PRINCIPLES COURSE - JUNE 10, 2025

WHEEL/RAIL DAMAGE MECHANISMS

RICHARD STOCK

GLOBAL HEAD OF RAIL SOLUTIONS

PLASSER AMERICAN / PLASSER & THEURER

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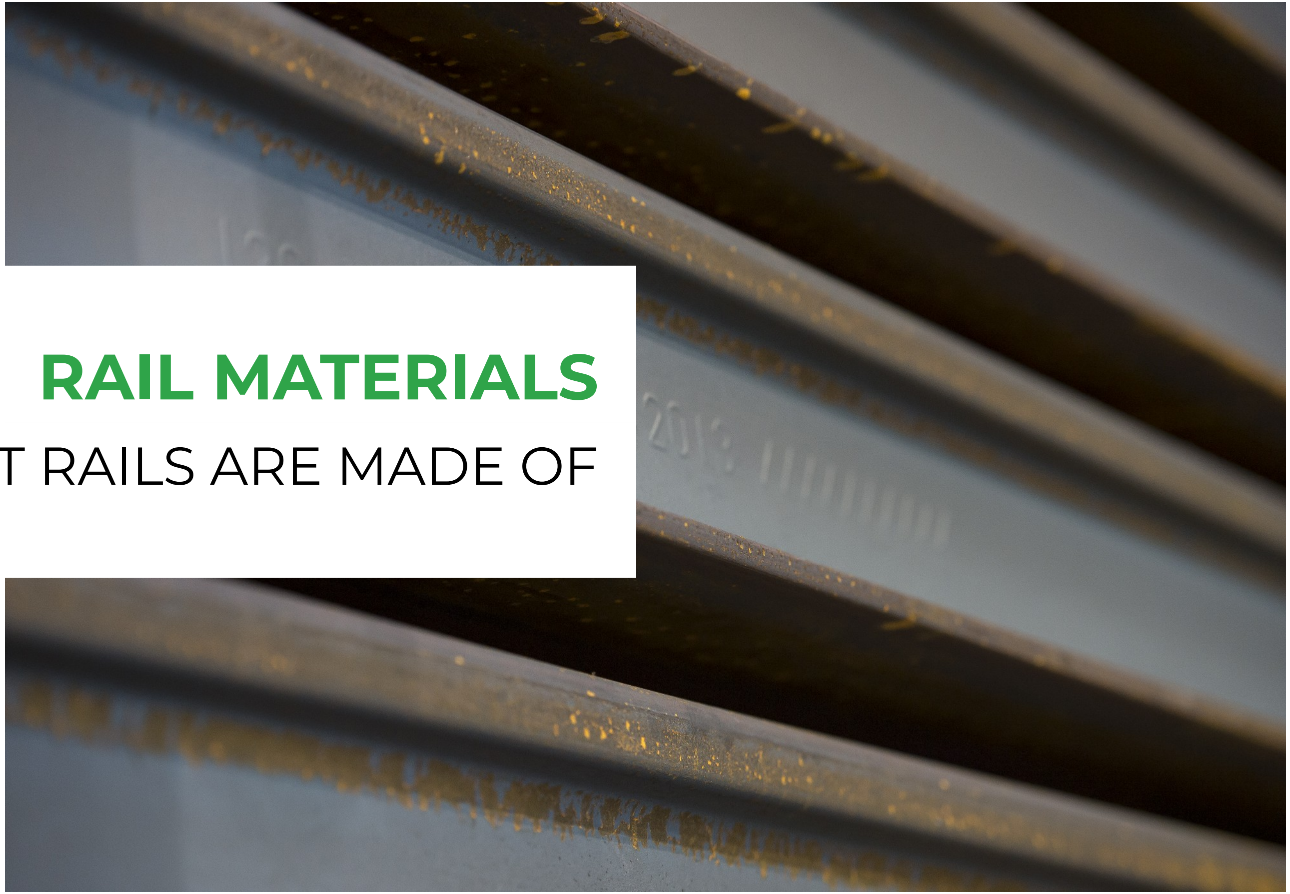
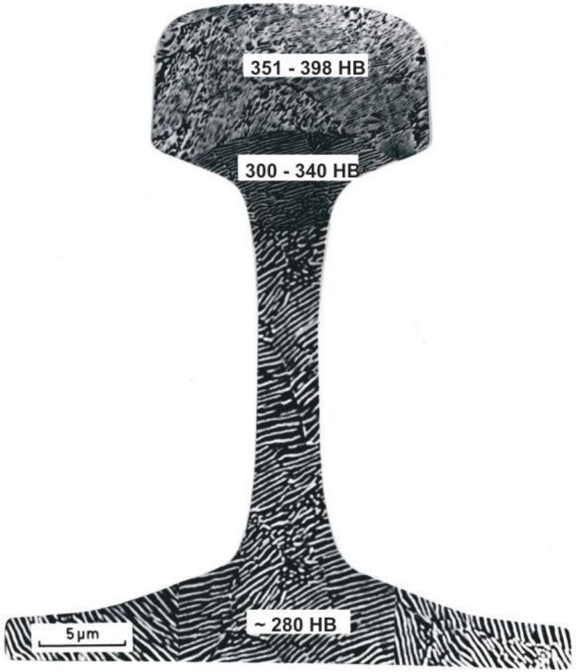


RAIL MATERIALS

WHAT RAILS ARE MADE OF

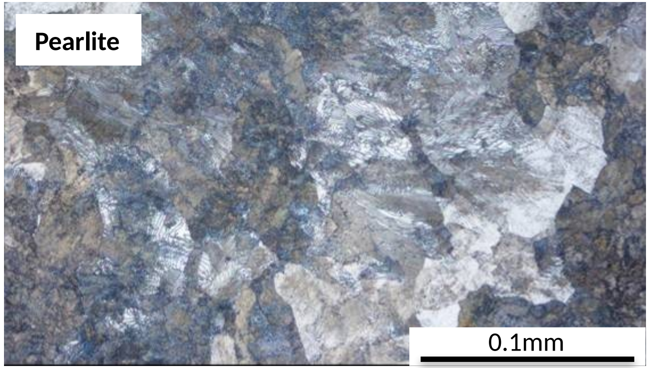
THE STEEL RAIL

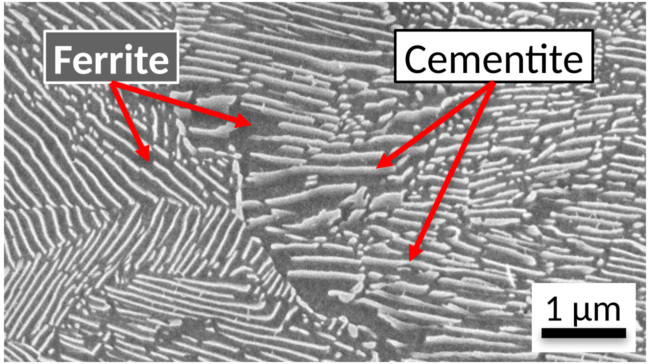
- Hardness: 200-450 BHN
- Sufficient Toughness and Strength
- Ductile material behaviour
- Sufficient electric conductivity
- Reasonable weldability
- Excellent machineability
- Reasonable price



