voestalpine´s Field Tests of Advanced Rail Steels

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Rail Field Testing at Different Conditions

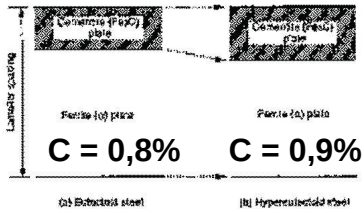
Rail Damage – Requested Material Properties

curve	radius [m]	damage	requirements for rail
tight	< 700	wear	highest wear resistance
average	500 – 2000	head checks	long HC incubation period slow HC growth
wide	1500 – 6000	corrugations squats belgrospies	high yield strength long HC incubation period
tangent	> 3000	corrugations squats	high yield strength long HC incubation period

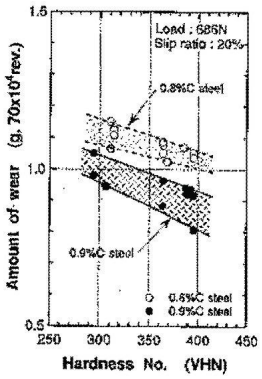
Advanced Pearlitic Rail Steels

Grade	composition	properties
R350HT	according EN13674-1 traditional HSH®-rail	approx. 370 BHN, wear rate approx. 1/3 of R260
R350LHT	according EN13674-1 HSH®-rail with Cr ~ 0,25 %	approx. 380 BHN, well established heavy haul grade of the 90s
370LHT	HSH®-rail with Cr ~ 0,50 %	390 – 400 BHN, higher wear and RCF resistance
400UHC	R350LHT with approx. 0,95 - 1,00 % Carbon – hypereutectoide rail steel	400 – 440 BHN, today highest wear resistance

Hypereutectoide Rail Steels – UHC Concept



Thicker cementite lamellae increase wear resistance



Lab testing:
10 – 20 % less wear

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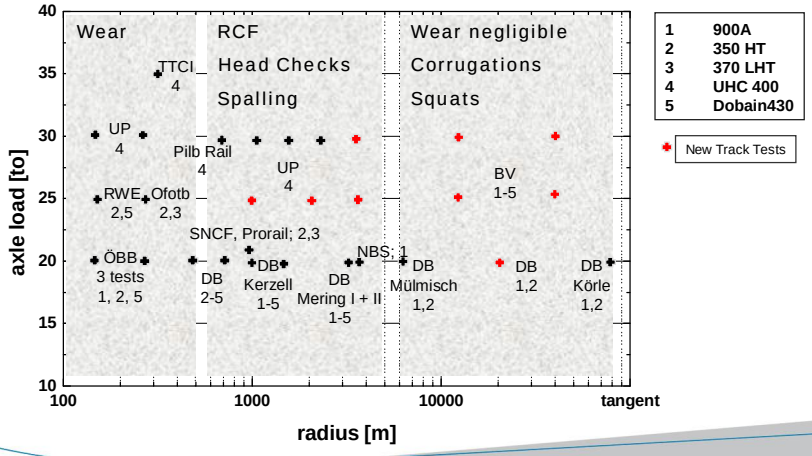
voestalpine‘s Track Tests



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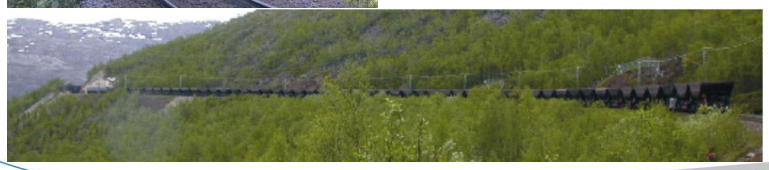
Track Testing at the Ofotbanan/Norway

- Iron ore line – LKAB
- 50 % curves with R < 500 m
- 40 % declanation with 20 ‰
- Axle load 25/30 tons
- 30 Mio t/a

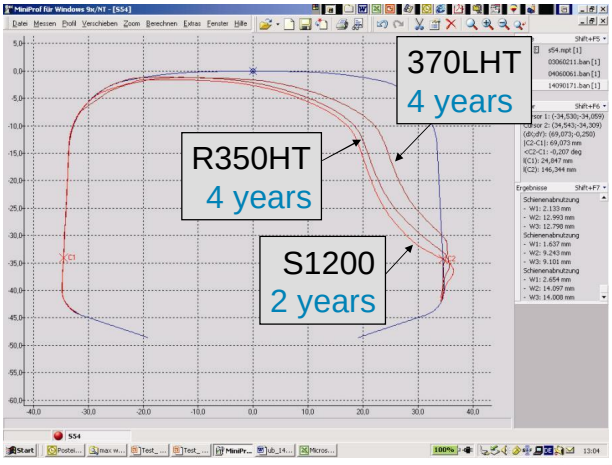


Track Testing at the Ofotbanan/Norway

Ofotbanan – Test Conditions

- status 1997 – Micro-alloyed S1200 best solution
- Test with head hardened rail steels:
  - R350HT – 370 BHN
  - 370LHT – 390 BHN
- Critical topic: aluminothermic welds

