Wheel-Rail Damage Mechanisms

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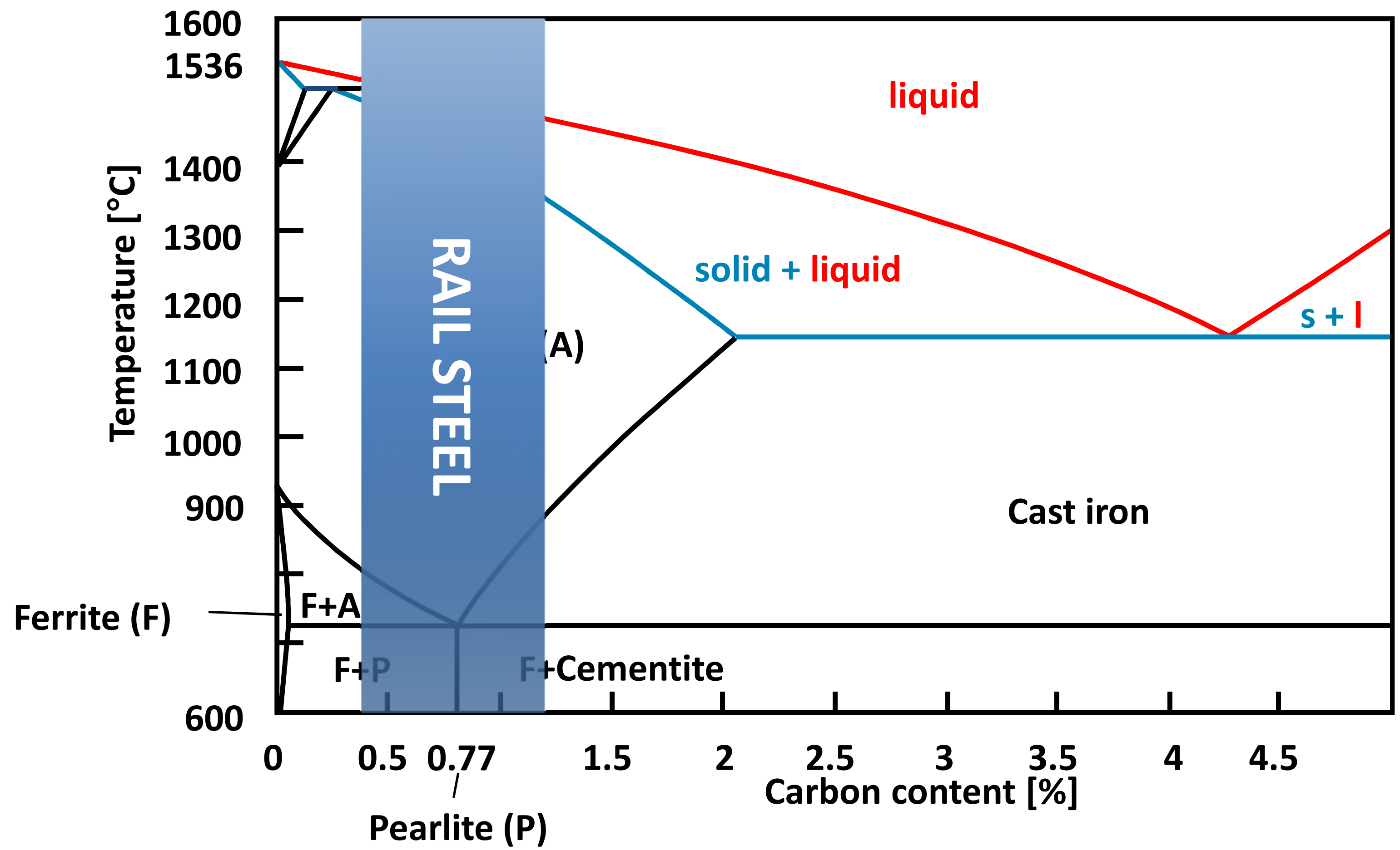
Outline

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

RAIL MATERIALS

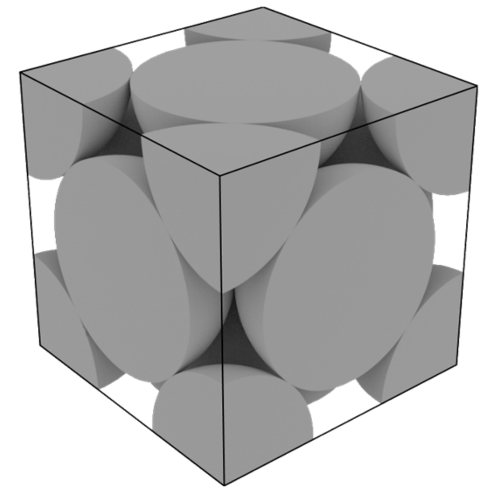
Fe-C Diagram (simplified)

- Iron: melting point: 1536 °C (2796.80 °F)
- Steel = Alloy of iron (Fe) + carbon (C)
- Iron phases:
  - Austenite (Gamma)
  - Ferrite (Alpha)
- Carbide: Cementite
- Pearlite structure
- Other alloying elements to adjust properties
- Rail steel: 0.4 – 1.1 % C

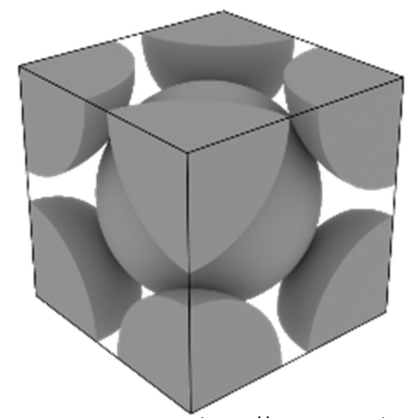


Lattice Structure of Steel

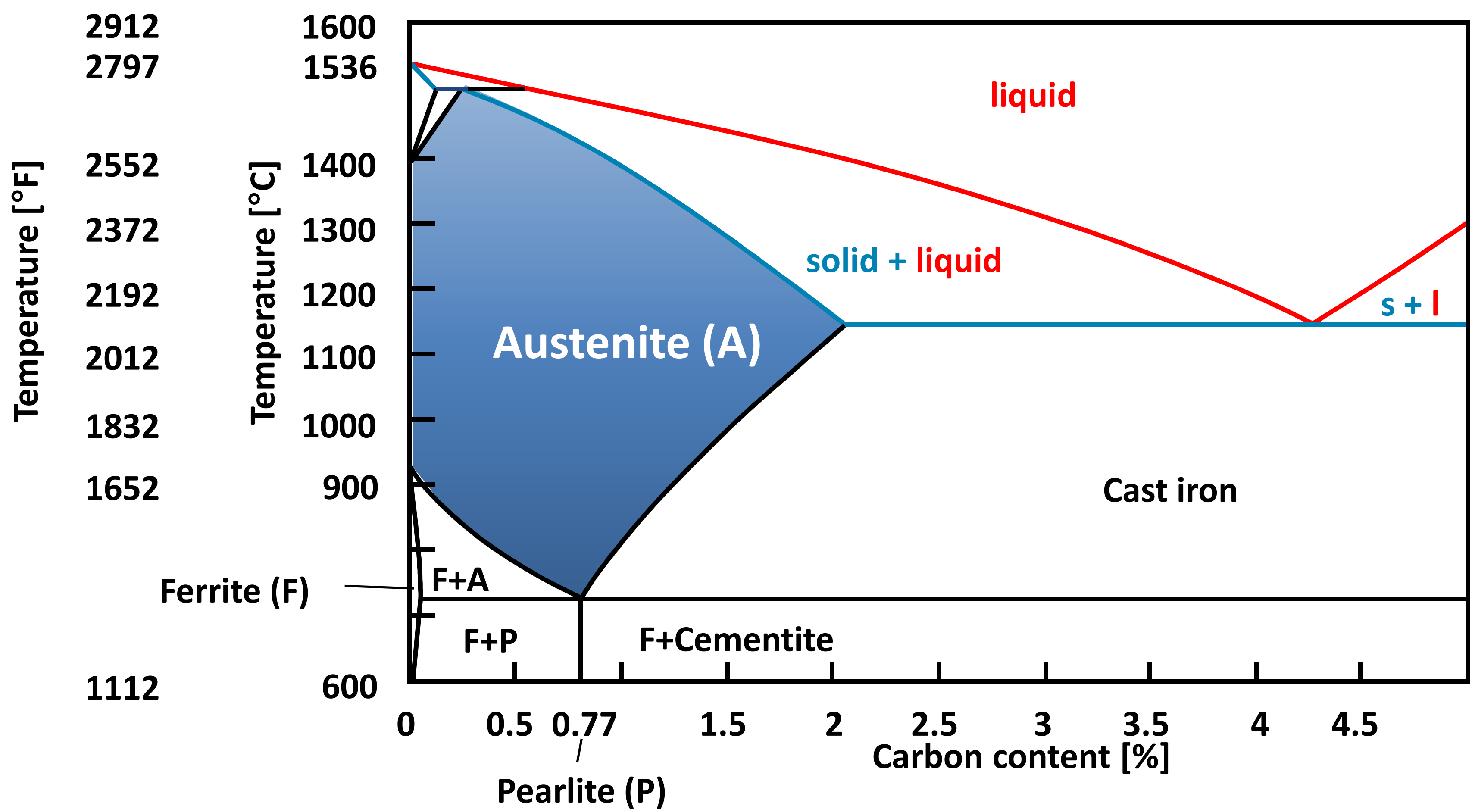
- Face centered cubic (fcc)
  - Austenitic steel
  - Sufficient space to dissolve C – atoms



- Body centered cubic (bcc)
  - Ferritic steel
  - Denser packing of C-atoms than fcc
  - Very limited space to dissolve C – atoms