PEARLITIC MICROSTRUCTURE

- Two phase material:
  - Ferrite: very soft, C_{max} = 0.02%
  - Cementite: Fe_3C, very hard, C = 6,67%
- Lamellar or layer structure
- Pure pearlitic structure at 0.77% C (Eutectoid point)
  - C > 0.77%: Hypereutectoid Steel
- Lamella spacing defines hardness and strength without influencing the toughness

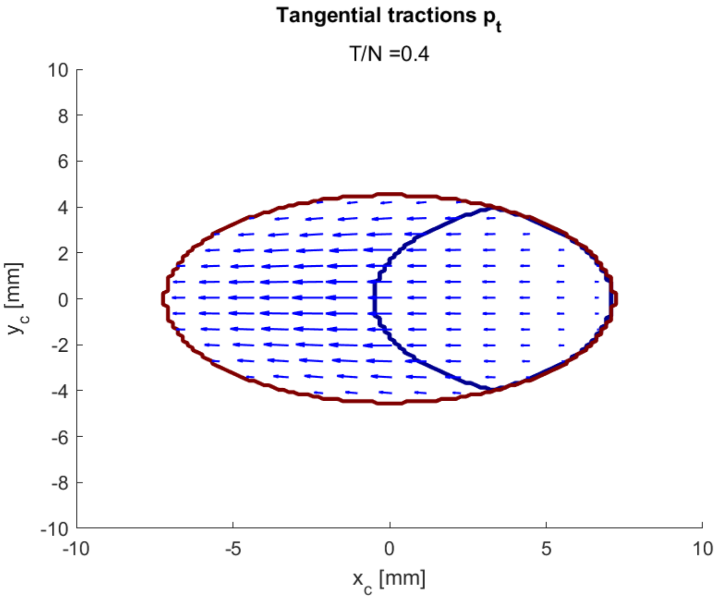


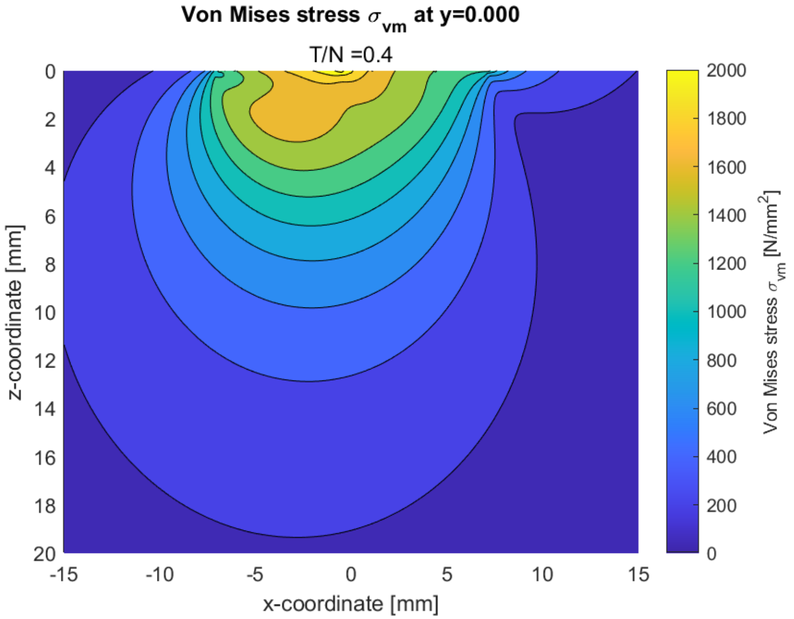


WHEEL / RAIL DAMAGE MECHANISMS

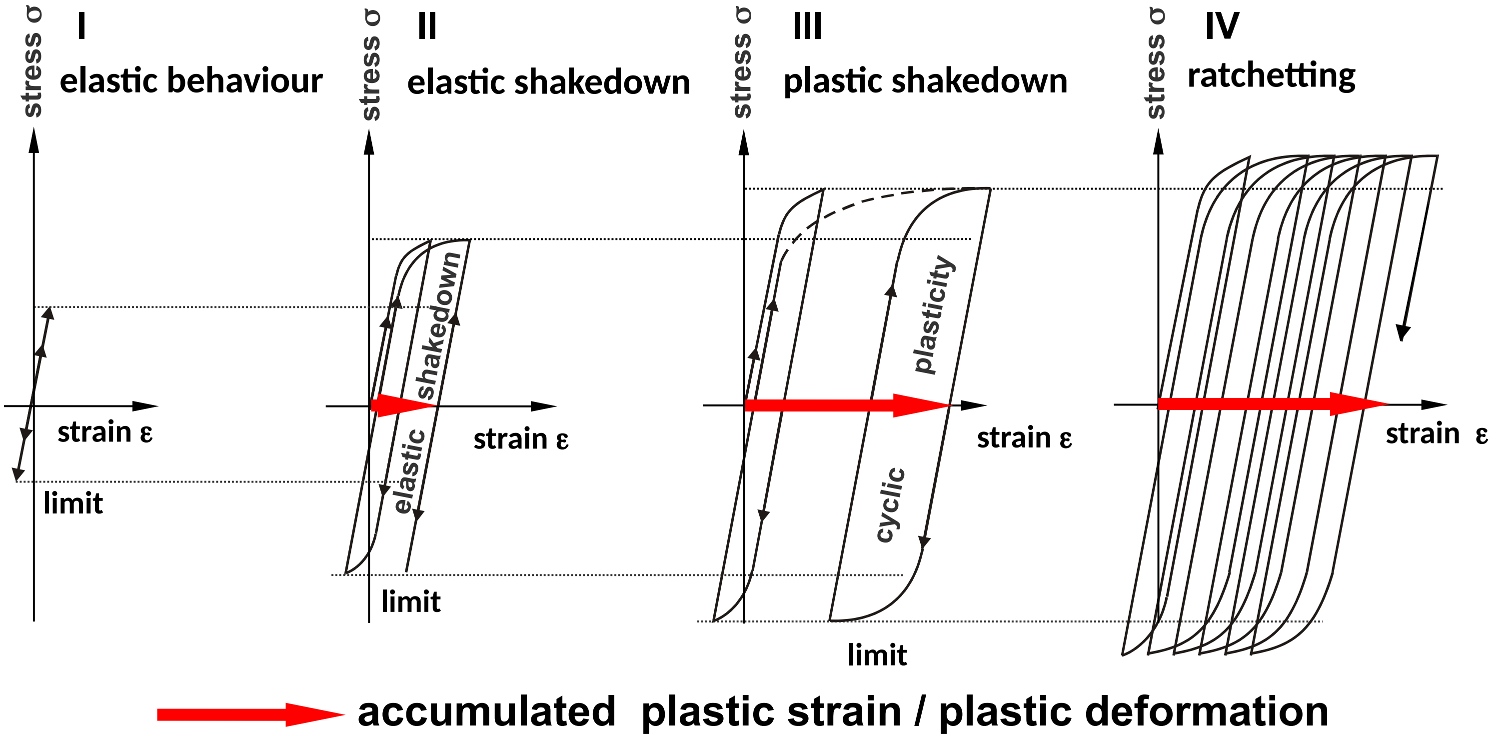
MATERIAL REACTION TO LOADING

INTERACTIONS BETWEEN CREEPAGE AND SUBSURFACE STRESSES





MATERIAL BEHAVIOUR UNDER LOAD



PLASTIC DEFORMATION

- Contact loads always above elastic material limit.
  - On a microscopic scale close to the rail surface
  - Incremental accumulation of plastic deformation - ratchetting
- Plastic flow enclosed by bulk elastic material
  - No “global” plastic flow