Ofotbanan – Wear Measurements



Ofotbanan – RCF Performance

- R350HT – 370 BHN
  - Head checks
  - Spalling
  - One year of service

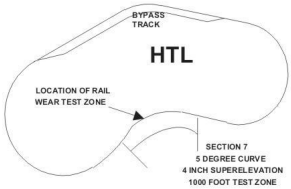
- 370LHT – 390 BHN
  - Head checks
  - No spalling
  - Two years of service

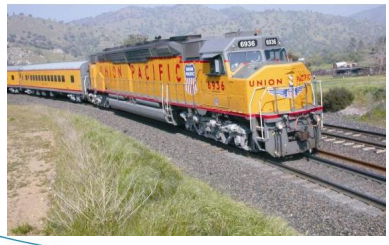
Ofotbanan – Weld Performance

- Z90HC weld:
  - Some battering
  - Spalling next to weld

- HPW weld:
  - Less battering
  - No spalling next to weld
  - Approved!

Track Testing with US Heavy Haul





- TTCI Pueblo:
  R = 350 m
  110 Mio to/a
  4 years
- Union Pacific:
  R = 175 – 250 m
  approx. 130 Mio to/a
  2 years
- Test rails:
  UHC 400 with 420 – 440 HB

Track Test with Union Pacific

- Photo shows typical surface after one year (!)
- Conclusions:
  wear resistance of newest generation pearlites is approx. 15 % higher compared to 400 BHN steels
  all manufacturers within ± 5 %
- New test with UP:
  R = 800 – 2000 m
  Focus: **RCF-performance**

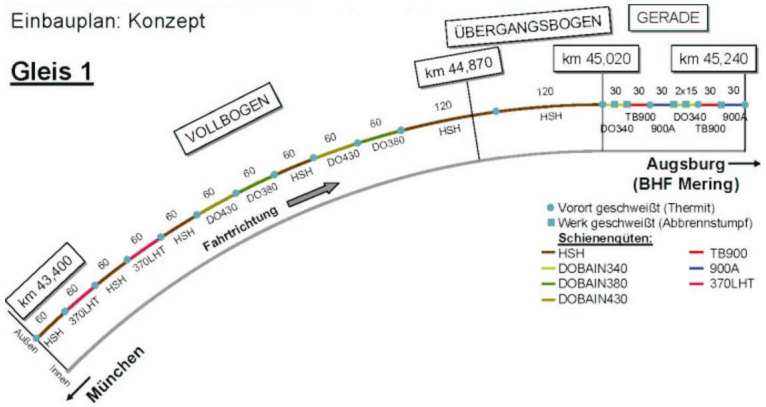
Summary of the Wear Tests

- Testing in tight curves confirm that:
- Wear resistance increases with rail hardness:
- R260 – HSH = 1 : 3
- HSH – 370 LHT = 1 : 2
- HSH – UHC 400 = 1 : 3
- Reduced RCF-damage at higher rail hardness

RCF Study with DB AG

- Comprehensive track testing at medium and high speed lines
- At tight, medium and wide curves
- Mixed traffic up to 22,5 to axle load
- 90.000 to/day – highest daily loads available at DB
- Monitoring, documentation and conclusions by FTZ

Track Testing – Typical Layout



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Wear and Corrugation Measurements

- Crossectional profiles: Miniprof
- Longitudinal profile: RM1200

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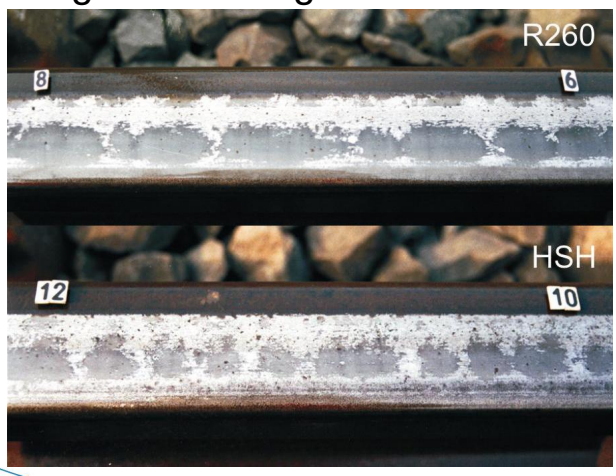
RCF – Crack Characterization