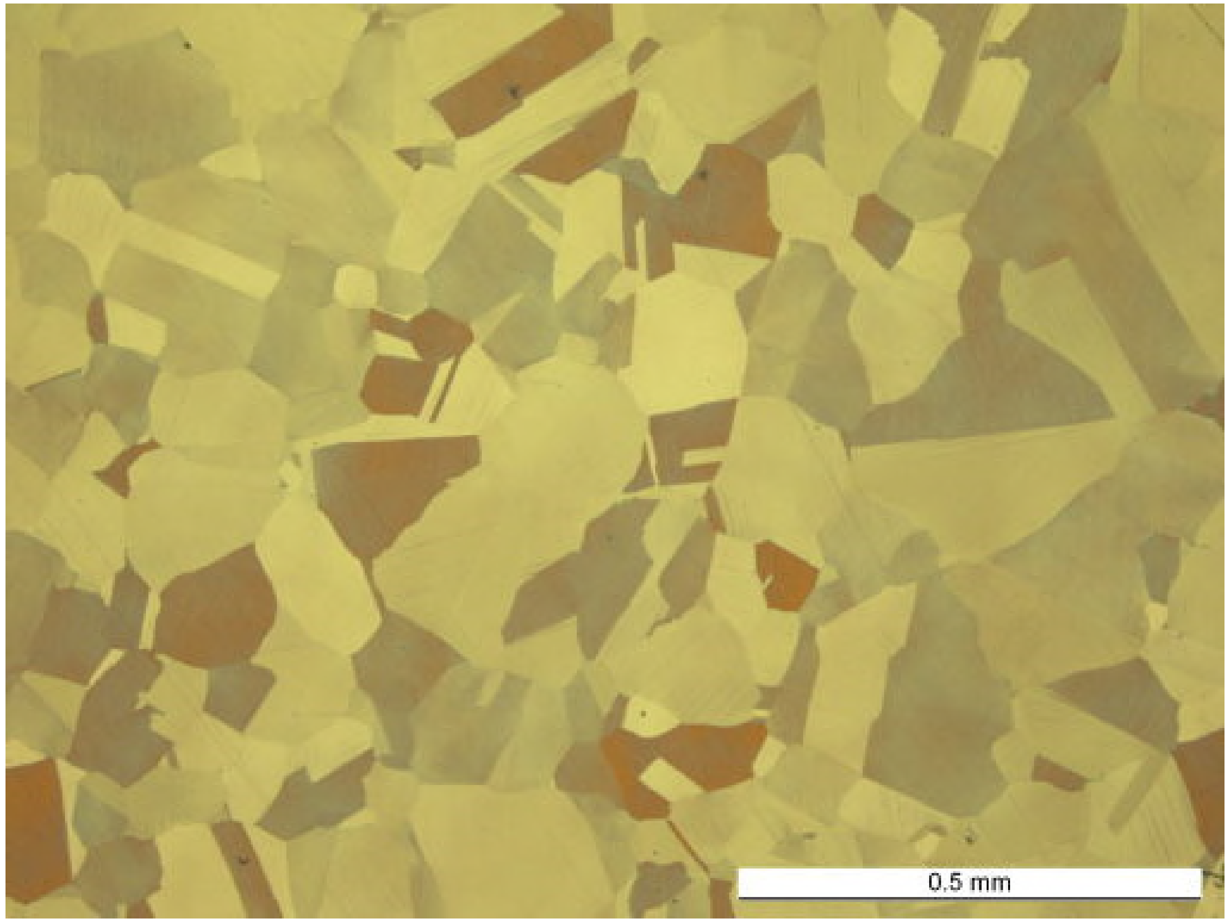
Austenite



2912
2797
2552
2372
2192
2012
1832
1652
1112
Temperature [°F]
1600
1536
1400
1300
1200
1100
1000
900
600
Temperature [°C]
liquid
solid + liquid
s + l
Austenite (A)
Cast iron
Ferrite (F)
F+A
F+P
F+Cementite
0
0.5
0.77
1.5
2
2.5
3
3.5
4
4.5
Carbon content [%]
Pearlite (P)

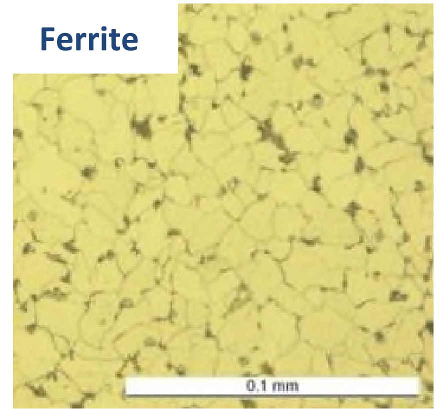
Austenite

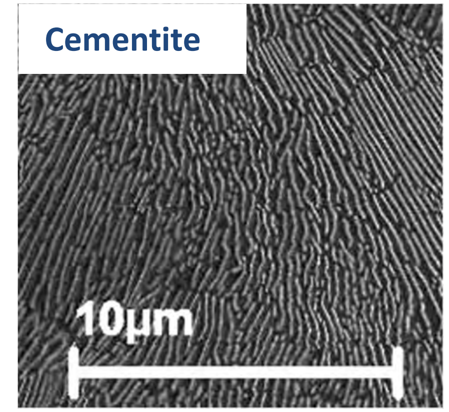
- Gamma-phase (face centered cubic)
- Can contain up to 2.06 % C
- Low hardness (70-250 BHN)
- Stable above 723°C (1333°F) or at RT by alloying Ni, Co, Mn
- Main part of corrosion resistant steels, shape memory alloys
- Non magnetic
- Not used in rail steels (usually)

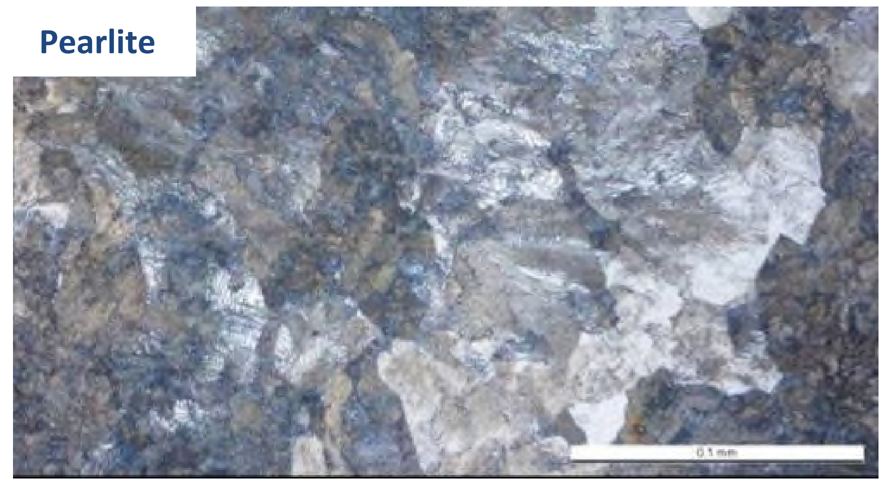


Pearlitic Microstructure

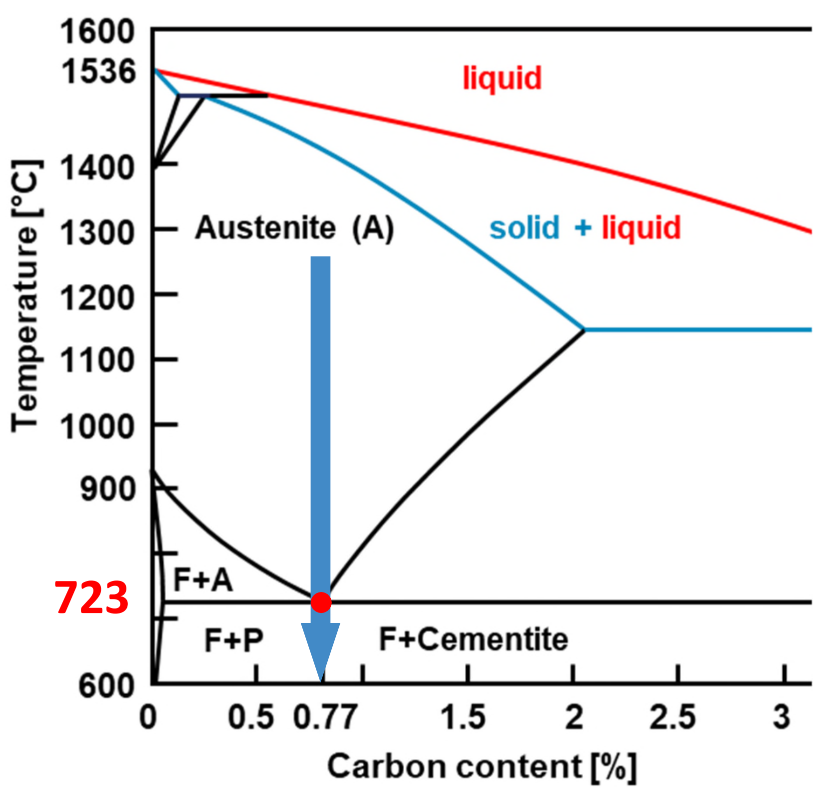
- Two phase material:
  - Ferrite: very soft, C_{max} = 0.02%, BCC lattice
  - Cementite: Fe_3C, very hard, C = 6,67%
- Lamellar or layer structure
- Pure pearlitic structure at 0.77% C (Eutectoid point)
  - C > 0.77%: Hypereutectoid Steel
- Lamella spacing defines hardness and strength without influencing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

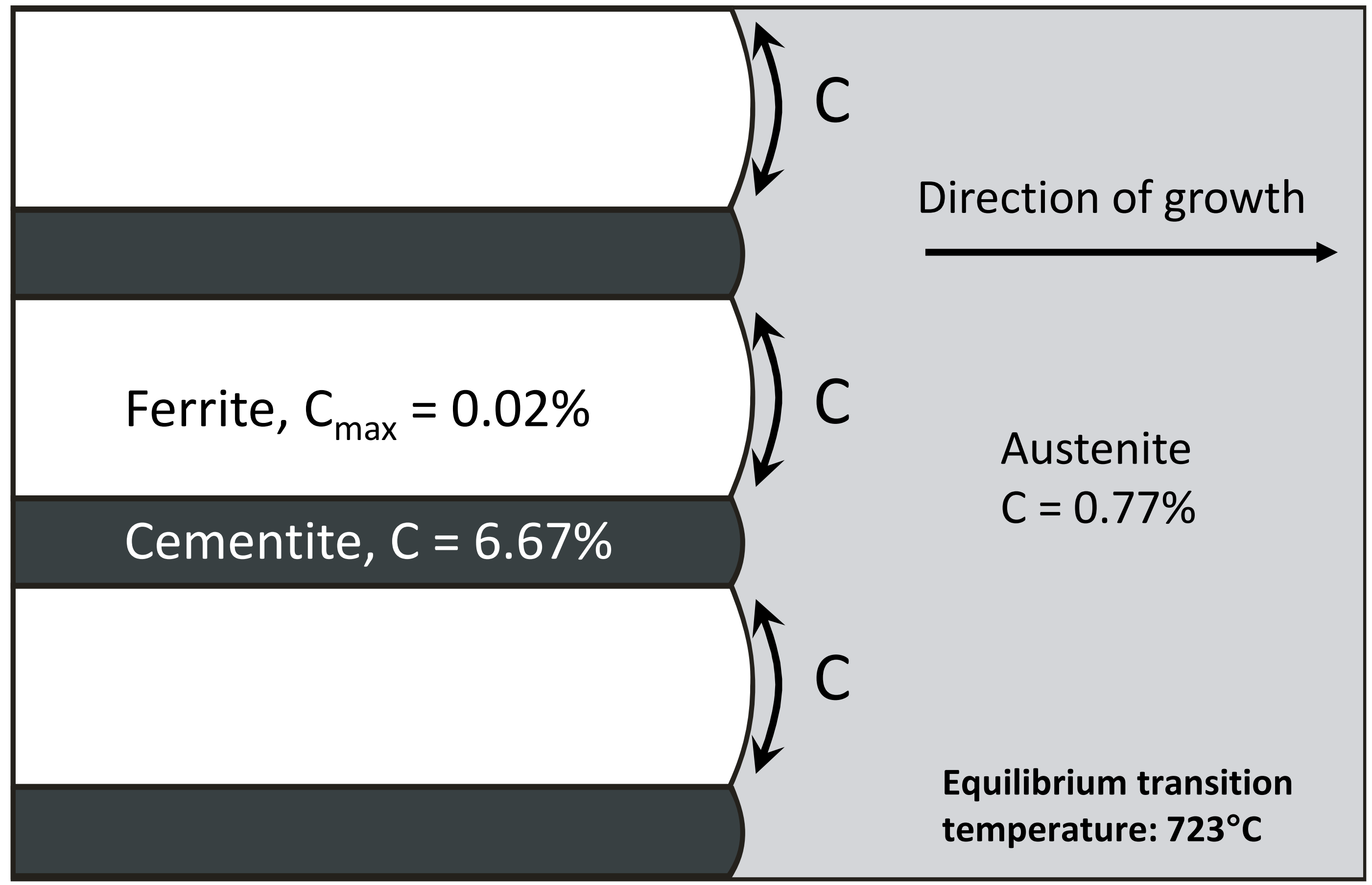






Austenite – Pearlite Transformation (simplified)

