Wheel-Rail Damage Mechanisms

Dr. Richard Stock

Global Head of Rail Solutions, Plasser American

Welcome to Vancouver


These Flower Beds
are metric.
Please... NO FEET !

Outline

- Rail materials
- Wheel / rail damage mechanisms
- Controlling rail damage

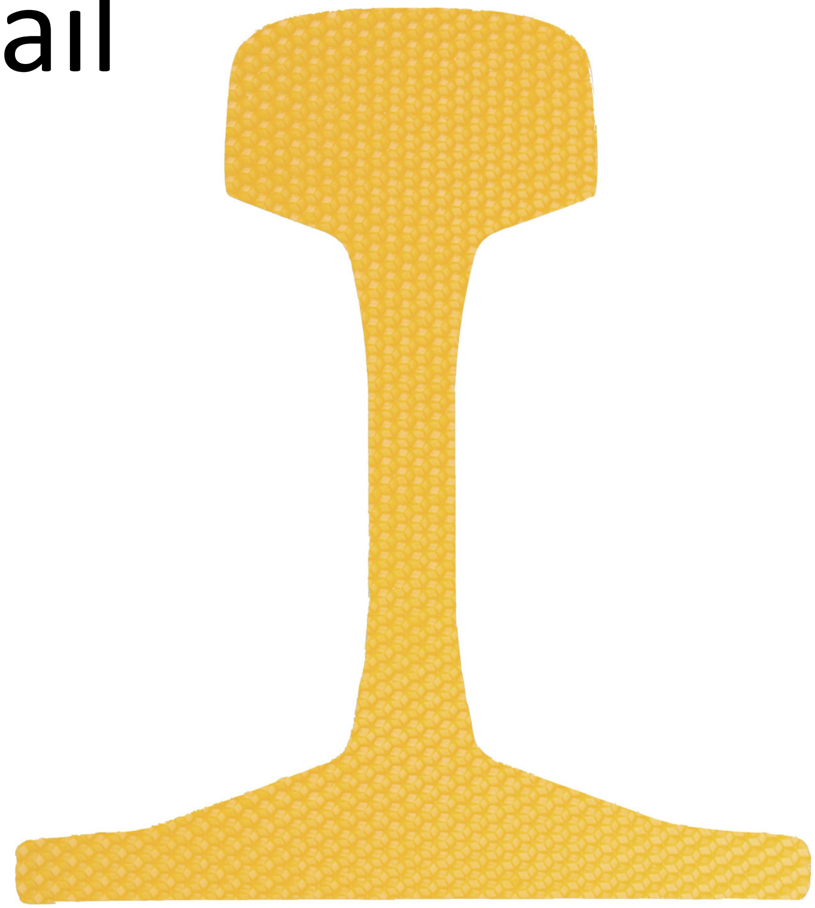
What rails are made of

RAIL MATERIALS

The Wax Rail

- Soft and deformable
- Massive plastic flow

- **Strength:** ability to withstand an applied load (stress) without failure or plastic deformation



The Wood Rail

- Increased Strength
- Low wear resistance
- Wear proportional to hardness

- **Hardness:** is a measure of the resistance to localized plastic deformation induced by either mechanical indentation or abrasion.

The Ceramic Rail

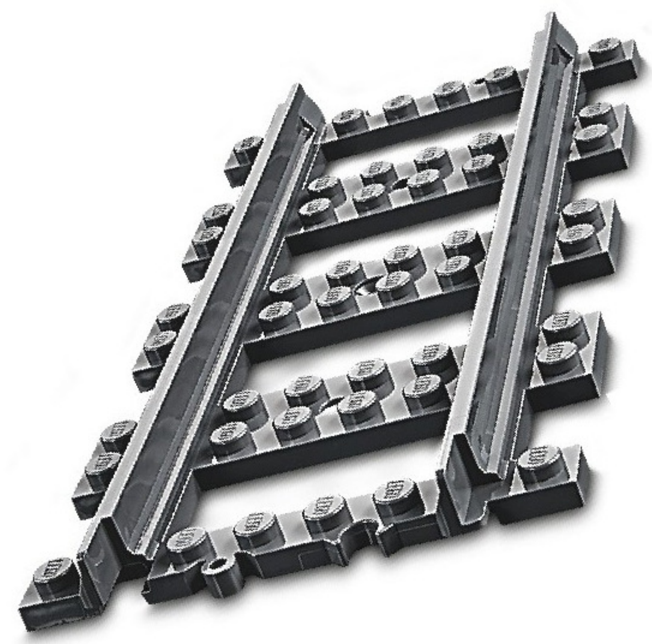
- High wear resistant
- Brittle – low toughness

- **Toughness:** ability of a material to absorb energy and plastically deform without fracturing

The Plastic Rail

- Increased material properties but still not sufficient
- No electric conductivity

- **Conductivity:** a measure of a material's ability to conduct an electric current



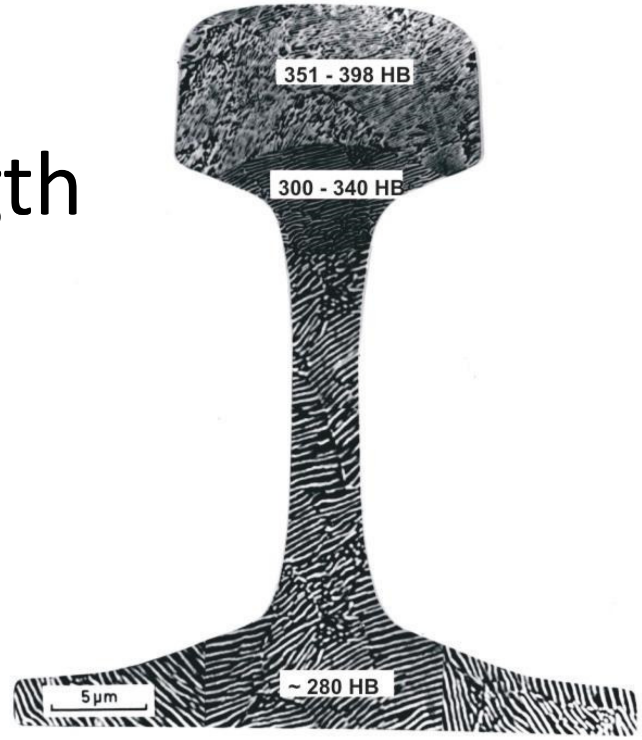
The Titanium Rail

- Excellent Toughness, Hardness and Strength
- Very lightweight material
- 50x more expensive
- Combination of properties not suitable for rails.

U.S. Air Force photo by Tech. Sgt. Michael Haggerty, Public domain, via Wikimedia Commons

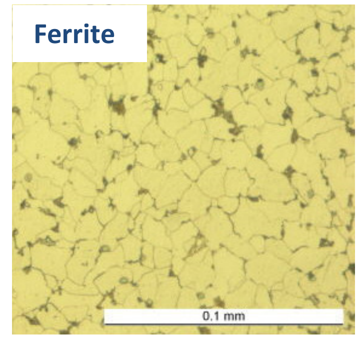
The Steel Rail

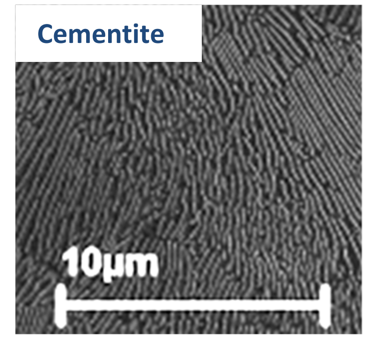
- Hardness: 200-450 BHN
- Sufficient Toughness and Strength
- Ductile material behaviour
- Sufficient electric conductivity
- Reasonable weldability
- Excellent machineability

