Rail maintenance and its impact on Squat mitigation

ICRI Webinar, 30/06/2020

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OVERVIEW

- A history of Squats
- The Squat staircase concept
- Maintenance technologies
- Rail maintenance and Squats
- Summary

HISTORY OF SQUATS

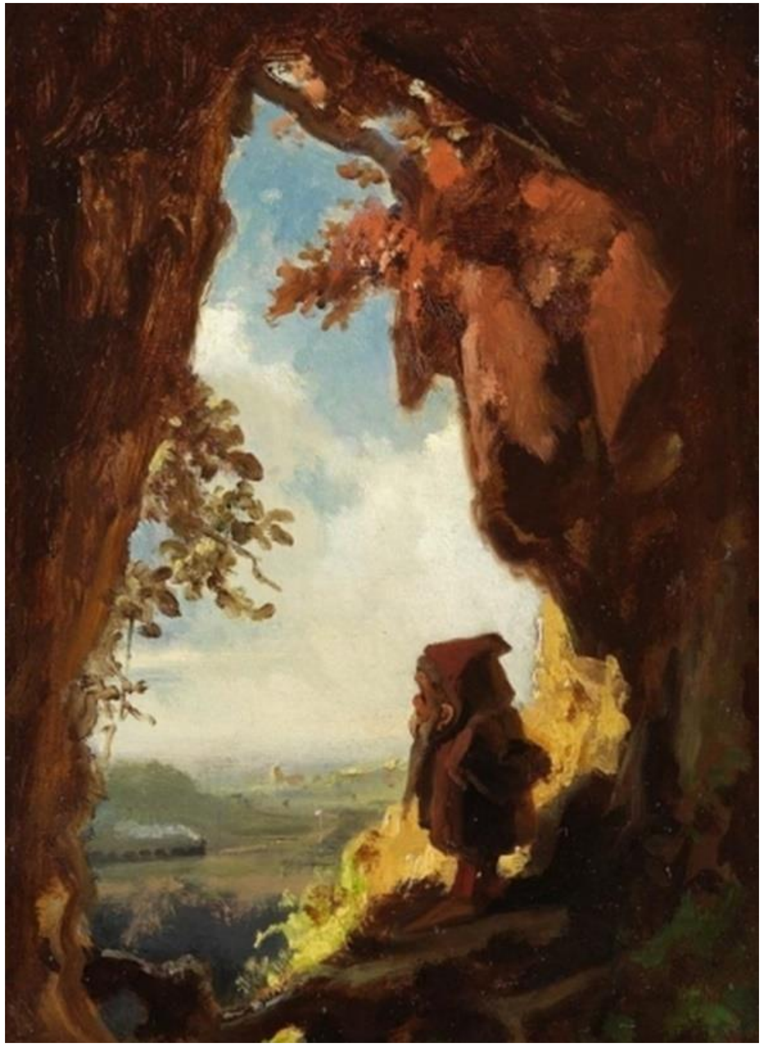
- In Japan observed since 1950s on Shinkansen high speed tracks – dark spots
- In France and UK since the late 1970ies
- Massed renaissance in Europe and other continents since the late 1990s

Photo: Wikipedia, CC BY-SA 4.0, © Alpsdake

Not a new defect

SQUAT DEFECTS AND GNOMES

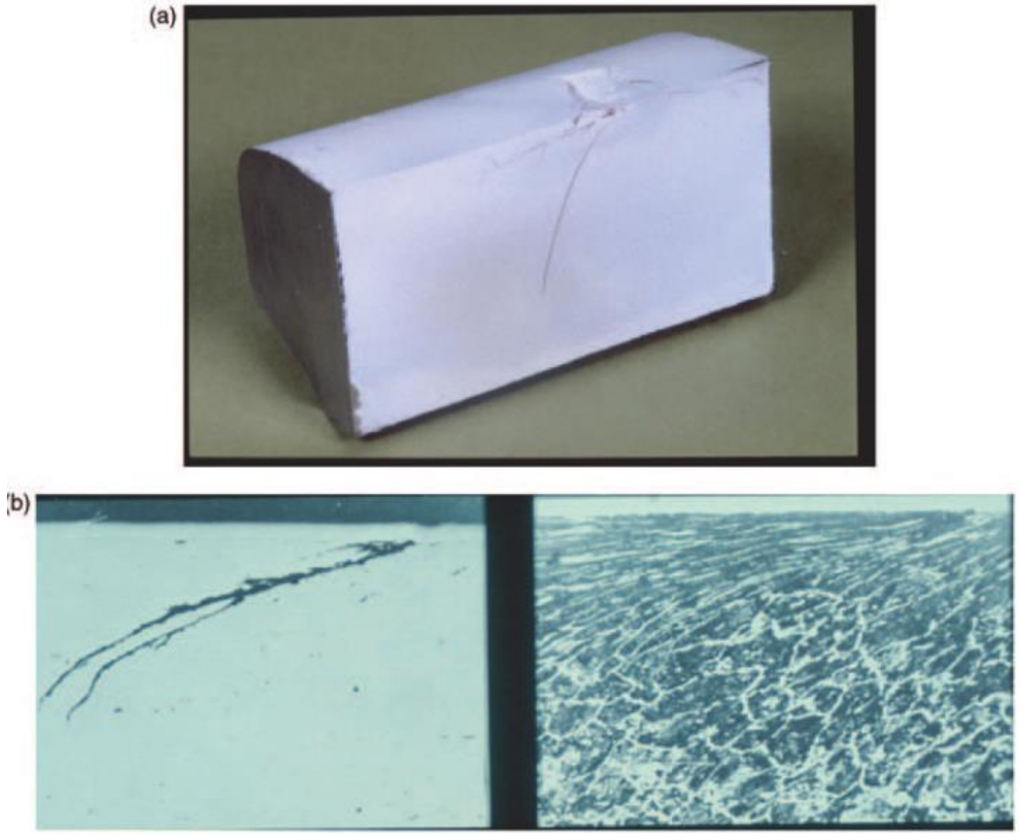
- Verb: to squat
- Definition: crouch or sit with one's knees bent and one's heels close to or touching one's buttocks or the back of one's thighs.
- British Railway employees defined the name
  - As if a Gnome was squatting on the rail and left a mark
- Proof of interest of Gnomes on railways
  - Painting by Carl Spitzweg, ca. 1848
    - “Gnome watching railway train”



Cropped painting by Carl Spitzweg, 1848, public domain

CHARACTERISTICS OF A SQUAT (PRE 1990)