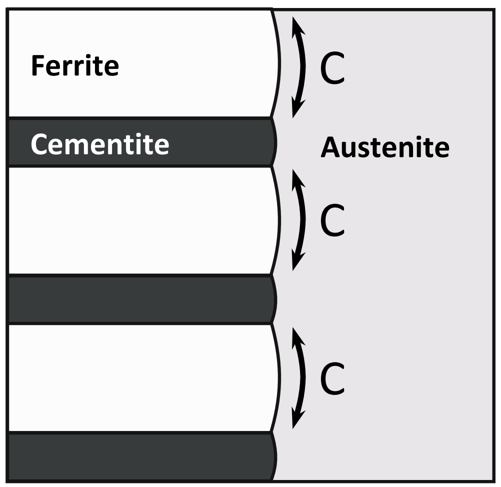




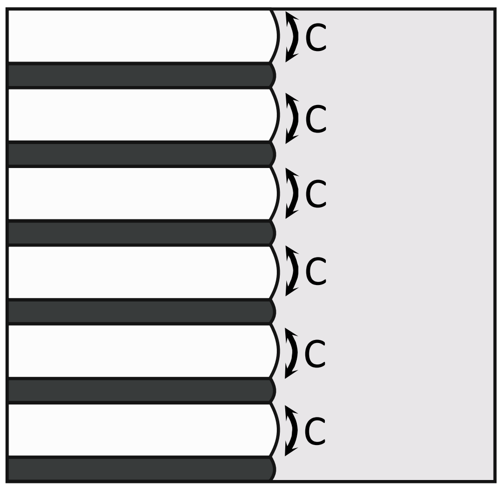
Impact of Heat Treatment

- Heat treatment = faster cooling (removal of heat)
- Less time for C diffusion / travel – shorter C travel distance
- Smaller lamella distance

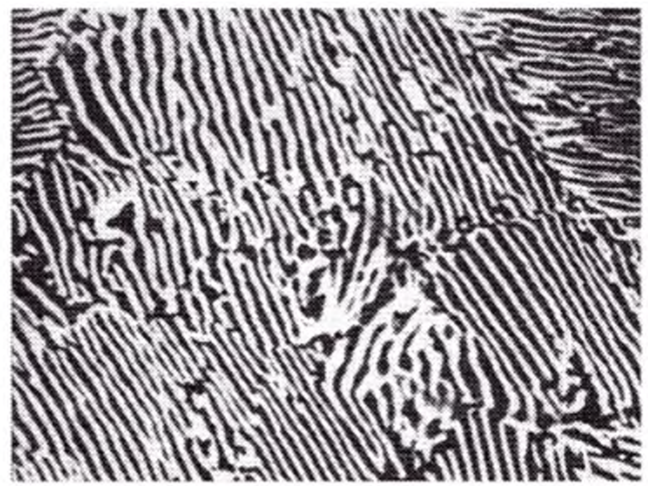
Standard cooling



Accelerated cooling



Grade R260
C: 0.7%



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

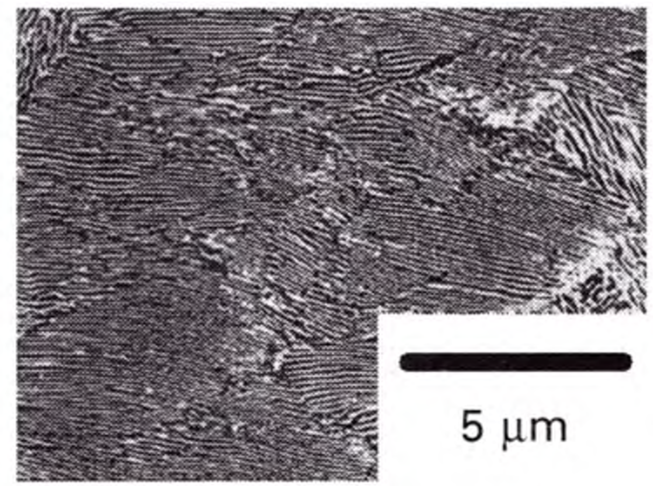
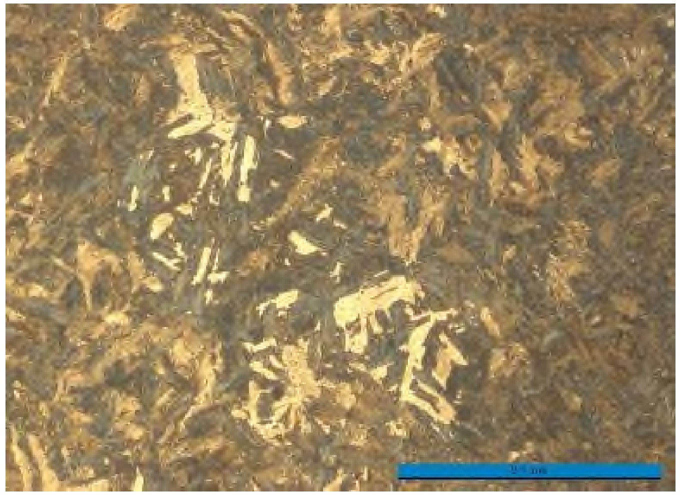
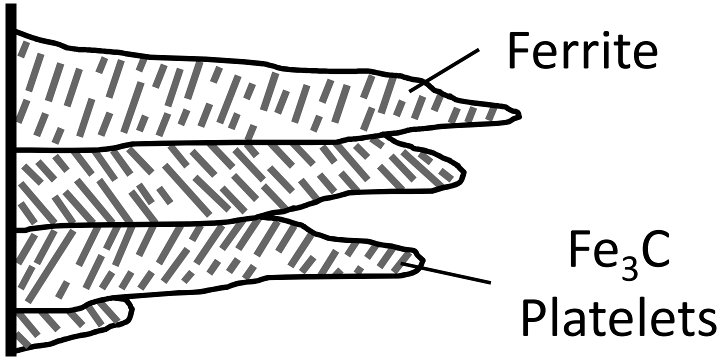


Photo from: Wheel-Rail Interface Handbook.

Bainite

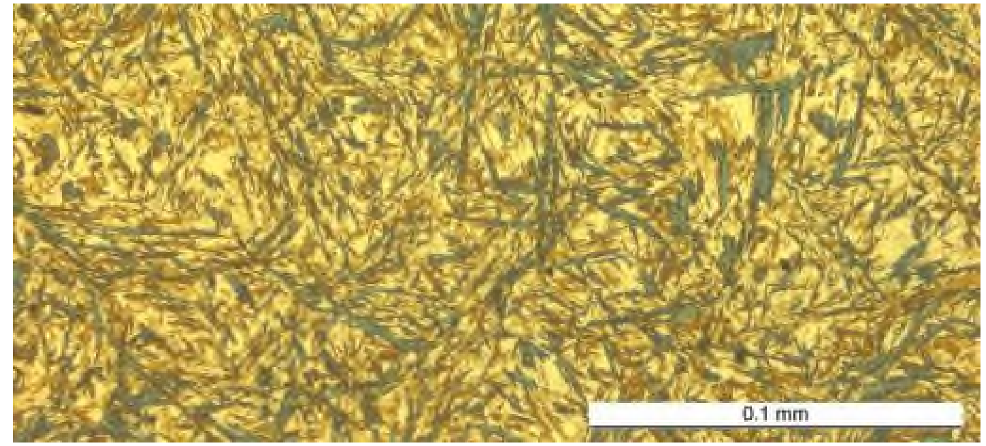
- Two phase material: Ferrite & Fe_3C
- Produced by accelerated cooling or alloying
- Intermediate structure, needle like or plate structure of ferrite and carbide
- Upper, lower or carbide free Bainite
- To some extend used for rail steels

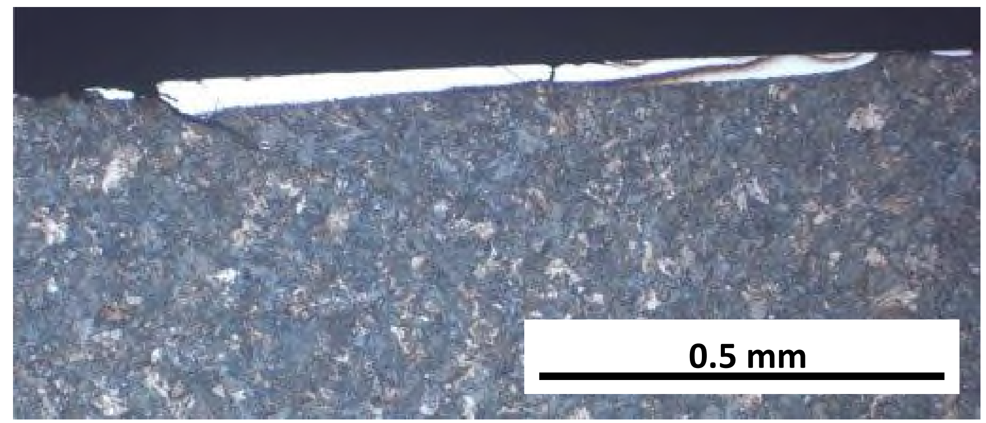




Martensite

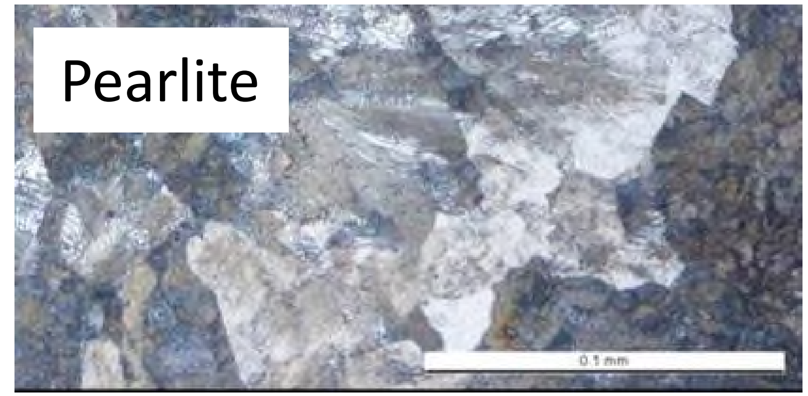
- Produced by high cooling rates, alloying
- Hard (450-760 BHN), low ductility
- Tool steels (cold working-, hot working-, high speed steels)
- Trip steels (transformation induced plasticity)
- Must not have for rail steels
  - The dose makes the poison!
  - White etching layer (WEL) on rail surface

