Quantifying Rail Surface Damage

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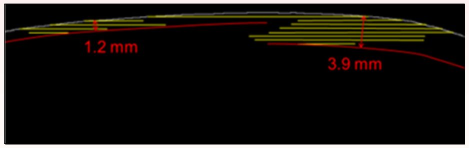
Overview

- Current approach to RCF analysis
- Fe-C metallurgy
- Effect of rail position in curve
- Quantitative RCF assessment
  - NDT evaluation: Rohmann, MRX, Sperry
  - Other NDT methods: DP & MP
  - Microstructural analysis of RCF: depth & angle
- Qualitative RCF assessment
- Cataloguing RCF: Atlas, Matrix



RCF – Current Approach

RCF

Inspection Methods

- Visual surface assessment
- Non-destructive:
  - Dye penetrant
  - Magnetic particle
  - Walking stick (Rohmann, MRX, Sperry)
- Destructive:
  - Cutting
  - Milling
  - Metallography
    - LOM, SEM

Factors to Consider

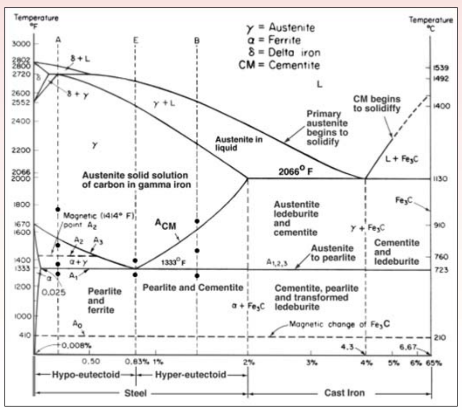
- Rail type
- Position in curve
- Track curvature
- Lubrication
- Traffic:
  - Axle load
  - MGT accumulation
  - Frequency
- Maintenance practices
  - Grinding/Milling
    - Frequency
    - Amount

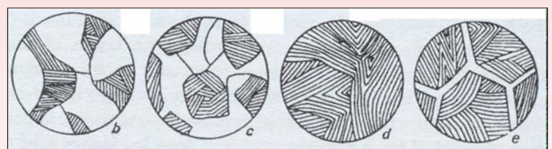
Outcomes to Evaluate

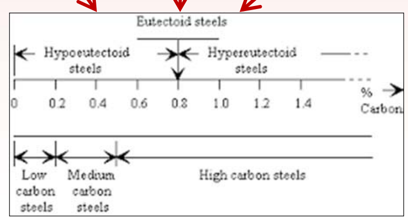
- RCF location:
  - TOR vs. GF
- RCF severity:
  - Mild vs. Severe
  - Depth of spalling
- RCF crack morphology:
  - Length, depth, angle to rail surface, density & distribution, amount of branching
  - Propagation in rail microstructure
    - Trans-granular vs. inter-granular
    - Assisted by inclusions (rail cleanliness)

Rail Metallurgy – Fe-C Phase Diagram

- Increasing carbon content in rail increases rail hardness and improves wear resistance
  - Microstructure needs to be fully-pearlitic to achieve best mechanical and wear performance
  - Only one carbon composition (approx. 0.83%C) gives fully-pearlitic structure
    - < 0.83%C we get ferrite at grain boundaries
    - > 0.83%C we get cementite at grain boundaries







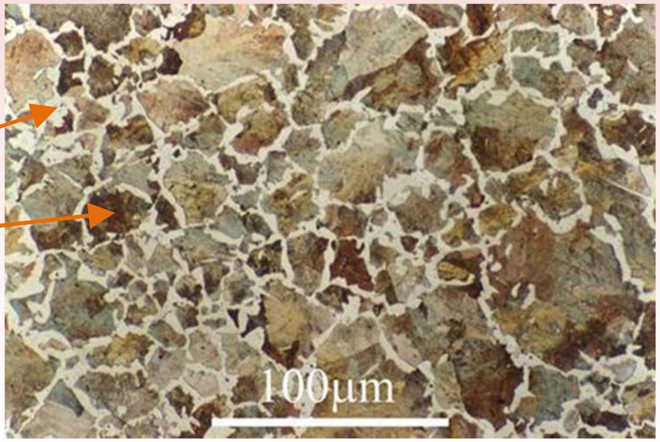
Reference: Fe-Fe_3C Phase Diagram
Materials Science and Metallurgy,
4th ed., Pollack, Prentice-Hall, 1988

Rail Metallurgy – Decarburization Layer

- Solid State Diffusion (SSD) of Carbon
  - Fick's First Law (i.e. Carbon migration down a concentration gradient)
  - Takes place at rail rolling surface
  - Temperature activated process (during rail production)
- Results in Carbon-poor (i.e. decarburized) phase (ferrite) at the grain boundaries

Decarburized Layer (ferrite)

Pearlitic Grain



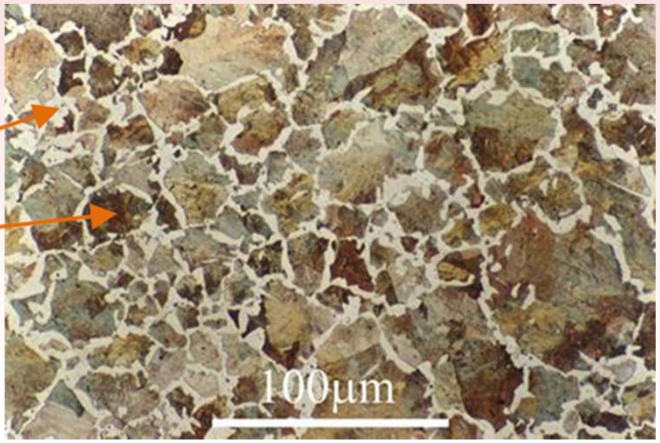
Typical Decarburized Pearlitic Rail Microstructure

Rail Metallurgy – Decarburization Layer

- Decarburization is only an issue with new rails
- Decarburized rail microstructure is less uniform (less homogenous) below W/R contact zone
- It is softer than surrounding pearlite matrix structure:
  - Easier to plastically deform the decarburized layer
  - Rolling Contact Fatigue (RCF) cracks form more easily in the decarburized zone

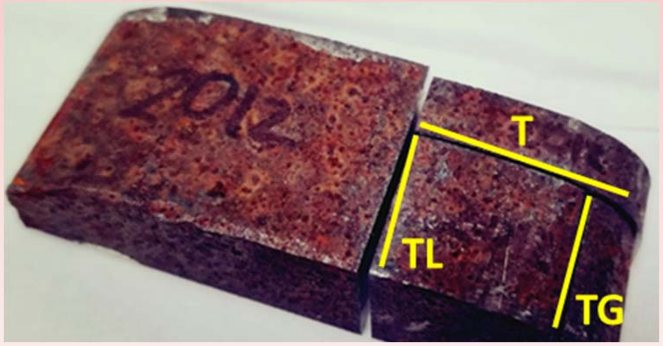
Decarburized Layer (ferrite)
Approx. 80HB

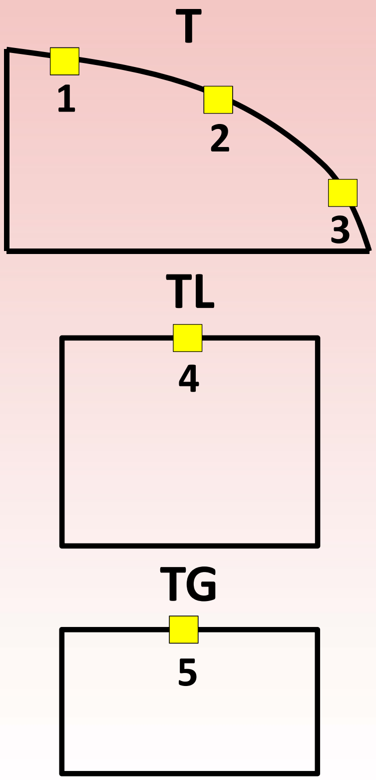
Pearlitic Grain (**300-400HB**)