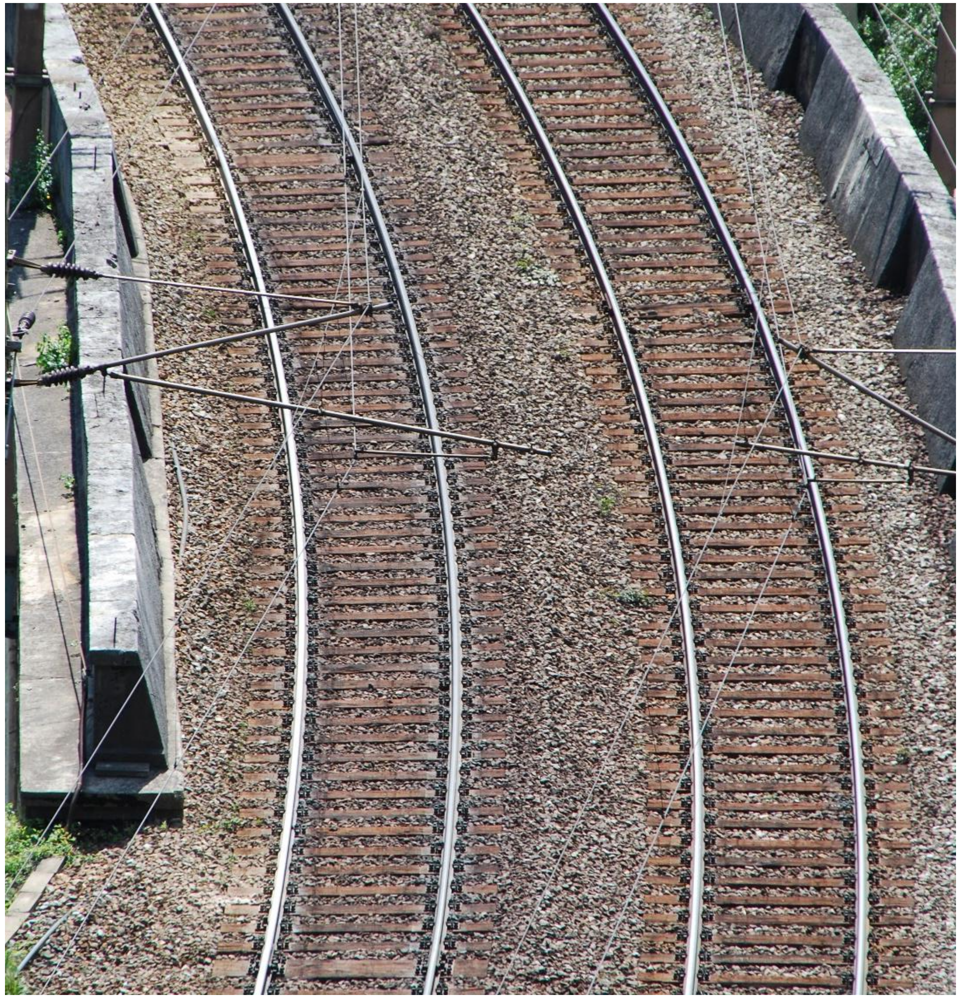
- Characteristics
  - Heavily sheared rail surface
  - Crack initiation and growth by ratcheting (RCF)
  - Initiation after a few 10s of MGT
  - Slow growth (within 100+ MGT) to full size
- Straight track and shallow curves
- Can result in rail break



Photos taken from: S.L. Grassie: Squats and squat-type defects in rails: the understanding to date. In Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit, 2012, Volume 226, Issue 3, 235 – 242
Original: British Rail Research, CO Frederick

SOLUTION TO THE PROBLEM

- Introduction of cyclic-preventive maintenance
  - Removal of damaged layer
- Introduction of higher strength rail grades
  - From R200/R220 to R260
  - Less plastic deformation and damage



THE NEW SQUAT

- Massed re-appearance in 90ies
- Superficial similarity to "old" Squats
- Characteristics:
  - Almost no plastic deformation
  - Formation within 10MGT or less
  - Low wear conditions
  - No directly related rail breaks reported
- Preventive rail maintenance strategies of limited mitigation success
- Also called Stud or Squat Type Defect

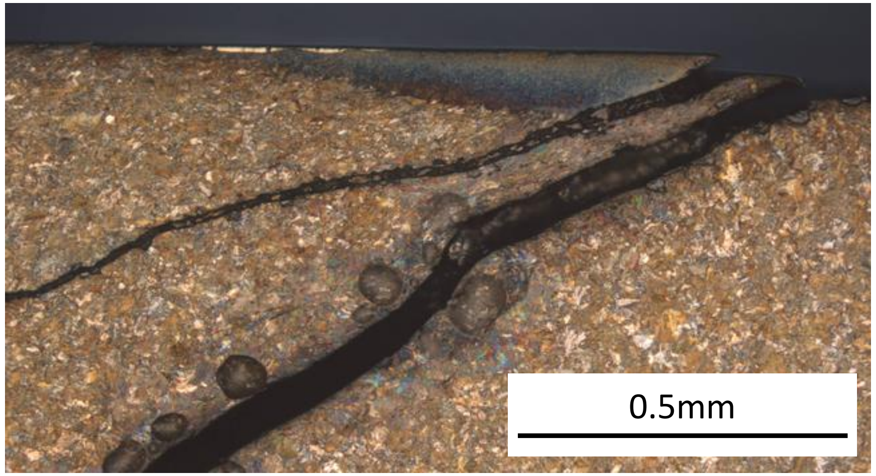
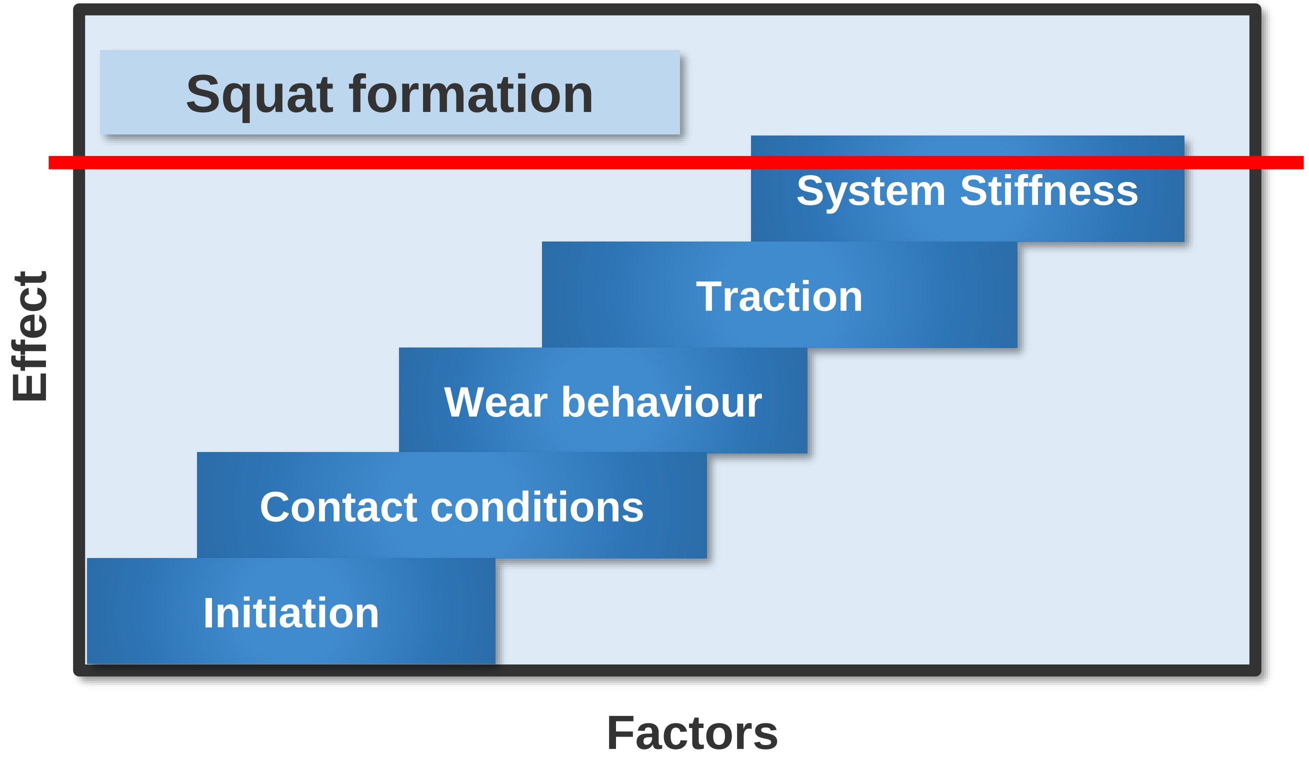


Photo by voestalpine

CONDITIONS FOR SQUAT FORMATION

- Development of Squat Damage Staircase Concept
- Complex and multi-factor problem