- Magnetic particle inspection
- In-Track Eddy current testing
- Metallography of cut samples

High Speed Line Hannover-Würzburg

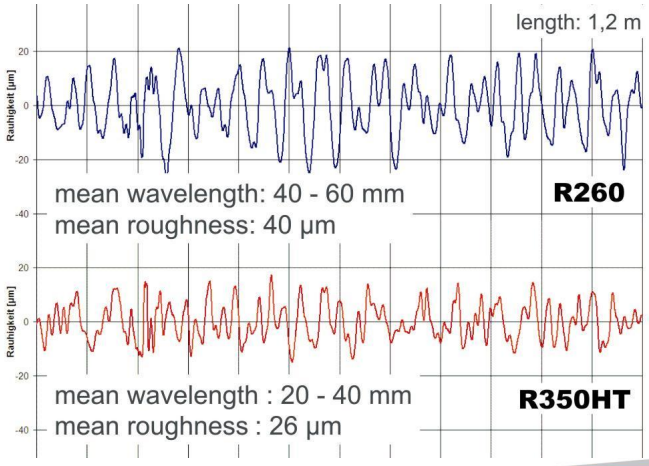
- Speed up to 280 km/h = 175 mph
- Mixed traffic up to 20 to/axle
- R = tangent, 6.000 m
- Load: 60.000 to/day
- Rail grades:
  - R260
  - R350HT (HSH)
- Track inspection and measurements by DB-Systemtechnik at ½-years intervals
- Testing for 3 years

Tangent – Corrugations after 66 Mio to



- Surfaces etched to show the White Eching Layers (WEL)
- WEL identifies damaged material
- Can be starter for vertical cracks

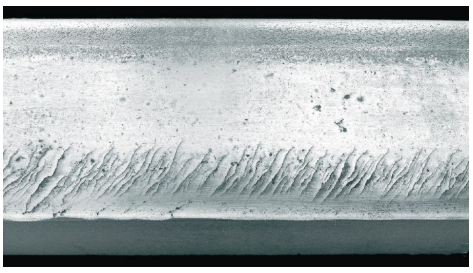
Longitudinal Profiles after 66 Mio to



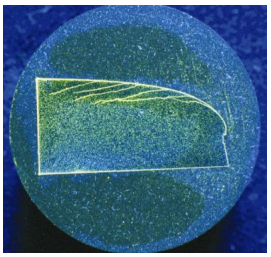
Medium Speed Line München-Augsburg

- Speeds up to 200 km/h
- Mixed traffic
  up to 22,5 to/axle
- R = 3.300 m
- Load: 90.000 to/day
- Three rail grades:
  - R220 (800)
  - R260 (900A)
  - R350HT (HSH)
- Track inspection and measurements by DB-Systemtechnik at ½-years intervals
- Testing for 3 years

Compare:
Head Checks on the Old Grade 900A Rails



- Rail surface after 9 years
- 300 Mio to total load
- Grade 900A

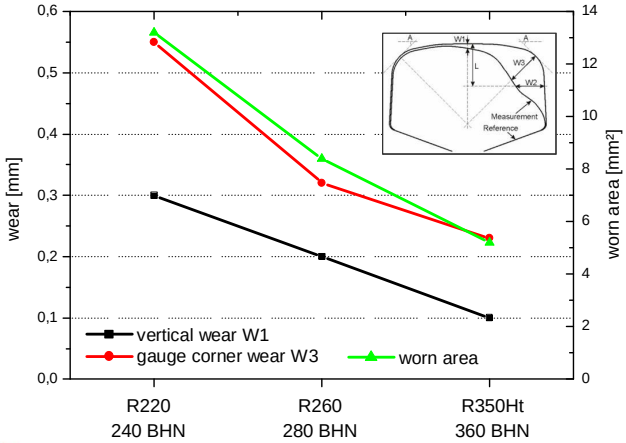


- Severe head checks
- 5 mm deep (!)
- Rail was never ground
- Had to be replaced