Rail Metallurgy – Decarburization Layer

- Typical intermediate rail type

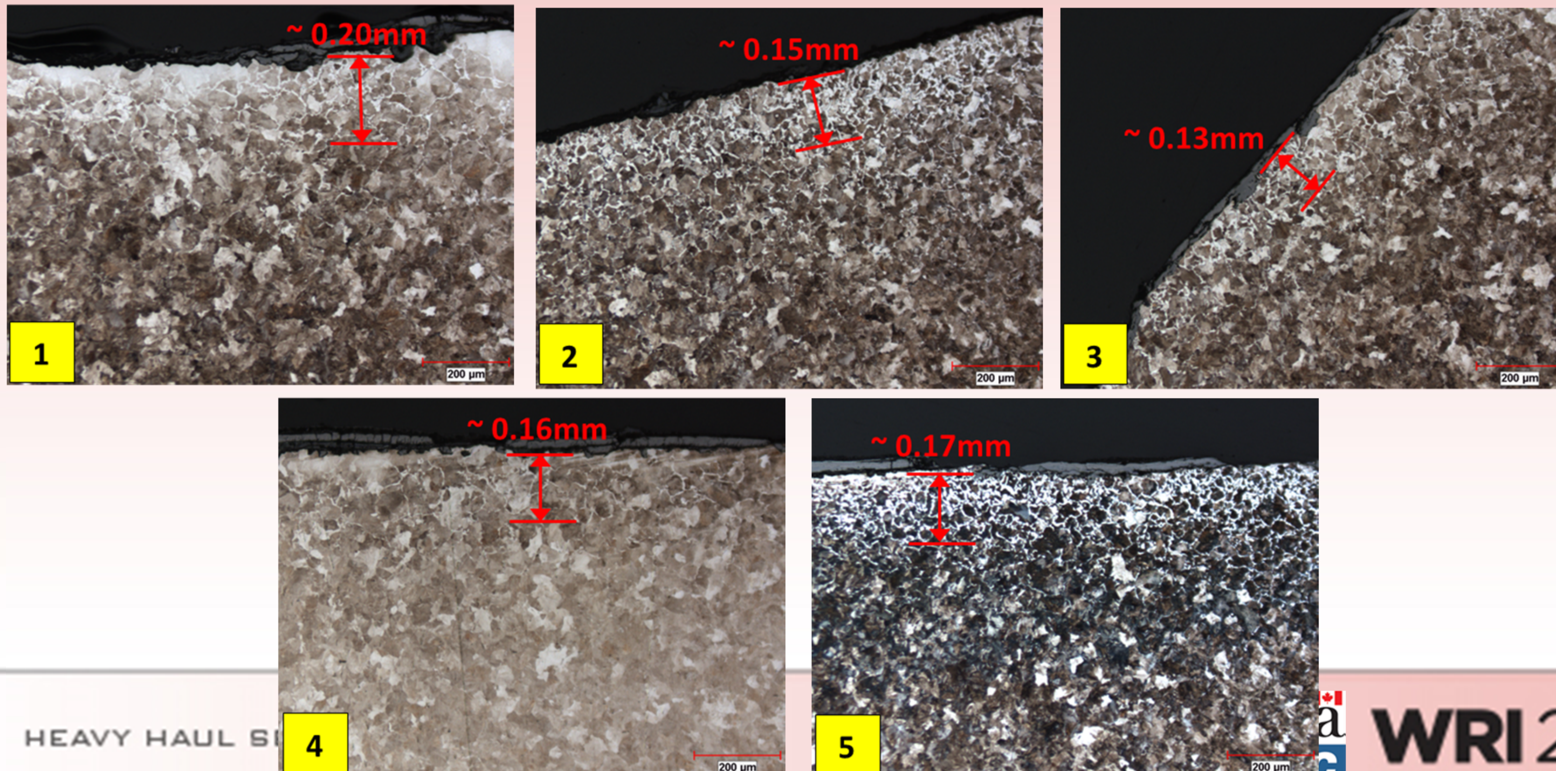




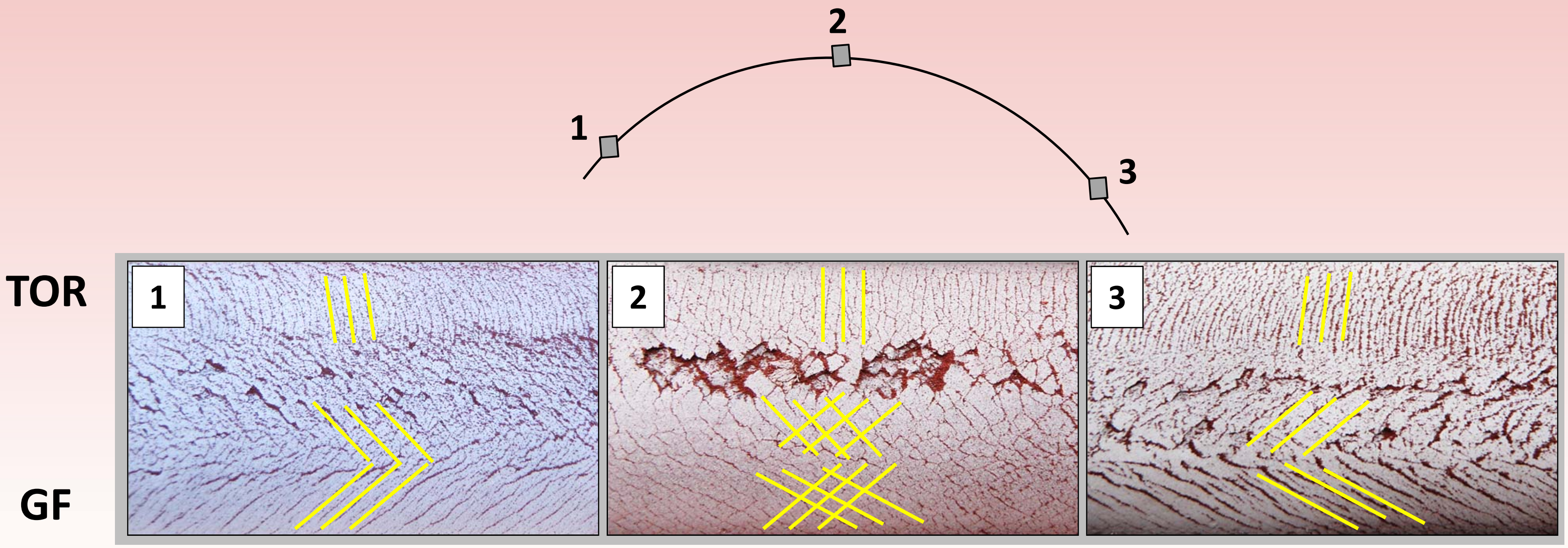
T – Transverse section
TL – Transverse Longitudinal section
TG – Transverse Gage section

Rail Metallurgy – Decarburization Layer

- 5 microstructure locations:
  - Decarburized layer present in all 3 cross-sections
  - Average decarburized layer thickness: 0.16±0.03mm (~0.006in)



Quantifying Rail Surface Damage
Effect of Rail Position in Curve



Quantifying Rail Surface Damage Non-Destructive Evaluation Methods

Three Electro-Magnetic Based Techniques were Evaluated by NRC Under the FRA Program:

- Eddy Current (Rohmann)
- Magnetic Flux Leakage (MRX)
- ACFM (Sperry)

Rohmann Drasine® trolley (eddy current)

MRX RSCM (magnetic flux leakage)