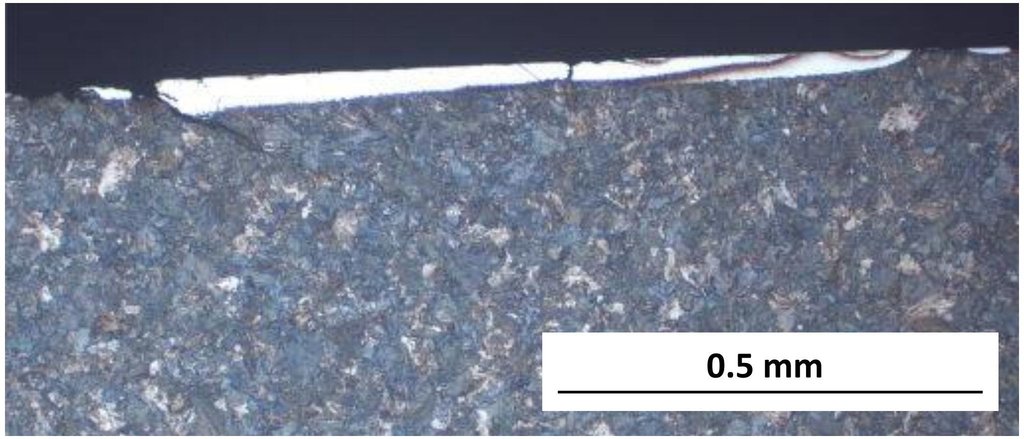


Squat Damage Staircase Concept

Original version: Jörg, A.; Stock, R.; Scheriau, S.; Brantner, H.P.; Knoll, B.; Mach, M.; Daves, W.: The squat condition of rail materials – a novel approach, in: Proceedings of CM 2015, Colorado Springs.

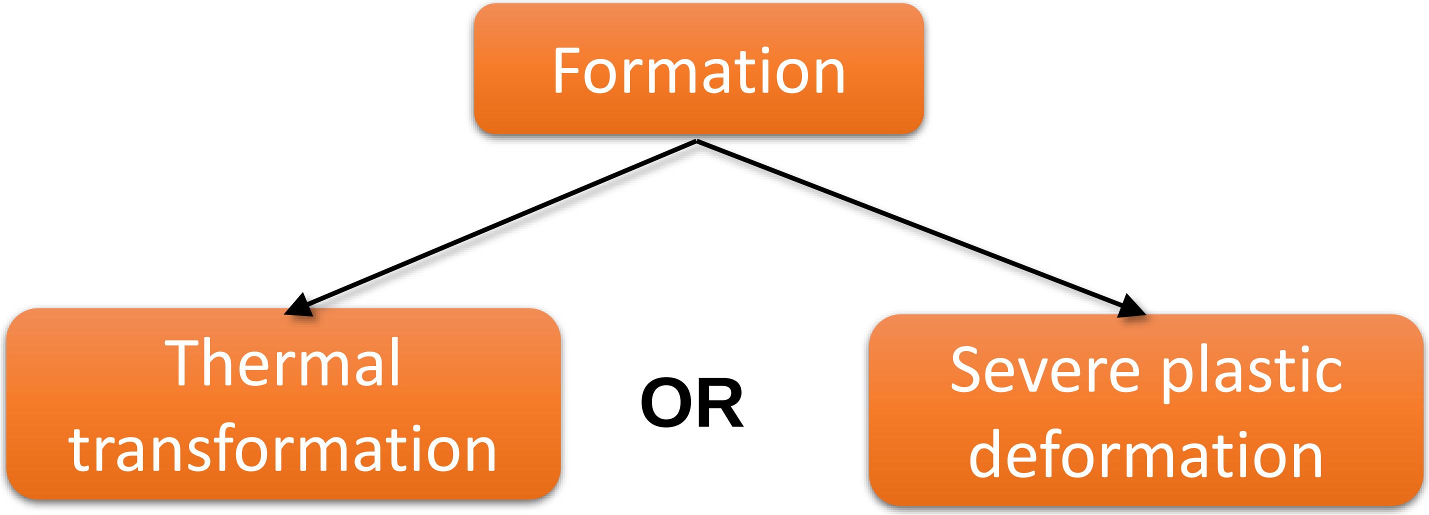
INITIATION POINTS

- Initiation points necessary for Squats
  - Imprints
  - Corrugation
  - Welds
  - Head Checks
  - Surface structure after rail grinding
  - *White Etching Layers / martensitic layers*
  - Rail surface deviation
- Right order of magnitude
- Direct or indirect initiation point



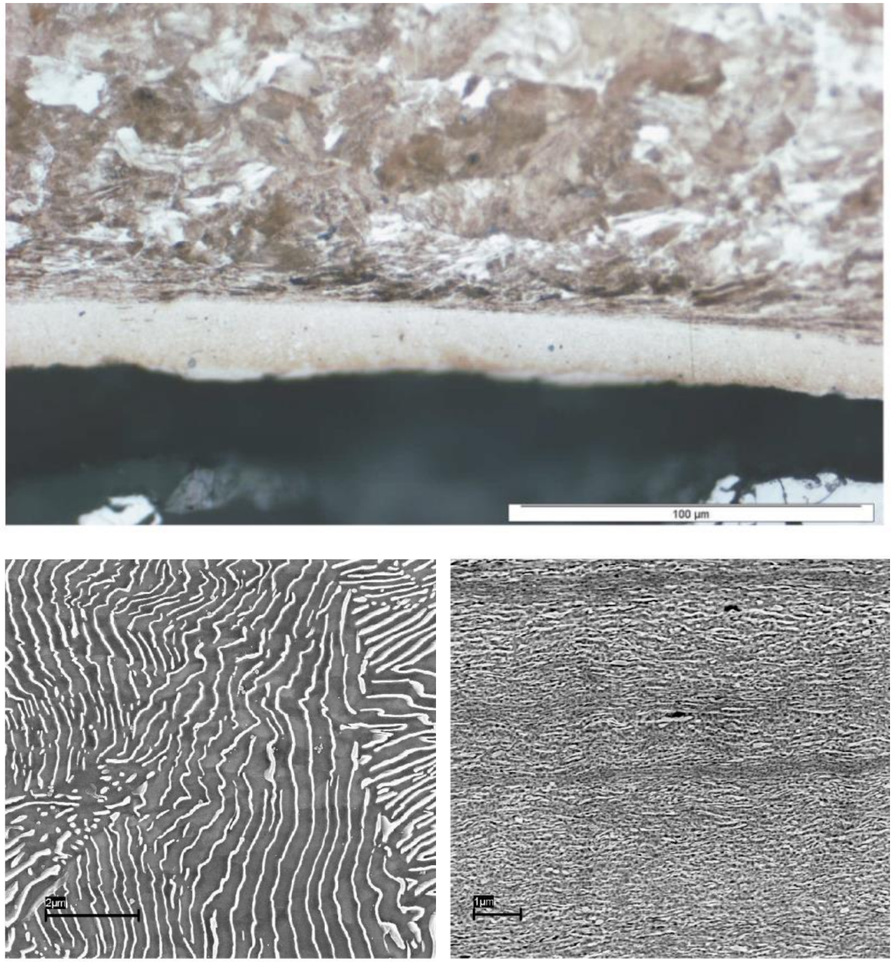
WHITE ETCHING LAYERS

- Area that is not etched by 3% Nital Acid will appear white in light microscope
- Hard and brittle layers



Martensitic Structure

Amorphous Structure



Photos: Florian Wetscher, Effect of Large Shear Deformation on Rail Steels and Pure Metals, Doctoral Thesis, 2006, University of Leoben

WEL AND SQUATS

- Origin → vehicle traction (accelerating and braking)
- Origin → rail grinding activities

- WEL are widely found in track – initiation point for Squats?