Results after 3 Years – 100 Mio to

- Wear
- Head Checks

Wear – Cross Sectional Profiles

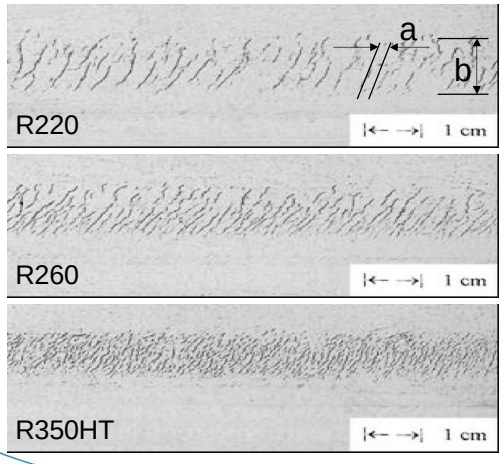


- Higher hardness
- Less wear

RCF-Defects at Three Different Grades

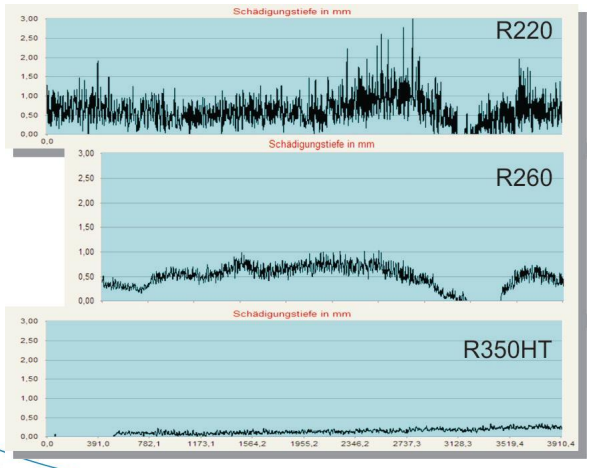
- All three in the same curve
- 800 – softer than usual
- 900A – regular steel grade for these curves
- HSH – head hardened rail steel

Dimensions of the Head Checked Area



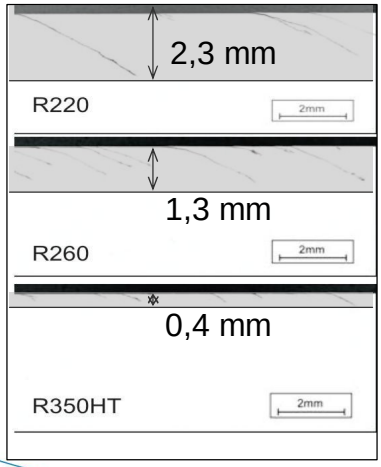
grade	a [mm]	b [mm]
R220	1,7	18
R260	1,2	15
R350HT	0,8	12

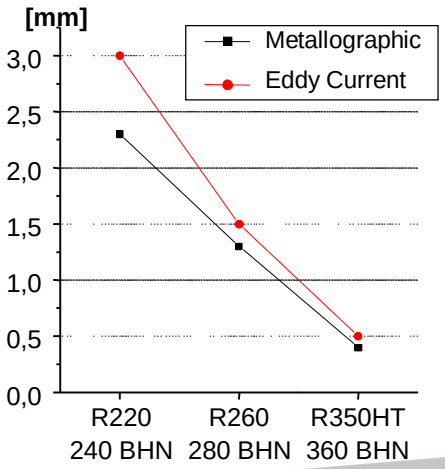
Crack Depth – Eddy Current Testing



Crack depth [mm]		
grade	mean	Max.
R220	1,5	3,0
R260	1,0	1,5
R350HT	0,3	0,5

Crack Depth – Metallography





Summary of the RCF Tests

- Testing in medium curves confirm that:
- Wear resistance increases with rail hardness
- Corrugation damage reduces with increasing hardness
- Higher RCF-resistance at higher rail hardness:
- R220 – R260 = 1 : 1,7
- R260 – R350HT = 1 : 3,2

Bainitic Rail Steels

Status of Pearlitic Rail Steels

- Heavy Haul impossible without high strength steels
- clean rail steels avoid detail fractures

- high productivity
- QA guarantees consistent high quality

- advanced pearlitic metallurgies perform well:
- 370LHT – 0,5% Cr
- UHC400 – hypereutectoide pearlite with 1 % C

- so why BAINITE?