Sperry Surface Crack Detection + Walking Stick

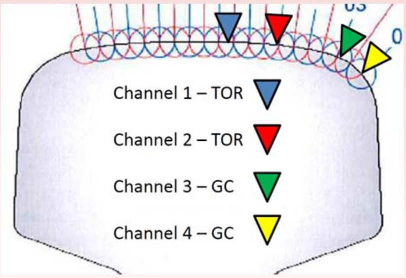
Quantifying Rail Surface Damage
Rohmann Technology

- Provides RCF crack depth vs. rail distance travelled
- A walking unit with 4 eddy current probes
- Staggered design, each probe covers a portion of the rail head
- **Voltage output is converted to crack length, which combined with crack angle yields crack depth**
- RCF measurements made by Rohmann at CSX, CN and NS

Quantifying Rail Surface Damage
Rohmann Technology

Specifications	
Technology	Eddy current
Measures	Crack length.
In dense cracks	Max. crack length per 5 mm of rail head
Range	Length to 12 mm
# of probes	4 individually adjustable
Probe Spot size	6 mm for each probe
Operating speed	0 up to jogging speed

Typical Draisine® Output



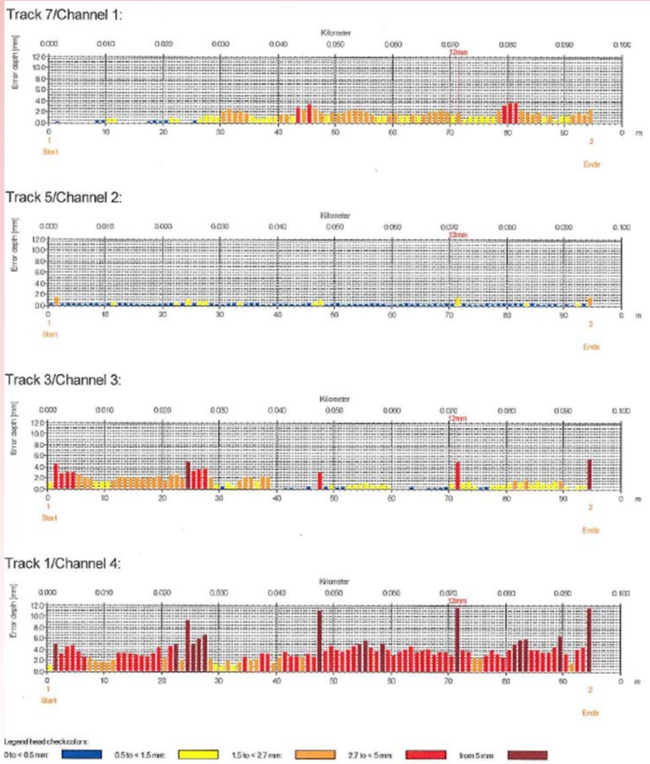
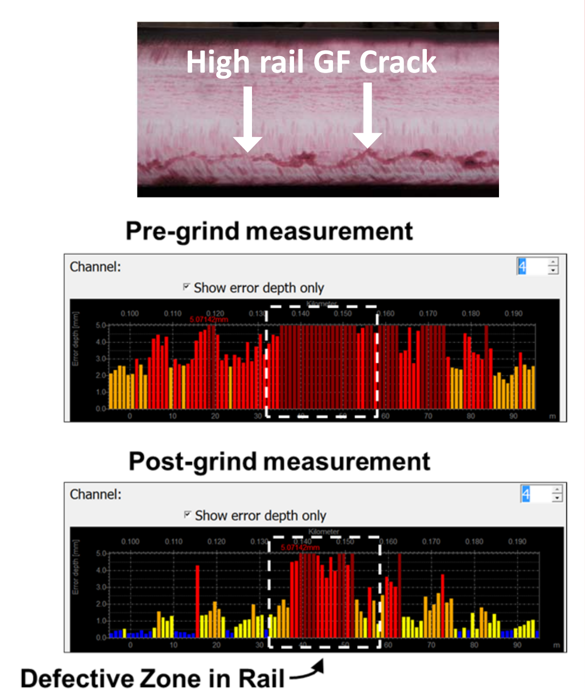


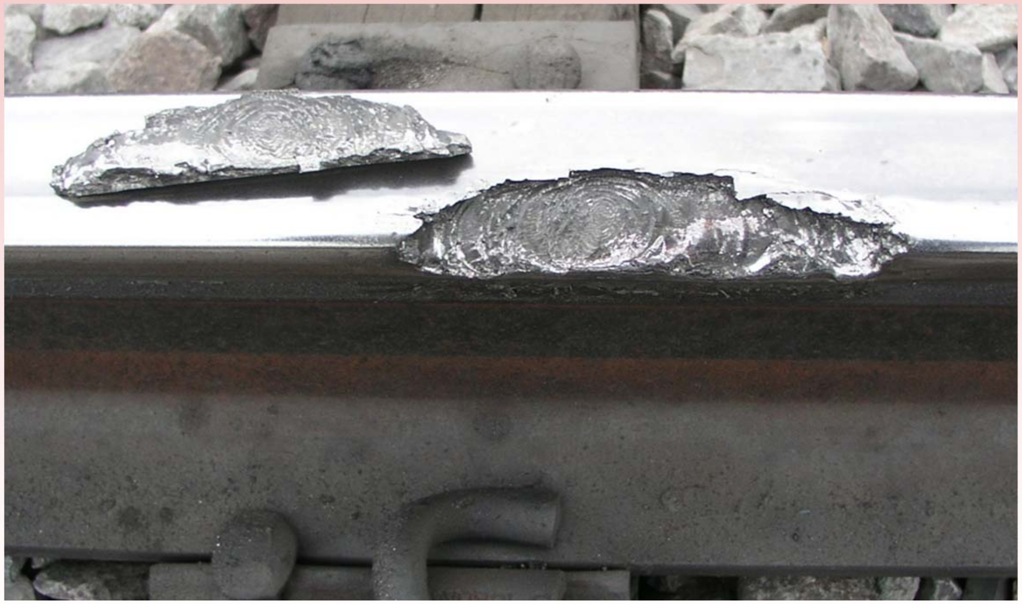
Table from: FRA, 2016, Eric Magel, "Validating Electromagnetic Walking Stick Rail Surface Crack Measuring Systems"

Quantifying Rail Surface Damage
Rohmann Technology

- Also used to detect defects in track
- Gage corner shear crack
  - Pre-grind measurements showed depth > 5mm
  - Approximately 3mm of railhead was taken off in grinding
  - Post-grind measurements still indicated max depth > 5mm
- Rail was taken out of service



Quantifying Rail Surface Damage
Eddy Current for Shelling Detection?



Quantifying Rail Surface Damage
MRX Technology

- Magnetic Flux – Magnetic field floods the rail. Cracks disrupt the field at the surface. Disruptions detected by sensors.
  - Provides crack depth vs. rail distance travelled
  - An operator propelled unit (OPU) with 19 sensors
  - Lateral positioning accuracy better than 5mm
  - **Disruption to magnetic field is seen as a volume of damage, which is converted to depth**
  - RCF measurements made by Loram at CSX

Quantifying Rail Surface Damage MRX Technology

Specifications	
Technology	Magnetic flux leakage
Measures	Damage depth
In dense cracks	Deepest crack every 0.25 m
Range	7 mm
# of probes	19
Probe Spot size	5 mm
Operating speed	2-5 km/hr