Multiple open questions:

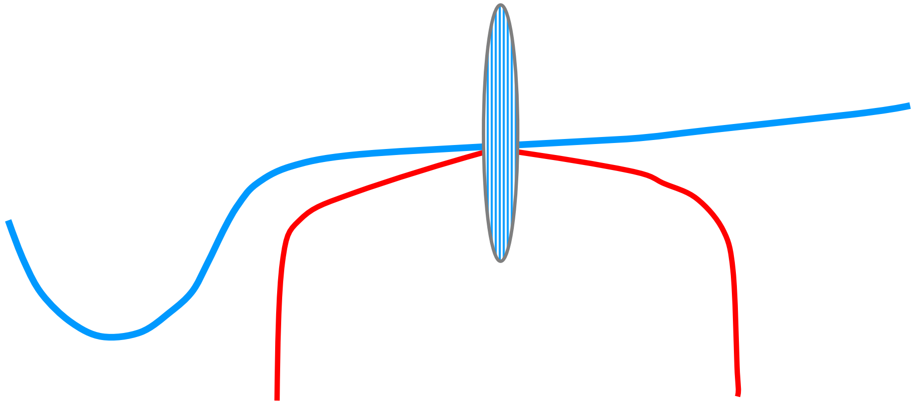
- Only a certain % of WEL contribute to Squats
- What is the characteristic of a Squat-WEL (thickness, structure, interface to base material, wear behaviour,…)?

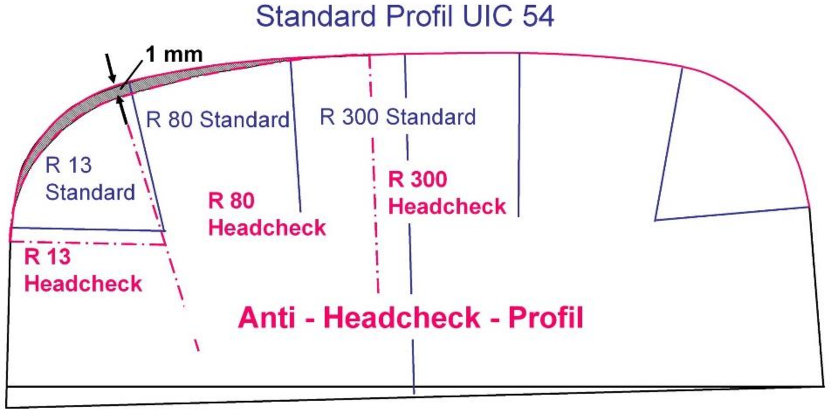
Other influencing factors: Squat Staircase Concept

CONTACT CONDITIONS

- Narrow contact patch – high stress conditions
  - Favor formation of Squats
  - Wear resistant grades keep unfavorable contact condition over longer time period
- Implementation of Anti-Head Check profiles
  - Gauge corner relieve by undercutting
  - Shifting contact to concentrated area on TOR
  - AHC might/will favor Squats

- <u>Low wear conditions and unfavorable profile combinations will favor Squats</u>

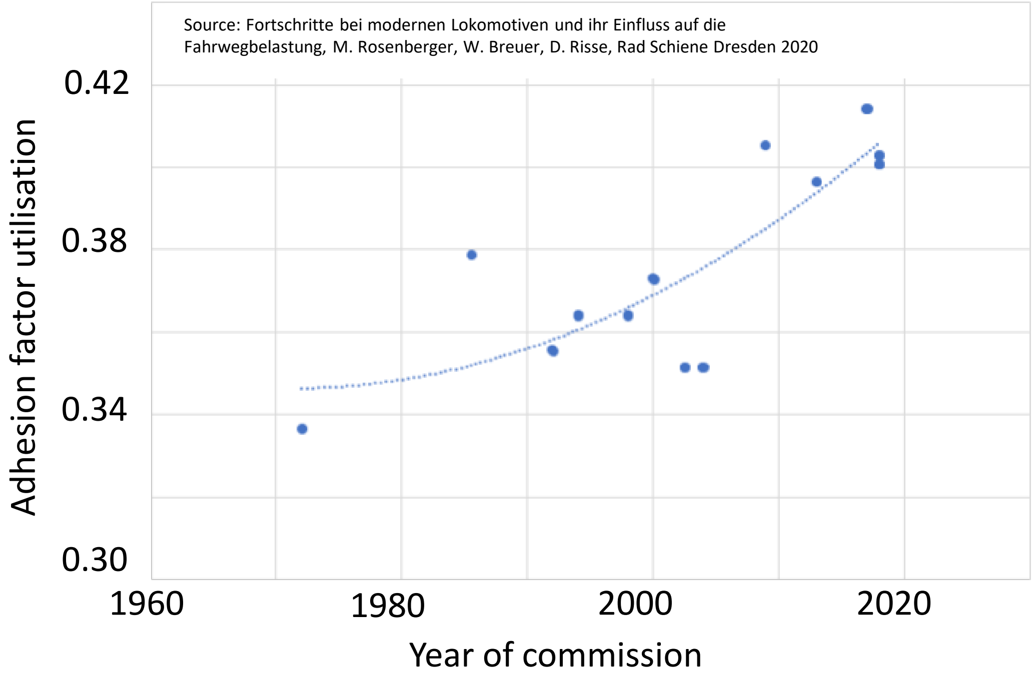




R. Stock, W. Schöch: Keeping Rolling Contact Fatigue under Control - Steel Grade Selection & Appropriate Rail Maintenance. WRI 2011 Conference, Chicago

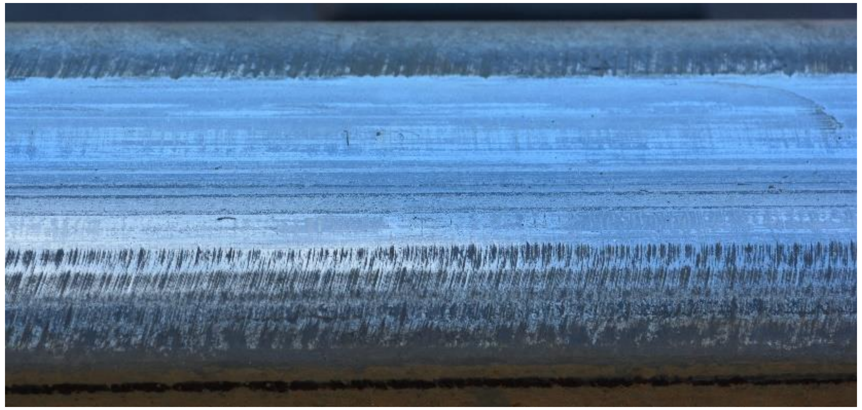
TRACTION CONDITIONS - I

- Squats at sites with high tractive forces
  - Signals, train stations and open track -> WEL
- Since 1990s change from DC to AC traction
  - AC traction allows controlled operations with high traction forces at higher slips
  - Higher adhesion utilisation
- Continuously increasing traction power



TRACTION CONDITIONS - II

- Traction control systems (TCS) / wheel slip prevention systems (WSP)
  - Aggressiveness of TCS will impact damage formation
  - Adhesion recovery strategies
  - Drive oscillations
  - Regular traction marks on the rail surface (WEL)
- Distributed power for EMU/DMU



Photos by Ingolf Nerlich / SBB
Presented at WRI EU 2019 in Vienna

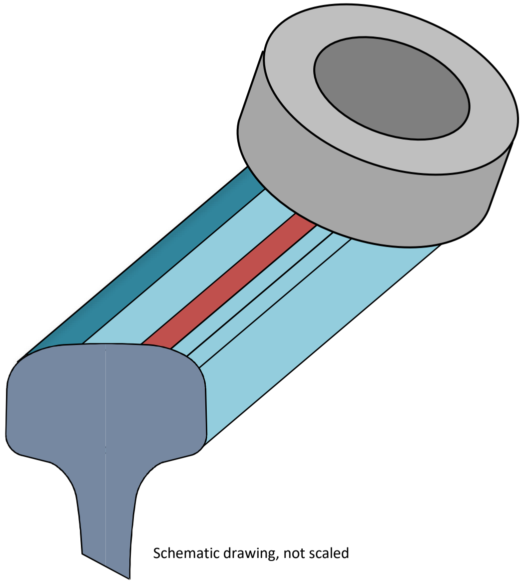
SYSTEM STIFFNESS

- Empirical evidence was found that “stiff” rail-wheel systems will favor Squat formation
  - Stiff suspension systems of vehicles
  - Stiff track constructions (stiff rail pads, concrete sleepers, slab track)
- Increased dynamic forces
  - Possible interaction with traction systems to favor wheel slip events
- Increased rotational boogie stiffness during curving
  - Passenger trains need to run stable at high speeds
  - Increased lateral forces and lateral creep
- Quantification difficult