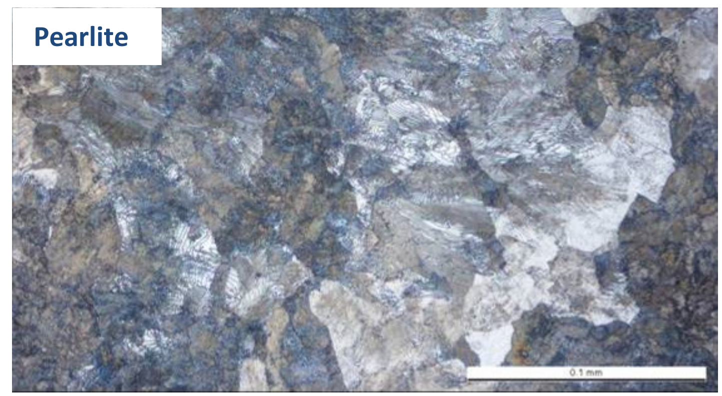


Pearlitic Microstructure

- 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



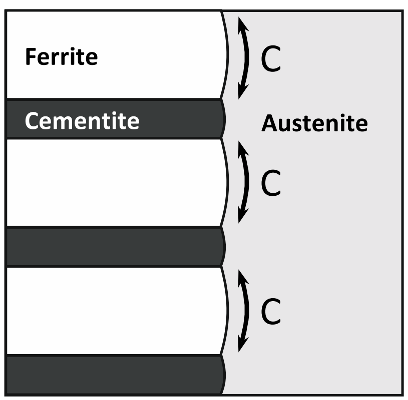




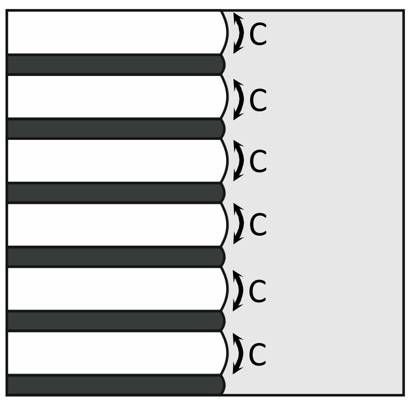
Impact of Heat Treatment

- Heat treatment = faster cooling (removal of heat)
- Less time for transformation process at 723°C
- Smaller lamella distance

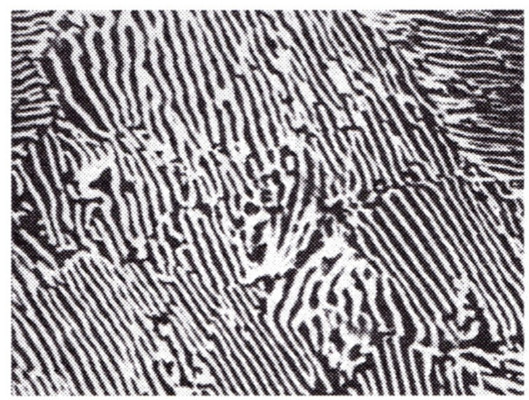
Standard cooling



Accelerated cooling



Grade R260
C: 0.7%



Grade R350HT
C: 0.7% + **heat treatment**

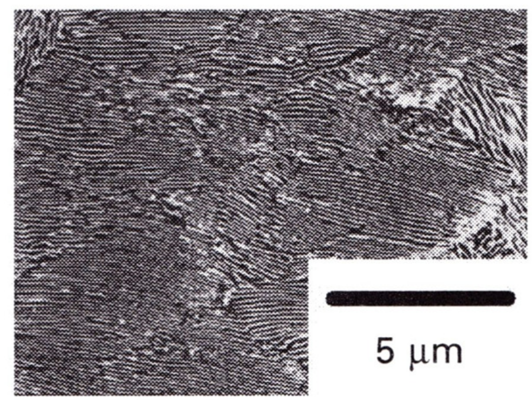
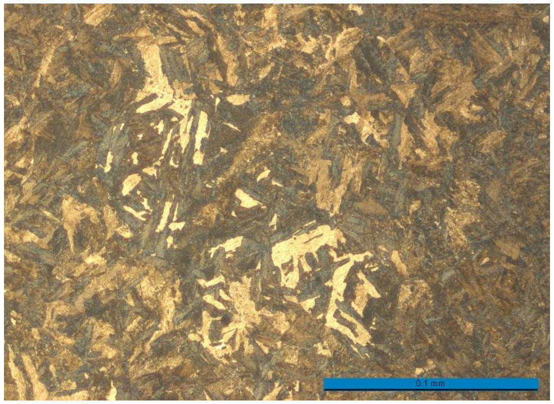
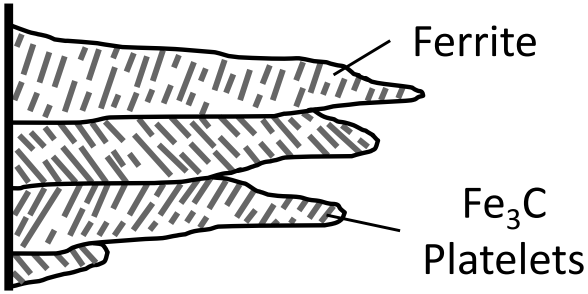


Photo from: Wheel-Rail Interface Handbook.

Bainite

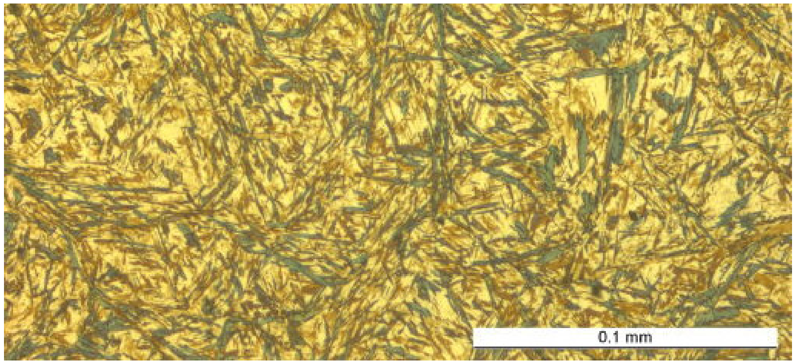
- Two phase material: Ferrite & Fe_3C
- Produced by accelerated cooling or alloying
- Intermediate structure, needle like or plate structure of ferrite and carbide
- Upper, lower or carbide free Bainite
- To some extend used for rail steels

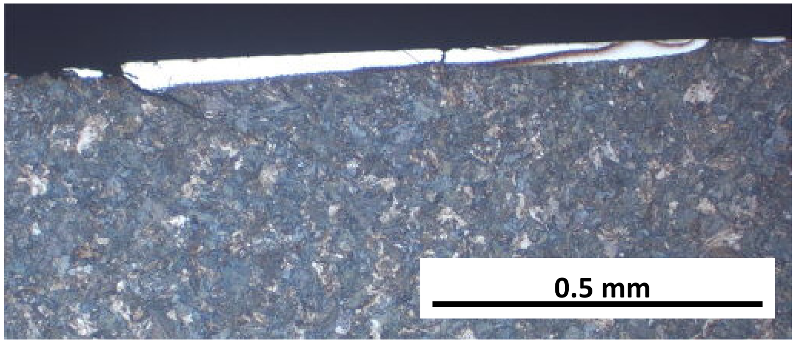




Martensite

- Produced by high cooling rates, alloying
- Hard (450-760 BHN), low ductility
- Tool steels (cold working-, hot working-, high speed steels)
- Trip steels (transformation induced plasticity)
- Must not have for rail steels
  - The dose makes the poison!
  - White etching layer (WEL) on rail surface