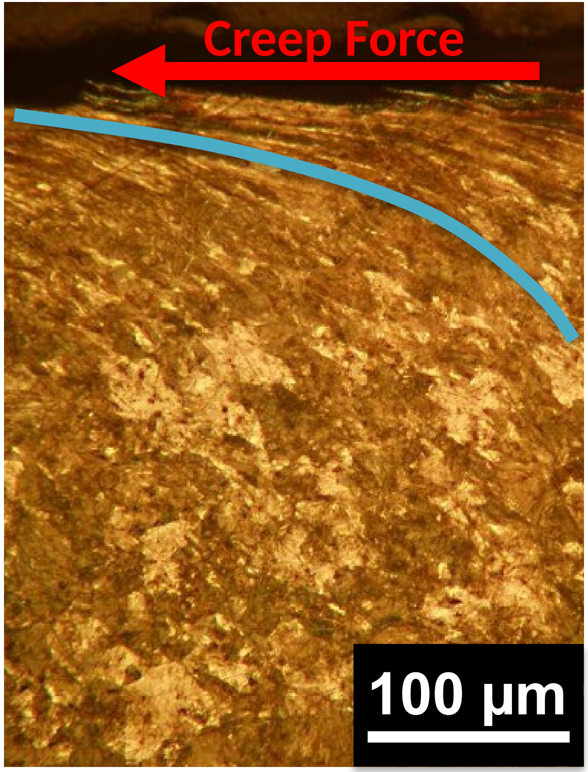
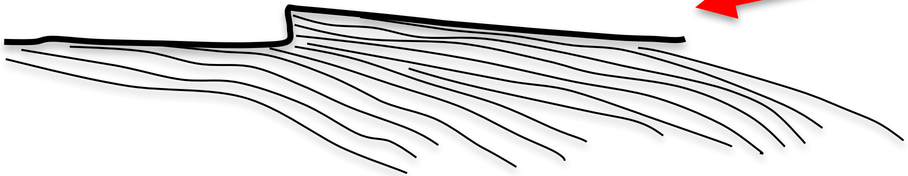


Photo: voestalpine

MATERIAL RESPONSE: DEFORMATION

Severely deformed and aligned material structure at the rail surface



Non-deformed material structure

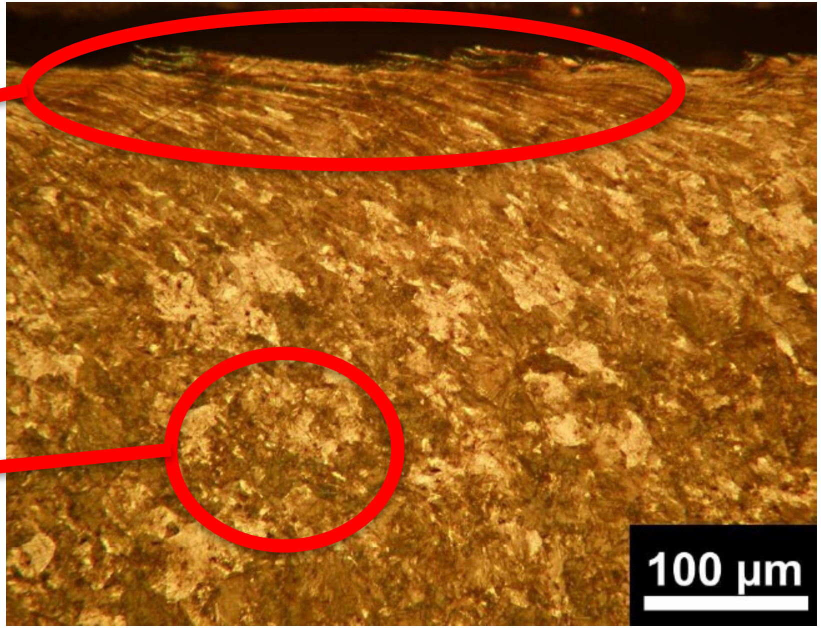


Photo: voestalpine

PLASTIC DEFORMATION

- On a macroscopic scale – change of profile shape.
- Material flow – e.g. lipping

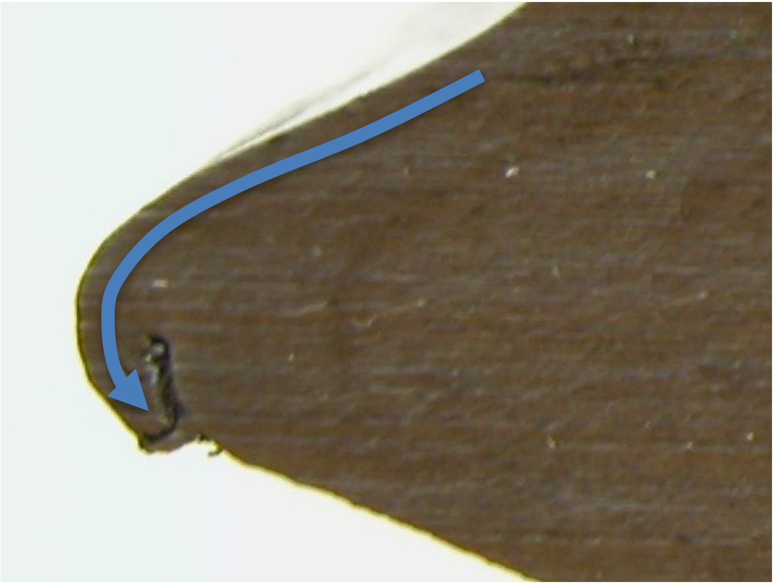


Photo: voestalpine

WEAR OF RAILS

- Continuous material removal from the rail surface due to interaction of wheel and rail.
- Several modes of wear
  - Adhesive wear
  - Abrasive wear
  - Fatigue wear
  - Corrosive wear
- Several types of wear
  - Natural Wear
  - Artificial Wear