Typical MRX output

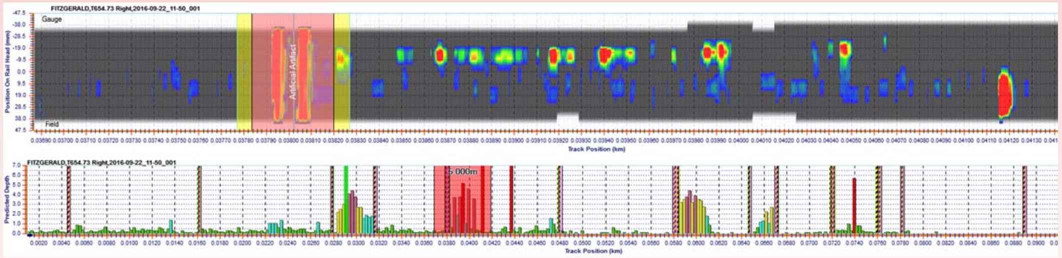
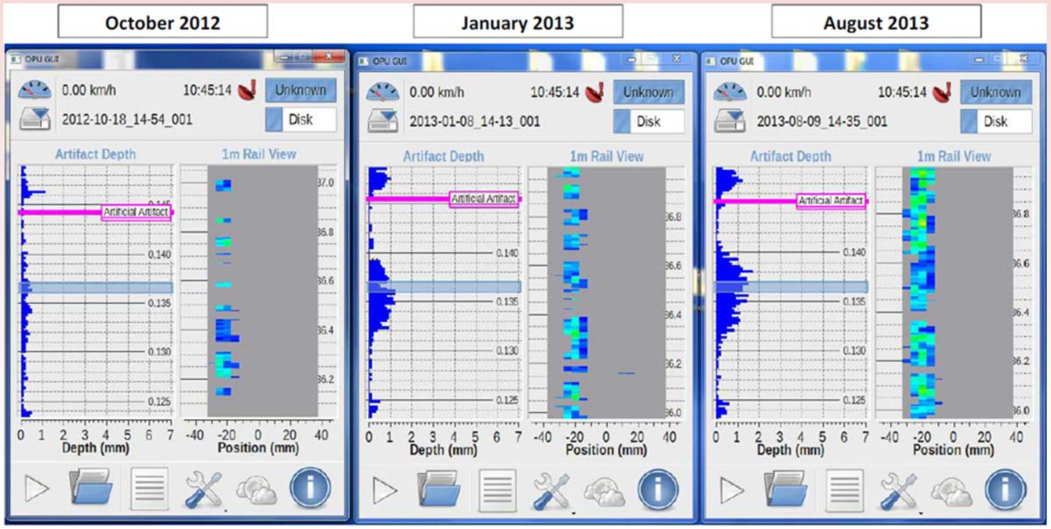


Table from: FRA, 2016, Eric Magel, “Validating Electromagnetic Walking Stick Rail Surface Crack Measuring Systems”

Quantifying Rail Surface Damage MRX Technology

- Ongoing testing at CSX Fitzgerald and Jessup sites in Georgia
- Progress of damage as measured with the MRX RSCM
  - Depth and extent of cracking is observed to grow with time



Quantifying Rail Surface Damage
Dye Penetrant and Magnetic Particle NDT

Dye Penetrant NDT

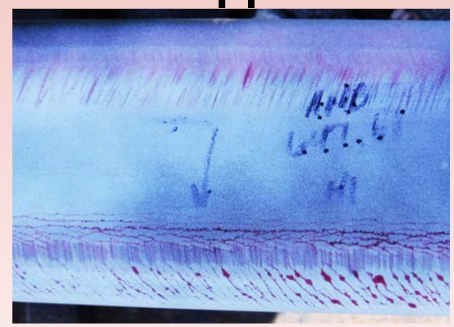
- The rail is coated by a dye formulated to penetrate cracks. After cleaning dye from the surface, a white developer powder is sprayed that draws dye from within the cracks.

Magnetic Particle NDT

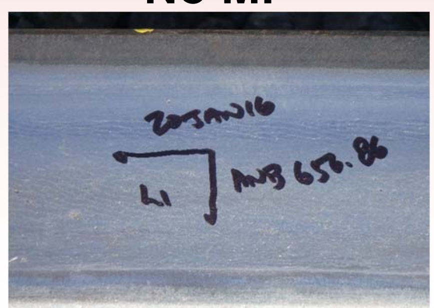
- A magnetic field is applied across the field of view and then iron powder is sprayed to the surface. Particles congregate around disruptions to the magnetic field, highlighting surface cracks.