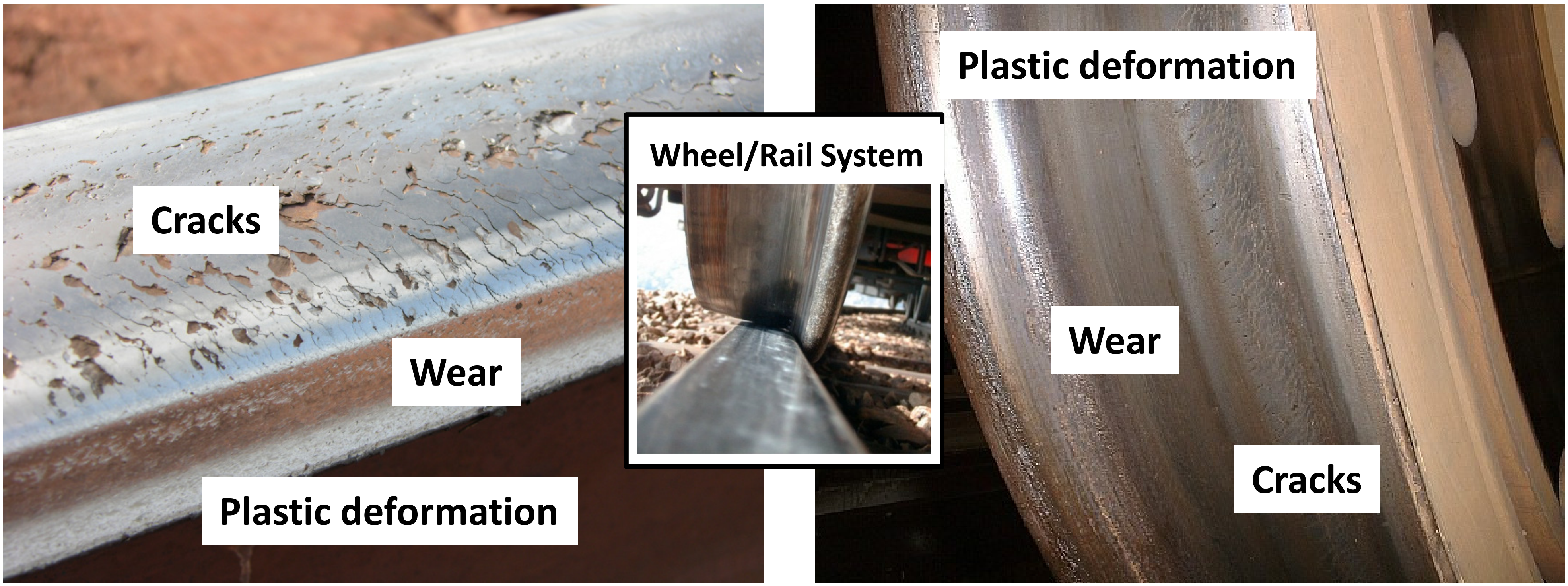




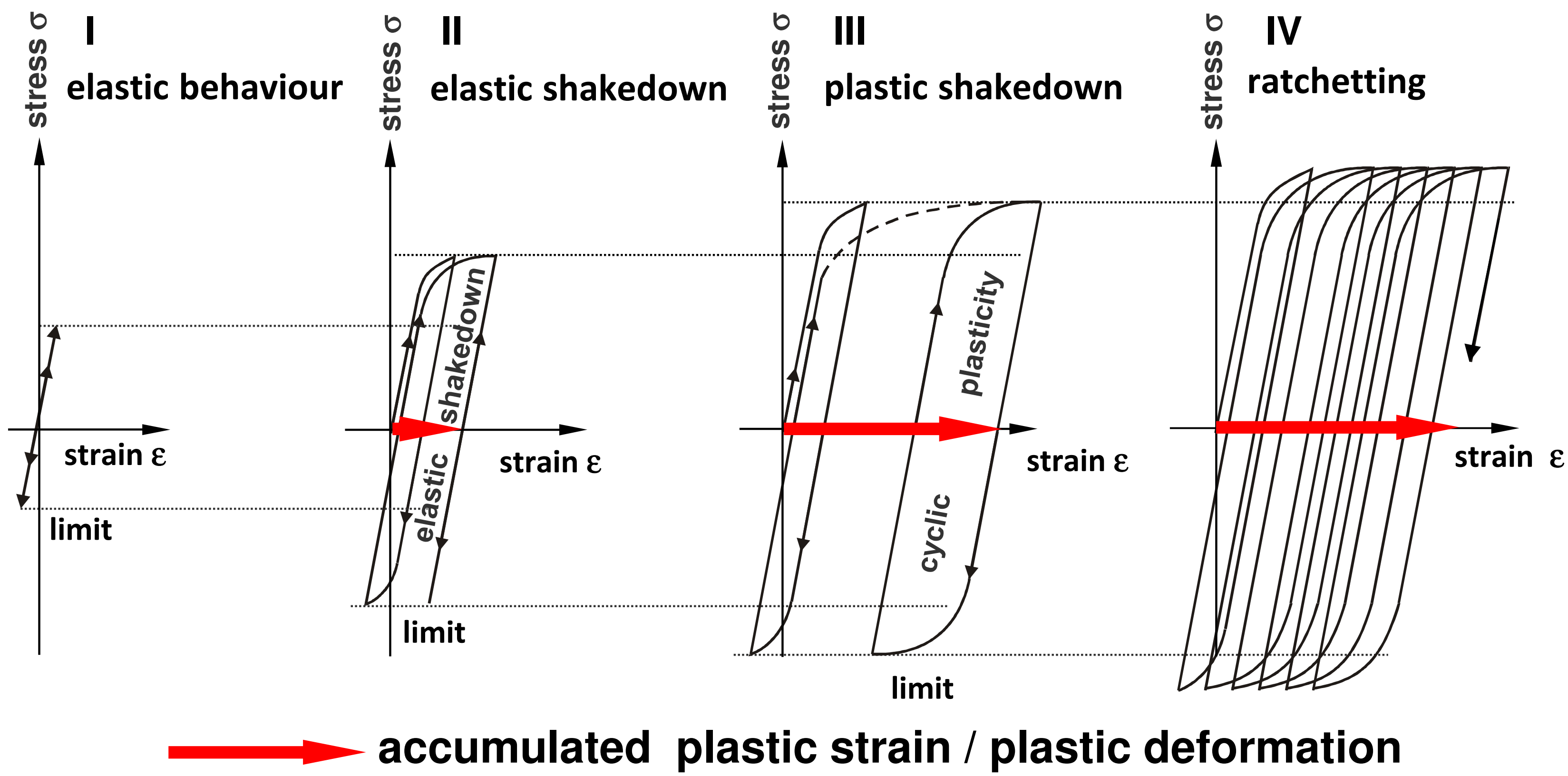
Material reaction to loading

WHEEL / RAIL DAMAGE MECHANISMS

System Deterioration



Material Behaviour Under Load



Plastic Deformation

- Contact loads always above elastic material limit.
- On a microscopic scale close to the rail surface.
- Plastic flow enclosed by bulk elastic material

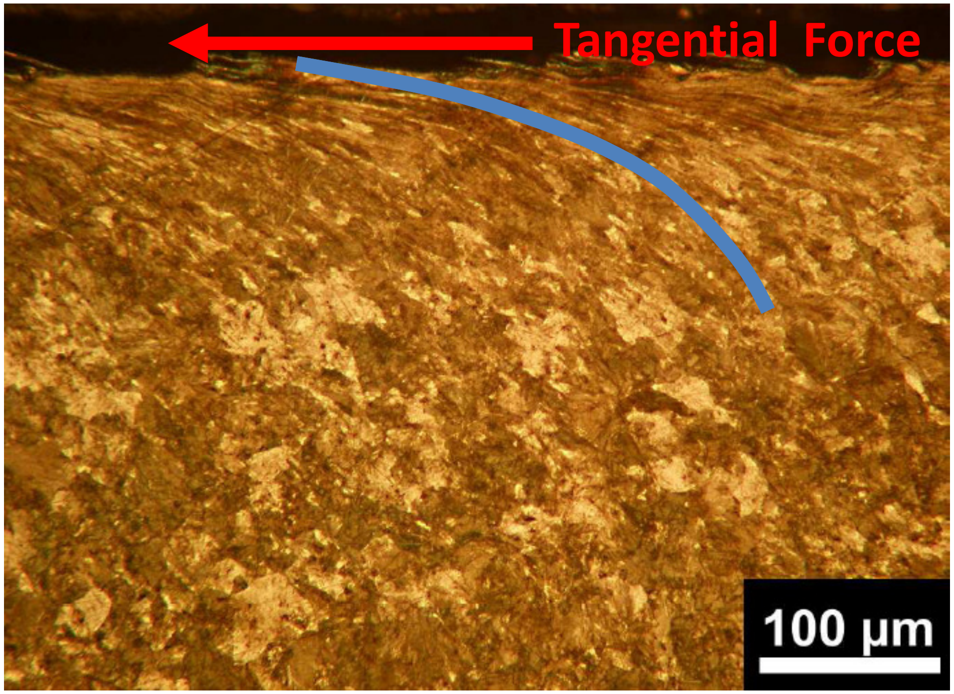
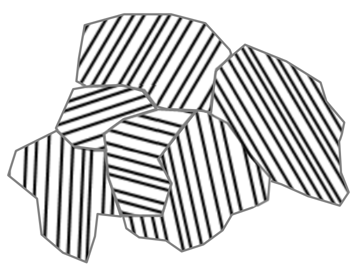