Bainitic Rail Steels – Concepts

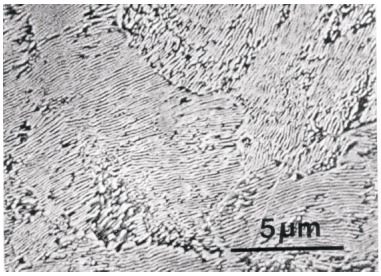
- Carbide free Bainite:
  - Good against RCF
  - But low wear resistance

- Hardened and tempered:
  - High wear resistance
  - But difficult to industrialize

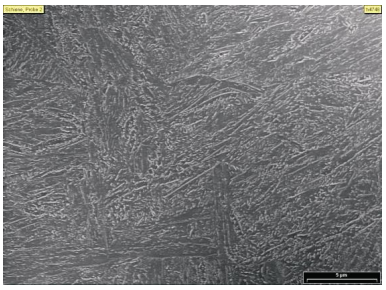
- Lower Bainite:
  - Combines large wear resistance with
  - Sufficient wear resistance

Microstructure of Pearlite and Lower Bainite

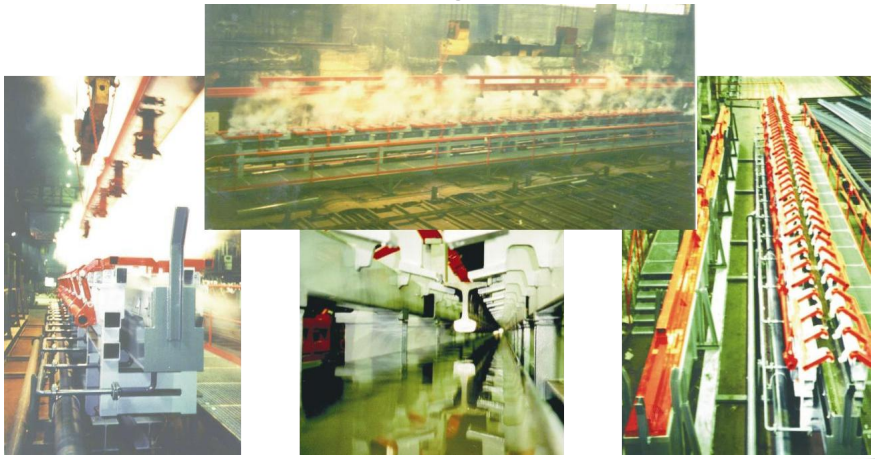
Pearlite



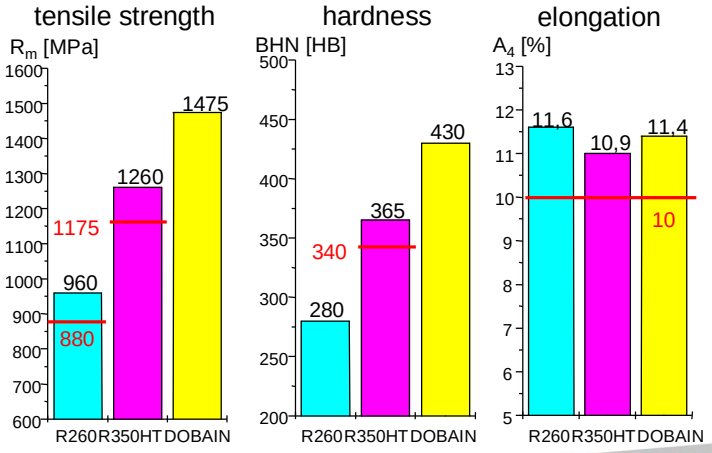
Bainite



DOBAIN – Pilot Hardening Plant

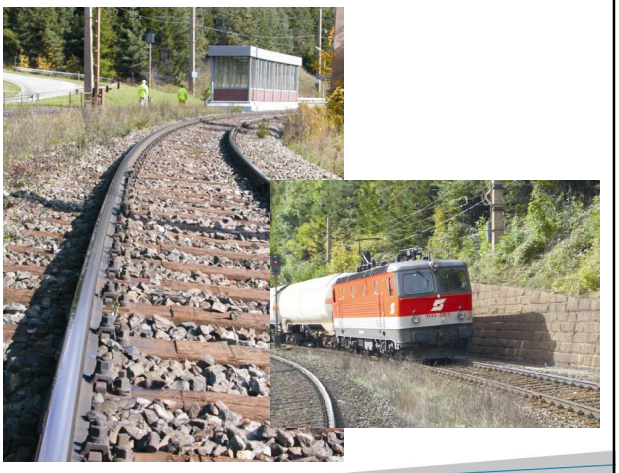


Properties of R260 – R350HT – DOBAIN

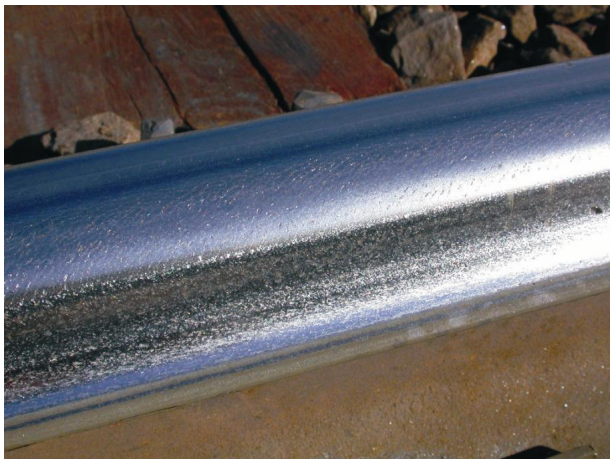


Semmering – Bainitic Rails

- mountain track
- mixed traffic up to 22,5 to/axle
- max. 80 km/h
- R = 185 m
- ~ 20 MGT/year
- two DOBAIN 1 rails compared to premium HSH
- Installed 1999
- Still in track