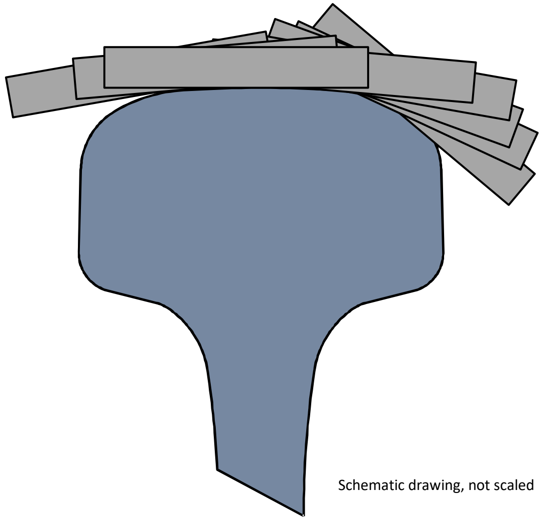
MAINTENANCE TECHNOLOGIES: GRINDING

- Abrasive process with rotating grinding stones
- Flexible profile adjustment through stone alignment
- Variable machine size (4-120 stones)
- Process speed up to 15 km/h
- Capable of treating mainline track and switches (dedicated machines)

Photo by Glucke, Wikipedia, CC BY-SA 3.0



Schematic drawing, not scaled



Schematic drawing, not scaled

RAIL GRINDING AND SQUATS

- Despite preventive maintenance strategies squat defects still persistent
- Removal of cap and extended spalling
- Repeatedly high temperature input above 723°C
- Formation of WEL layers
- Creating of characteristic surface roughness and morphology

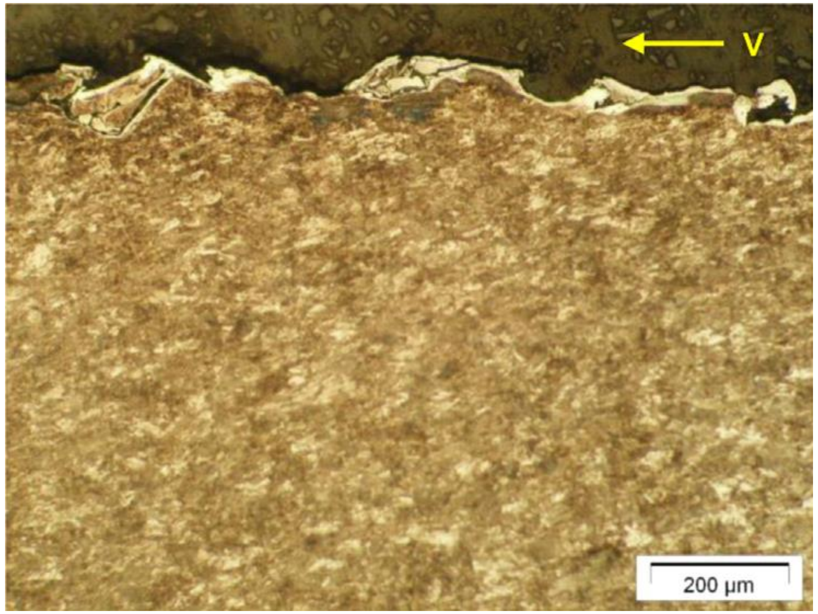
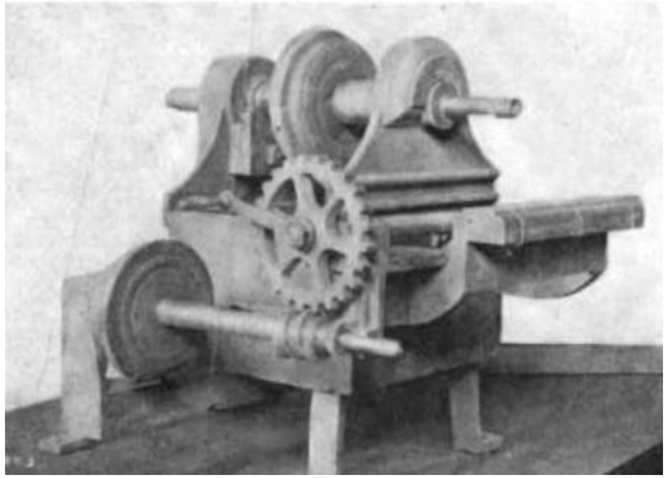


Photo: M. Steenbergen. Rolling contact fatigue in relation to rail grinding, Wear 356-357 (2016) 110-121

Surface condition after grinding

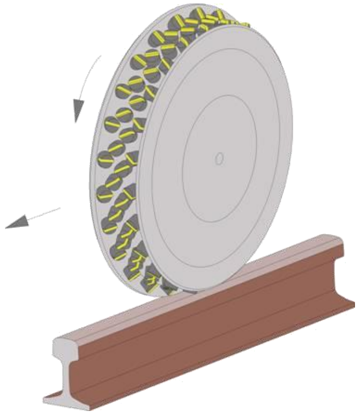
MAINTENANCE TECHNOLOGIES: MILLING

- Milling of work pieces since 19th century
- Non - abrasive rotary cutting process
  - Chips cut out of surface
  - High quality surface finish
  - High precision geometry
- High precision CNC machine upside-down on a locomotive
- Mainline and switch treatment with same machine