Photo: voestalpine

Material Response: Deformation

Severely deformed and aligned material structure at the rail surface

Non-deformed material structure



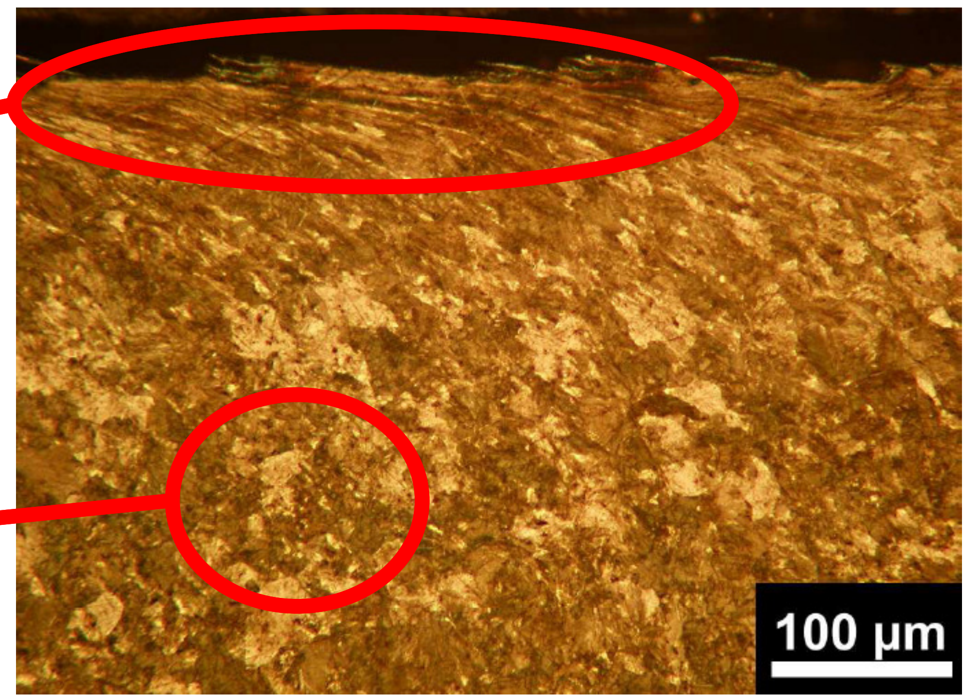


Photo: voestalpine

Plastic Deformation

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

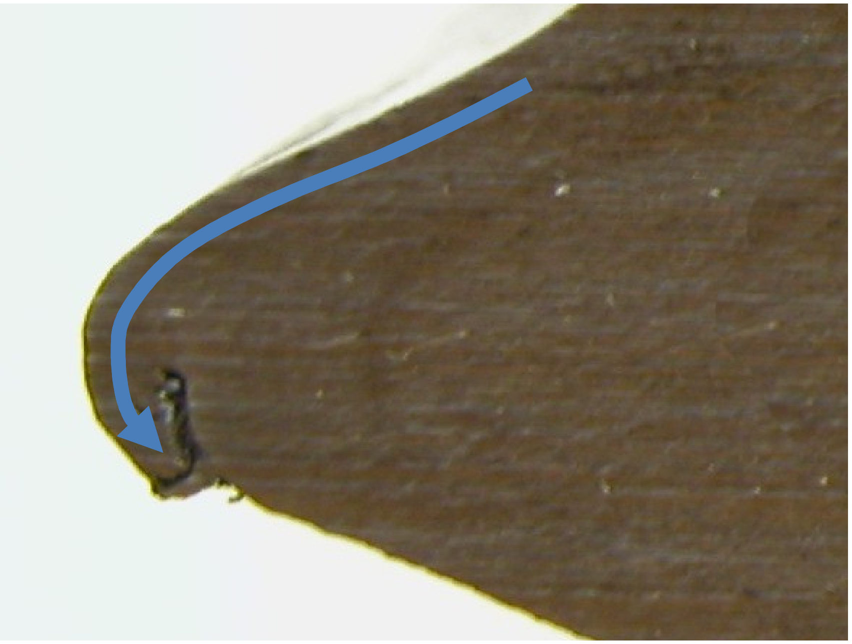


Photo: voestalpine

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

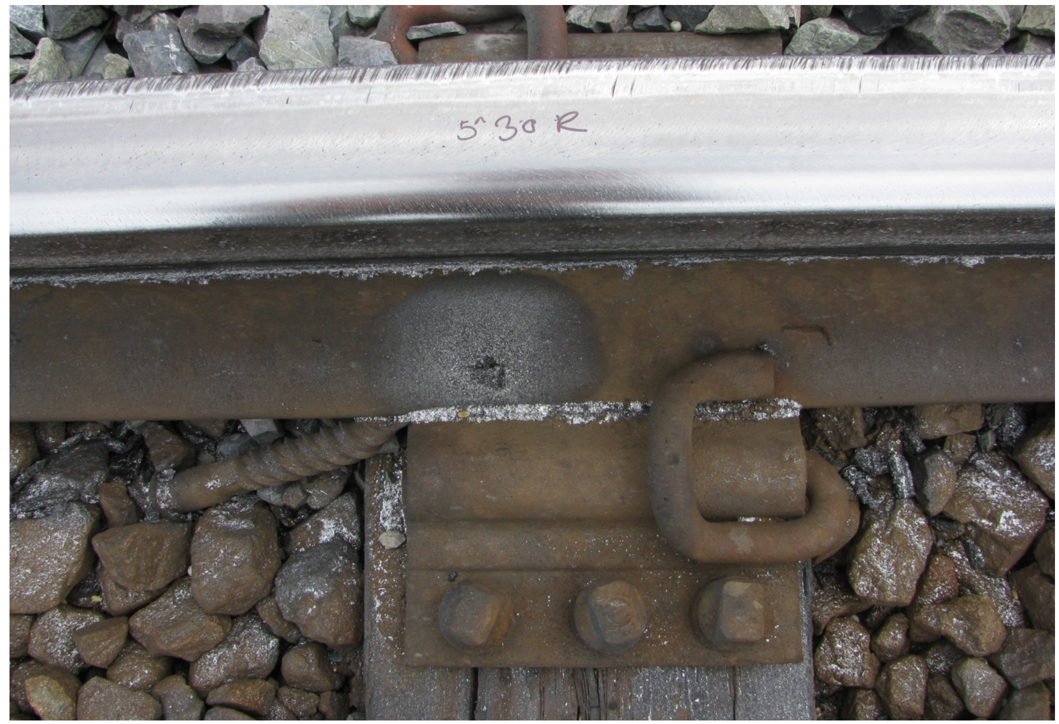
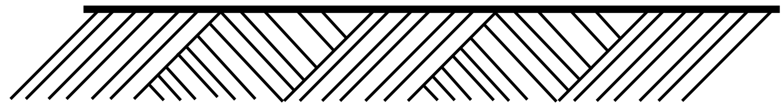


