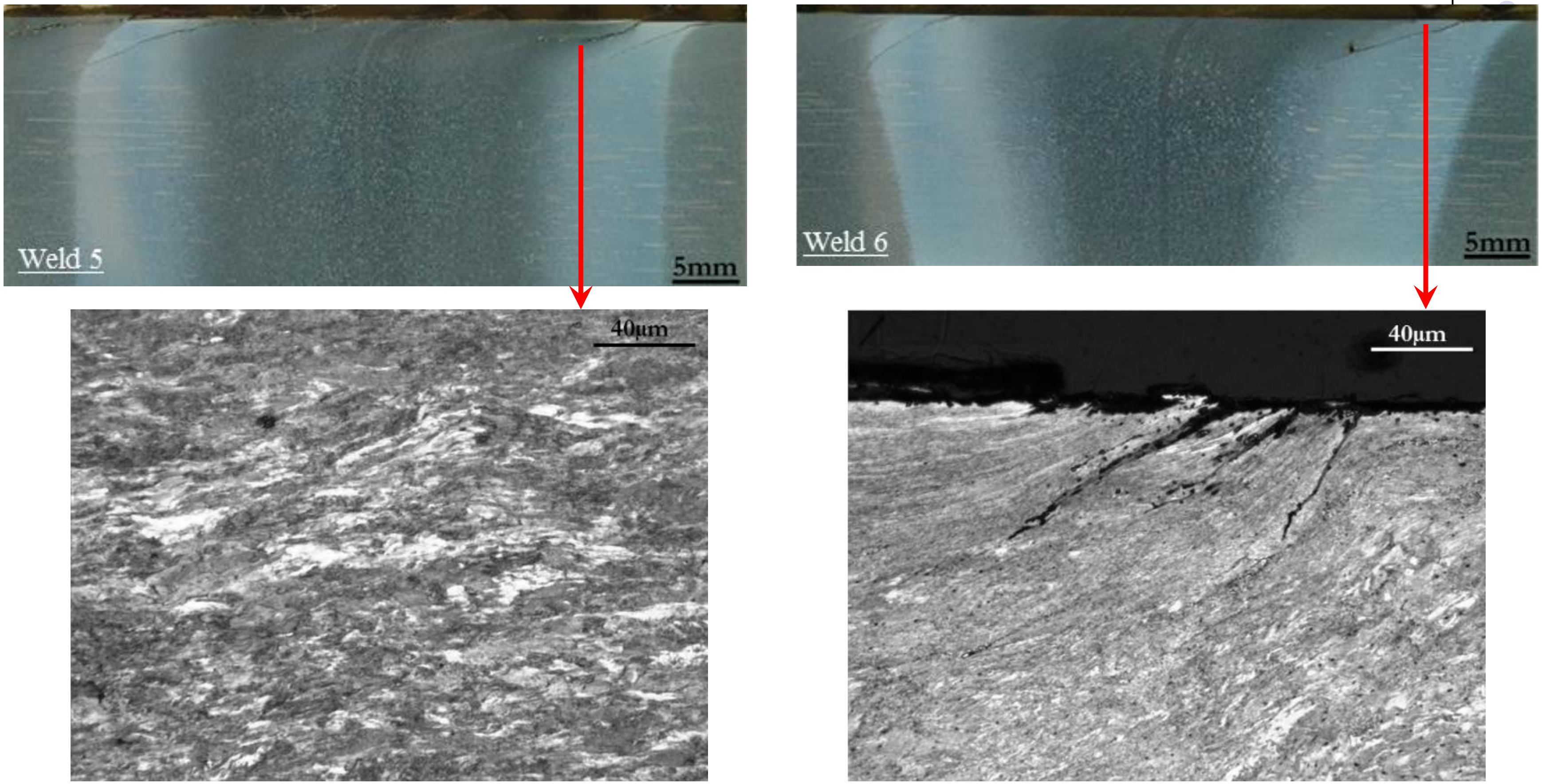




Weld 6

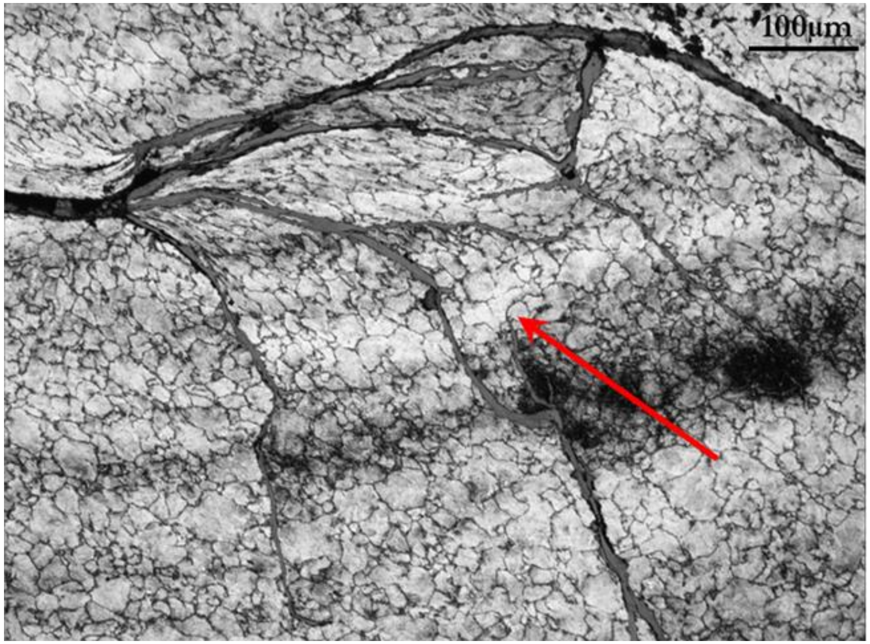


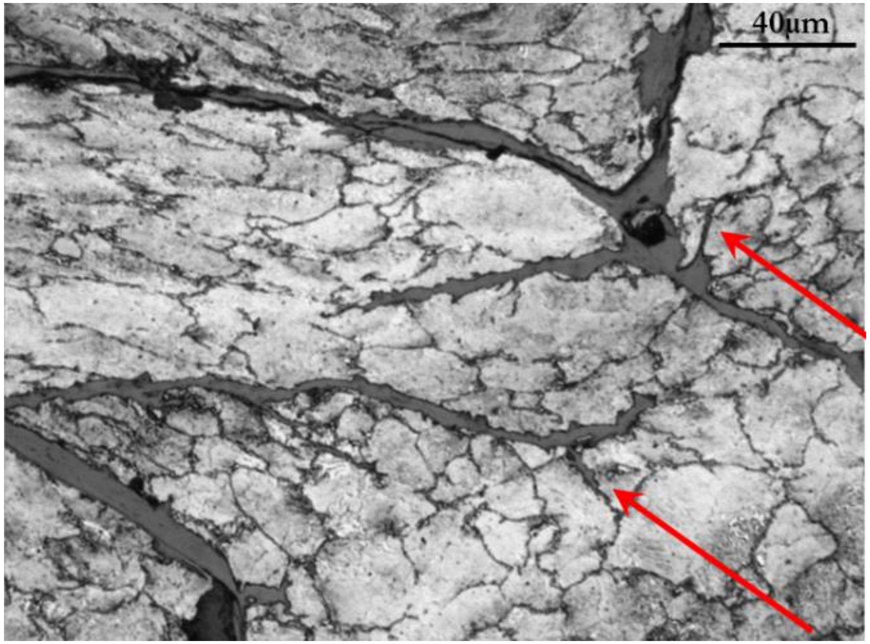
Ex-service welds: Crack initiation



- Heavily deformed microstructure near the surface.
- Cracks penetrated deeper in the softened zones