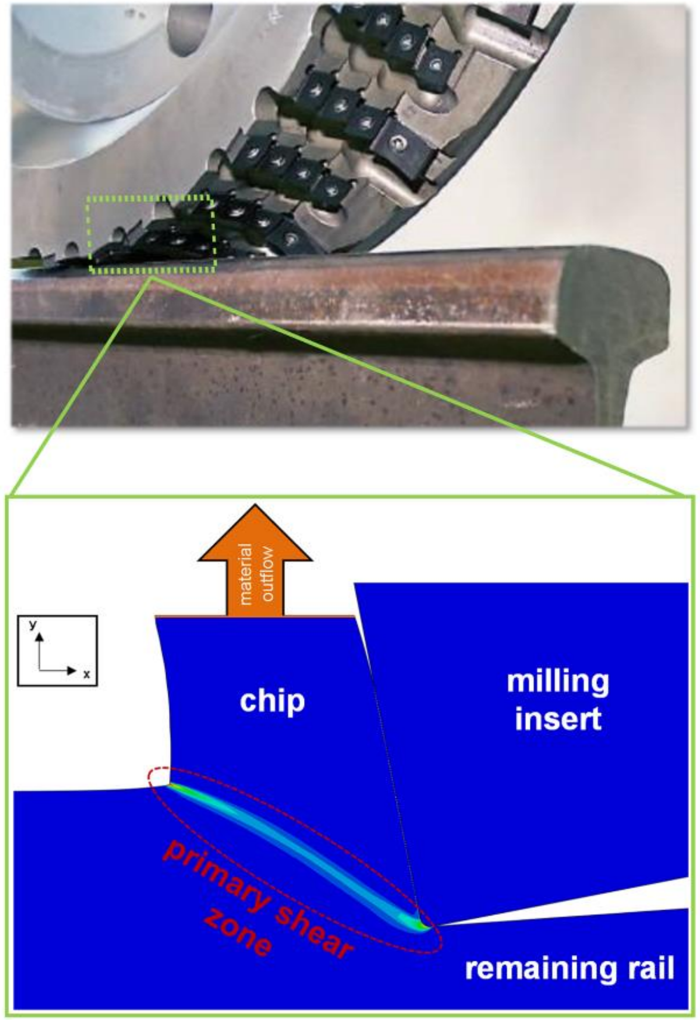
Milling Machine, 1818, wikipedia

Rail Milling Machine SF02, 2016, LINMAG



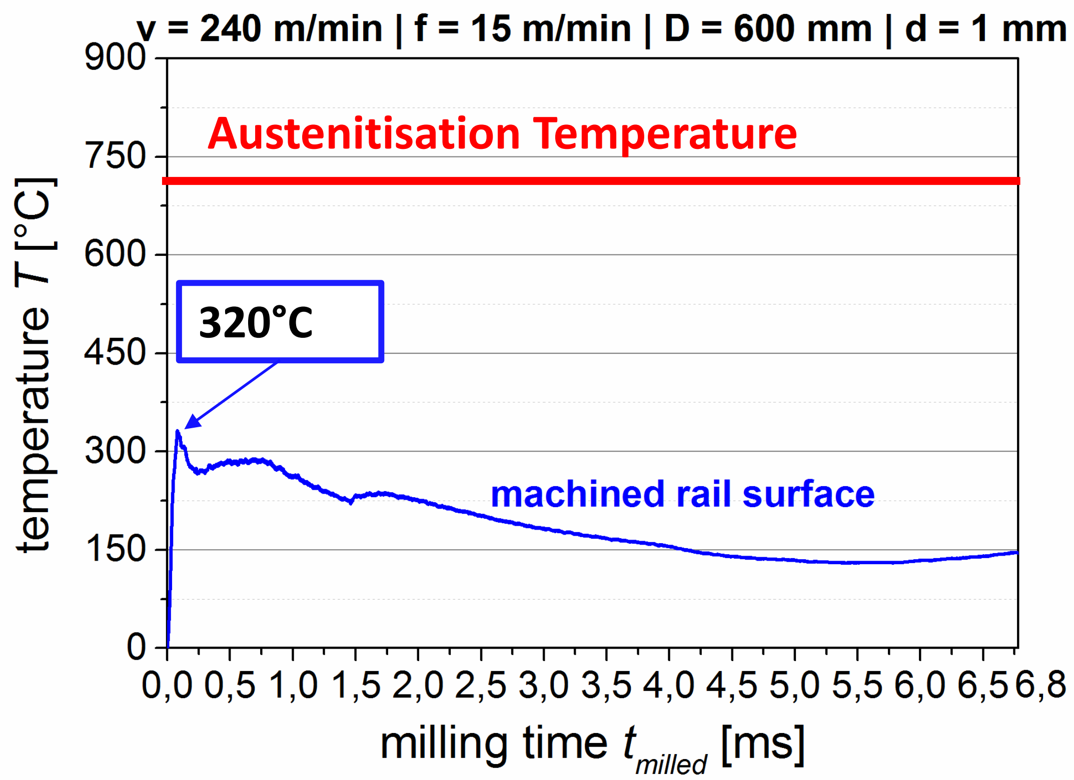
MILLING RESEARCH COLLABORATION

- Collaboration with Materials Center Leoben and University of Leoben in Austria
- Simulation of Milling Process
  - 3D and 2D simulation model developed
  - Simulation of complete process
- Simulation of material removal and chip development
- Detailed analysis of temperature development during milling process



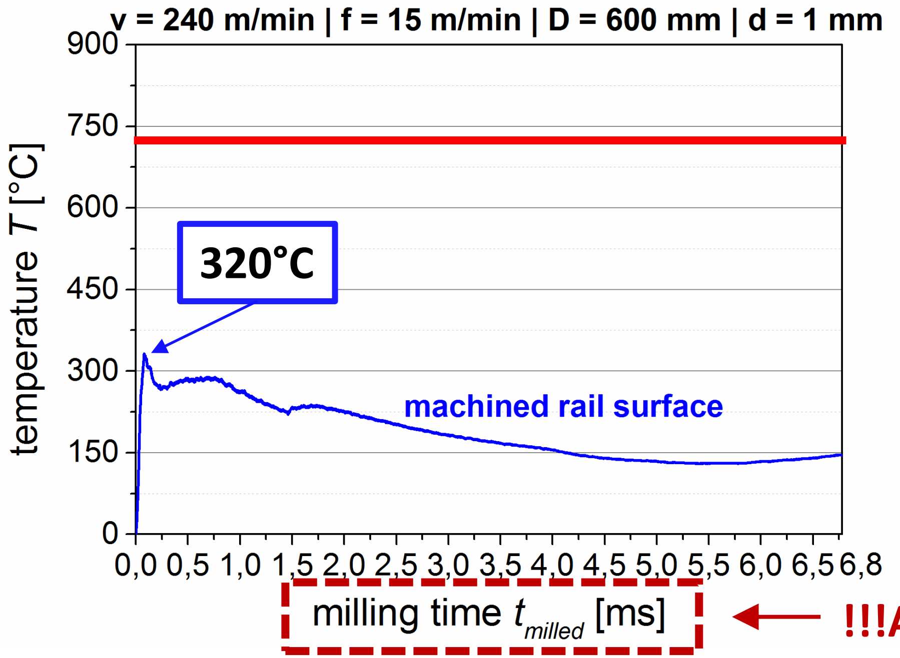
SIMULATION OF RAIL MILLING

- Simulation of the milling process (2D)
- Process heat flows into milling insert and chip
- Rail temperature stays well below austenitizing temperature during and after milling
  - Temperature threshold for material transformations



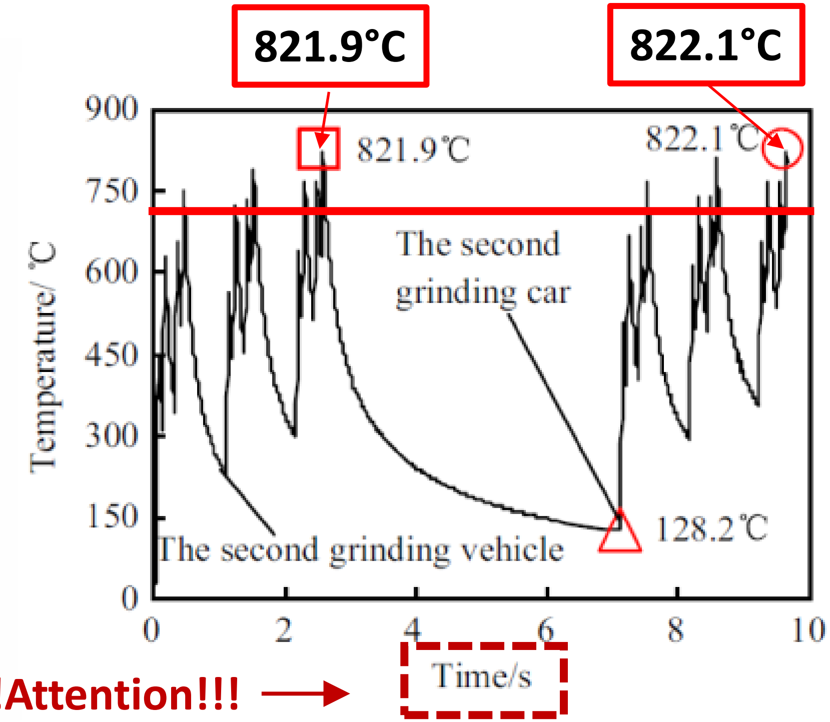
PROCESS COMPARISON (SIMULATION)

milling



!!!Attention!!!

grinding



Z.Y. Zhang et. al., Thermal model and temperature field in rail grinding process based on a moving heat source, Applied Thermal Engineering 106 (2016) 855-864.

