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Squat-Type Defects in Light Rail: Experiences in Inspections, Laboratory Tests, and Maintenance Approaches

Presentation to ICRI - CM

20 September 2025

Overview

- Squat-type Defects
  - Characteristics and causes
- Transit Experience
  - Inspections and Technologies
  - Studies – metallurgical, monitoring, root causes
  - Maintenance Strategies
  - Summary
- Next Steps
  - Defect initiation – wheel slips and martensite

Squat-Type Defects

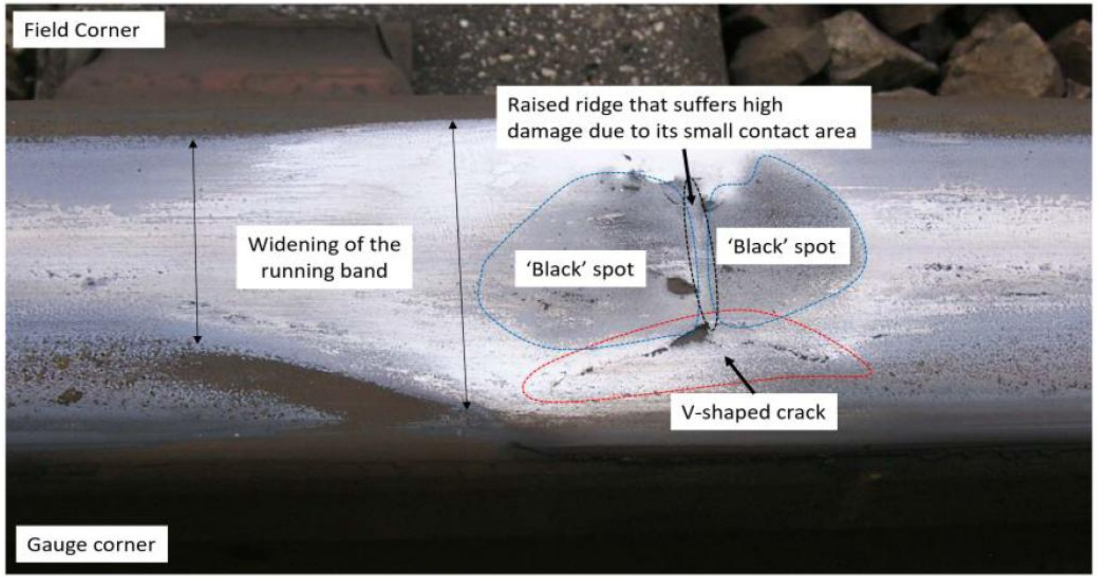
- Also referred to as studs
- Definitive root cause not identified
  - Theories, contributing factors, and exceptions

Squats vs Squat-Type Defects (Studs)

Squats	Studs
• RCF initiated usually at gauge corner	• Wheel slip initiated in middle of running band
• Martensite may be present	• Martensite always present
• 40-100 MGT to develop	• **Can develop within 10 MGT**
• Clear unidirectional plastic deformation (ratcheting) of the surface layer	• Minimal subsurface plastic deformation exists
• Cracks follow sheared inter-granular ferrite	• Cracks wander around and through pearlite grains
	• No consistent crack angle inclination
Cracks initiate at about 20^{o} to rail surface	• Hydraulic entrapment not involved
• Hydraulic entrapment common	• **Not seen to progress to TDs and broken rails**
• Can progress to TD’s	• Found in locations with high driving and braking traction
• Found in locations with high driving traction	
	• Can be found in high, low and tangent rails
• Are most common on the high rail of curves	