Ex-service welds: Crack growth



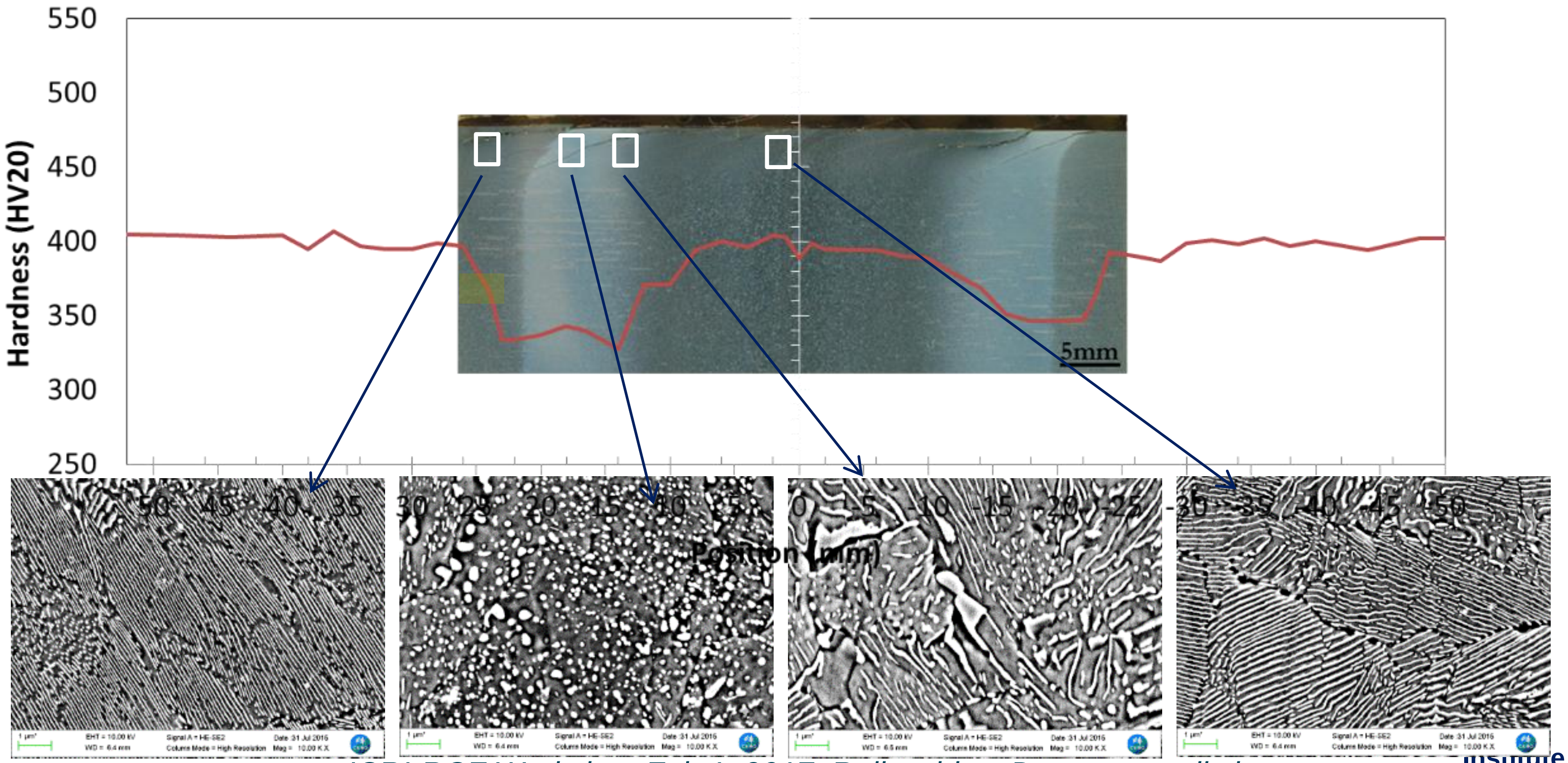


Weld 6

- Grain boundary Fe_3C does has a minor effect on crack propagation
  - Some crack tips penetrated along grain boundary, but most crack paths transgranular.

Initiation of gauge corner damage

- Cracking initiates in the lower hardness material in the softened zone of the welds
  - Increased sensitivity cracking due to lower hardness or yield strength *and* limited work-hardening capacity of the spheroidised microstructure

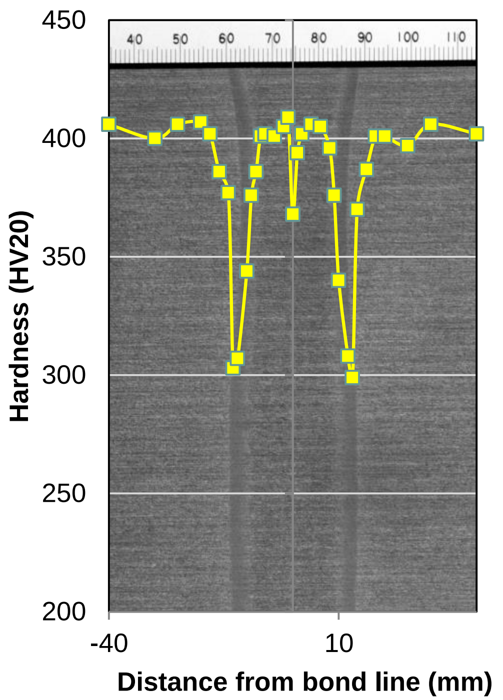


Propagation of cracks

- Cracks propagate more readily in softened zone due to greater depth of plastic deformation
- Direction of crack propagation can change at ~5mm below the surface, resulting on a transverse defect growth mode
- More extensive damage (spalling) develops on down side of welds (in direction of loaded train travel)