Photo by L.B. Foster

Material Response: Wear

Rail surface

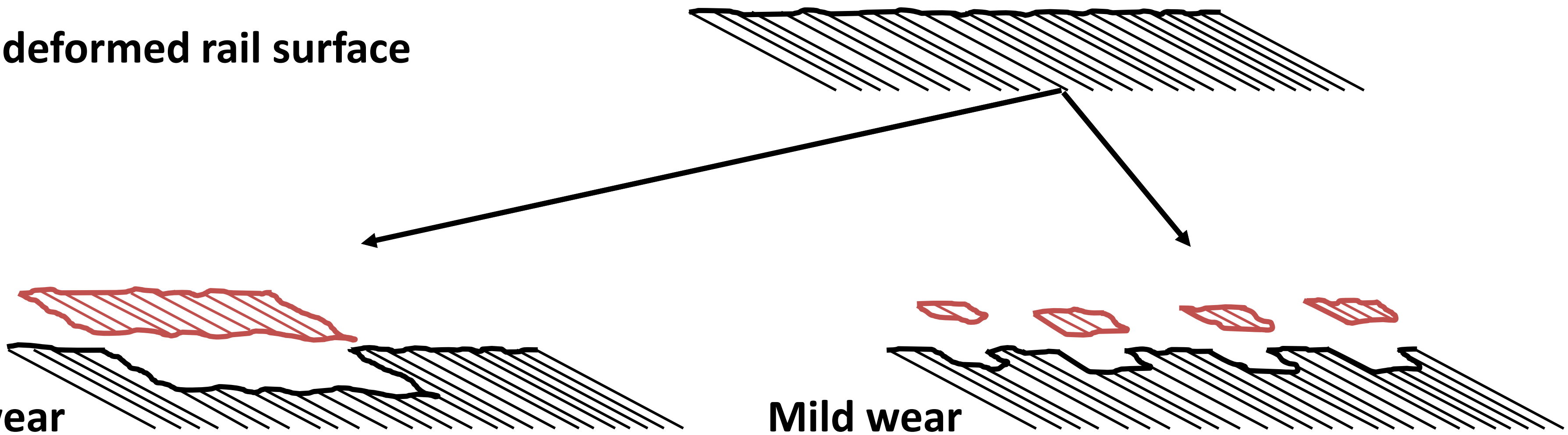


Schematic drawings

Non-deformed, initial material condition

⇩ Loading conditions, material properties

Severely deformed rail surface



Severe wear

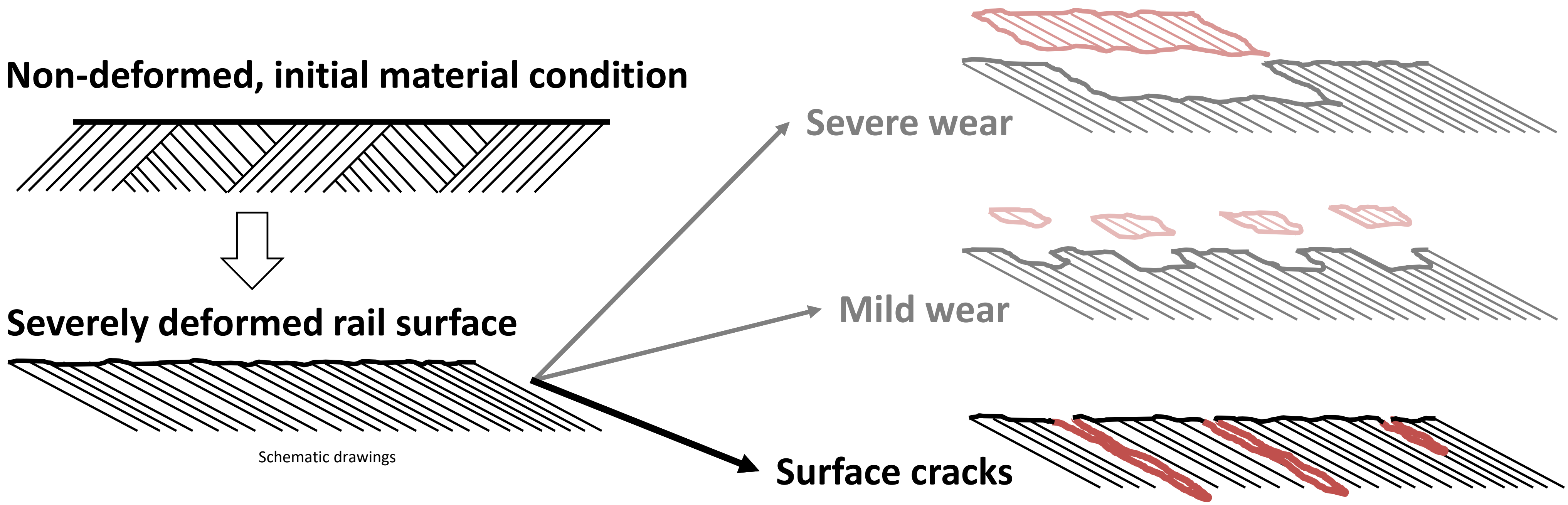
Mild wear

Corrugation

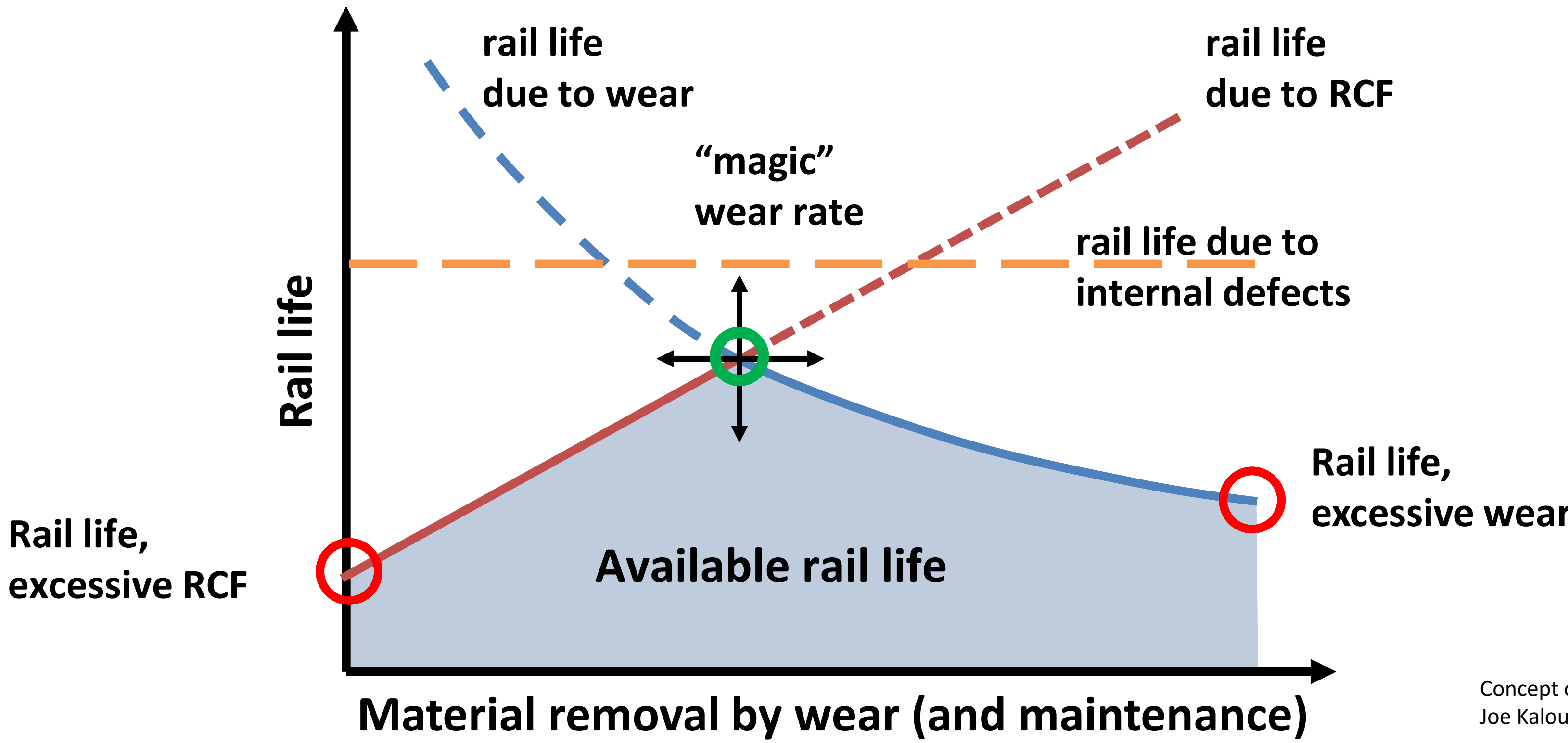
- Wave structure on the rail surface (tangent / curve)
- Short wave (25mm-80mm wavelength) or long wave (100-300mm) corrugation
- Multiple sub-classifications
- Combination of wear and plastic flow