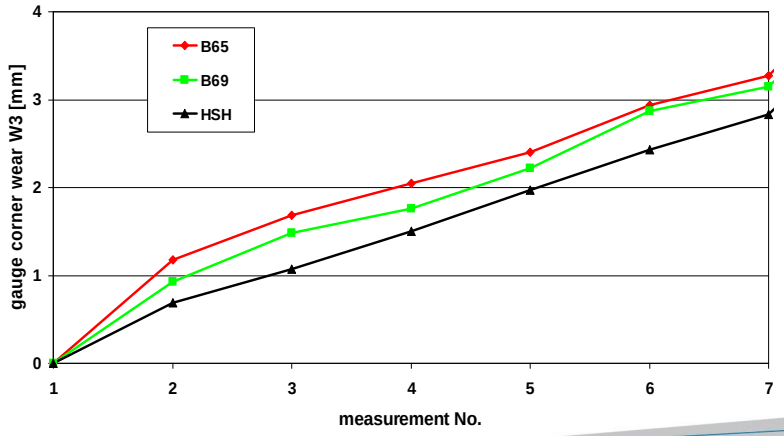


Semmering – Typical Defects

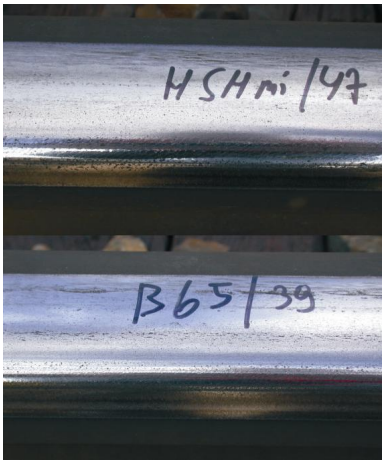


- Wear
- Head Checks
- Corrugations at the Low Rail

Semmering – Gauge Corner Wear at 60 Mio to



Semmering – RCF at 60 Mio to



- Regular rail for Semmering
- HSH = R350HT
- Light Head Checks

- Bainitic test rail
- DOBAIN
- No Head Checks

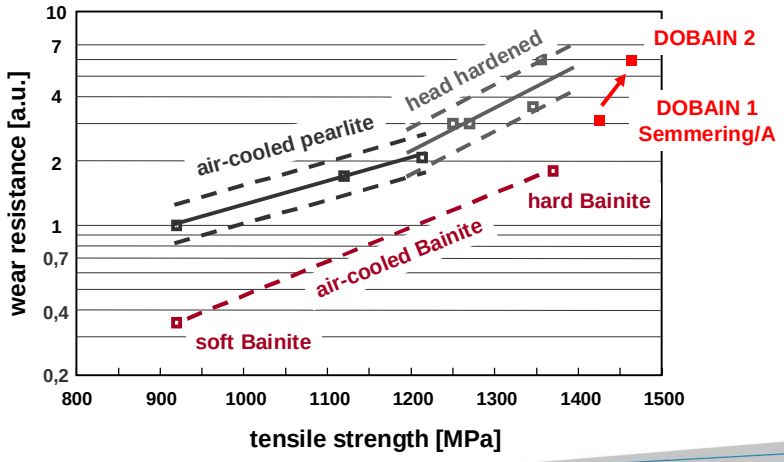
Semmering – Flashbutt Weld at 120 Mio to

- Weld joins two 15 m DOBAIN rails
- Softer than the rail
- Battering
- Welding needs optimization

Semmering/ÖBB – Conclusions

- DOBAIN 1 Rails tested in wear regime
- wear resistance close to head hardened
- RCF resistance larger – no head checks present
- continue testing to wear limits
- Optimization required to improve wear resistance and weldability
- Now more than 120 Mio to carried

Wear of Bainitic Rail Steels



DOBAIN 2 – Optimization Steps

- Adjust chemical composition to higher C-levels
- Adjust heat treatment to appropriate hardness