  } Combined Wear
- Profile Degradation

Photo by L.B. Foster

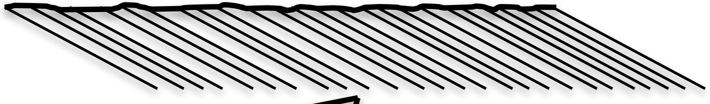
MATERIAL RESPONSE: WEAR

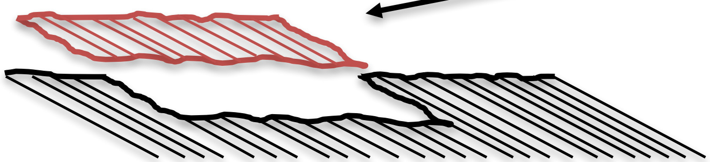
Schematic drawings

Non-deformed, initial material condition

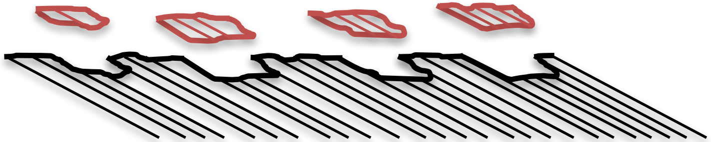
⇩ Loading conditions, material properties

Severely deformed rail surface





Severe wear



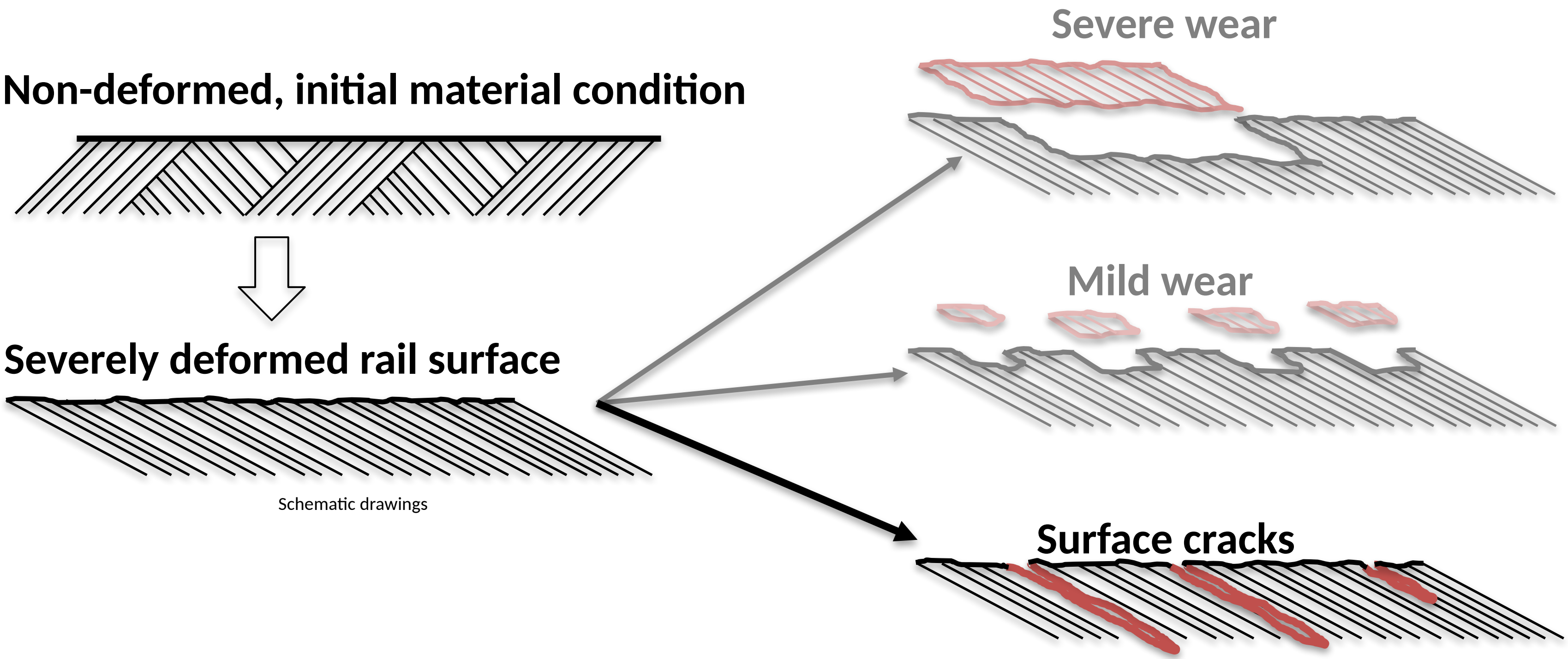
Mild wear

CORRUGATION

- Combination of wear and plastic flow
- Wave structure on the rail surface (tangent / curve)
- Short wave (25mm-80mm wavelength) or long wave (100-300mm) corrugation
- Multiple sub-classifications