Photos by L.B. Foster

Material Response: Cracks



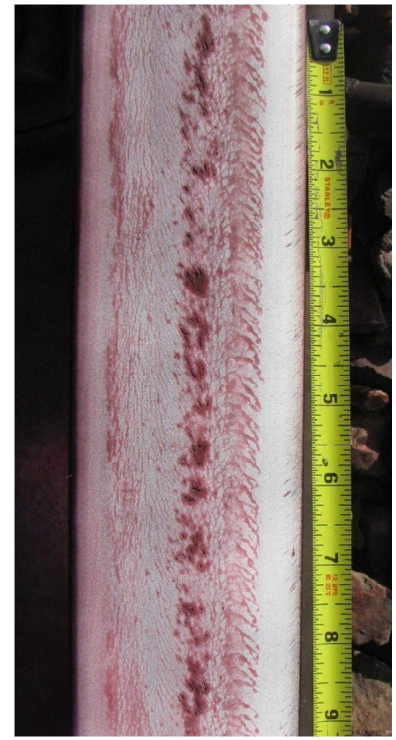
Magic Wear Rate



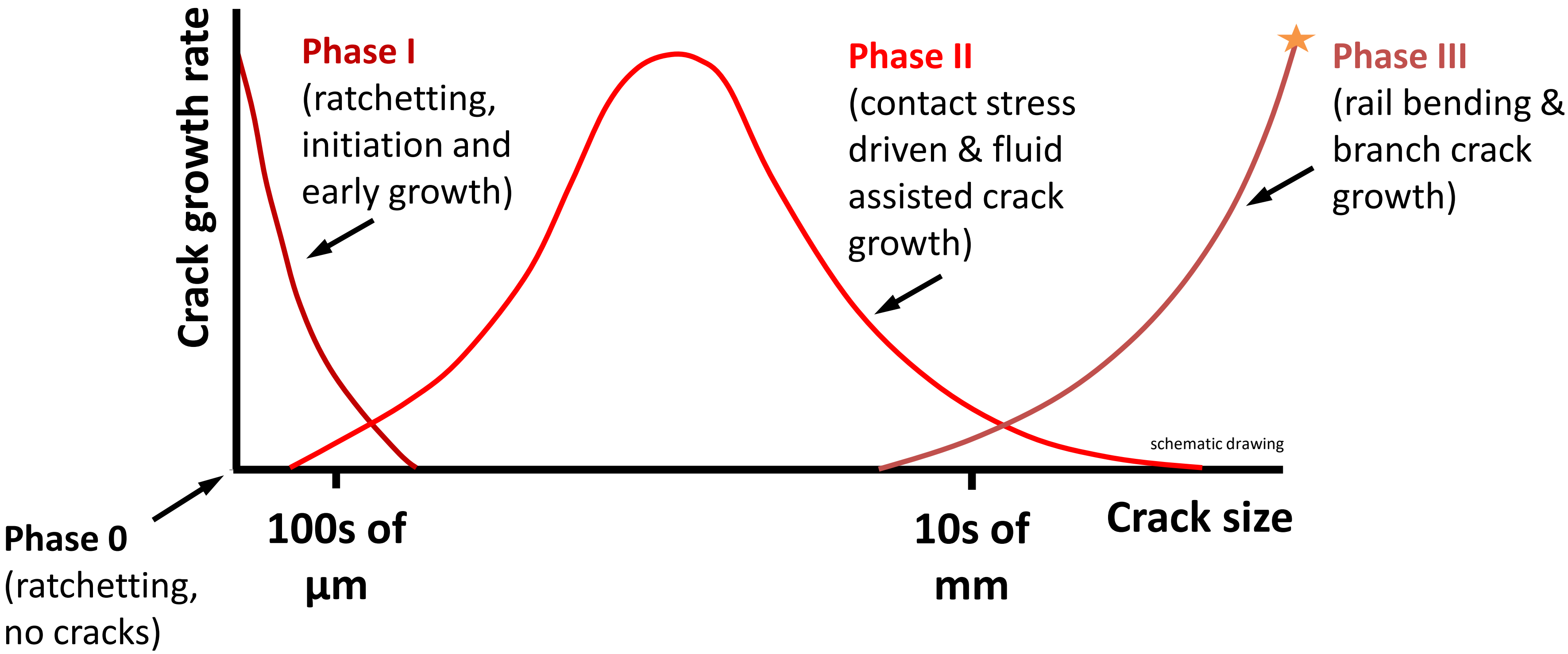
Concept of Magic Wear Rate by
Joe Kalousek and Eric Magel, 1997

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



Crack Growth Phases



Flaking and Spalling

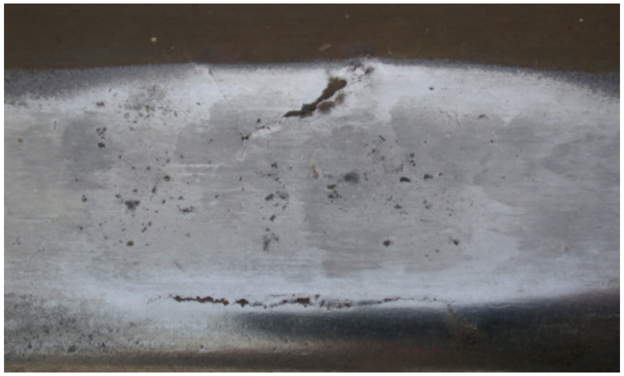
- Head Checks can combine causing material to break out of the rail surface.
- Head Checks – Flaking – Spalling