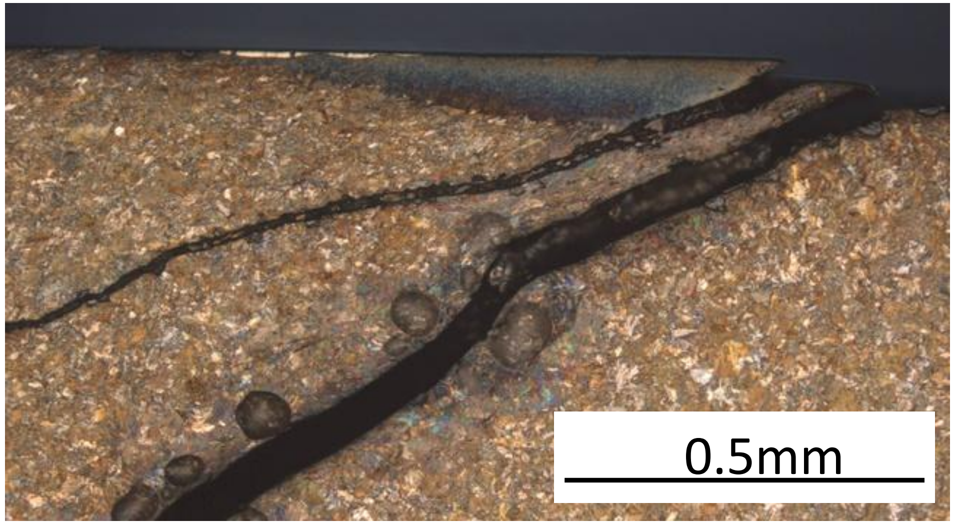
Squat-Type Defects - Characteristics

- Several millimetres across the railhead
- Before spalling can cause rough ride
- Damage fasteners, ballast, ride quality, noise & vibration
- Increase track and vehicle maintenance
  - Substantially shortens the usable rail life
- Appear the same as Squats, but causes and consequences are different



Squat-Type Defects - Characteristics

- Almost no plastic deformation
- Formation within 10 MGT or less
- Old and new rails, tangent and curves
- Presence of WELs
- Not found in tunnels



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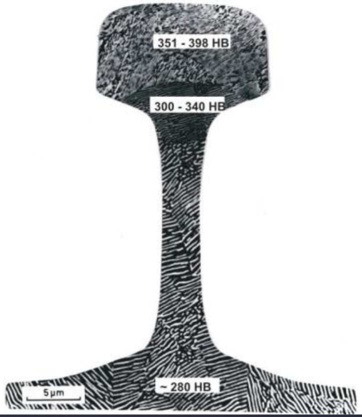
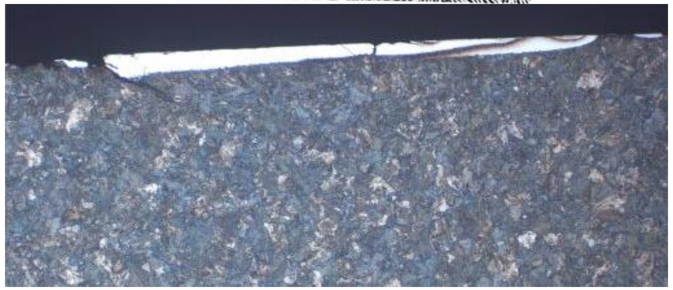
Squat-Type Defects – contributing factors

- Premium Heat Treat rails
  - Increased hardness, strength, similar toughness
  - Increased wear and RCF resistance
  - Studs form in areas with low rail wear
- Anti-head check profiles
  - Gauge corner undercutting
  - Concentrating contact on TOR
- White Etching Layers
  - Contributing factor but usually wear away
- Traction Effort
  - DC to AC, multiple driven axles
  - Significant increase of traction forces in last 30 years
- System Stiffness
  - High system stiffness will increase dynamic reaction





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Squat-Type Defects

- Surface defect size can create an exception in APTA or other track standards developed by North American standards resulting in slow orders or watch and proceed
- Some maintenance activities like rail head welding have caused rail breaks that are associated, indirectly, with squat-type defects
- Early rail replacement / reduced asset life

Why do some areas develop studs while others, with similar operational characteristics, do not?