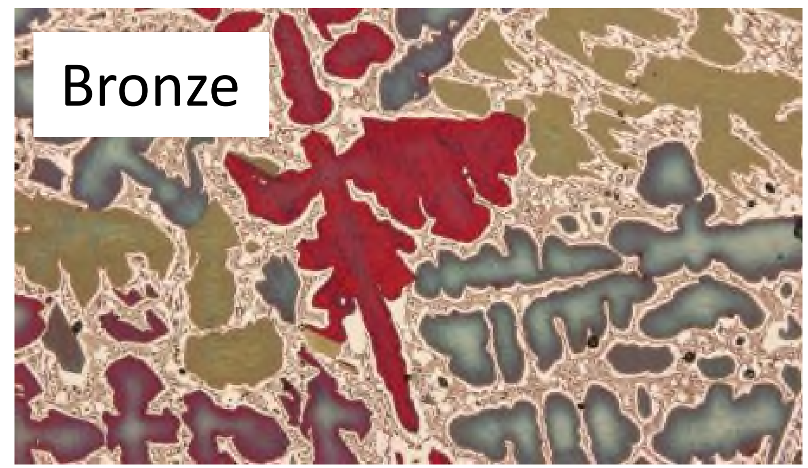




Important to Consider – Properties

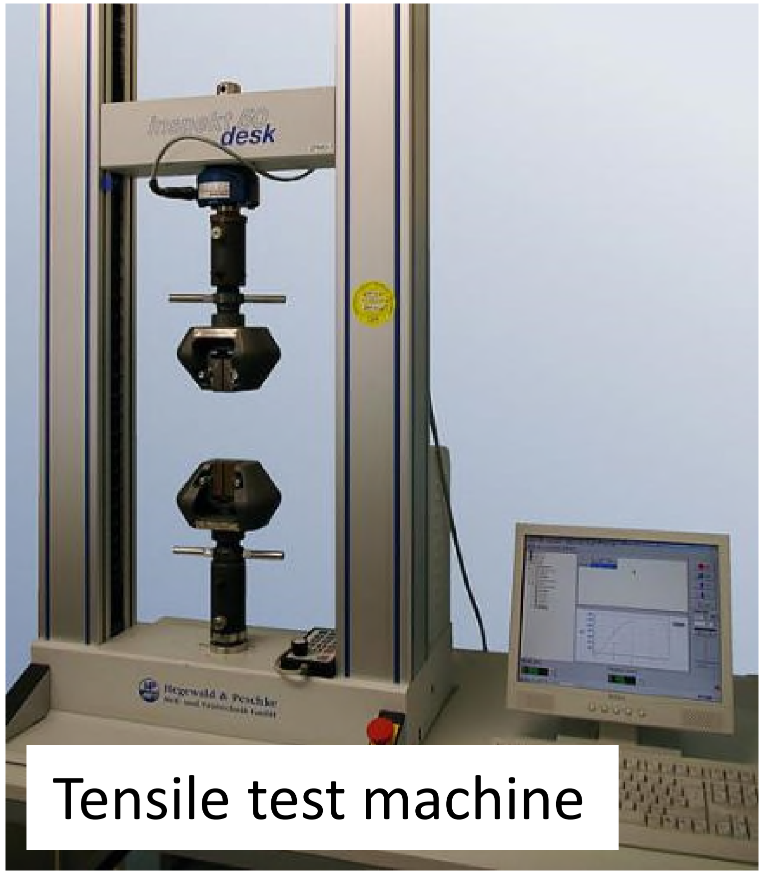
- Different microstructures:
  - different steel types and applications
- Steel material properties:
  - function of the microstructure
  - Hardness, strength, toughness etc.: response of material structure to specific loading/testing situation





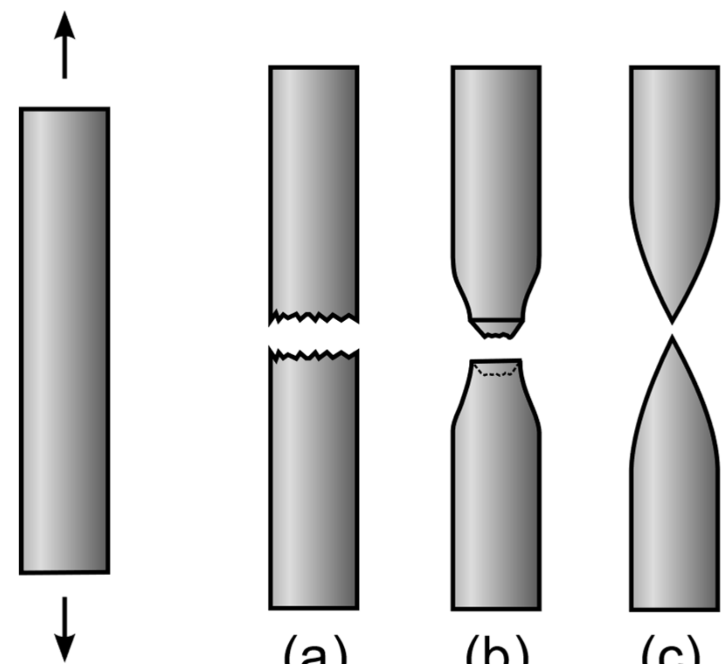
Important to consider - comparability

- Steel material properties:
  - Comparable result only for similar microstructures
  - Loading conditions in wheel-rail contact significantly different from standard test/loading conditions



Important to Consider – Hard and Brittle

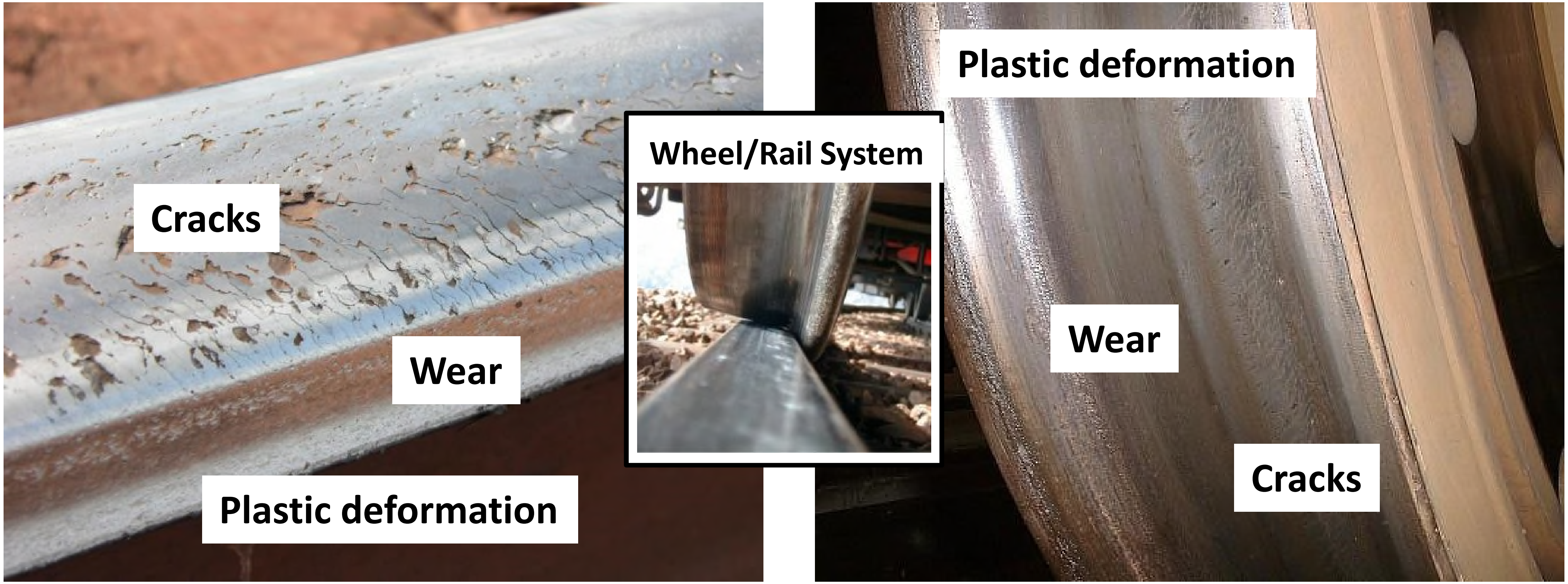
- All rail steels are ductile
  - Different ductility for different grades
  - **No** rail steels shows brittle behaviour
  - However: rail breaks can/will show a brittle fracture component
- Premium steels are heat treated
  - Head hardening only tells half the story
  - Hardness and strength increased