No DP

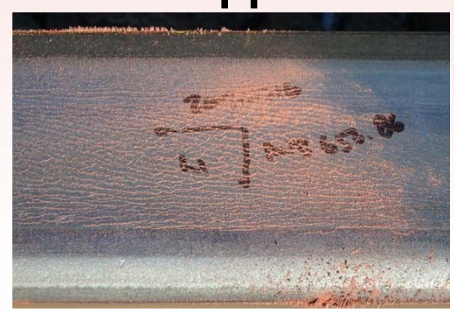
DP Applied



No MP



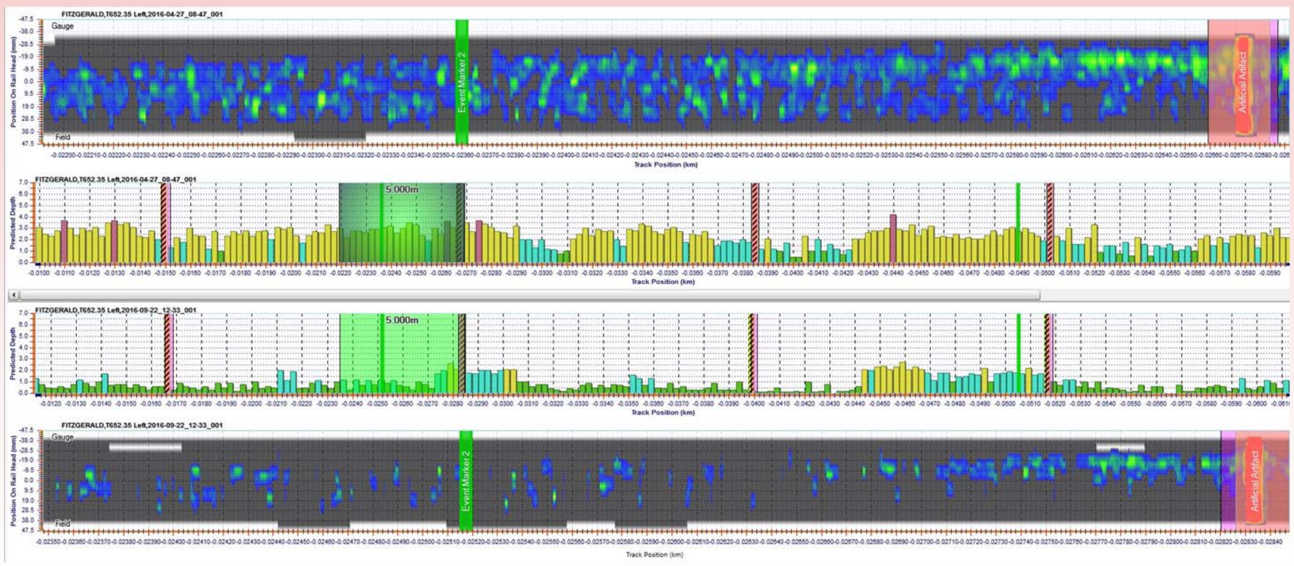
MP Applied



Quantifying Rail Surface Damage Combining NDT Methods

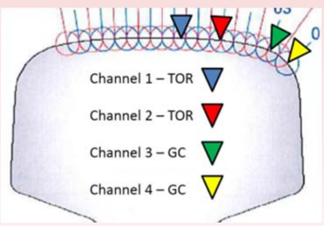
MRX - CSX Tangent site

Pre-Grind April 27, 2016

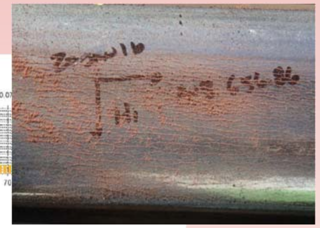


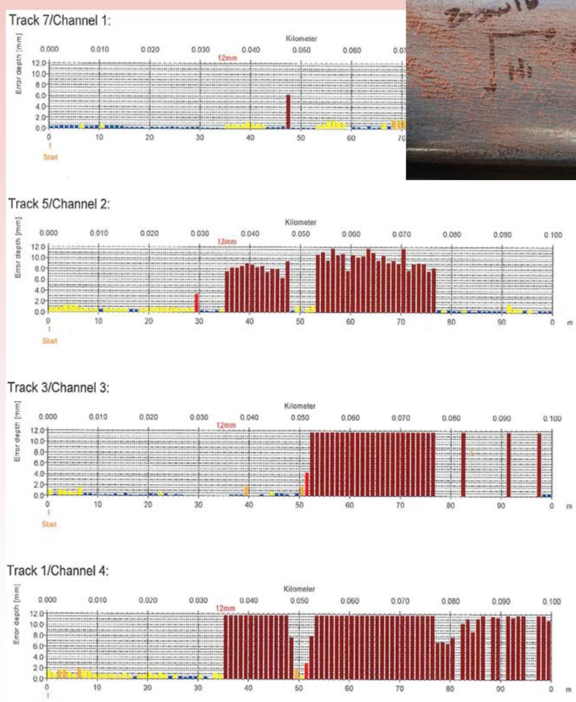
Post-Grind Sep 22, 2016

Quantifying Rail Surface Damage Combining NDT Methods

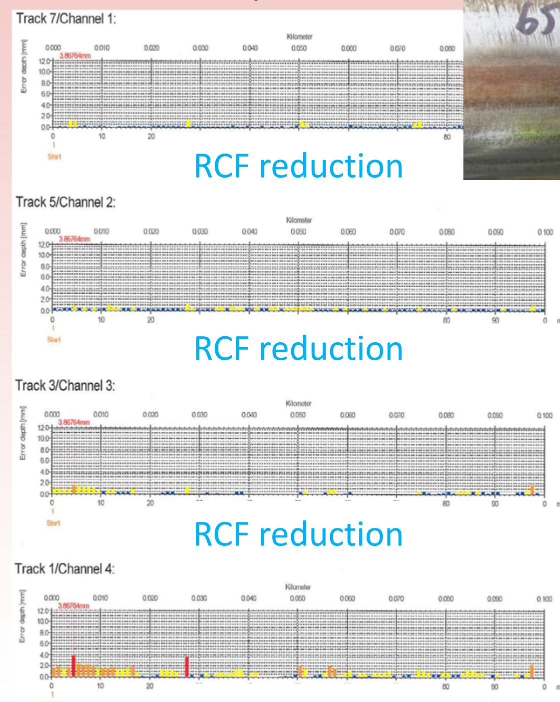


Jan 2016





Sept 2016



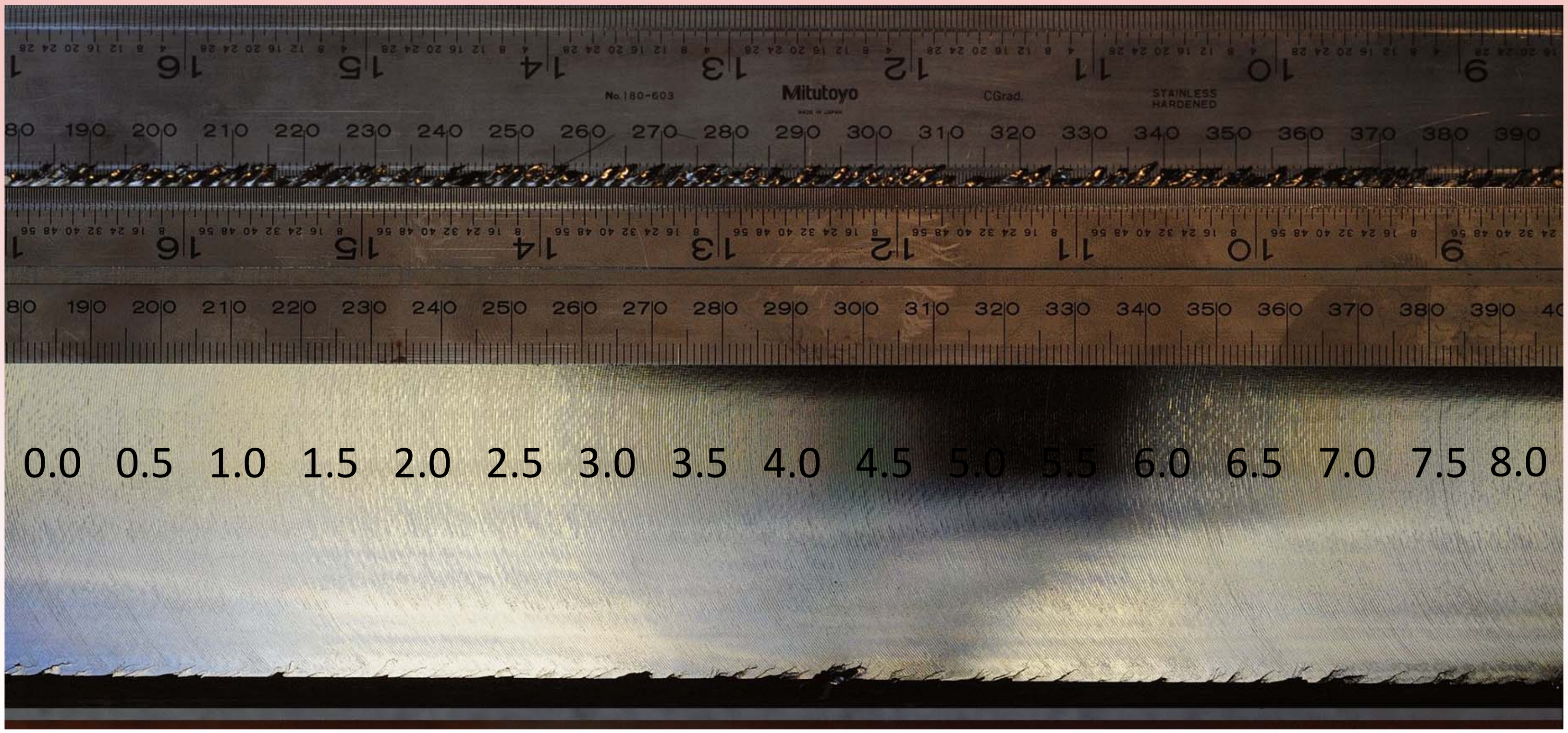
RCF reduction

RCF reduction

RCF reduction

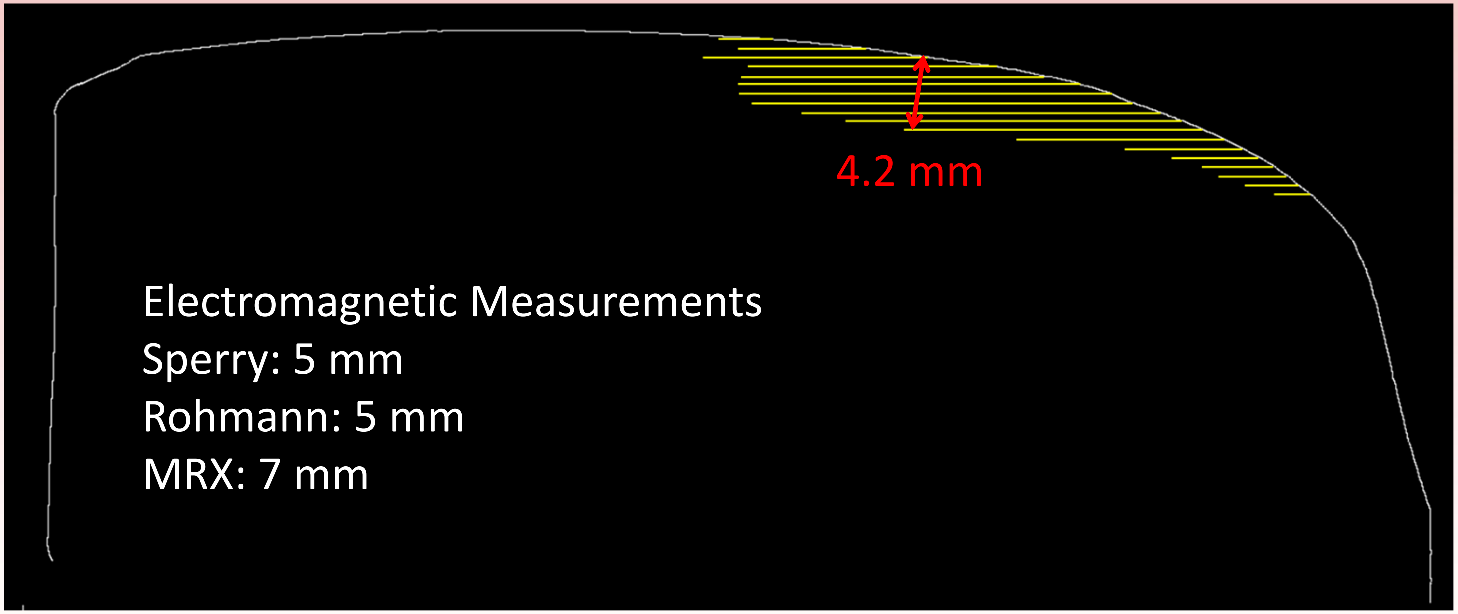
RCF reduction

Quantifying Rail Surface Damage: Rail Milling



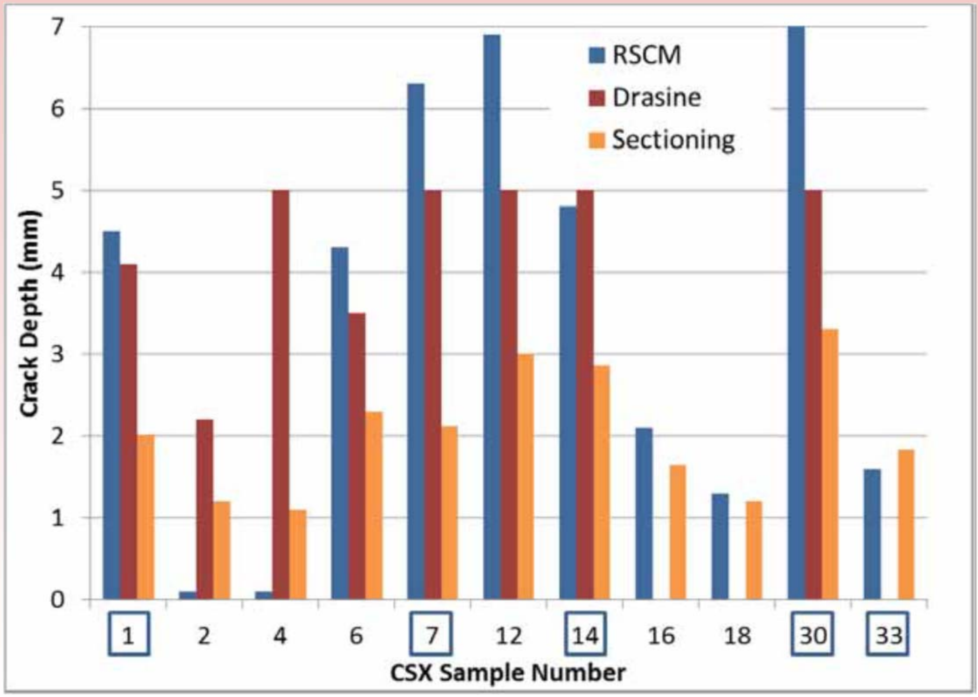
Rail from BNSF line

Quantifying Rail Surface Damage: Rail Milling



Rail from BNSF line

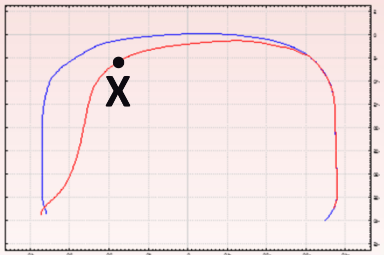
Quantifying Rail Surface Damage
Comparison of RCF measurements