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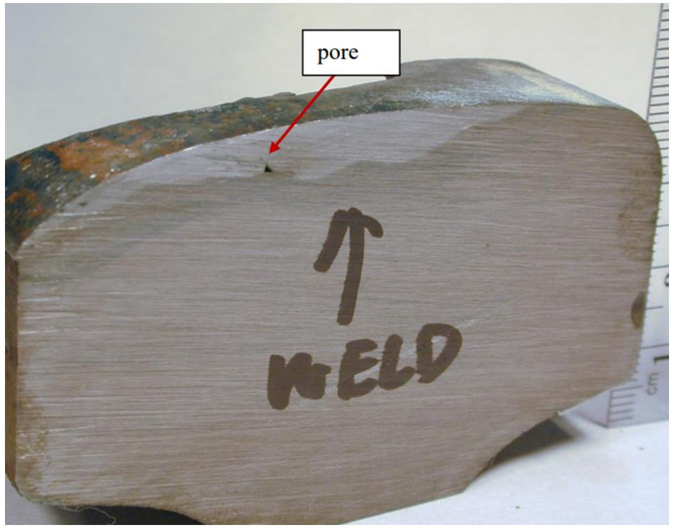
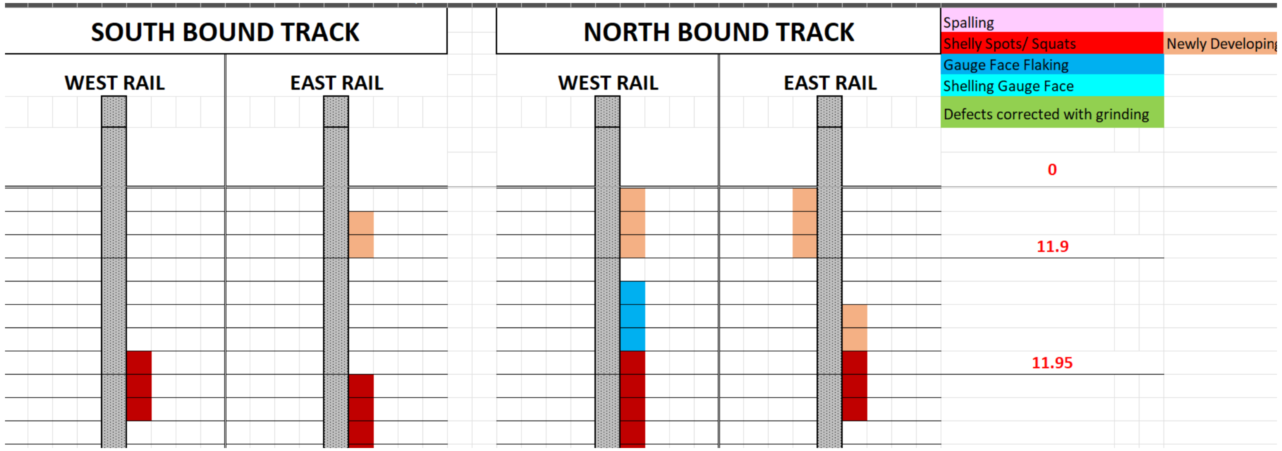
Squat-Type Defects - Consequences



Inspection and Technologies

- Initial mostly visual observations
  - Lead to creation of a rail damage tracking sheet for area of concern
- A series of slow orders and stop and proceed required an increased effort in understanding and documenting what was going on
- Use of different technologies included:
  - Eddy Current (Rohmann Draisine)
  - EMFI (RAGA)
  - Ultrasonic Testing B-Scans (Sperry)
  - Accelerometers
  - Corrugation Trolley