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

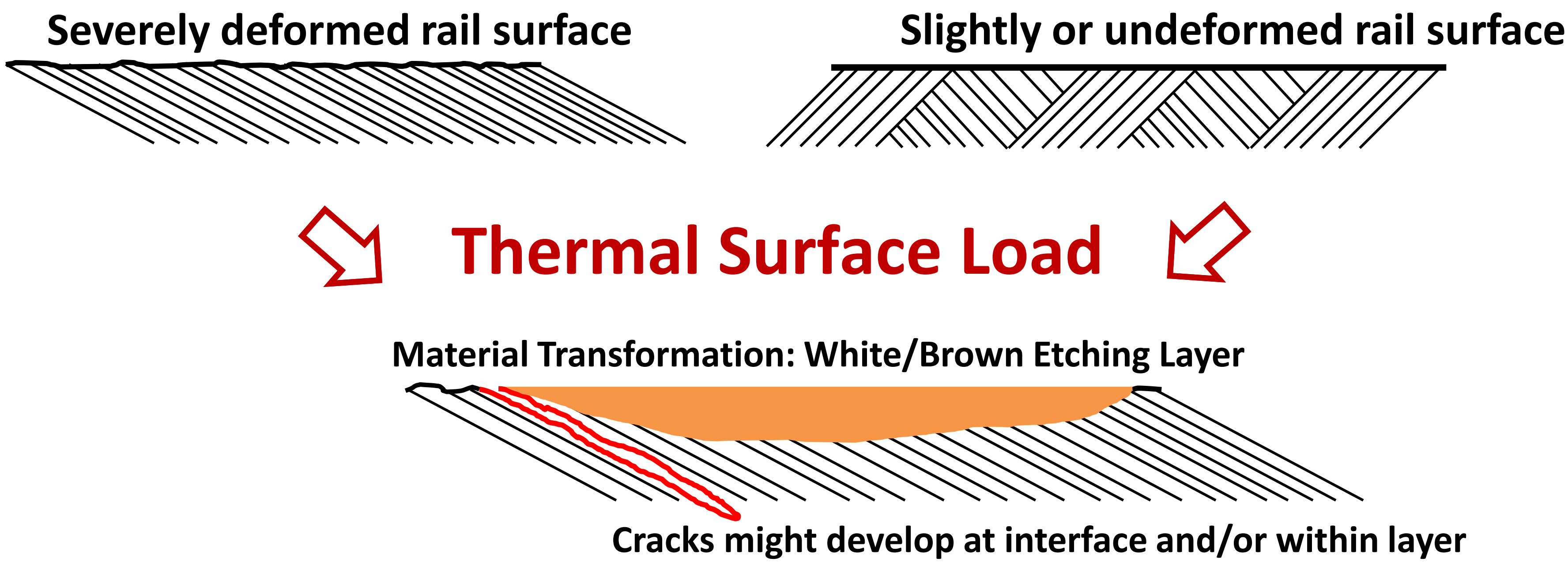
Squats

- 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



Schematic drawings

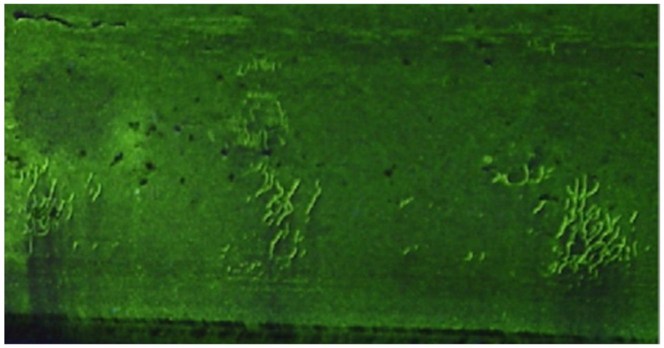
Squat Type Defects / Studs

- 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
- Multiple contributing factors
  - Wear behaviour, R/W profiles, traction/friction conditions, system stiffness, rail maintenance activities

Photo: Rene Heyder, DB

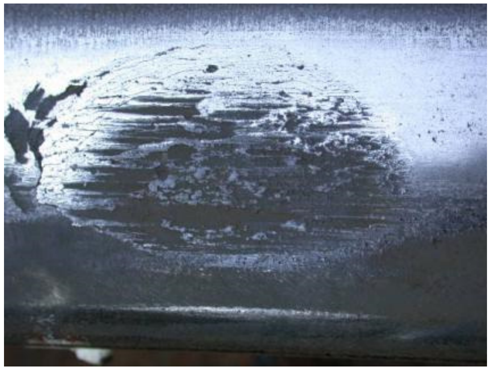
Belgrospies

- First detected at high sped lines in Germany.
- Associated with high-speed traffic only (v > 200kph / 125mph).
- Crack nests at corrugation peaks.
- First found by three railway employees named Belz, Grohmann and Spiegel



Wheel Burn

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

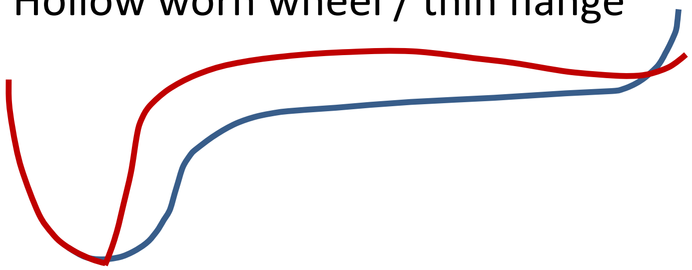


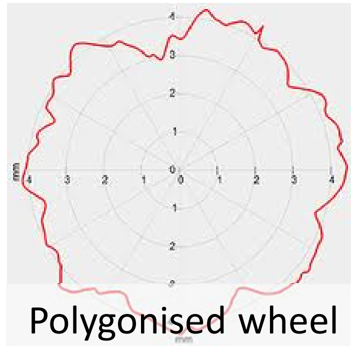
Selected Damage on Wheels

- Wear
- Polygonised wheels
- Wheel flat
- Wheel spalling
- Wheel shelling
- Fish scales / tread checking

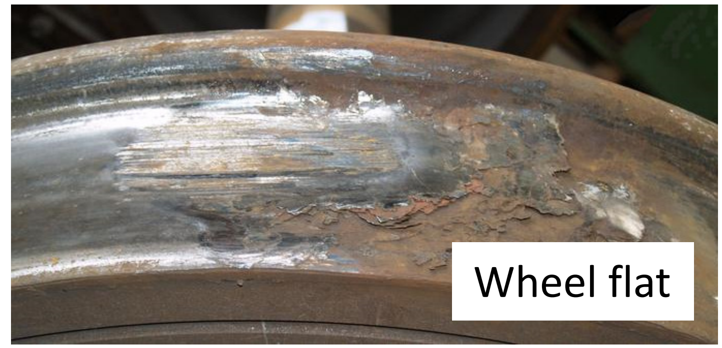
Wheel damage examples

Hollow worn wheel / thin flange

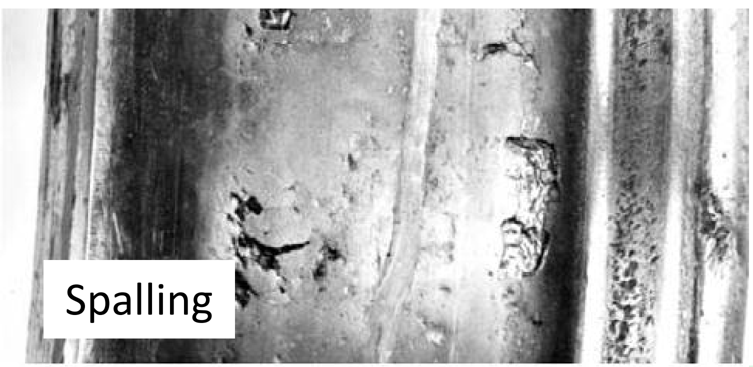




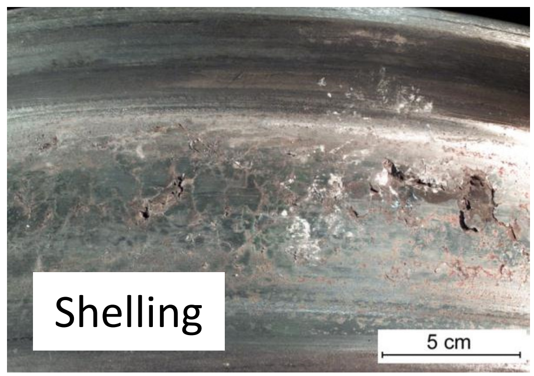
Polygonised wheel



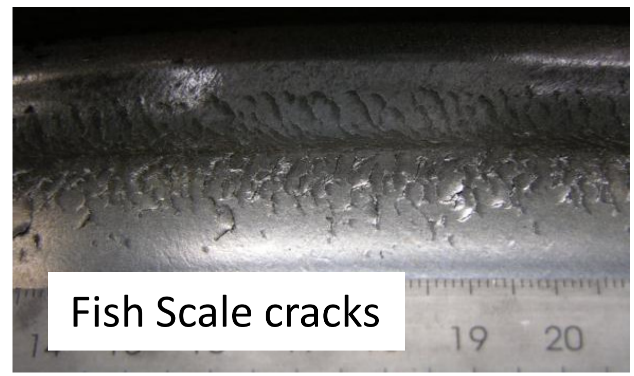
Wheel flat



Spalling



Shelling



Fish Scale cracks

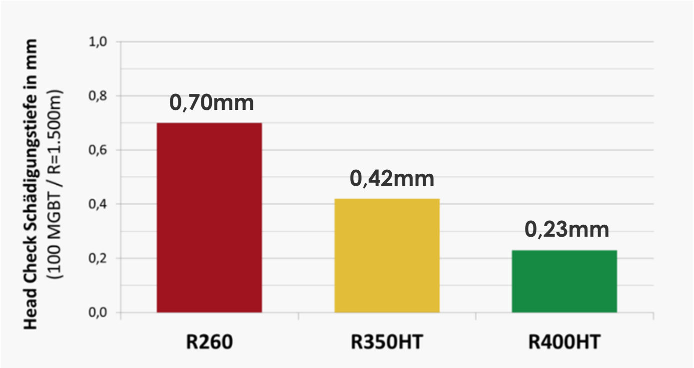
How to extend the rail life

CONTROLLING RAIL DAMAGE

Controlling Rail Damage: Material

- Rail Grade Selection
  - Premium (heat treated) rails
  - Optimised material structure for superior behaviour
  - Improved damage and wear resistance
    - Rail life extension