Graph from: FRA, 2016, Eric Magel, “Validating Electromagnetic Walking Stick Rail Surface Crack Measuring Systems”

Quantifying Rail Surface Damage
Metallography of Crack Morphology

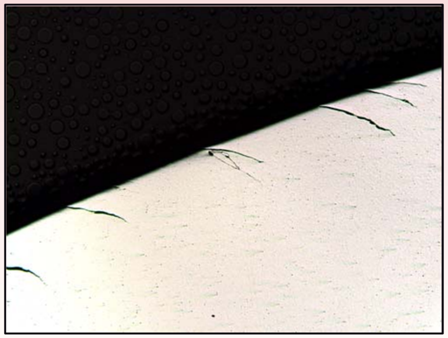
- Typical micrographs at location **X** in each rail type



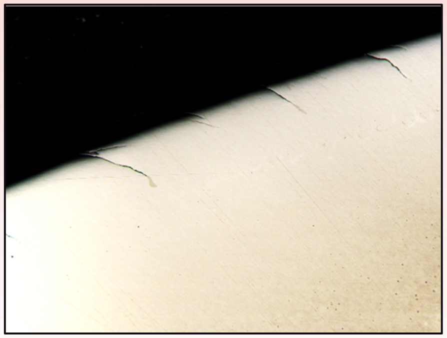
Premium Rail 1 (1.01wt.% C)

Hyper-eutectoid

Premium Rail 2 (0.93wt.% C)



Premium Rail 3 (0.83wt.% C)

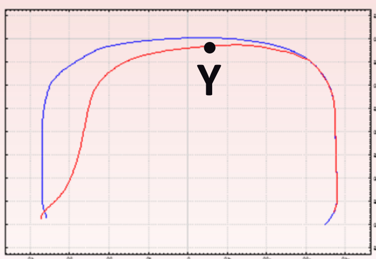


Eutectoid

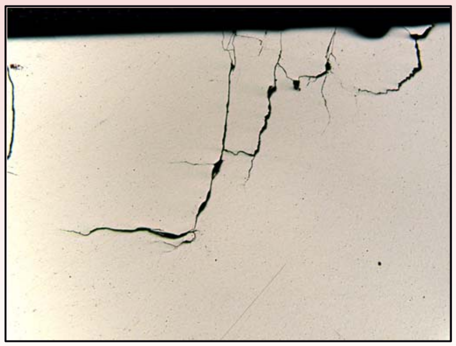
Transportation Technology Center, Inc. Reference: 2013 TTCI Annual Review

Quantifying Rail Surface Damage
Metallography of Crack Morphology

- Typical micrographs at location **Y** in each rail type



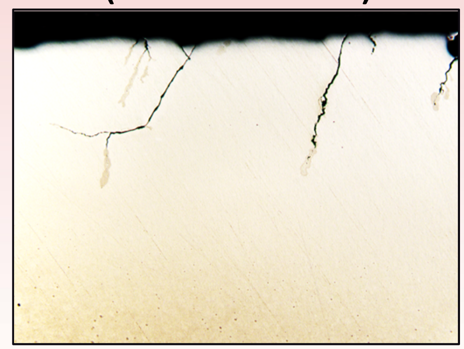
Premium Rail 1
(1.01wt.% C)



Hyper-eutectoid

Premium Rail 2
(0.93wt.% C)

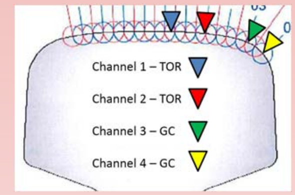
Premium Rail 3
(0.83wt.% C)