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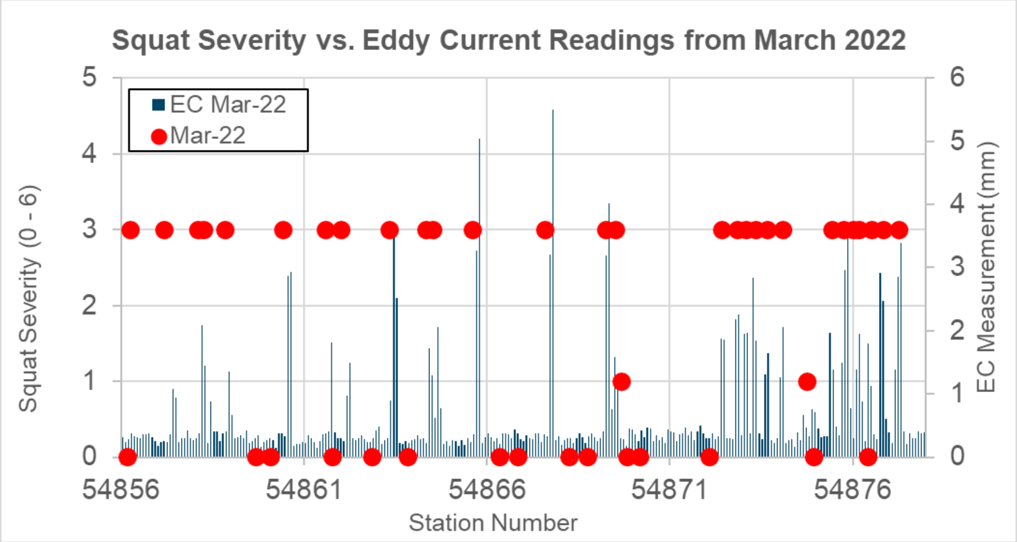
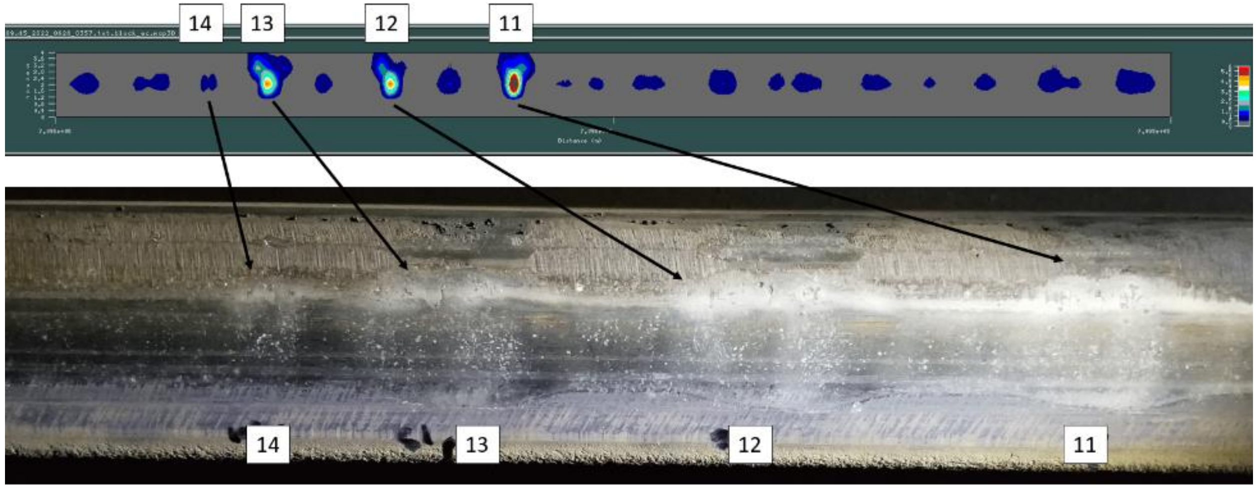
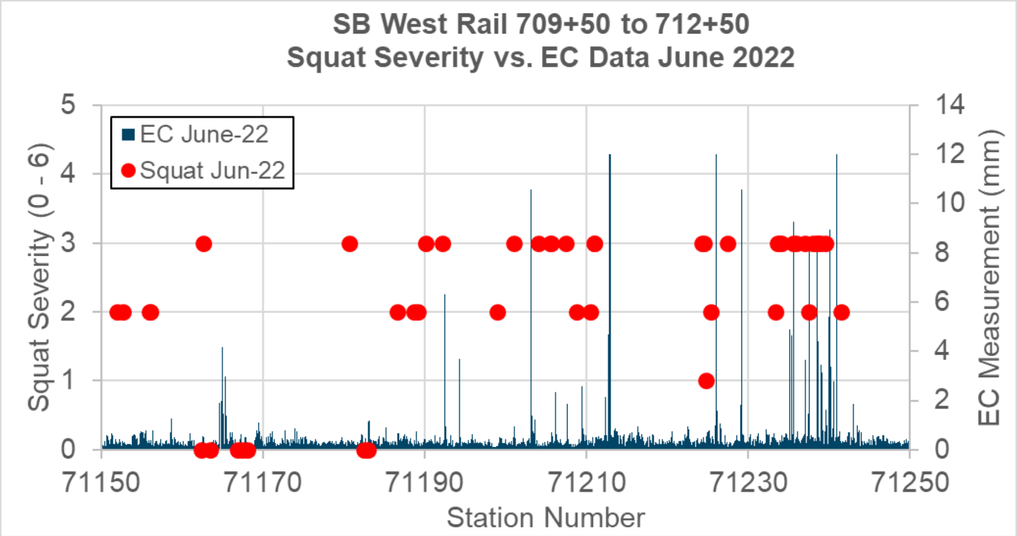
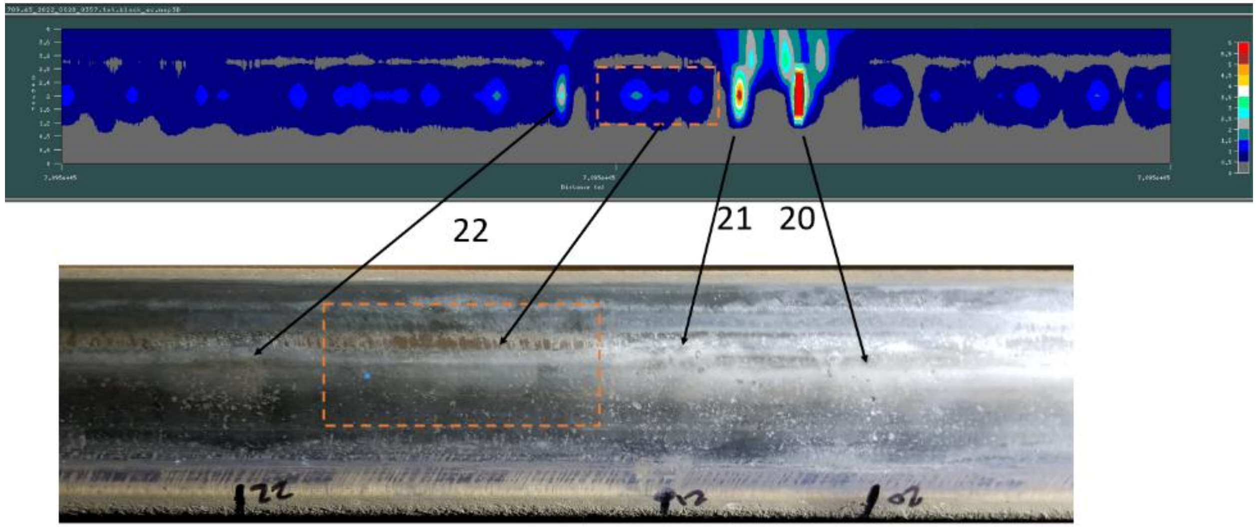
Eddy Current



