



Materials Testing of Railway Wheelset Components

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Essen – World Heritage „Zeche Zollverein“

Company

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Location

Essen (Ruhr Area),
World Heritage „Zeche Zollverein“



Business Fields:

Materials Testing

- Accredited testing lab (EN17025)
→ Testing of wheels, axles, rails, ...

Consulting

- Accredited inspection body (EN17020)
→ Failure analysis of railway components
→ Technical approval of railway NDT processes
→ Appointed expert of the German federal railway authority

Training

- Certified and approved training facility (ISO 9001, DGZfP)
→ Destructive testing, non destructive testing
→ Heat treatment, materials engineering

- Carrying the load of the vehicle
- Guiding the vehicle on track
→ Straight track and curves
- Transmission of acceleration forces
- Transmission of deceleration forces
- Wheels part of braking system
→ Tread of freight waggon wheels
- Assuring high running comfort
→ Passenger traffic



Finished railway axles



Finished railway wheels

Wheel hub

Axle-wheel interference fit assembly

Wheel centre

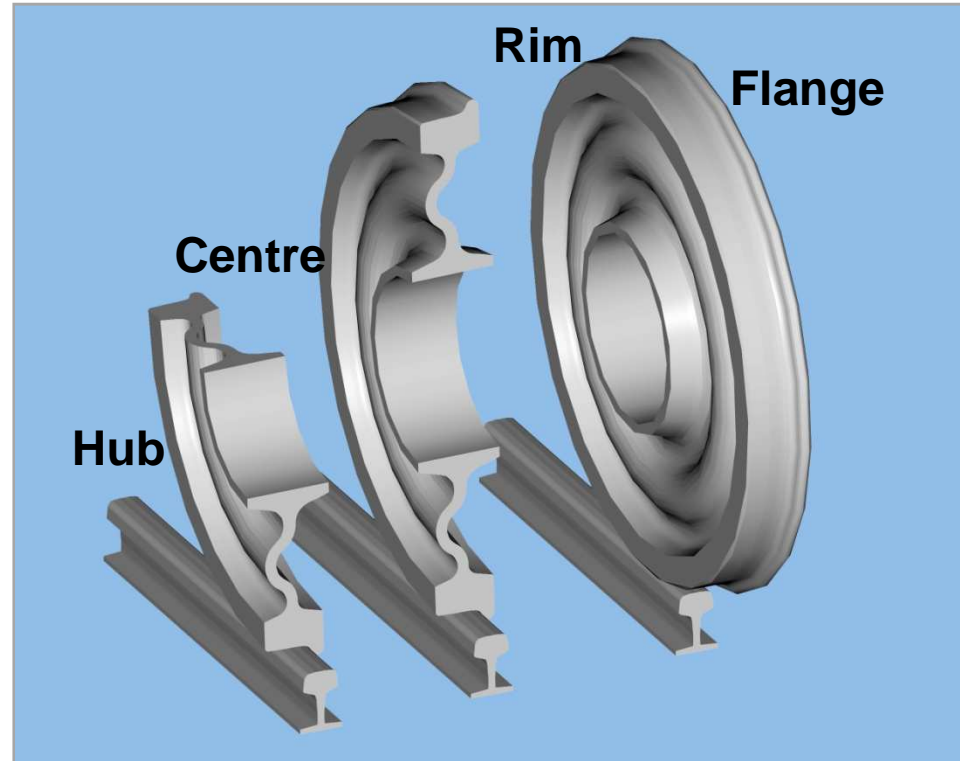
Flexible hub-rim connection

Wheel rim

Running surface, rail-wheel contact

Wheel flange

Guidance of the wheel set on the rails



Functional elements of a wheel

Summary

Different functional elements need different properties!

Manufacturing and testing have to address that!