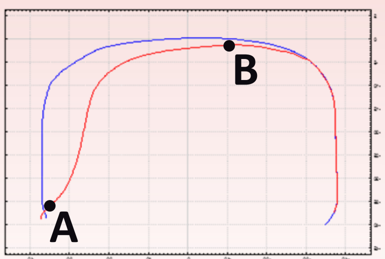
Eutectoid

TTCI® Transportation Technology Center, Inc. Reference: 2013 TTCI Annual Review

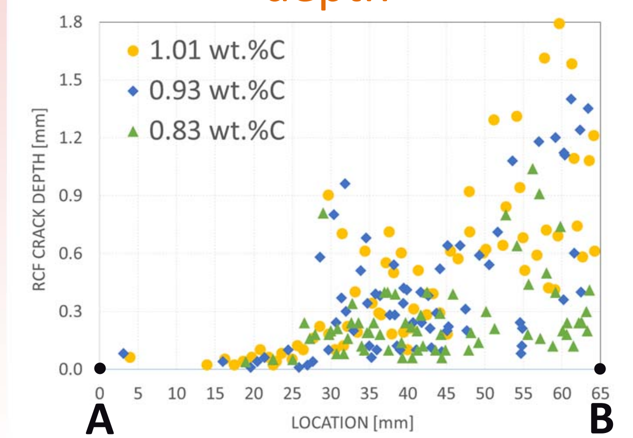
Quantifying Rail Surface Damage
Metallography of Crack Morphology



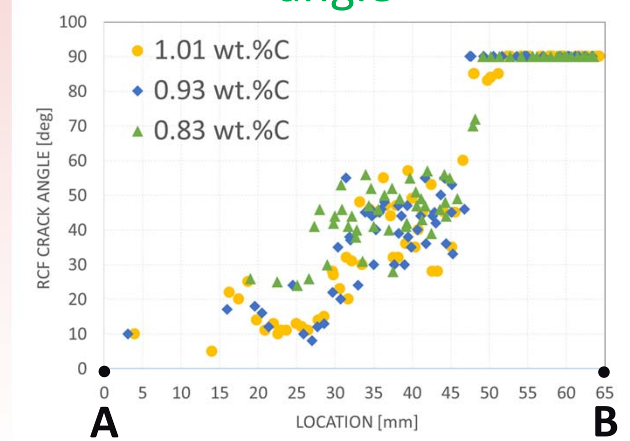
- High rail quantitative RCF assessment
- RCF crack depth & angle analyzed in three rail types with varying Carbon content



depth

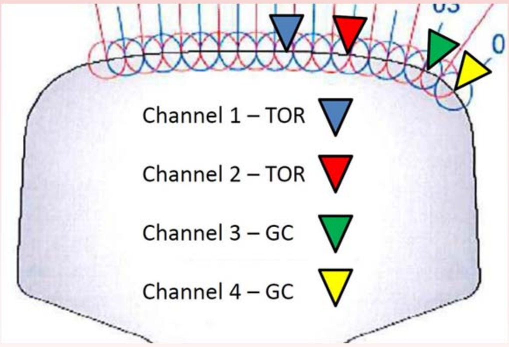


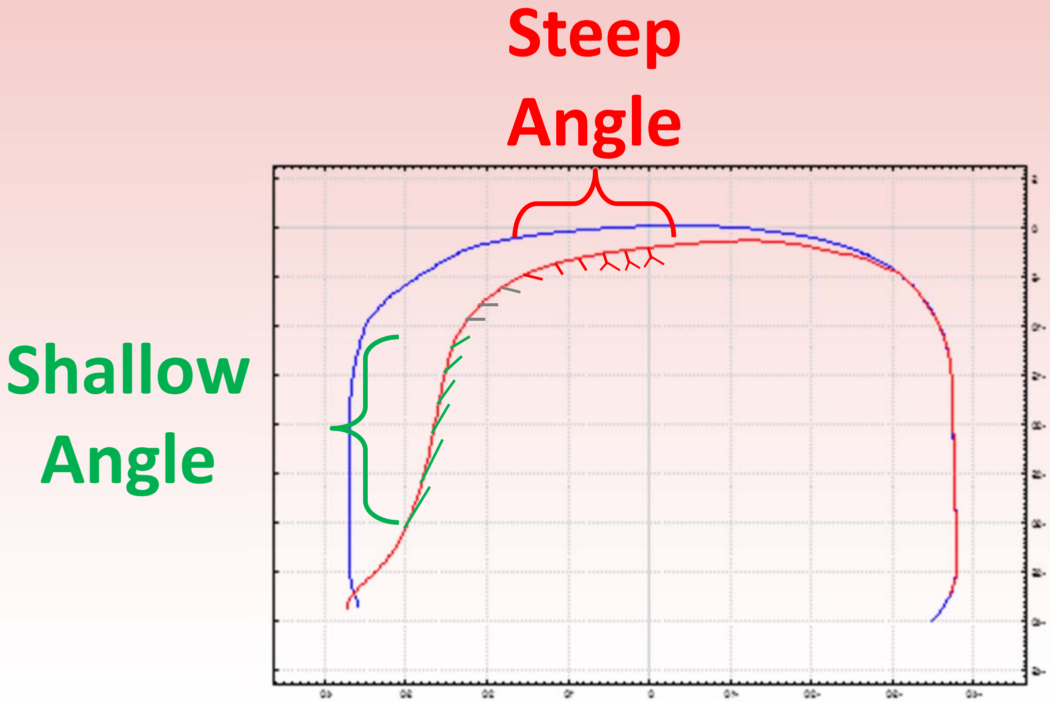
angle



TTCI Transportation Technology Center, Inc. Reference: 2013 TTCI Annual Review

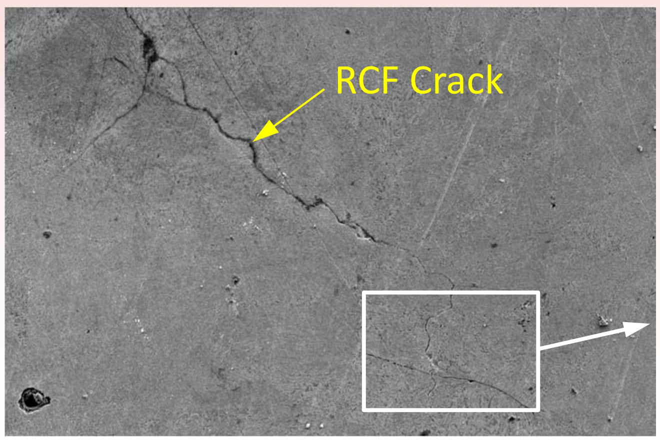
Quantifying Rail Surface Damage
Metallography of Crack Morphology

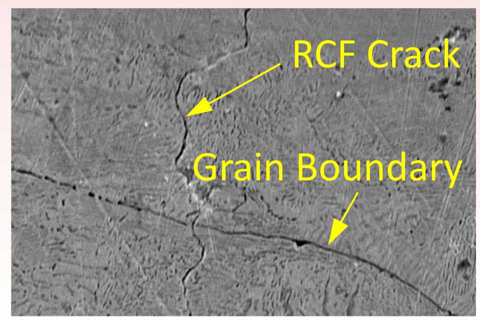




Quantifying Rail Surface Damage
Metallography of Crack Morphology

- Other crack features should be analyzed as well:
  - Length, branching, density
- In addition, crack path in the microstructure should be considered
  - Inter-granular vs. trans-granular cracking





Quantifying Rail Surface Damage – Rating Scale

- One method applied utilizes visual rating of RCF cracks
  - Qualitative, user dependent (subjective to some extent)
  - Used to rate RCF in premium rails tested at TTCI