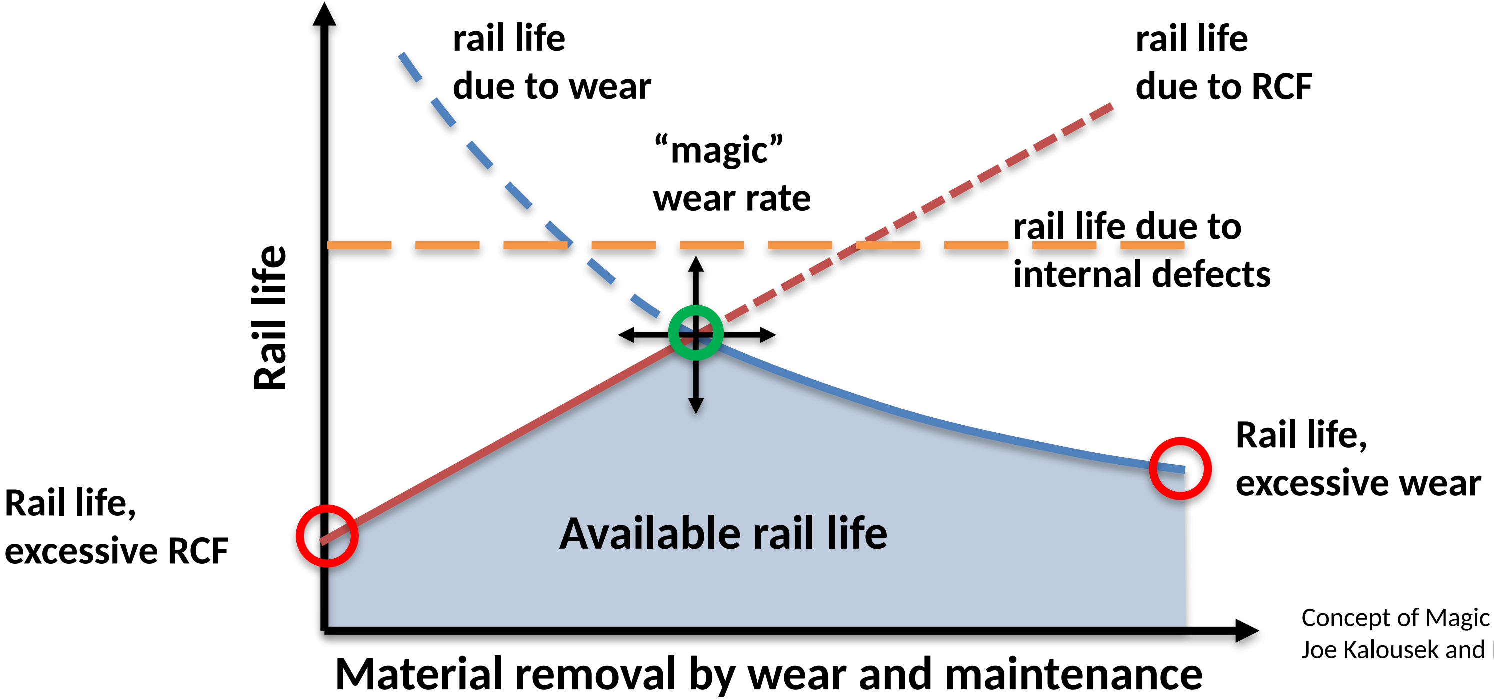
Photos by L.B. Foster

MATERIAL RESPONSE: CRACKS



Schematic drawings

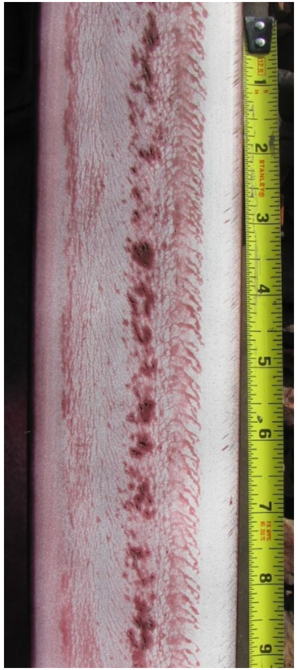
MAGIC WEAR RATE



Concept of Magic Wear Rate by
Joe Kalousek and Eric Magel, 1997

HEAD CHECKS / PERIODIC CRACKS

- Head Checks: periodic cracks at the gauge corner (gauge corner cracking)
- Heavy Haul: periodic cracks and crack networks also on the running surface
- Can cause detail fracture if not treated



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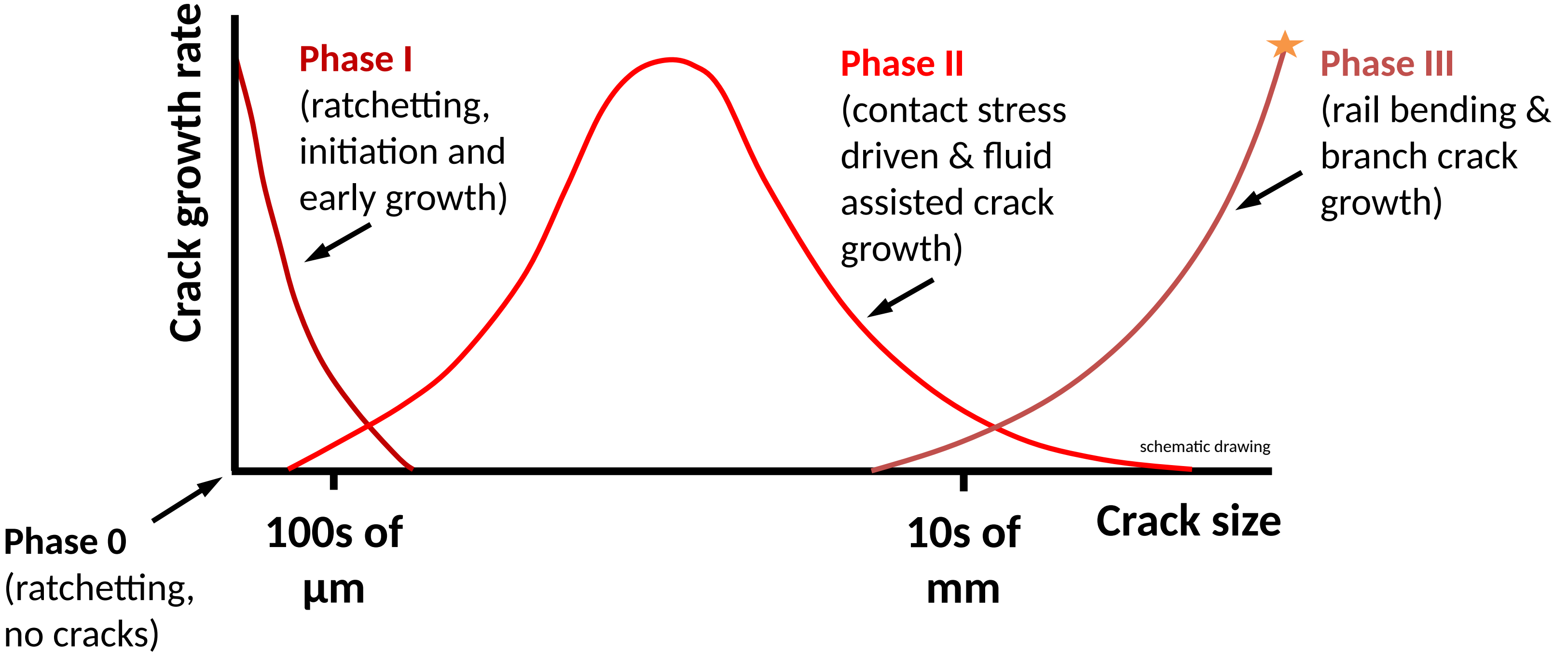
CRACK GROWTH PHASES



FLAKING AND SPALLING

- Head Checks can combine causing material to break out of the rail surface.
- Head Checks – Flaking – Spalling

SHELLING

- Originates underneath the rail surface
- Delamination of rail material – crack will surface at gauge corner and cause break-outs
- High loading conditions favor formation – overstressing of subsurface area

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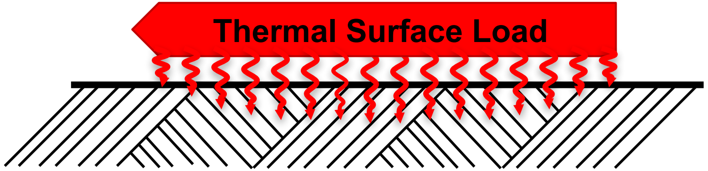
SQUATS

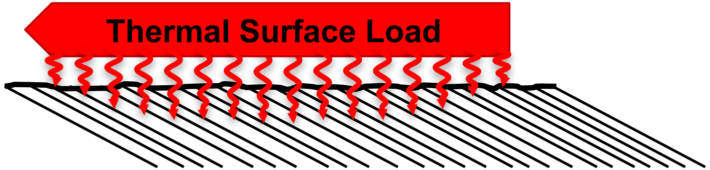
- Widening of running band / dip
- Typical kidney shaped
- Surface and subsurface crack(s)
- Singular or massed occurrence
- Characteristics
  - Heavily sheared rail surface
  - Crack initiation and growth by ratcheting (RCF)
  - slow growth (within 100 MGT)
  - Can result in rail break

Photos by voestalpine

MATERIAL RESPONSE: THERMAL TRANSFORMATION



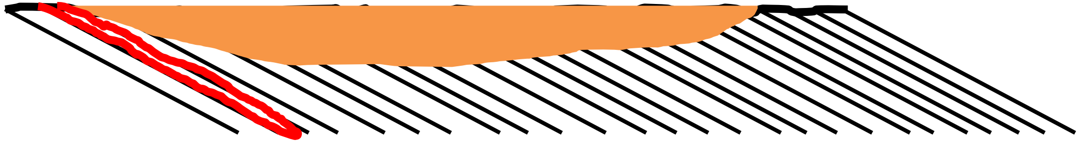
Undeformed or slightly deformed surface



Severely deformed rail surface

Quenching by rail mass (heatsink)