- **Static axle loads**
 - Wheelset loads up to 25 to (and more)
- **Dynamic loads**
 - Speeds partly far beyond 300 km/h
 - Load cycles far beyond 10^7 (one trip from Hamburg to Munich and back: $5,5 \cdot 10^5$ cycles)
- **Fatigue – depending on the wheelset type**
 - Rolling contact fatigue
 - Bending fatigue („basic“ fatigue process)
 - Torsional fatigue (driven wheelsets)
 - Thermal fatigue (braking of the treads)
- **Wear due to rail wheel contact**
 - Tread: running comfort
 - Flange: safe guidance
- **Corrosion and surface damages** during service
- **Temperatures** between -50°C and $+50^\circ\text{C}$



High speed wheelset

Residual stresses

→ Requirement: compressive circumferential stress

Ultimate strength

- To be tested per batch
- To be tested in different areas of the components
- Values restricted to a min.-max. range
- Typical values: 600 – 1000 MPa

Yield strength

- To be tested in different areas of the components
- Minimum values required
- Typical values: 400 – 600 MPa

Hardness

- Wheel surface: 100%
- Cross section: to be tested per batch
- Minimum values required – depending on speed

Toughness / elongation / reduction of area

- To be tested in different areas of the components
- Typical impact „toughness“: starting from 5 J
- Typical elongation 15 – 20%



Tensile test on railway steels



Typical tensile sample

Fatigue strength

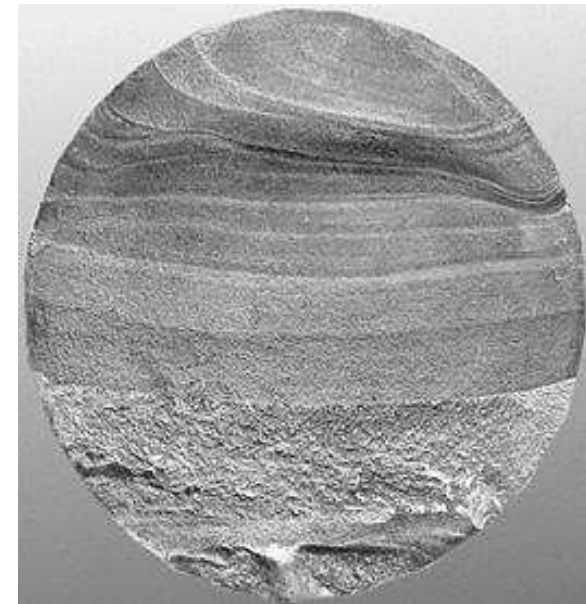
- Values and testing conditions defined by railway standards
- Especially important for axles (fatigue endurable design)
- Typical values: 200 – 450 MPa

Crack propagation rate

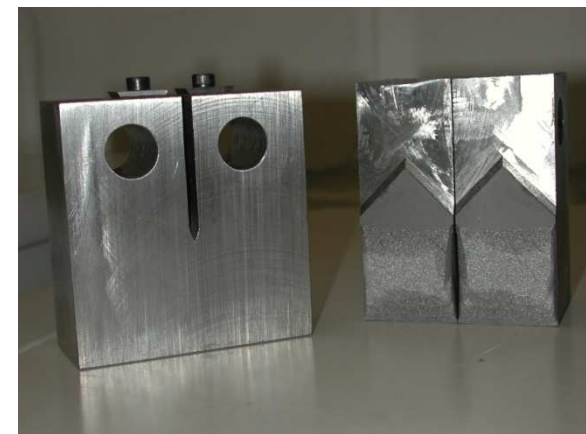
- Not defined by standards
- Increasingly important to define NDT testing intervals

Fracture toughness

- Relevant for freight waggon wheels
- Defined by railway standards
- Result: K_Q -values (due to sample geometry)
- Typical values: 80 – 100 MPa $\cdot\sqrt{m}$
- Two-step testing: pre-cracking and tensile test (rupture)



Fatigue failure of an axle



Compact tension fracture toughness samples



Residual stresses

- Product qualification: by strain gauge, X-ray diffraction or ultrasonic measurement
- Production: saw cut
- Typical value: -100 MPa or 1mm (wheel rim)