(a) Brittle fracture
(b) Ductile fracture
(c) Completely ductile fracture

WHEEL / RAIL DAMAGE MECHANISMS

System Deterioration



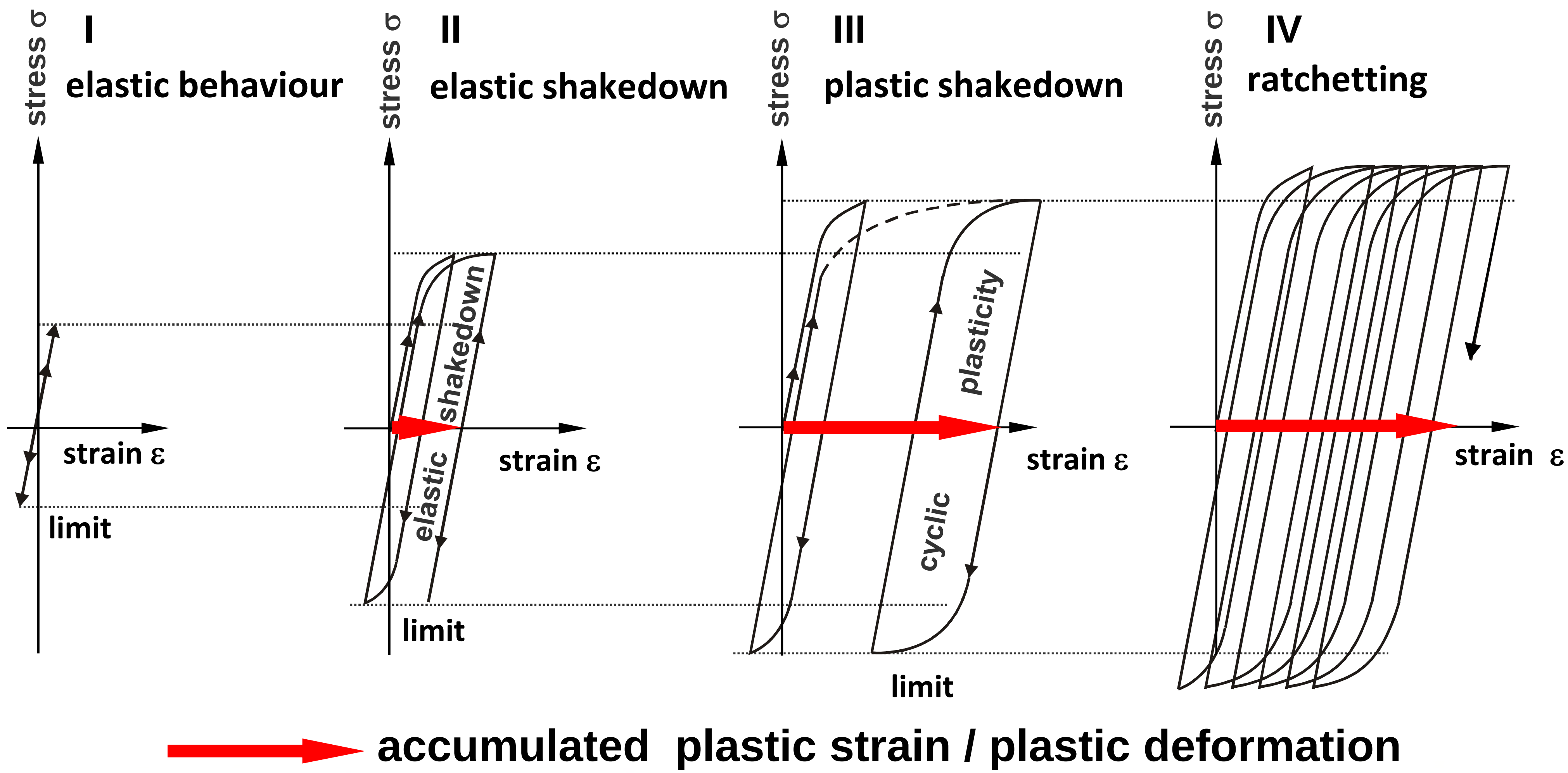
Rail Damage

- Plastic deformation
- Wear
- Corrugation
- Head Checks / GCC
- Flaking and Spalling of Head Checks
- Shelling
- Squats
- Belgrospies
- Wheel Burn

Damage Behaviour

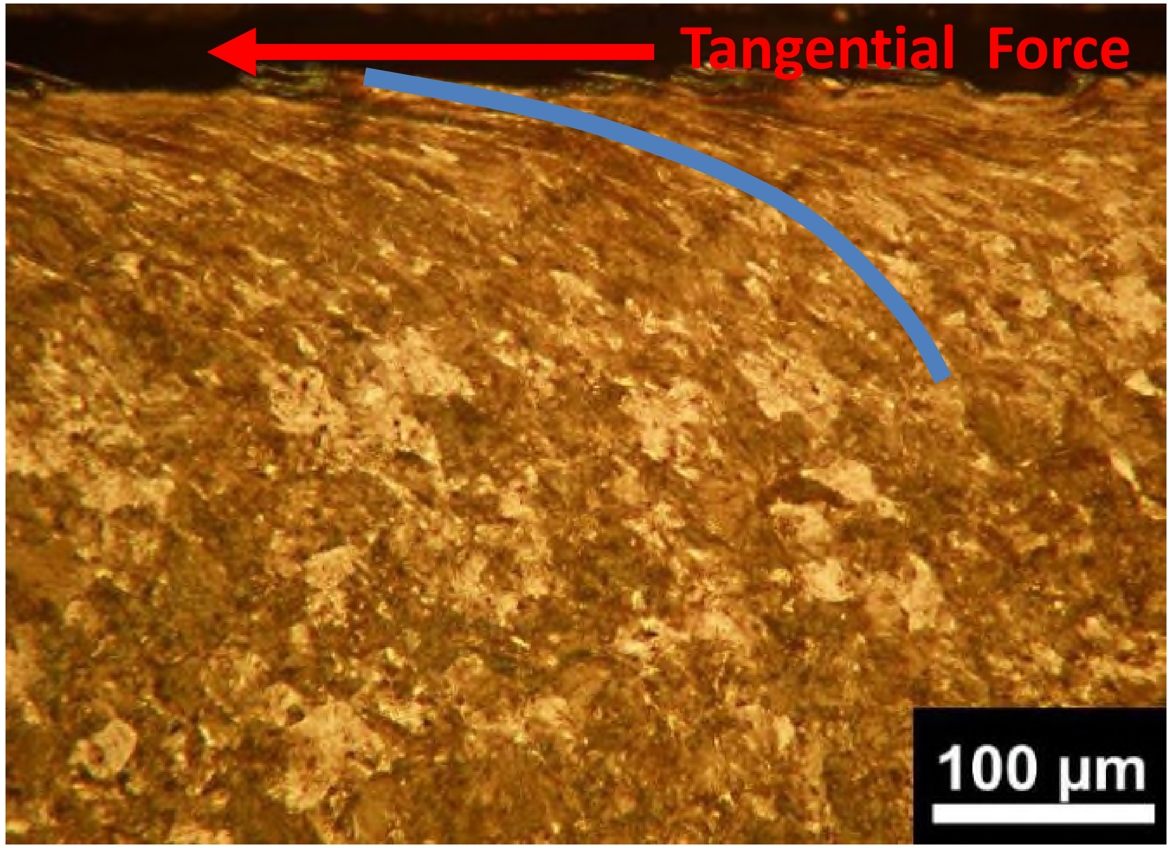
- Material:
  - Material structure (Pearlite, Cementite, Ferrite,…)
  - Mechanical properties (strength, hardness, ductility, …)
- W/R Load:
  - Vertical (contact pressure), tangential (creep, shear)
  - Duration and severity

Material Behaviour Under Load



Plastic Deformation

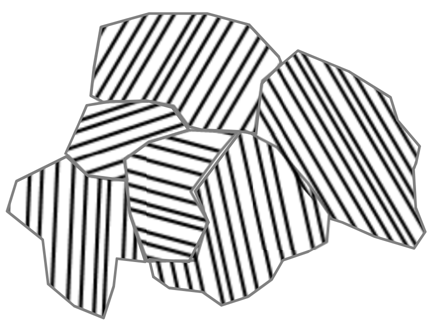
- Contact loads always above elastic material limit.
- On a microscopic scale close to the rail surface.