Mild: Scale 1

Heavy: Scale 2

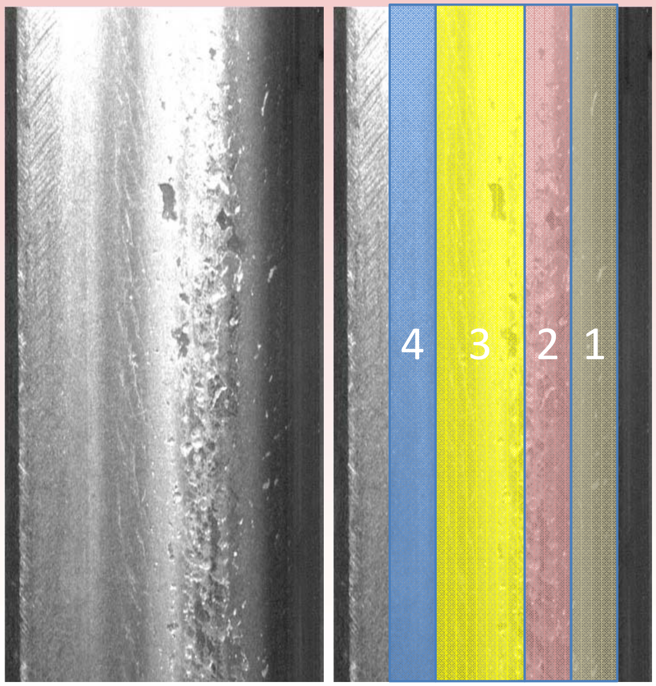
Severe: Scale 3

Transportation Technology Center, Inc. Reference: 2016 TTCI Annual Review Poster

Quantifying Rail Surface Damage – Rating Scale

- Another method utilizes a Machine Vision System to rate the crack surface appearance. Not user dependent (more objective)

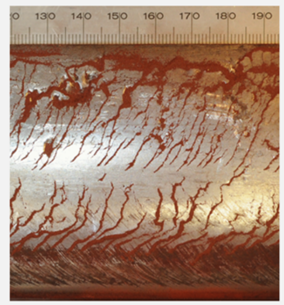
0	None
1	Barely perceptible, but clearly regular pattern (preventive grinding < 0.5mm)
2	Clear, well-defined, distinct individual cracks – but no pitting > 1.5mm (maintenance, depth < 1.0 mm)
3	Clear cracking, pits up to 4 mm diameter (corrective grinding 1.5-2.5 mm deep)
4	Pitting greater than 4mm < 10 mm (preventive gradual, up to 3.5 mm deep), or "heavy" cracks with clear lifting of metal or separation of crack faces
5	Isolated pitting/shelling/spalling > 10, diameter (up to 5 mm deep)
6	Shelling/spalling: regular pitting, >10mm diameter (near impossible to catch up on)
7	Shelling/spalling: any defect > 16 mm diameter, >20mm length



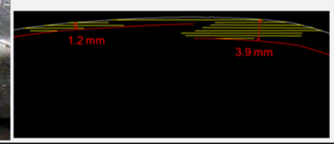
Note: Machine Vision System was developed with KLD Laboratories

Quantifying Rail Surface Damage – RCF Atlas

High Low Tangent **S&C** Metallurgy: **136RE VT**	Railroad: **BNSF** Subdivision: **Staples** MP: **200.69** Curvature: **2 degree** Lubricated: Yes **No**	Date: Removed from track **November 2014** Sample: **C8**



Cross-Section

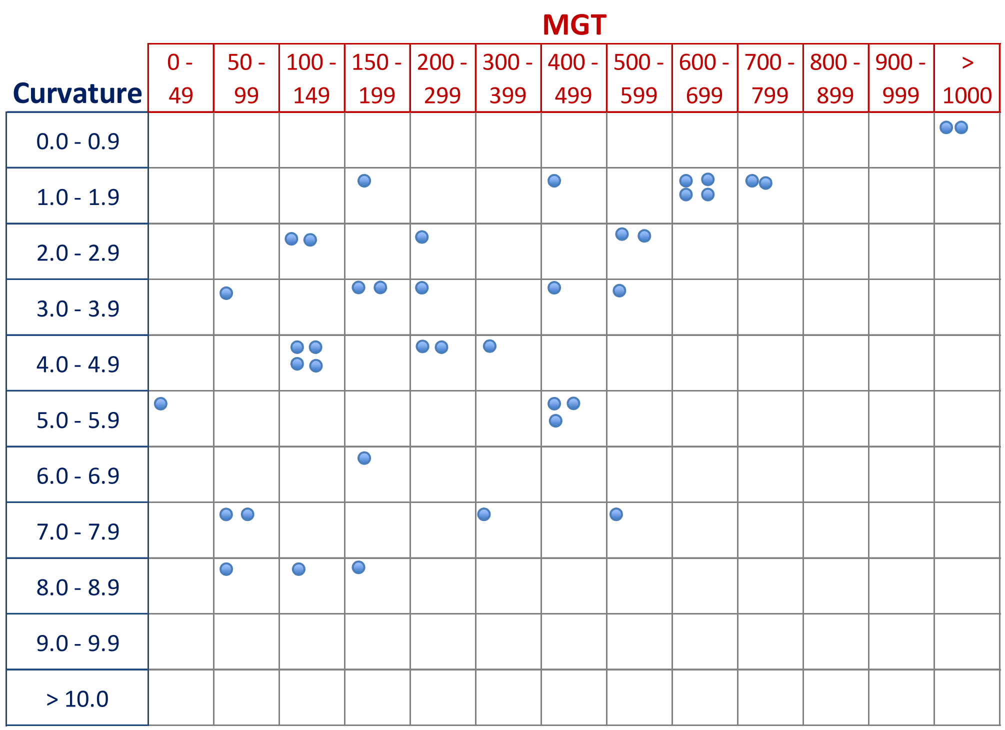


Surface Crack Length	approx. 25 mm
Start/End Position	approx. 5 - 55 mm
Surface Angle (to Longitudinal Direction)	approx. 70 degrees
Crack Depth (Milling)	3.9 mm
Spacing Avg. = approx. 2 mm	
Comment: SSC – through crossing	

Quantifying Rail Surface Damage – RCF Matrix

	MGT												
Curvature	0 - 49	50 - 99	100 - 149	150 - 199	200 - 299	300 - 399	400 - 499	500 - 599	600 - 699	700 - 799	800 - 899	900 - 999	> 1000
0.0 - 0.9													
1.0 - 1.9													
2.0 - 2.9													
3.0 - 3.9													
4.0 - 4.9													
5.0 - 5.9													
6.0 - 6.9													
7.0 - 7.9													
8.0 - 8.9													
9.0 - 9.9													
> 10.0													

Quantifying Rail Surface Damage – RCF Matrix



Example:

- 40 rails placed in the matrix:

Additional layers:

- standard, intermediate, premium rails (variable Carbon content)
- High/Low rail locations
- crack assessment:
    - Depth, length, angle, branching, density

Summary

- RCF is a complex problem with a multitude of contributing factors
  - Track curvature, rail position in curve, rail type, lubrication, traffic, others
  - Different inspection methods yield different results:
    - **Quantitative methods** are more objective
      - Rohmann and MRX overestimate crack depth
      - Rail milling/metallography: most accurate way to assess RCF
      - Metallography is important to map out crack morphology as a function of position on the railhead
    - **Qualitative methods**
      - Provide only surface information
  - RCF results need to be:
    - RCF Atlas & Matrix (a more systematic approach to mapping RCF)

Acknowledgements

- Special thanks to Rohmann, MRX, Sperry, KLD Laboratories, CSX, CN, NS, BNSF and TTCI for reference materials
- FRA for funding of study to validate crack measuring systems
- Eric Magel (NRC) for guidance on work at CSX and CN
- Ali Roghani (NRC) for MRX assessment of CSX data

Thank You