Fatigue strength

- During design and product qualification
- Testing of wheels and axles
- Supported by FEM calculations
- Main test system in Germany: resonance pulsator

Brake test

- For freight waggon wheels (1:1 Test)
- Testing for geometric stability and crack resistance (thermal stresses)



In-production measurement of residual stresses



Fatigue test (source: www.sincotec.de)



- Unalloyed (wheels) or low-alloyed (axles) steels
- High quality steel with high degree of purity (important for fatigue behaviour)
 - Minimised S- and P-content
 - H-content below 1,5 - 2 ppm
- Main difference in steel grades:
C-content (0,25 – 0.65 % carbon)
- Narrow tolerances of the main alloying elements (e.g.: C-content of the cast/product analysis within range of 0,04%)
- Testing by optical emission spectrometry and metallography
- **„Ordinary“ steels, but very well done!**



High quality steel making



Blue brittleness test for non-metallic inclusions



Primary material

- Ingot casting
- Continuous casting

Objectives of hot forming

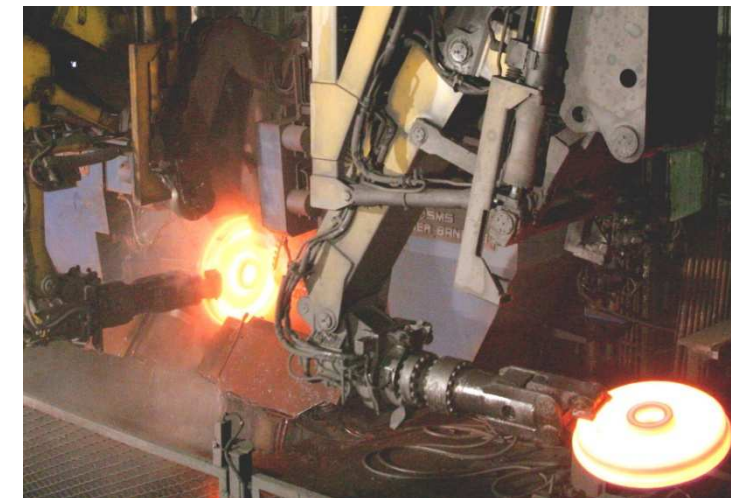
- Removal of defects such as pores and shrinkages cavities (degree of deformation - reduction of cross section - up to 5x)
- Optimising the grain flow towards geometry (beneficial for fatigue behaviour)
- shaping

Control of hot forming by

- Ultrasonic testing
- Laser based measurement of geometry
- Metallography (hot etched slices)



Forging of axles



Rolling of wheels



Desired microstructure

- Axle: Quenched and Tempered
- Wheel: Pearlite-Ferrite
- Fine grained (class 6 and better)

Targets of microstructural design

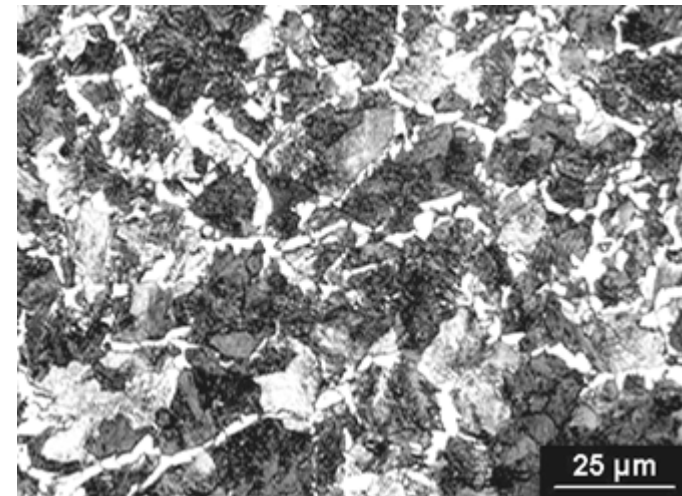
- Axle: strength and fatigue strength
- Wheel: strength and optimised wear
- Wheel: homogeneous structure in circumferential direction
- Wheel: minimal changes of structure / properties along rim cross section