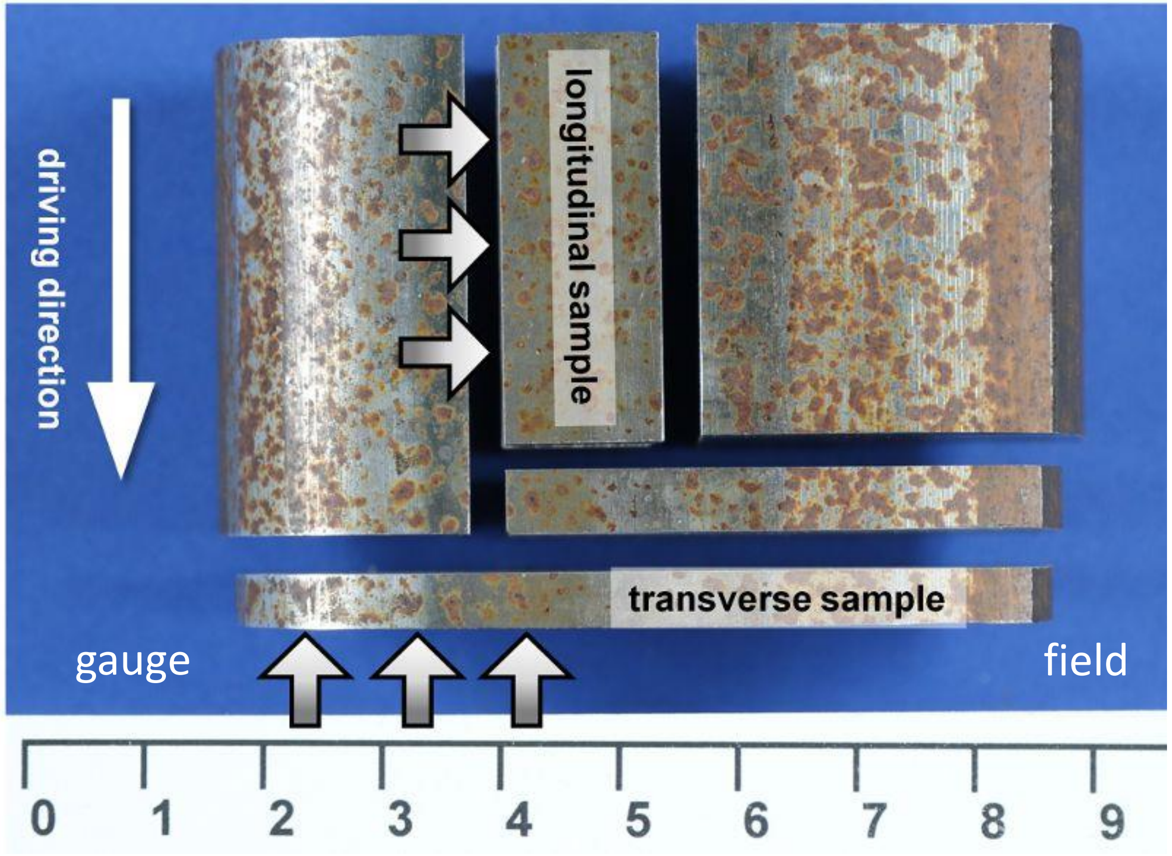
- Heat of the grinding process:
  - T > 723°C – austenite transformation
  - Significantly higher heat input over longer time for grinding
  - Grinding will lead to the formation of WEL

MILLING TESTS

- Milling tests at the factory of LINSINGER and at a European IM
- EC tests before and after milling to characterise damage condition
- Metallographic analysis of rail samples:
  - Right after milling
  - A specific time / MGT traffic after milling

SAMPLE POSITIONS

- Metallographic sectioning:
  - Longitudinal direction
  - Transversal direction
- Arrows indicate viewing direction



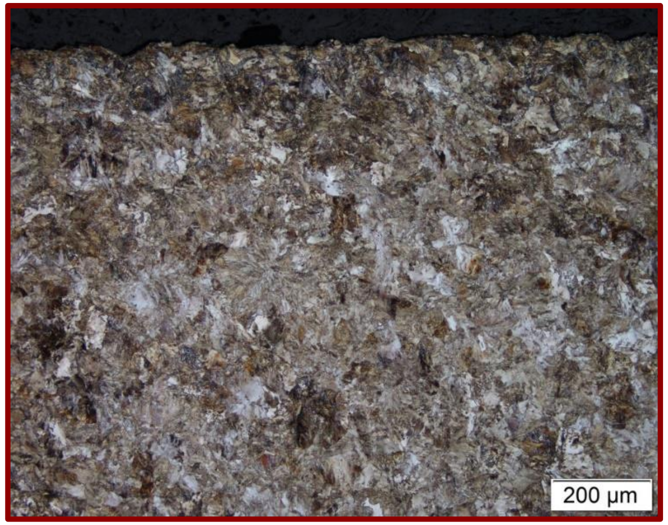
Scale: cm

FACTORY TRACK - MILLED

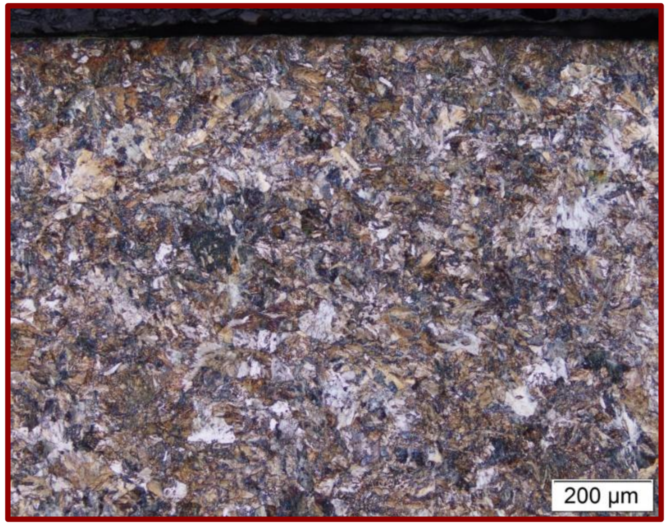
- Original conditions:
  - Rail grade R260
  - EC indicated 0.5mm max. crack before milling
  - 1 milling pass with 0.9mm metal removal
  - EC indicated no remaining damage after milling
- Rail sample removed from track directly after milling
- Micrographs revealed
  - Damage completely removed
  - No evidence of thermal material transformation
  - Smooth rail surface (no grinding marks)

condition 1

transverse



longitudinal

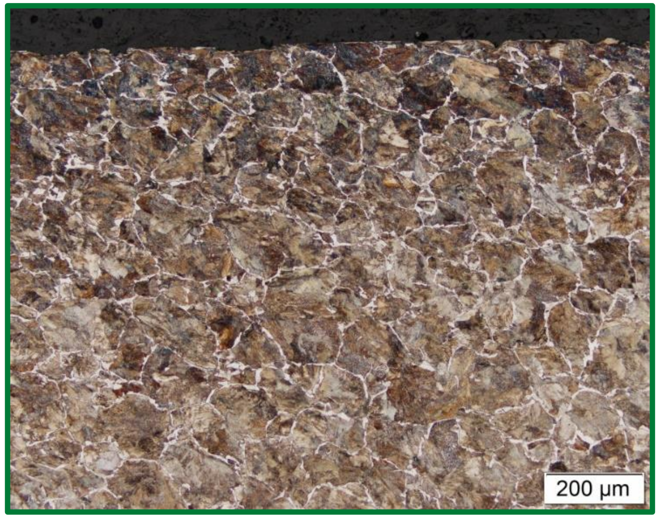


RAIL FROM TRACK - MILLED

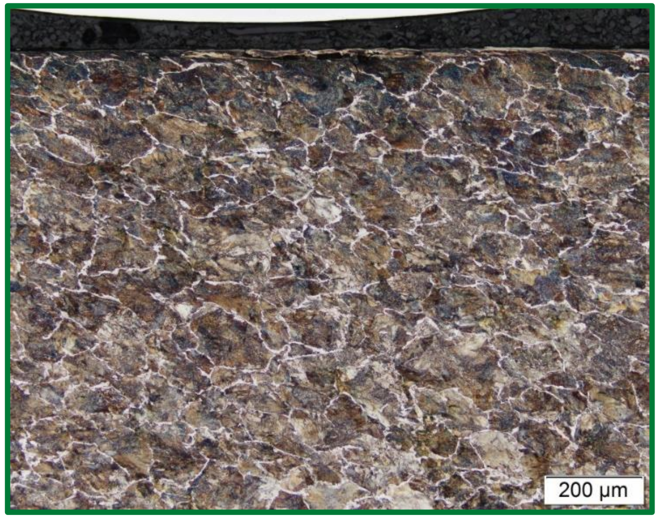
- Original conditions:
  - Rail grade R220
  - EC indicated 1.5mm crack depth
  - 2mm metal removal
  - Test area free of cracks after milling
- 11 days of traffic after milling – 0.12 MGT
- Micrographs revealed
  - Damage completely removed
  - No evidence of thermal material transformations
  - Smooth rail surface