- DOBAIN 430: heavy haul, mixed traffic
- DOBAIN 380: mixed traffic, high speed, Metro
- DOBAIN 340: high speed, low axle loads

- Goal: no RCF, adjust wear rates acc. to loads

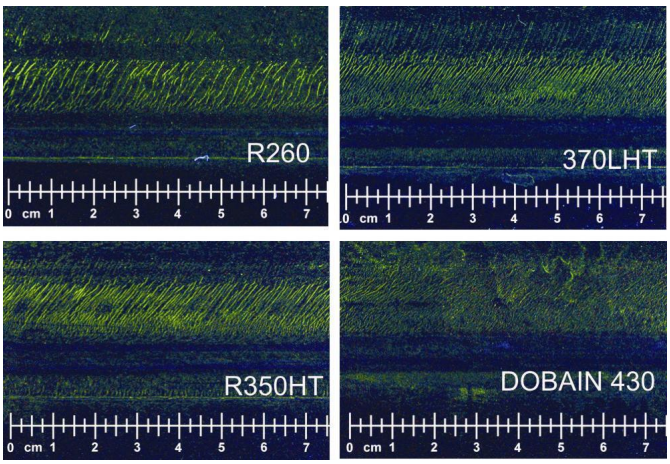
Medium Speed Line München-Augsburg

- Same curve, other direction used

- Similar installation like first test

- Now four rail grades in test:
  - R260 Pearlite
  - R350HT HSH
  - 370LHT Pearlite
  - DOBAIN 430 Bainite

Preliminary MPI Results for Medium Speed Line



Bainitic Rail Steels – Summary

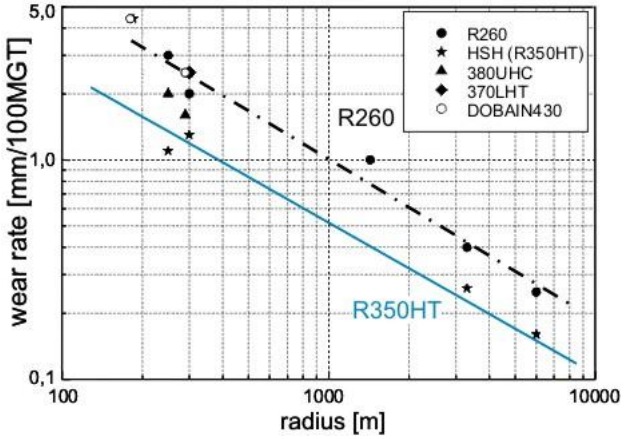
- Wear properties similar to HSH – sufficient for EU conditions
- RCF:
  - Much better than R260
  - better than HSH
  - comparable to high end pearlites – to be verified in current tests
- Continue with all tests:
  - Semmering: mixed traffic in tightest radii
  - Rheinbraun/FRG: heavy haul conditions
  - DB AG: three test at low, medium and wide radii
- Welding must be optimized – cooperations with ET and VAE
- Start new tests!

Steel Grade Impact on Maintenance Strategy and Costs

voestalpine´s Track Tests

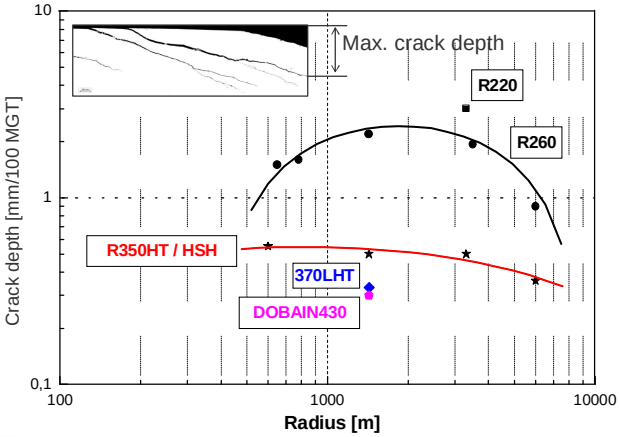
- Tests are done with different customers
  - at different load conditions
  - on different levels of maintenance capabilities
  - with different rolling stock
  - in open (revenue) or closed (TTCI, ore-lines) systems
  - ...
- Not all tests are done on the same level of sophistication (DB AG)
- See summary of Wear results
- See summary on Head Checking

Track Test Results – Gauge Corner Wear



- Advanced rail steels drop wear rates significantly
- Wear is the primary replacement criterium in tight curves below 500 m radius