Testing methodes

- Metallography
- Hardness profiles



Heat treatment of wheels



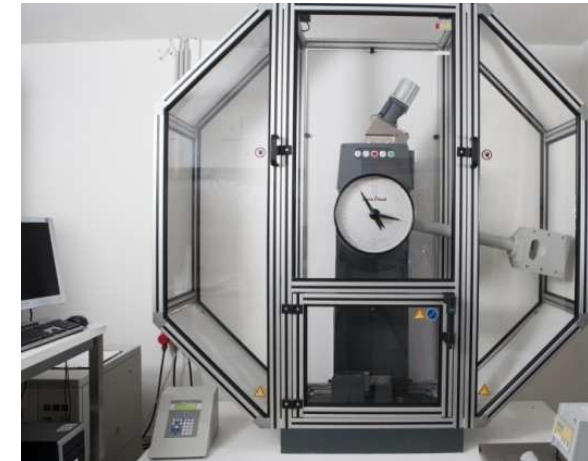
Pearlitic-ferritic microstructure of a wheel steel



Microstructure defines mechanical properties!

Typical amount of testing

- Hardness (100% of the batch)
- Residual stress (per batch)
- Hardness (cross section)
- Tensile samples from different locations (ultimate strength, yield strength, elongation)
- Impact toughness samples from different locations and at different temperatures
- Fracture toughness
- Microstructure
 - Phase composition
 - Grain size
 - Cleanliness
- Testing frequently on-site-monitored by state-owned railway operators / classification societies



Impact toughness test



Impact samples (Charpy-U)

Dimensional control

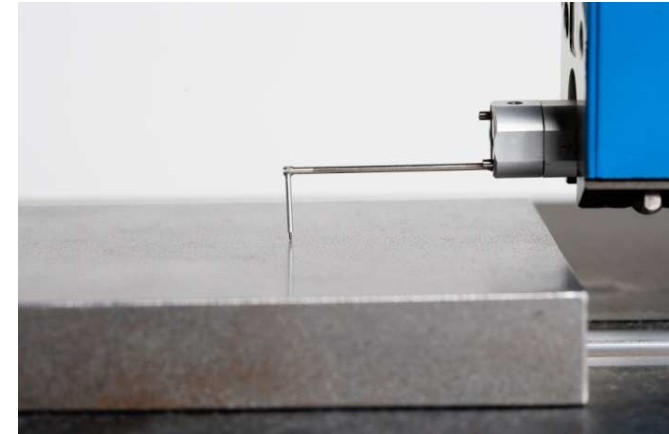
- Accuracy to 1/1000 mm (axle journals, seats)
- Out of roundness less than 5/100 mm for wheel diameters of up to 1250 mm

Roughness

- R_a less than 1,6 μm (for fatigue reasons)
- Problem: fatigue improvement vs. adhesion of paint

Non destructive testing

- Carried out by certified staff
- 100% visual inspection (VT) of the components
- 100% surface crack detection by magnetic particle testing (MT), acceptance criterion can be as low as 1mm
- 100% ultrasonic volume testing – partly up to 4x per piece



Roughness measurement



Non destructive testing of an axle

Conditions of components are intensively monitored during service and maintenance

Testing is mandatory and defined by standards

Testing intervalls ranging from several 10.000 km to several 100.000 km (depending on type of vehicle and service conditions)

Extent of testing

- Visual testing (surface damages and corrosion) of wheels and axles (e.g. EVIC catalogue)
- Magnetic particle testing of wheels and axles (surface defects)
- Ultrasonic testing of wheels and axles (surface defects)
- Residual stress measurements



Ultrasonic testing of a railway wheel



In-service residual stress measurement



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Thank You for Your Attention!