condition 2

transverse



longitudinal

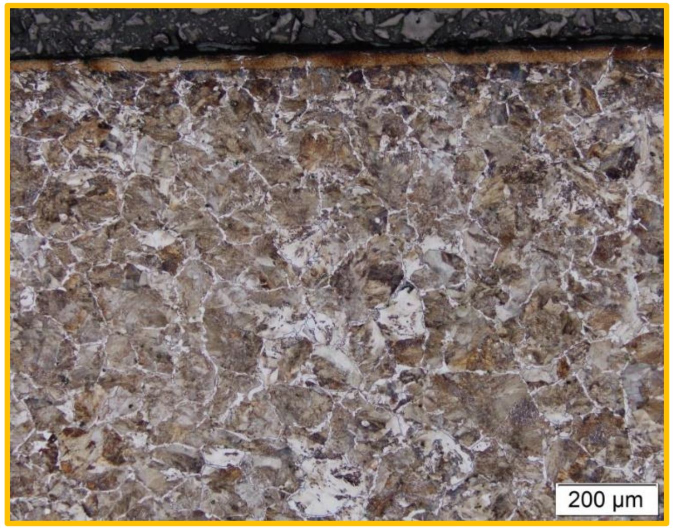


RAIL SURFACE AFTER 7 MONTHS

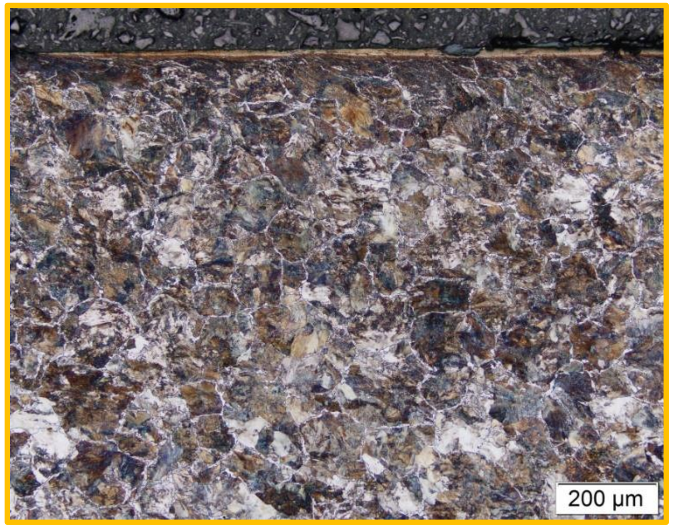
- Same location as sample before (condition 2) with same history
- 7 months of light traffic – 2.3 MGT
- Micrographs revealed
  - No cracks
  - Smooth rail surface
- WELs visible
  - Caused by train operations (traction)
  - Thickness around 30µm

condition 3

transverse



longitudinal



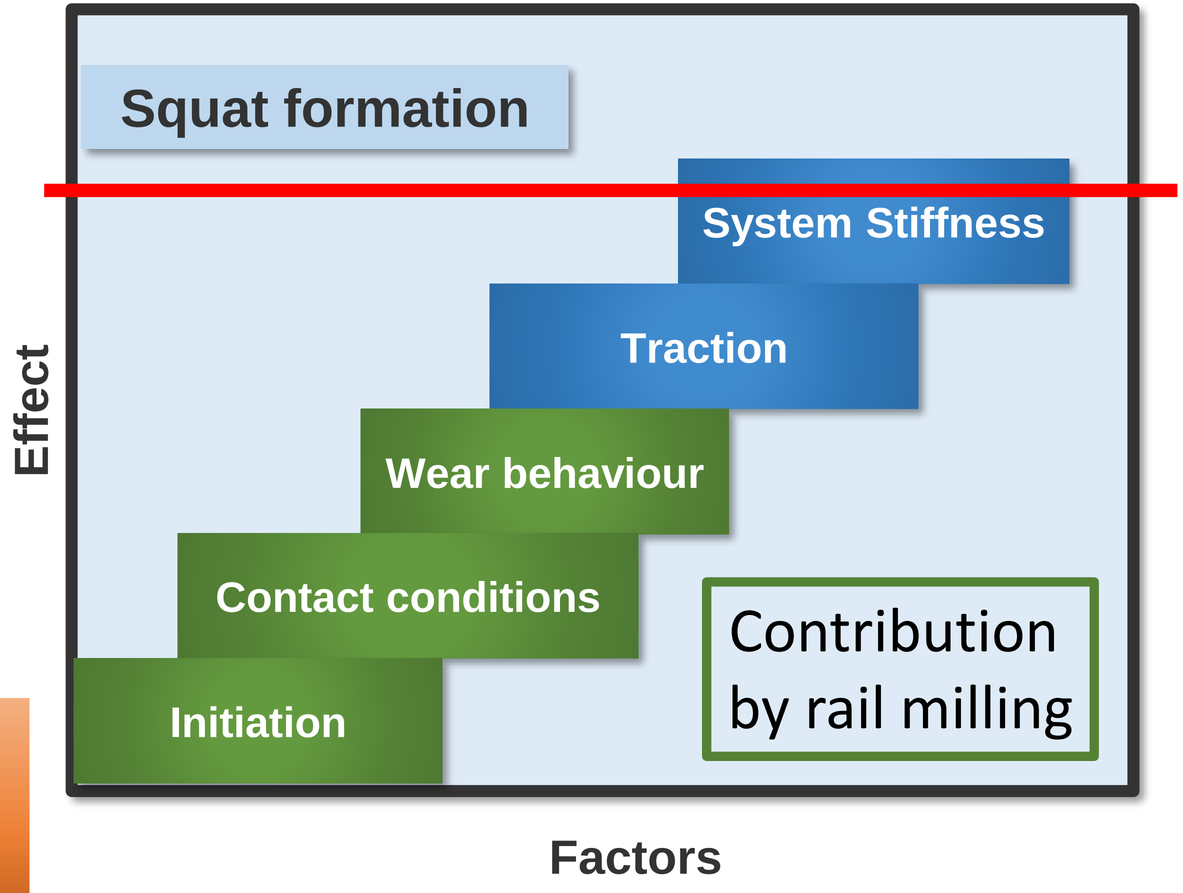
APPLICATION EXAMPLE – SQUAT REMOVAL

- DB specification: Milling for defects deep > 0.8mm
- Severe Squat defects
  - Measured depths up to 7mm
- High performance milling machine MG 31
- Regenerative Maintenance:
  - Complete damage removal
  - Max. 2 passes

SUMMARY: CONTRIBUTION

- Contribution of rail milling to Squat mitigation:
  - Complete damage removal
  - Precise profile adjustment
  - Gentle surface treatment – no (new) initiation points
- Indicated by simulation results and track tests

Squat solution only possible on a system-level!



THANK YOU FOR YOUR ATTENTION

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Questions?