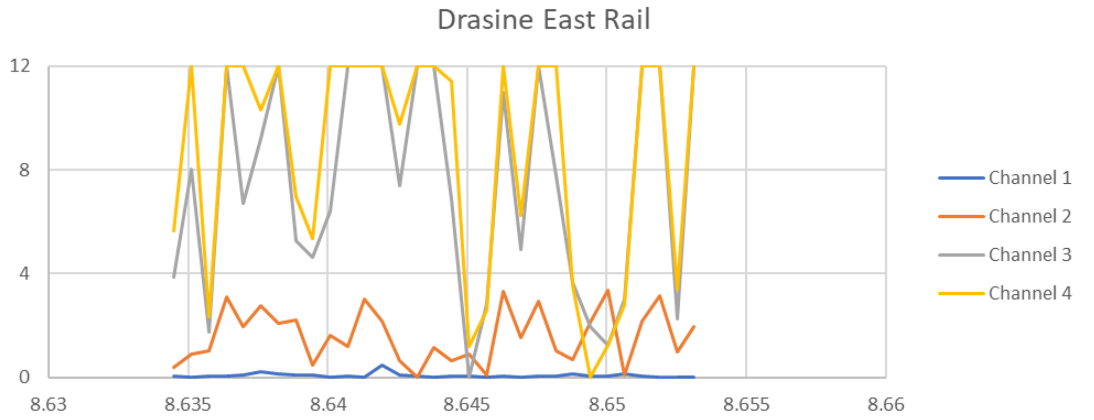


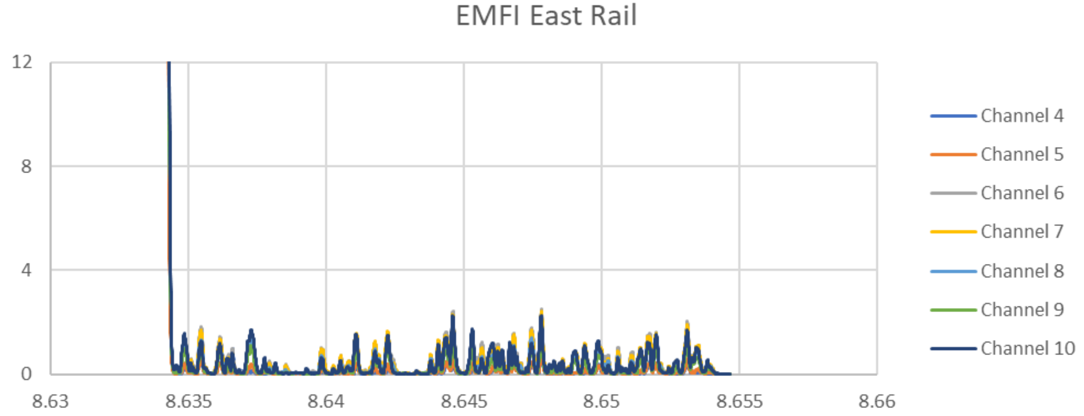




EMFI

- EMFI tow behind unit was trialed and returned almost zero defects
  - Further calibration is required and the technology still could be promising
- Ongoing scope of work to calibrate technology
  - Better pick up studs and possible rail head weld repairs (to pre-emptively map out possible locations for future failures)