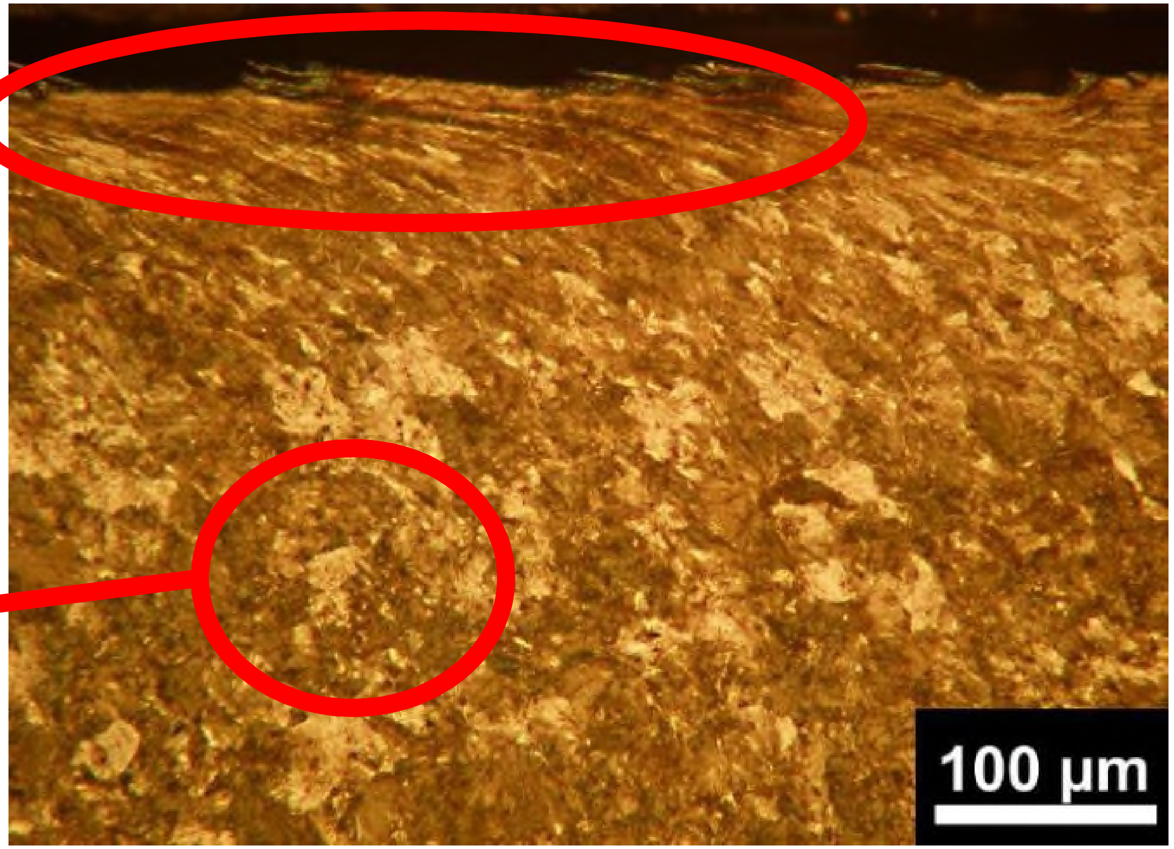


Material Response: Deformation

Severely deformed and aligned material structure at the rail surface

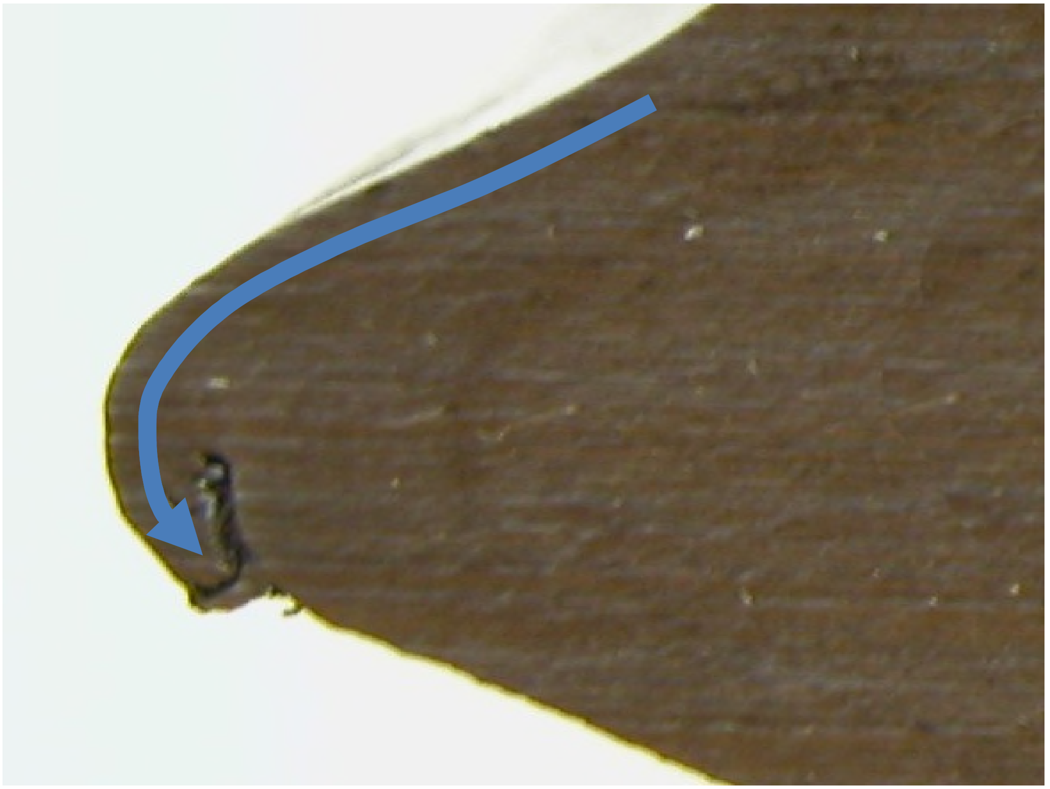
Non-deformed material structure





Plastic Deformation

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



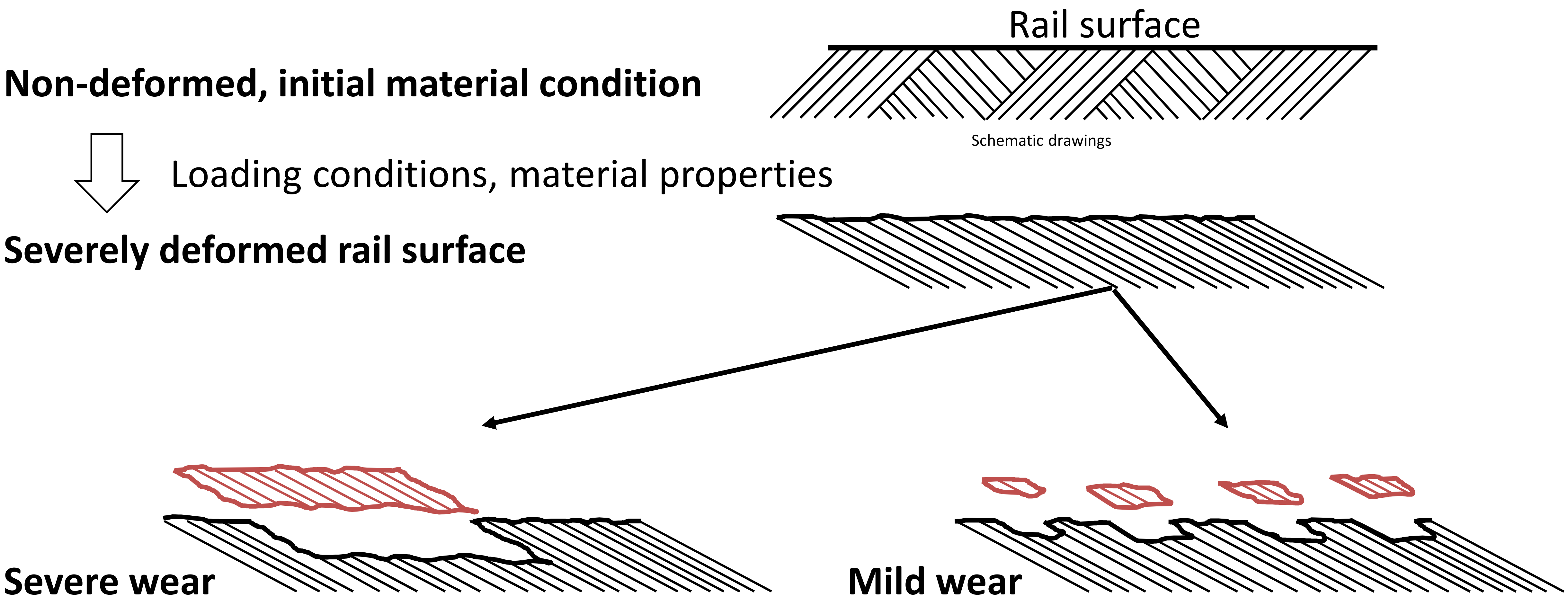
Wear of Rails

- 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

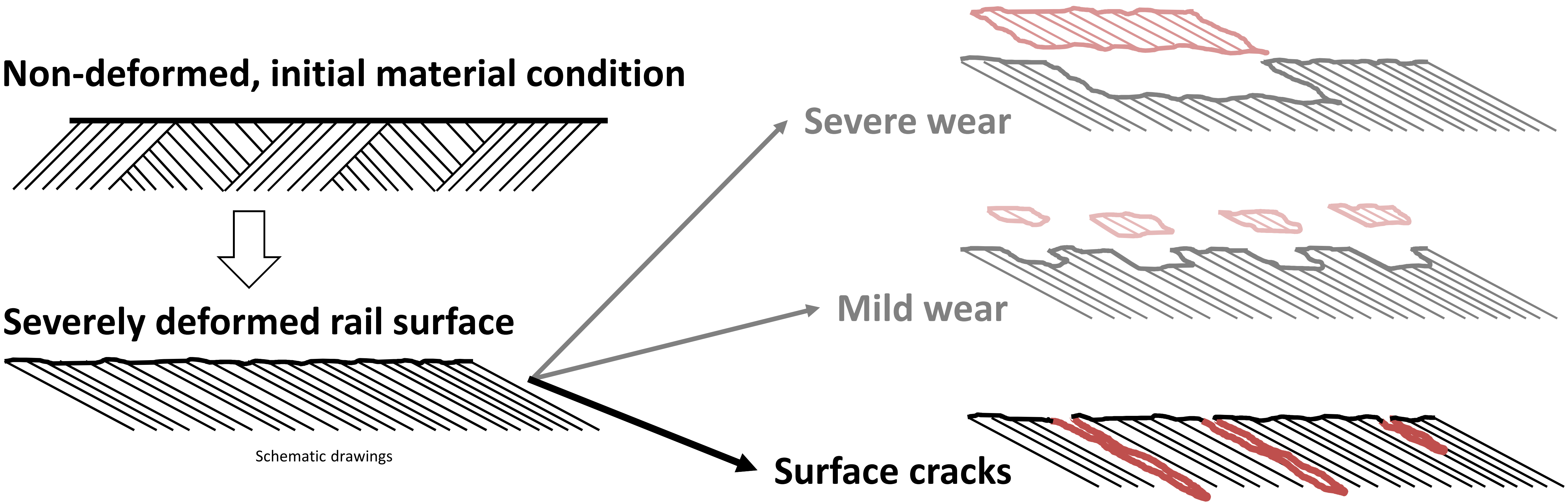


Corrugation

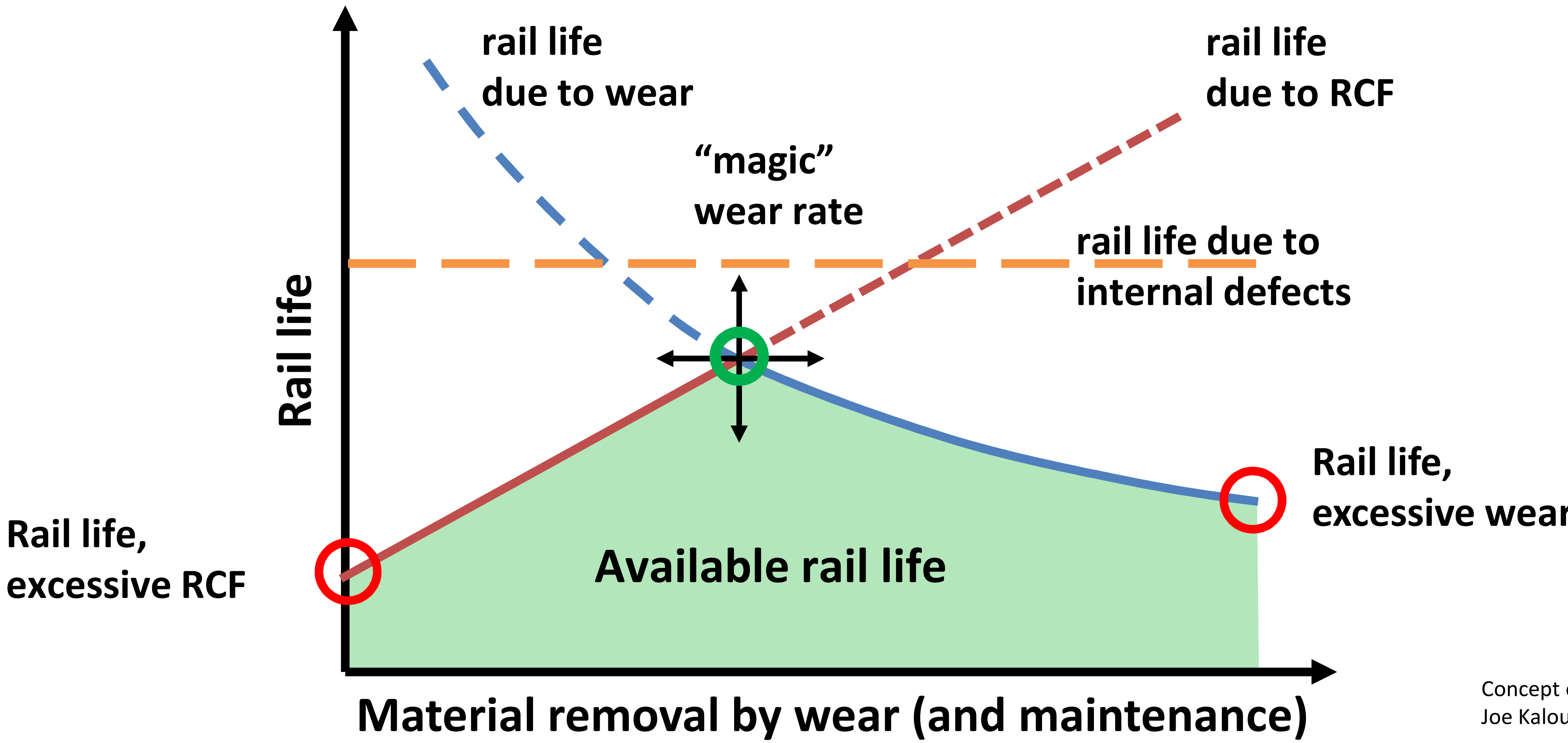
- Wave structure on the rail surface (tangent / curve)
- Short wave (25mm-80mm wavelength) or long wave (100-300mm) corrugation
- Multiple sub-classifications
- Combination of wear and plastic flow