Options for addressing the problem

- Modify the welding process to make HAZ less prone to gauge corner cracking
- Use rail grades which are more resistant to softening during welding, and have a lower tendency to develop pro-eutectoid cementite.
- Modify wheel-rail contact conditions to lower contact stress and creepage levels



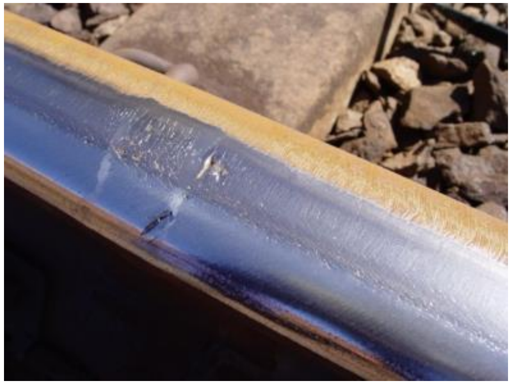
Research questions

- What is the influence of the rail grade and welding conditions on the extent of variation in microstructure and mechanical properties between the softened zone and the parent rail?
- Do we have adequate material damage models for the range of microstructures that are present in rail welds?

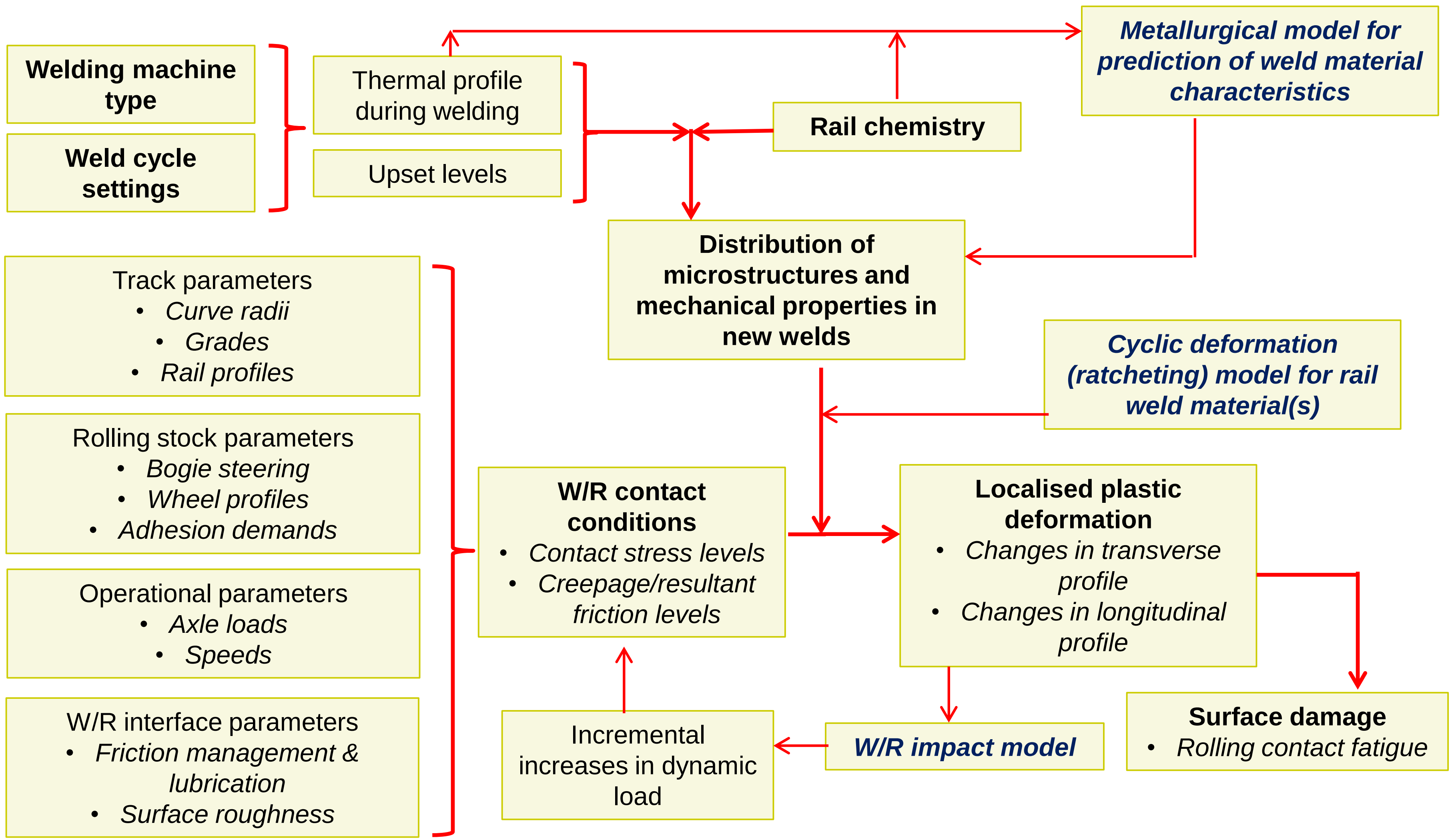
Plastic deformation and localised surface damage of rail flashbutt welds in heavy haul railway systems