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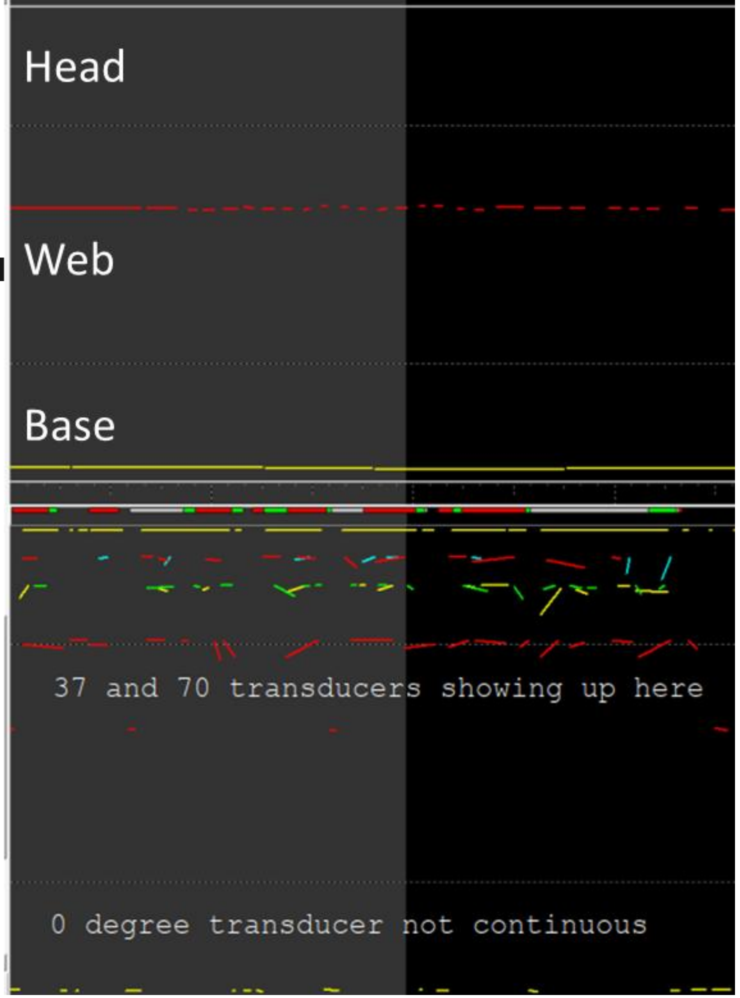
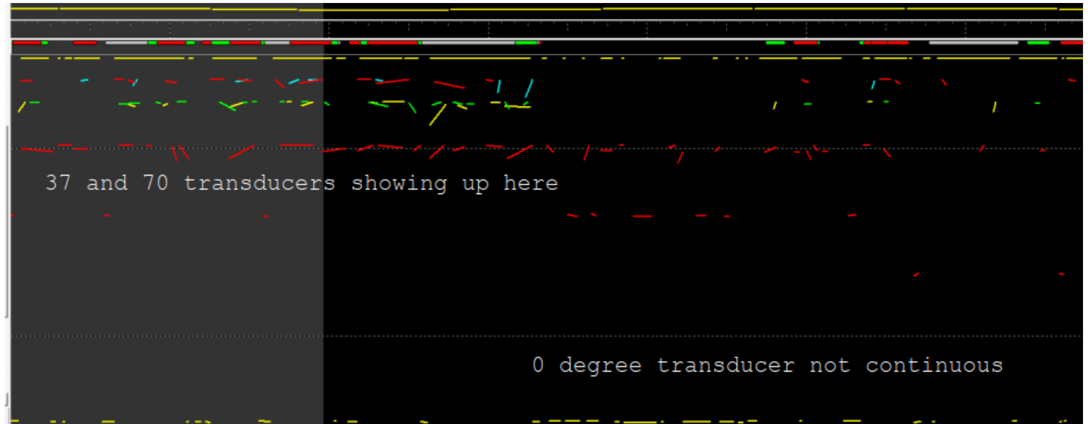
Ultrasonic Testing

- Review of the B-Scans and comparison between damaged rail and good condition rail
  - Promising results in terms of mapping out “infected” rail versus clean but no obvious signs to show severity (yet)
- Recommendation for client to adjust their customer profile to better target and map out rail conditions
  - An east coast passenger railway system did something similar to provide more granular detail as, again, defects weren’t apparent with prior specifications