Photos by L.B. Foster

Material Response: Cracks



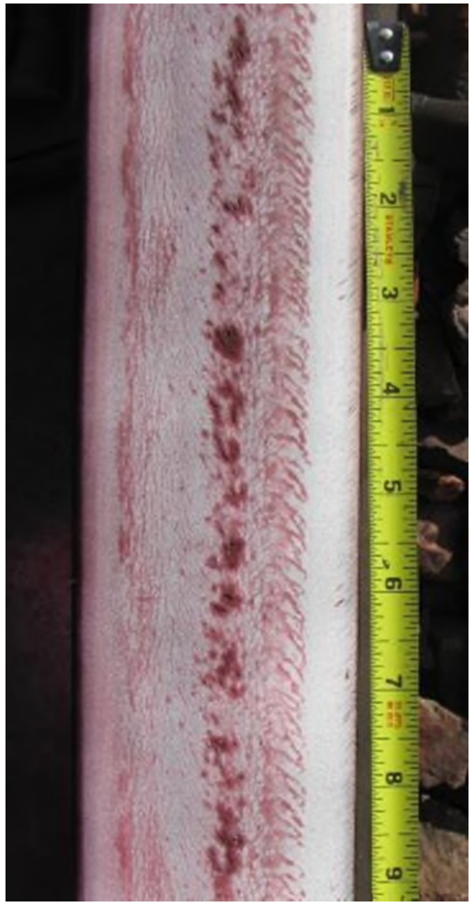
Magic Wear Rate



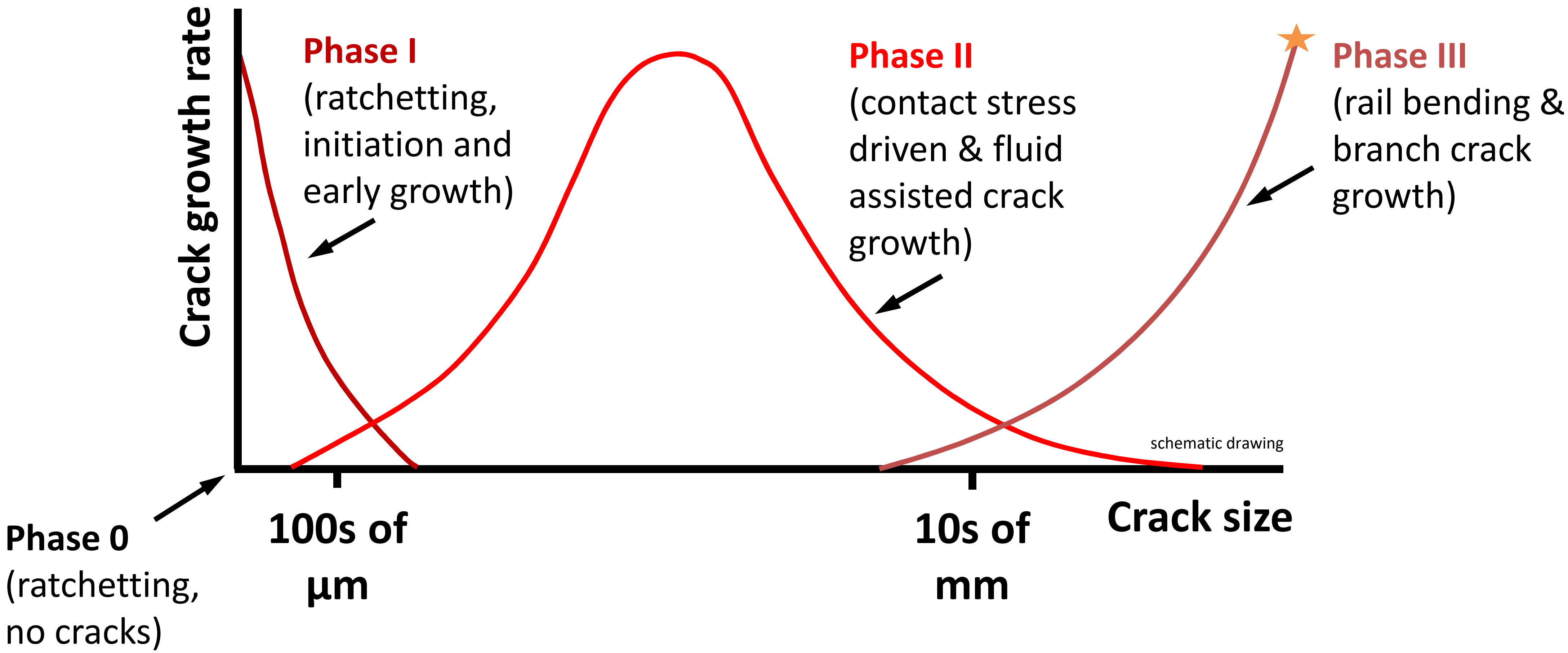
Concept of Magic Wear Rate by
Joe Kalousek and Eric Magel, 1997