Track Test Results – Head Checking

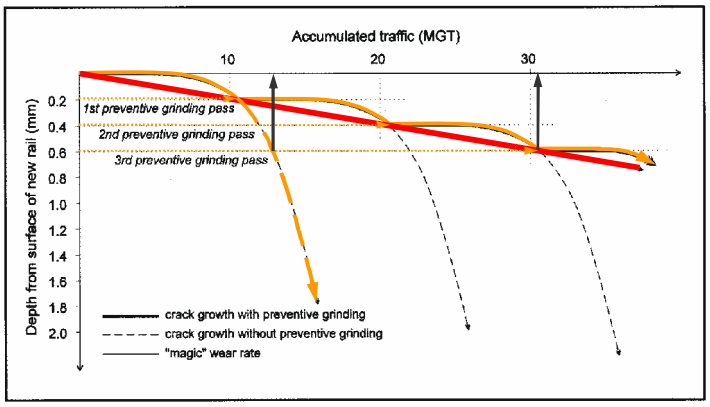


- Advanced rail steels reduce Head Check depth significantly
- RCF primary problem for curves larger than 700 m
- Grinding required

Maintenance Strategy

- Wear – clear answer:
  - use the hardest rail steel available – see Heavy Hauling
- Rolling Contact Fatigue – case dependent:
  - Grinding to remove the cracks
  - Preventive grinding
  - Corrective grinding
  - Repair welding of locallized defects
  - Rail replacement

Maintenance – The Magic Wear Rate



source: J. Kalousek and E. Magel: The “Magic” Wear Rate
RT&S March 1997, pp.50-52

Medium Speed Line München-Augsburg

- R = 3.300 m
- Load: 90.000 to/day
- Three rail grades:
  - R220 (800)
  - R260 (900A)
  - R350HT (HSH®)
- Testing for 3 years

- Grinding tests: determine material removal required for a defect-free surface

Grinding Tests – Head Check Removal

grade	no. grinding passes	material removal	result
R220	22	2,6 mm	continuous head checks
R260	12	0,8 mm	sporadic head checks
R350HT	6	0,6 mm	clean surface

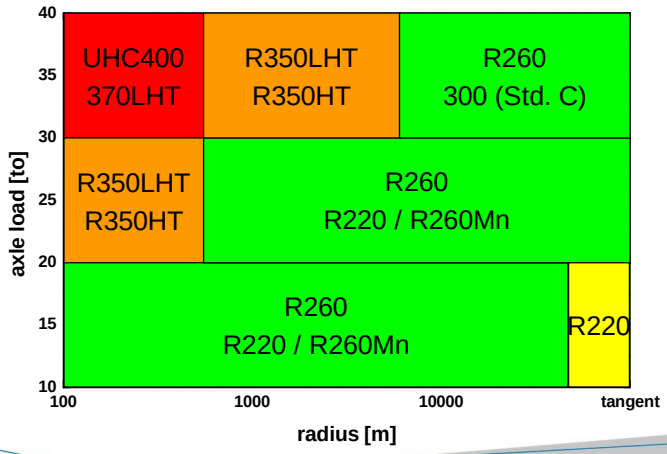
Grinding Tests – Life Cycle Prognosis

grade	Material loss [mm]	Expected service life	+/-
R220	3,5	6,6	- 60 %
R260	1,4	16,4	reference
R350HT	1,0	23	+ 40 %

Summary on R350HT vs. R260

- less corrugations:
  - 1/3 roughness and 1/2 wavelength
- approx. 40 % less wear
- Head Checks finer and shorter
- later crack initiation and slower crack growth
- 70 % lower crack depth
- only half of the grinding passes required
- 40 % increased service time

Rail Grade Strategy – Status 2006



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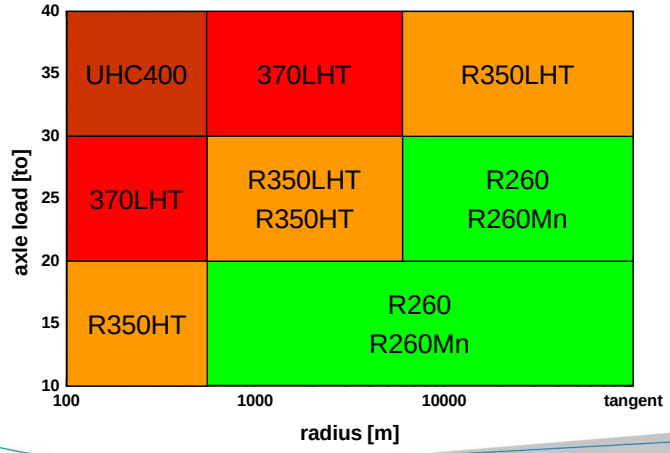
Rail Grade Strategy – Recommendation 2006



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