Right Rail

Left Rail





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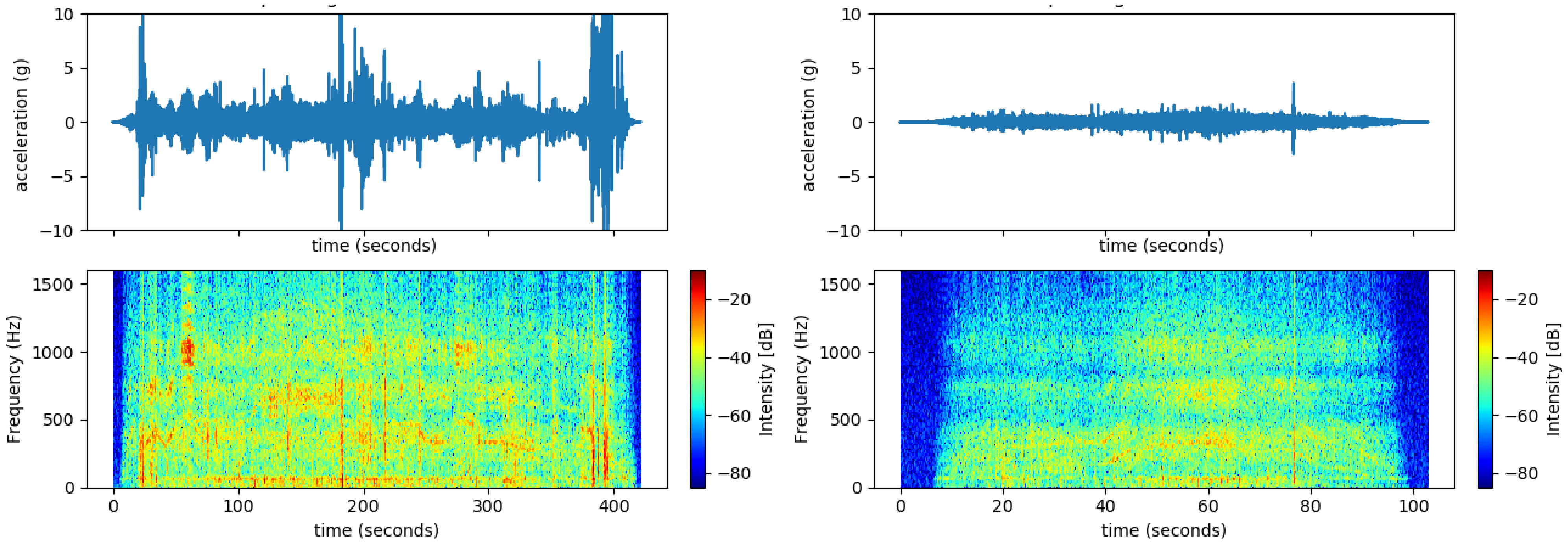
Accelerometers

- Axle box accelerometers can give some information on areas with the presence of these defects



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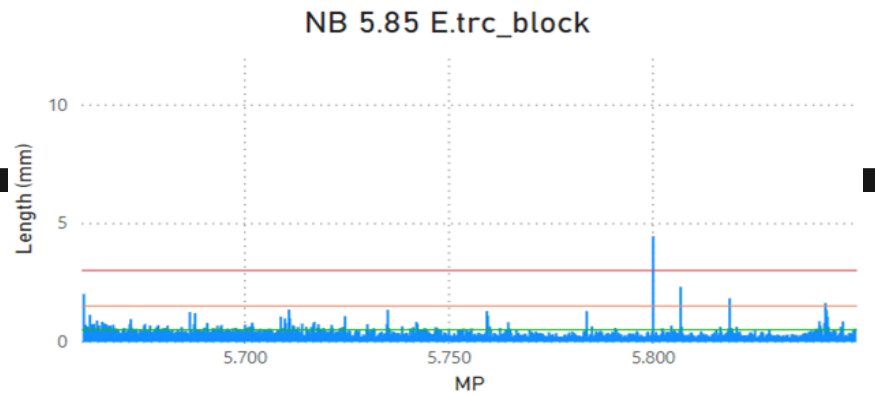
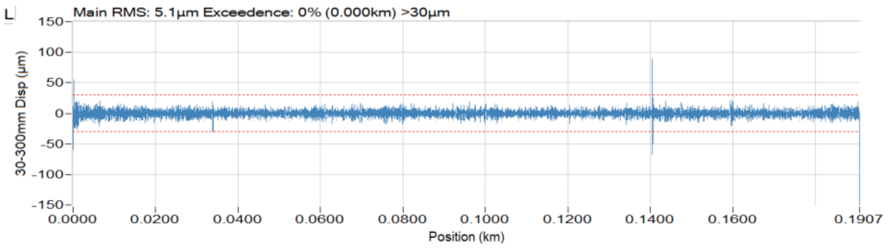
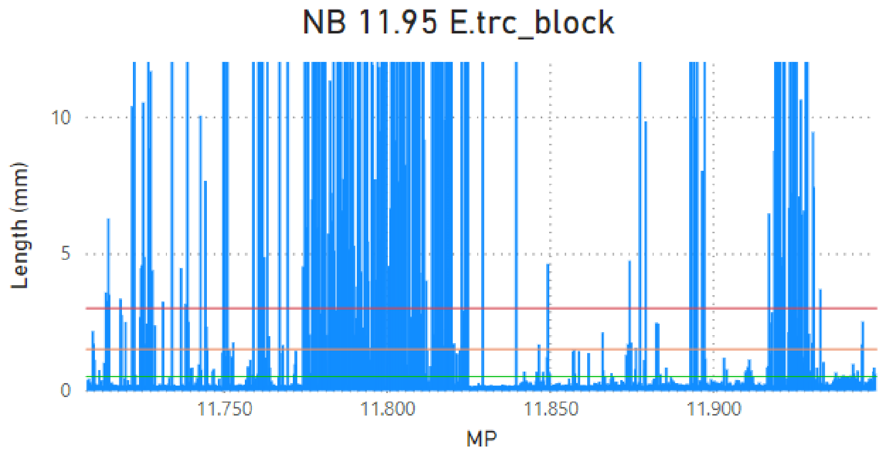
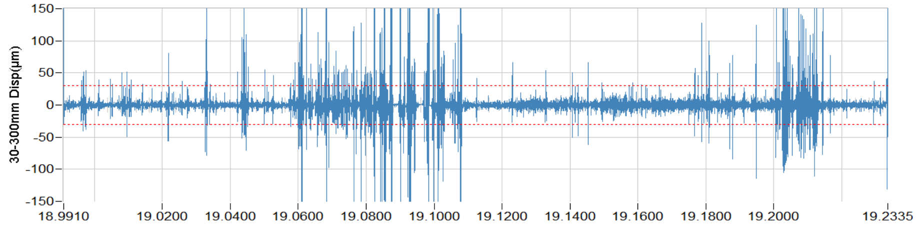
Corrugation Trolley