Material Transformation: White/Brown Etching Layer



Cracks might develop at interface and/or within layer

Schematic drawings

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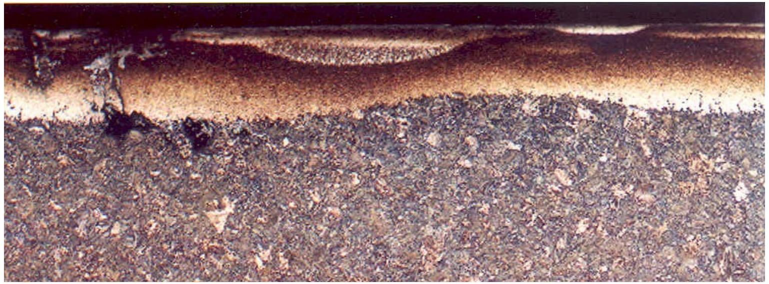
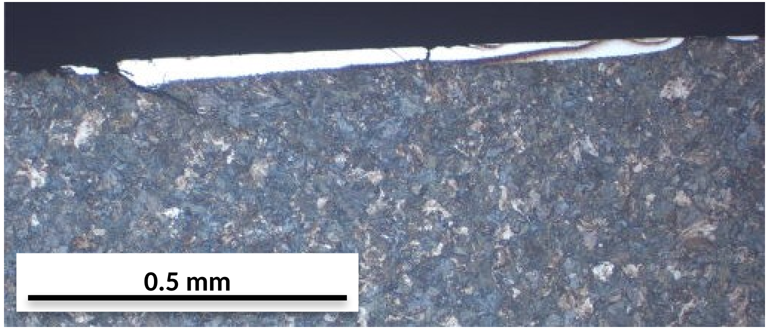
THERMAL TRANSFORMATION

- Thermal Transformation of rail surface
- Source: traction systems, rail maintenance
- Usually wears away
- White color in light microscope
  - Etching of surface to create contrast
  - 3% Nital Acid
  - Does not etch the Martensite / hard layers – appear white in LIMI





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SQUAT TYPE DEFECTS / STUDS

- Superficial similarity to Squats
- Mostly epidemic appearance
- Extended spalling of rail surface possible
- Characteristics:
  - Almost no plastic deformation
  - Associated with “white etching layers” (martensitic layers)
  - Formation within 10MGT or less

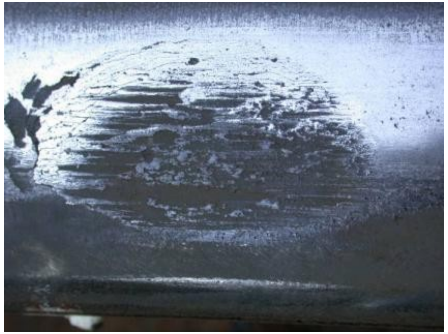
Photo: Rene Heyder, DB

STUDS – A COMPLEX PROBLEM

- Multiple contributing factors
  - Wear behaviour, R/W profiles, traction/friction conditions, system stiffness, rail maintenance activities
- Ongoing research and scientific debate

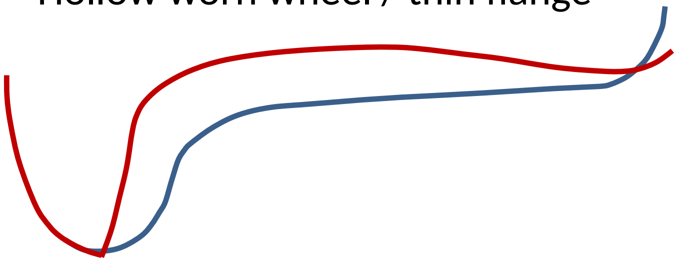
WHEEL BURN

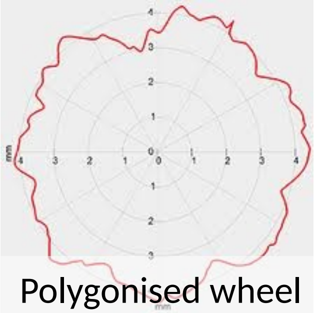
- Occurs in pairs (both rails)
- Continuous slipping of locomotive wheel set(s).
- High temperature input to rail surface.
- Wear, plastic deformation, material transformation, cracks, break outs