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

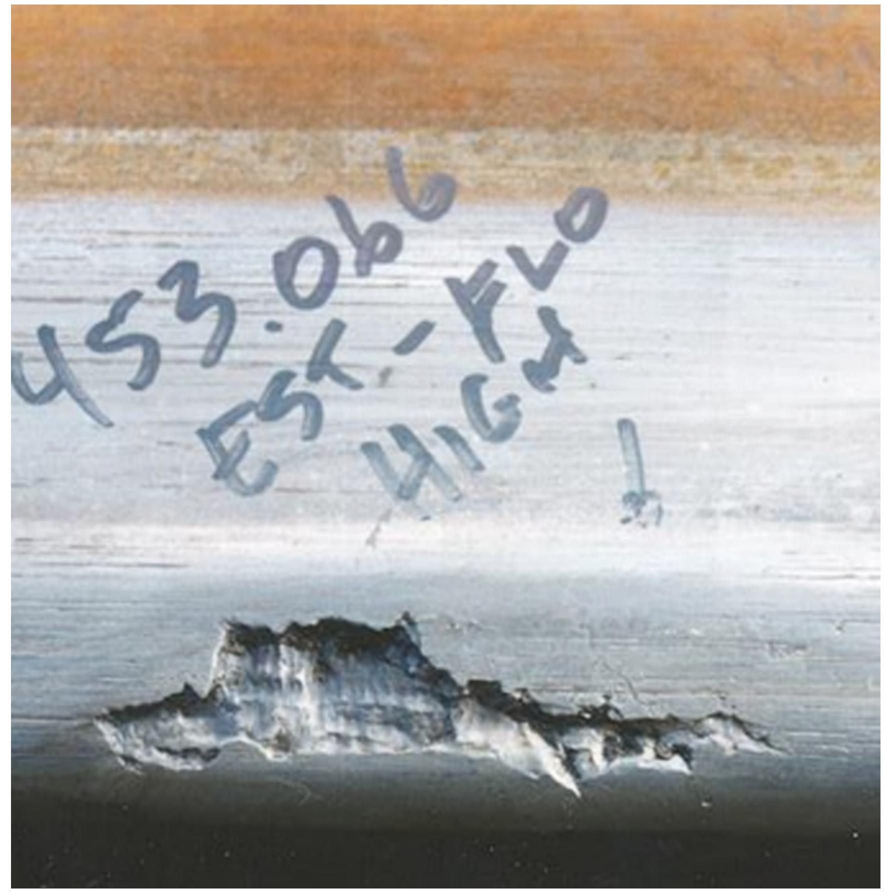


Flaking and Spalling

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

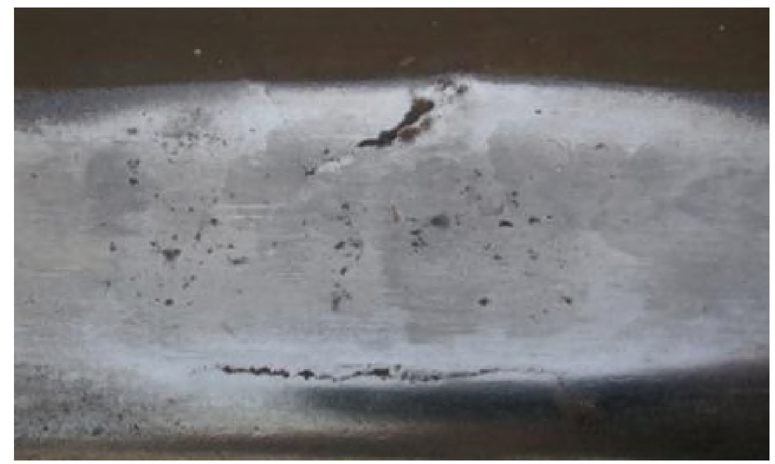
Shelling

- 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



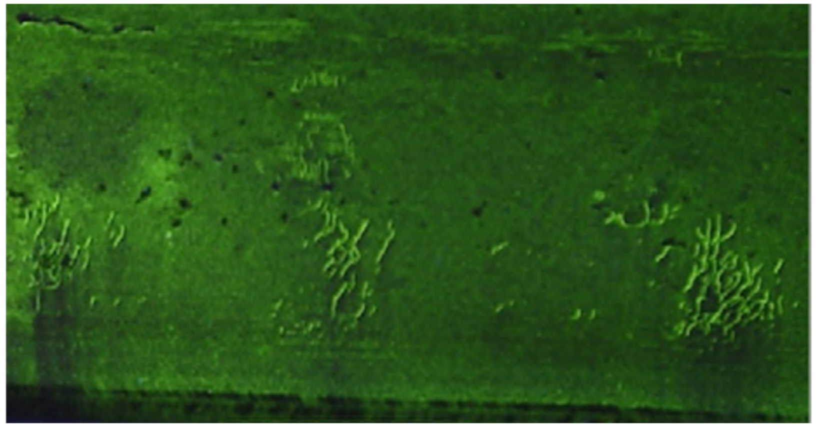
Photos by voestalpine

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

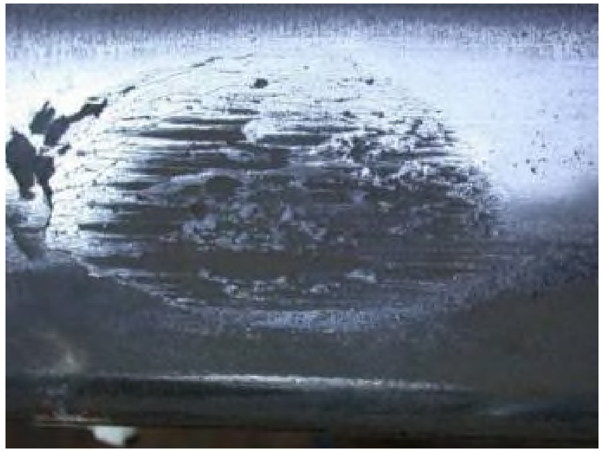
Belgrospies

- 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

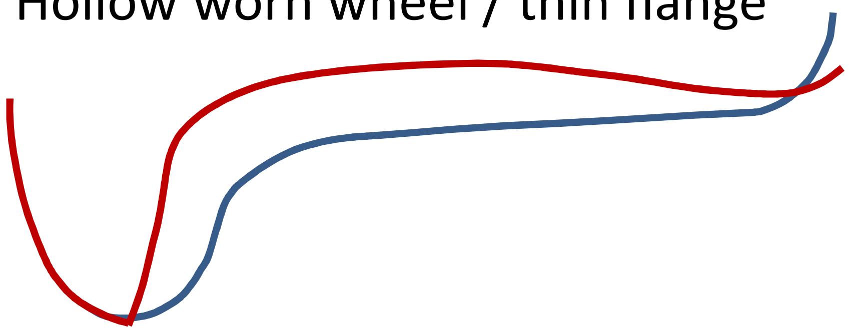


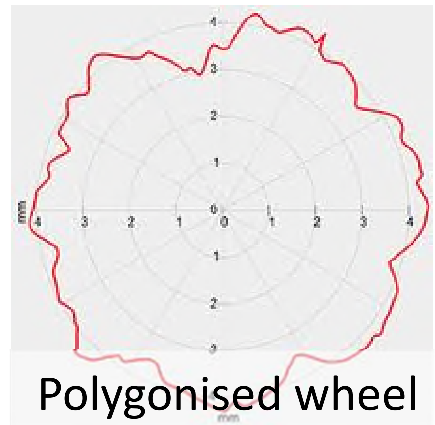
Selected Damage on Wheels

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

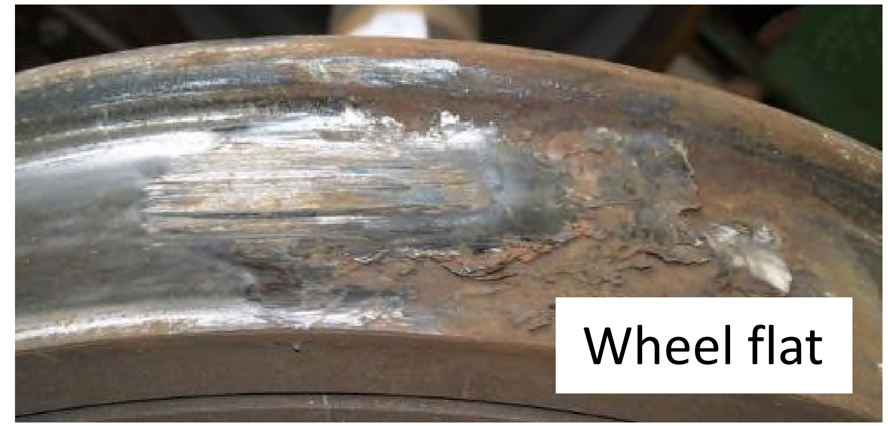
Wheel damage examples

Hollow worn wheel / thin flange

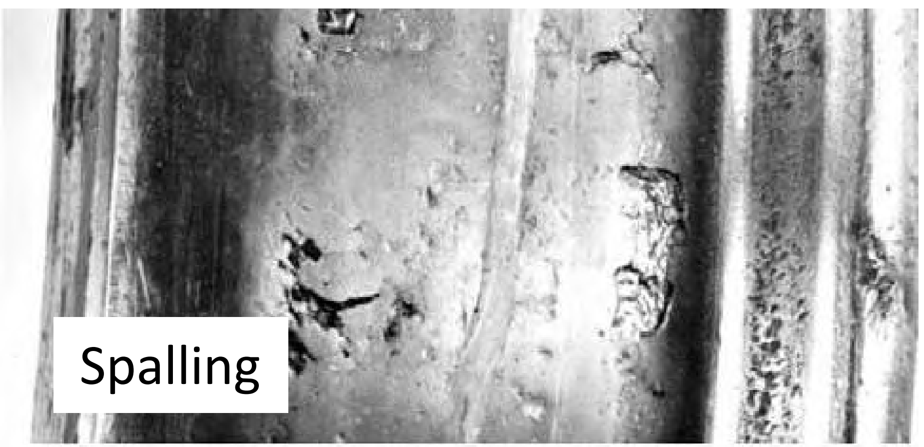




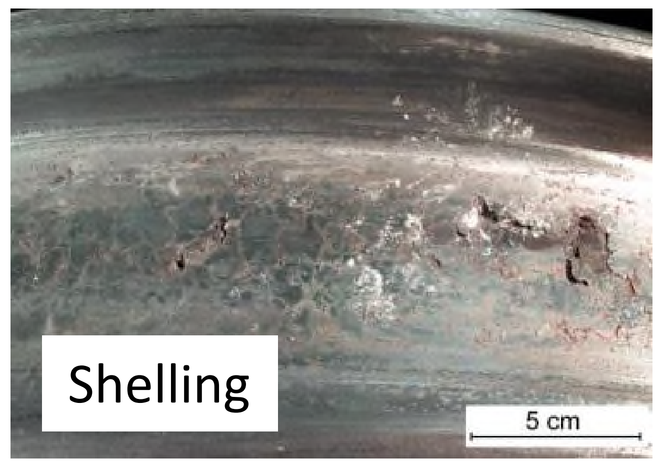
Polygonised wheel



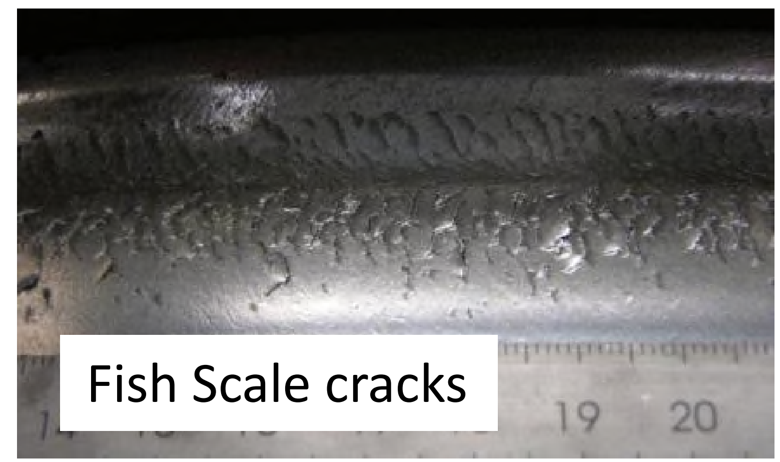
Wheel flat



Spalling



Shelling



Fish Scale cracks

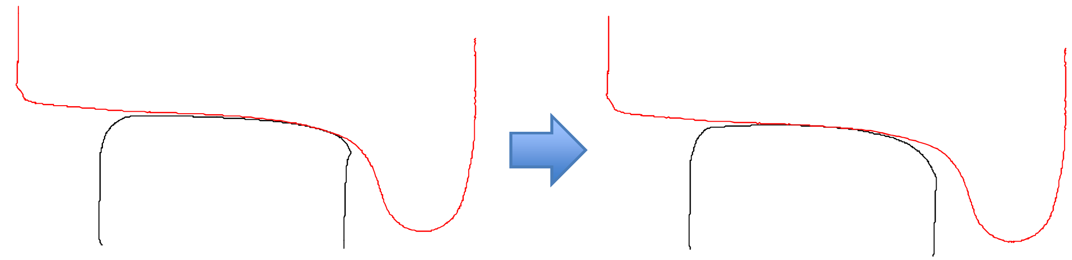
CONTROLLING RAIL DAMAGE

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

Controlling Rail Damage: Contact

- Profile optimisation
  - Reduction of contact stresses
  - Improved steering
- Track geometry optimisation
  - Reduced dynamic forces



Controlling Rail Damage: Friction

- Friction Management
  - GF & TOR friction control
  - Improved steering
  - Reduced (tangential) contact stresses
  - Reduced plastic flow, wear and RCF

Photo by L.B. Foster Rail Technologies

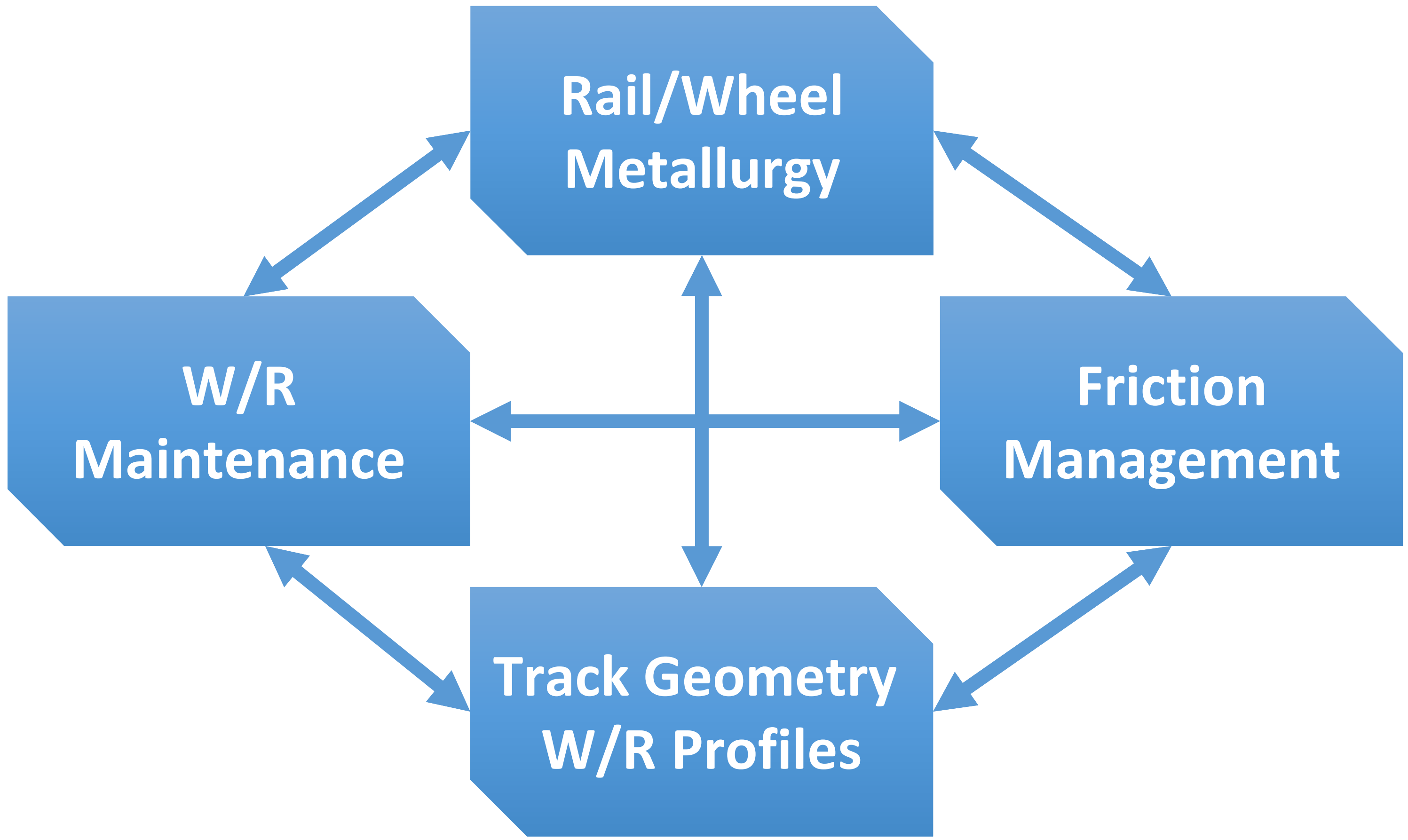
Controlling Rail Damage: Maintenance

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

Summary

- Steel material microstructure
  - Microstructure determines properties and behaviour
  - Typical rail steel: pearlitic steel
- Rail / wheel damage types
  - Plastic deformation, wear, cracks
- Controlling rail damage
  - Material selection, w/r profiles, track geometry, friction management, rail maintenance

Rail/Wheel System Management



Thank You for Your Attention

Questions?