Overall aim:

- To reduce the extent of localised surface damage at rail flashbutt welds in premium rail steels under heavy haul conditions through a combination of:
  - Developing a reliable tool to predict the extent of localised damage at rail welds, taking into consideration all of the influencing factors;
  - Optimising the combination of steel chemistry/grade and welding conditions to produce welds with an improved distribution of microstructures and mechanical properties;
  - Modifications to wheel/rail contact conditions and the associated rail maintenance procedures taking into consideration the cyclic deformation behaviour of rail welds.



Plastic deformation and localised surface damage of rail welds in heavy haul railway systems

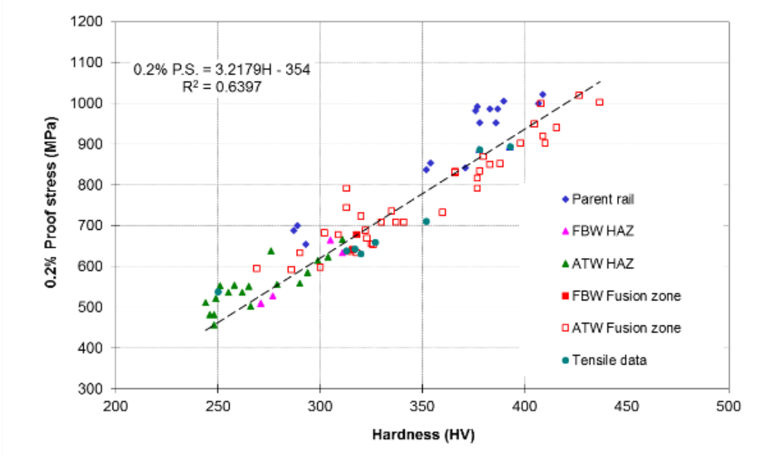


Key tasks

- ***Metallurgical model for prediction of weld material characteristics***
  - *Characterisation of rail welds*
    Measurement and analysis of mechanical properties in new flashbutt welds at macroscopic and microscopic scale
  - *Characterisation of rail welding*
    - Determine the thermo-mechanical processing conditions involved in flashbutt welding
- ***Cyclic deformation (ratcheting) model for rail weld material(s)***
  - *Characterisation of deformation and damage at rail welds*
    - Measurement and characterisation of surface and subsurface deformation and damage in rail flashbutt welds which have been in service under heavy haul conditions
  - *Experimentally study the ratcheting behaviour (accumulation of plastic deformation) of rail welds under cyclic loading conditions*
    - Develop a methodology for reproducing the range of microstructures/mechanical properties that are present in flashbutt welds; use these to produce a representative range of test materials
    - Monotonic and cyclic deformation testing to develop ratcheting parameters for rail welds
  - *Develop a model that predicts cumulative plastic strain in rail welds*
    - Develop a numerical analysis methodology that incorporates the distribution of mechanical properties in rail welds, the associated ratcheting parameters, wheel-rail contact conditions and dynamic load effects to develop a multi-axial plastic deformation model for rail welds.

Current status

- Previous compression tests to establish correlation between hardness and monotonic yield strength for parent rail and weld regions [1]



- Initial project to develop a preliminary approach forprediction of cyclic deformation parameters from monotonic test data

- New PhD project commencing March 2017

1. *Mutton P, Cookson J, Qiu C, Welsby D (2015), Wear (2016), Volumes 366–367, Pages 368–377.*

Preliminary estimation of cyclic deformation behaviour

- Microstructure ⇔ cyclic deformation behaviour
- Monotonic strength and hardness ⇔ cyclic deformation behaviour
  - Estimate:
    - Cyclic deformation parameters
      - Cyclic strength coefficient K'
      - Cyclic strain hardening exponent n'
      - Cyclic yield strength S_y'
    - From
      - Hardness (HB)
      - Yield strength S_y
      - Ultimate tensile strength S_u
      - Elastic modulus E

Questions?