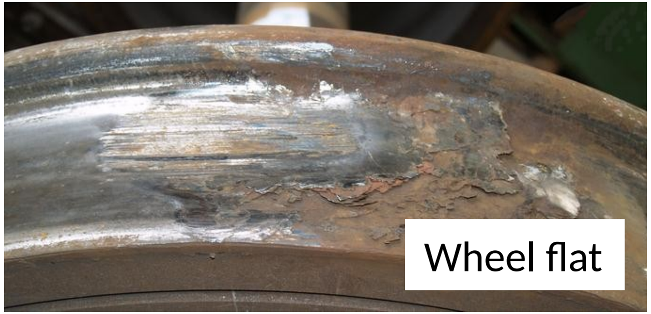
WHEEL DAMAGE EXAMPLES

Hollow worn wheel / thin flange

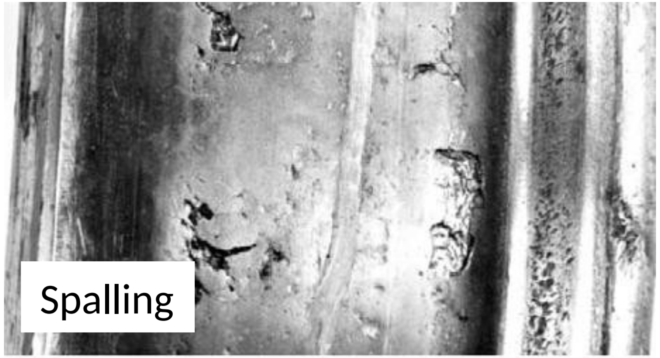




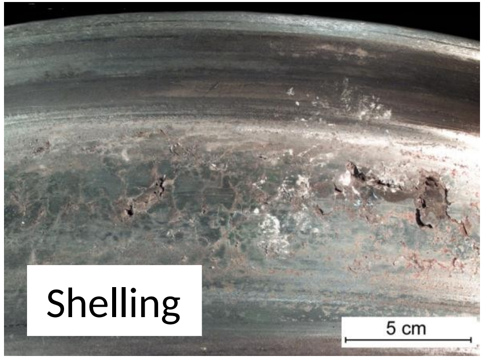
Polygonised wheel



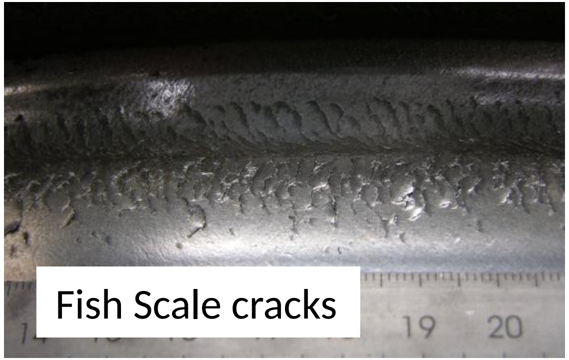
Wheel flat



Spalling



Shelling



Fish Scale cracks

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CONTROLLING RAIL DAMAGE

HOW TO MANAGE THE RAIL LIFE

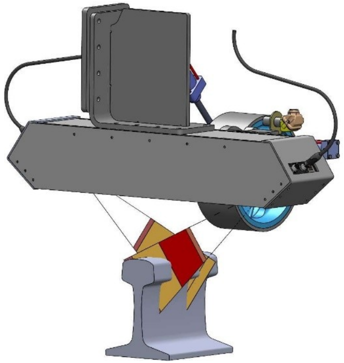
MITIGATING RAIL DAMAGE

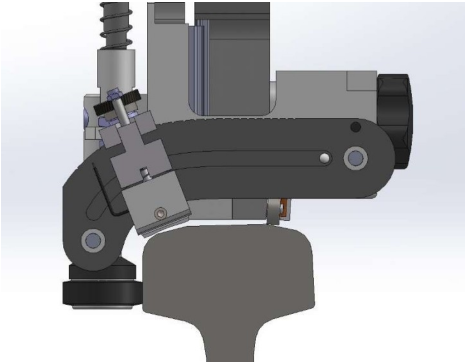
1. Measurement Technology
2. Material and Joining
3. Profiles
4. Track Quality
5. Friction Management
6. Rail Profiling / Rail Maintenance

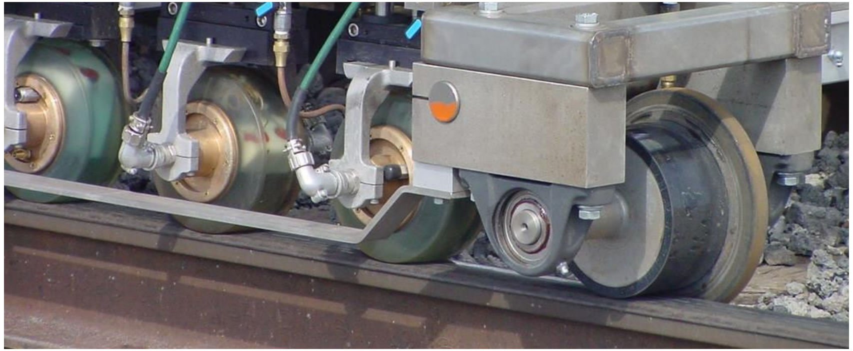
WITHOUT PROPER QUANTIFICATION THE BEST STRATEGY WILL FAIL

MEASUREMENT TECHNOLOGY

- Transversal Profile
- Longitudinal Profile
  - Waviness and singular defects
- Visual Track inspection
- Vision Technology
  - Surface features
- Electromagnetic Technology
  - Near surface damage
- Ultrasound Testing
  - Internal rail damage
- Integrated in maintenance machines or dedicated vehicles



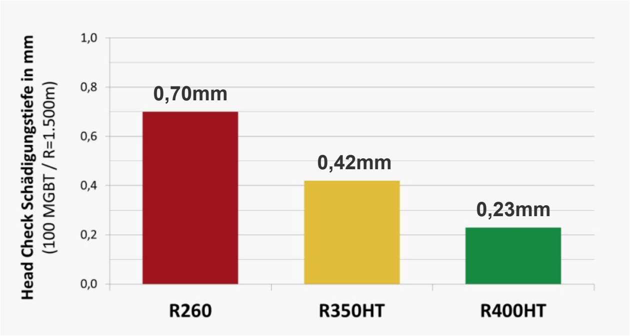




RAIL MATERIALS

- Rail Grade Selection
- Standard and heat treated (premium) grades
  - AREMA Chapter 4 Rail, EN 13674, Hyper-Eutectoid rail grades
- Optimised material structure for improved performance
- Higher resistance against wear and rolling contact fatigue (RCF)
- Extension of rail life

Source: voestalpine, WRI 2012 Conferenz



Source: voestalpine, SFT 2017

STEEL GRADES

AREMA Chapter 4 Rail (2021)

EN 13674-1:2011

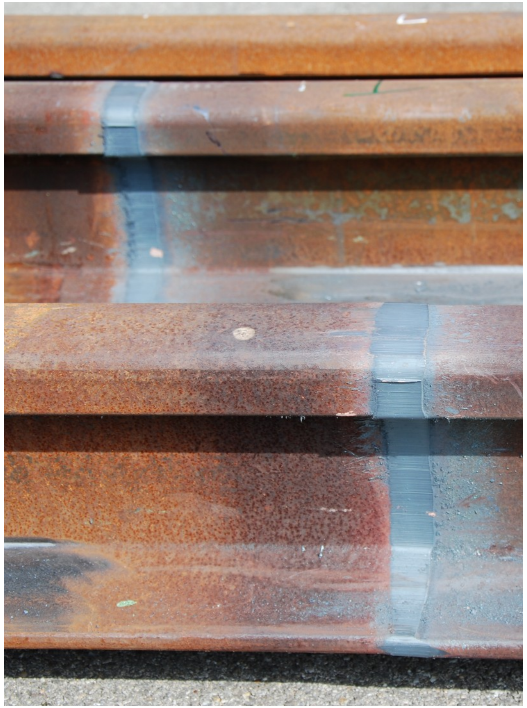
Steel grades according to EN 13674-1:2011 and AREMA Chapter 4 Rail (2021)

		Chemical composition (%)						Mechanical data		
	grade	**C**	**Si**	**Mn**	**P_{max}**	**S**	**Cr**	**R_m [Ksi] min**	**Ellong. [%] min**	**Hardness [HB]**
	R260	0.62-0.80	0.15-0.58	0.70-1,20	0.025	0.08-0.025	≤0.15	127	11	260-300
Carbon Standard Strength	**SS**	0.74-0.86	0.10-0.60	0.75-1.25	0.020	0.020	0.30	142.5	10	310
Low Alloy Standard Strength	**LA**	0.72-0.82	0.10-0.50	0.80-1.10	0.020	0.020	0.25-0.40	142.5	10	310
Carbon Intermediate Strength (HH)	**IS**	0.74-0.86	0.10-0.60	0.75-1.25	0.020	0.020	0.30	155	10	350
Low Alloy Intermediate Strength	**IH**	0.72-0.82	0.10-1.00	0.70-1.25	0.020	0.020	0.40-0.70	147	8	325
	R350HT	0.72-0.80	0.15-0.58	0.70-1.20	0.020	0.025	≤0.15	170	10	350-390
	R350LHT	0.72-0.80	0.15-0.58	0.70-1.20	0.020	0.025	≤0.30	170	10	350-390
High Strength (HH)	**HH**	0.74-0.86	0.10-0.60	0.75-1.25	0.020	0.020	0.30	171	10	370
Low Alloy High Strength (HH)	**LH**	0.72-0.82	0.10-1.00	0.70-1.25	0.020	0.020	0.40-0.70	171	10	370
	R370CrHT	0.70-0.82	0.40-1.00	0.70-1-10	0.020	0.020	0.40-0.60	185	10	370-410
	R400HT	0.90-1.05	0.20-0.40	1.20-1.30	0.020	0.020	≤0.30	185	10	400-440