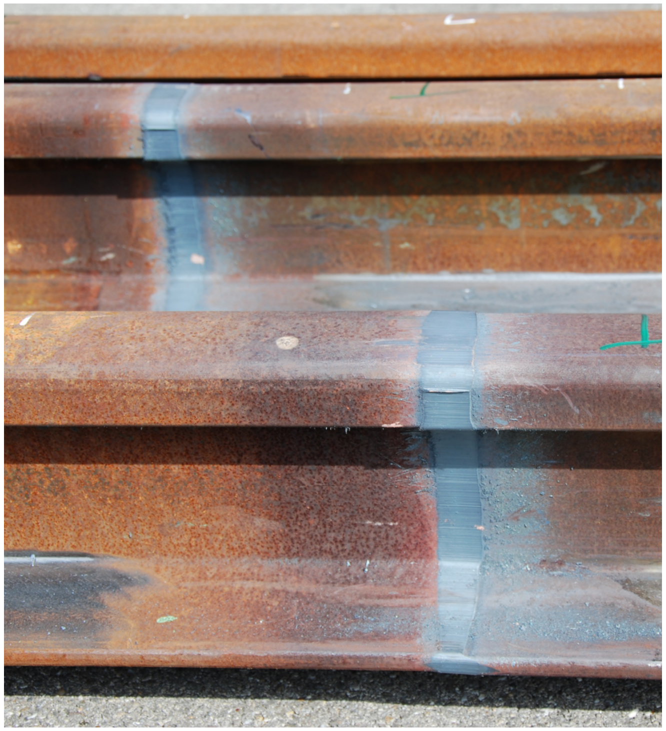
Source: voestalpine, WRI 2012 Conferenz



Source: voestalpine, SFT 2017

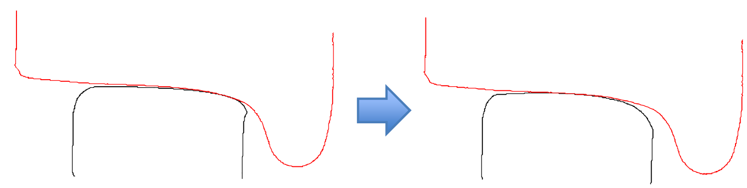
Rail Welding Technology

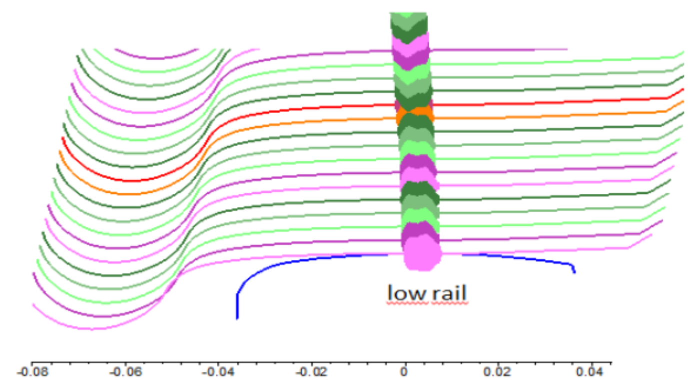
- Every connection is a discontinuity
- Welding technologies:
  - Thermite welding
  - Flash butt welding
- Goal: long lasting rail connection that has similar / same material properties as the rail material
  - Ideally: joint not "felt / seen" by passing train
- Prevention of premature damage on welds



Rail / Wheel Profiles

- Optimised profiles
- Reduced contact pressure
- 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

- Tangent, transition, curve
- Gauge, alignment (horizontal), profile (vertical), crosslevel
- Quality of subsoil, ballast, sleepers, rails
- Low track quality – high (dynamic) forces
- Optimised track quality – delay of degradation

Controlling Rail Damage: Friction

- Friction Management
  - GF & TOR friction control
  - Improved steering
  - Reduced (tangential) contact stresses
  - Reduced plastic flow, wear and RCF
- Wayside or on-board application
- Delay rail degradation

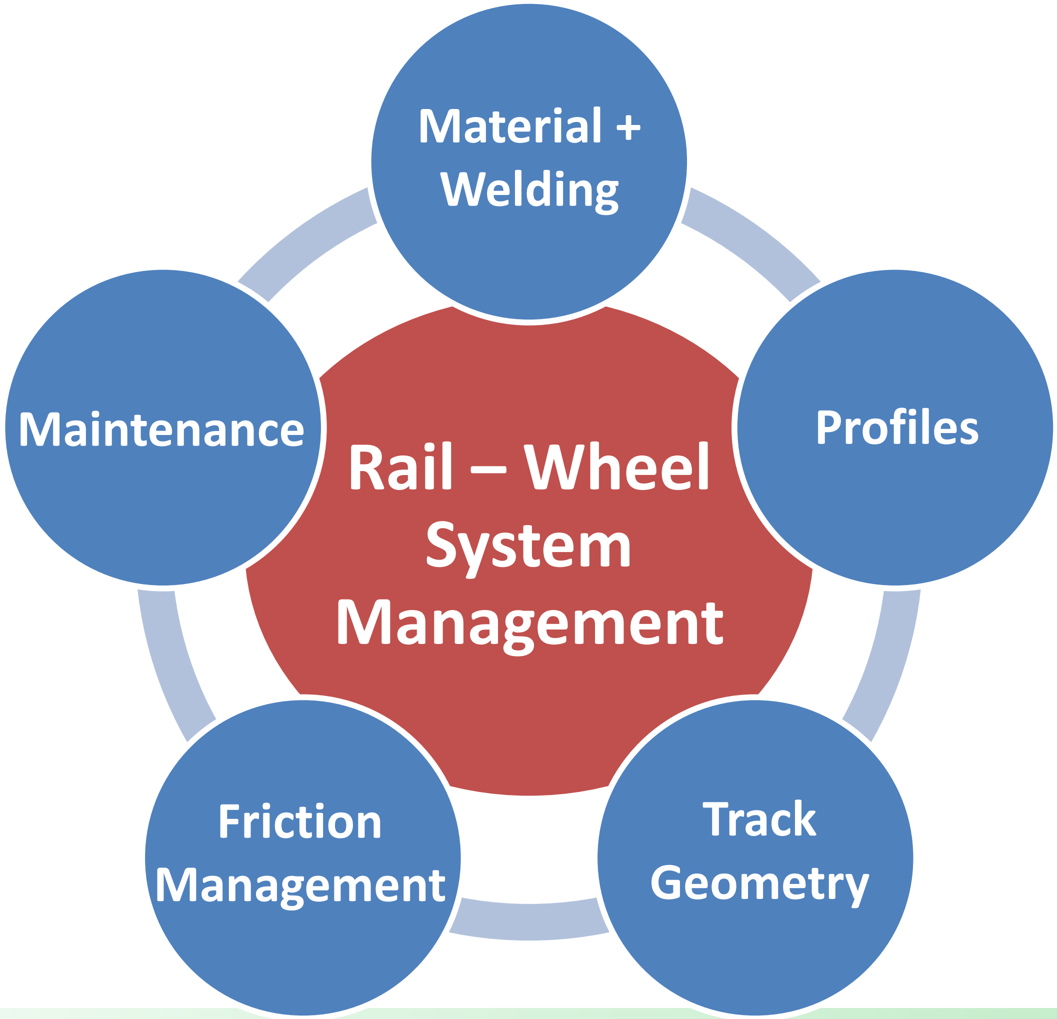
Photo by L.B. Foster Rail Technologies

Controlling Rail Damage: Maintenance

- Rail Maintenance
  - Grinding and Milling
  - Remove damage and keep profile in “shape”
  - Corrective/regenerative: reset/restore your rail condition
  - Preventive / Predictive: keep your rail in healthy condition

Summary

- Rail material
  - Material and microstructure for optimised properties
  - Typical rail steel: pearlitic steel
- Rail / wheel damage types
  - Plastic deformation, wear, cracks, thermal damage
- Controlling rail damage
  - Material selection, w/r profiles, track geometry, friction mgmt, w/r maintenance


Material + Welding
Profiles
Maintenance
Rail – Wheel System Management
Friction Management
Track Geometry

Thank You for Your Attention

Questions?