Several Hypereutectoid grades and experimental Bainitic grades

RAIL WELDING TECHNOLOGY

- Every connection is a discontinuity
- Rail joint, isolated rail joint, welded rail connection
- Welding technologies:
  - Thermite welding
  - Flash butt welding
  - Gas pressure welding
- Goal: long lasting rail connection that has similar / same material properties as the rail material
  - Ideally: joint not “felt / seen” by passing train
- Prevention of premature damage on welds



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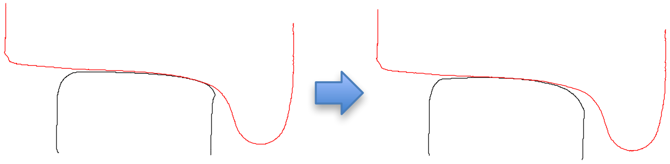
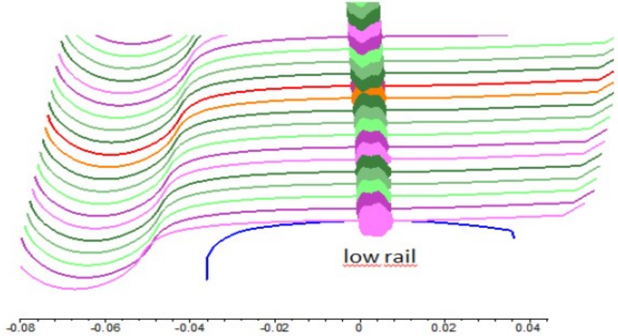
OPTIMISED RAIL / WHEEL PROFILES

- Reduced contact stresses
  - 2-point contact or small contact patch: high stresses / RCF
  - Move contact to/from specific areas
- Improved steering (curves) and stability (tangent)
  - Reduced tangential forces and flanging
  - No hunting in tangent track
- Delay rail degradation





A. Jörg, R. Stock, S. Scheriau, H.P. Brantner, B. Knoll, M. Mach, W. Daves. The Squat Condition of Rail Materials - a Novel Approach to Squat Prevention. Proceedings of CM2015 conference.

TRACK GEOMETRY – SYSTEM INTERACTION

- High track quality
  - Low dynamic forces
  - Desirable L/V
- Low dynamic forces
  - Delay in rail damage formation
- Damage free rail
  - Less dynamic forces and reduced track degradation

FRICTION MANAGEMENT

- Gauge face lubrication and top-of-rail friction control
- Gauge face: reduce friction to minimum
  - Rail lubricant
- TOR: Intermediate friction, sufficient traction
  - Friction Modifier

Photo by L.B. Foster Rail Technologies

FRICTION MANAGEMENT

- Benefits
  - Improved vehicle steering
  - Reduced (tangential) contact stresses
  - Reduced plastic flow, wear and RCF
- Wayside application systems and on-board application systems
- Delay rail degradation

Photo: L.B. Foster Rail Technologies

RAIL MAINTENANCE

- Grinding and Milling
- Restoration / adaption of rail profile (longitudinal and transversal)
- Removal of surface damage
- Defined surface condition
- Preventive, corrective and regenerative strategies

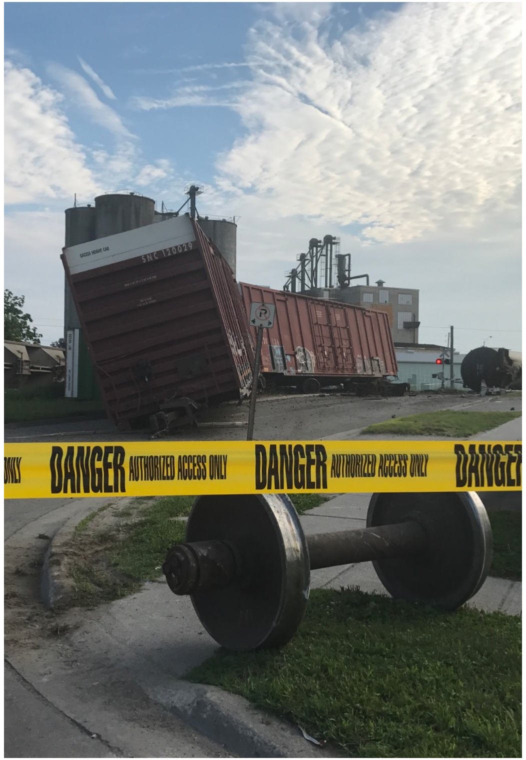
The only measure that can <u>remove</u> damage and not delay the formation!

SUMMARY

- Rail material
  - Typical rail steel: pearlitic steel
- Rail / wheel damage types
  - Plastic deformation, wear, cracks, thermal damage
- Controlling rail damage
  - Measurement Technology
  - Material selection, w/r profiles, track geometry, friction management, w/r maintenance

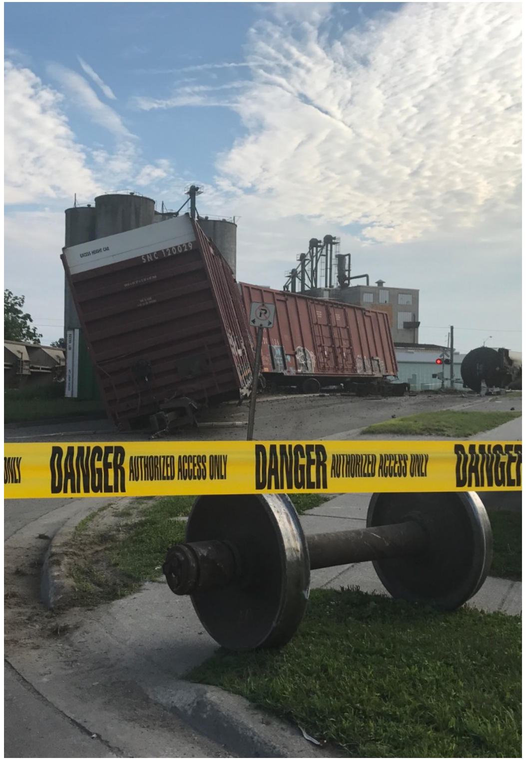
BACK TO THE DERAILMENT

- Rail Profile: AREA 132, AREA 136
- Rail Grade assumed: Standard
- Rail Wear: variable, within limits
  - Vertical: 2.76 – 11.89mm (limit 20mm)
  - Gauge: 0.06 – 7.28mm (limit 16mm)
- Track Inspection twice a week



BACK TO THE DERAILMENT

- US measurement: 12x a year – no defects
- Track geometry within limits – 4 measurements prior to incident
- Friction Management, Grinding: n.a.
- Rail breakage, Rail Damage: none



THANK YOU FOR YOUR ATTENTION

- QUESTIONS?

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