- Rail roughness measurements taken regularly in tandem with Eddy Current measurements
  - Mapped out and identified squat-type defects almost as reliably, possibly more-so as depressions form in the rail head without exposed cracks
  - If EC can’t provide meaningful depth values for studs then perhaps rail roughness measurement can be just as useful to map out and rank for severity









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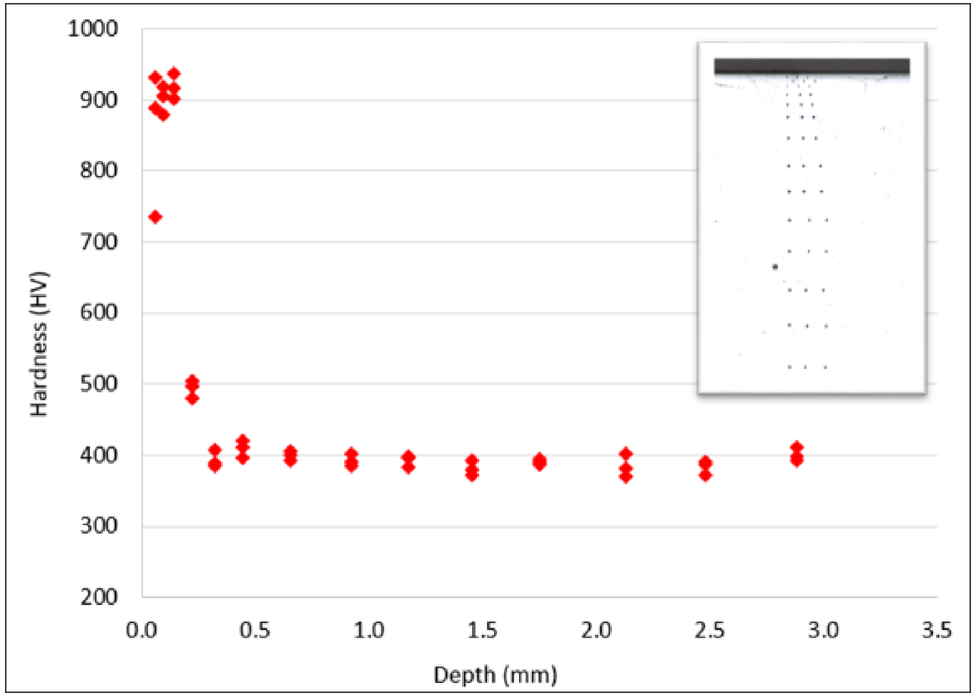
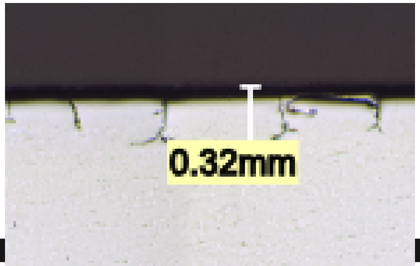
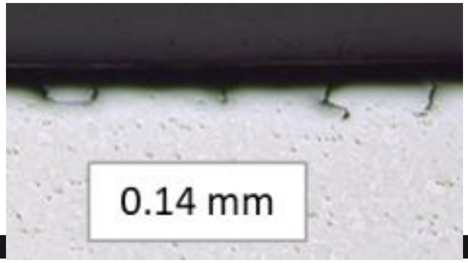
Root Cause Analysis

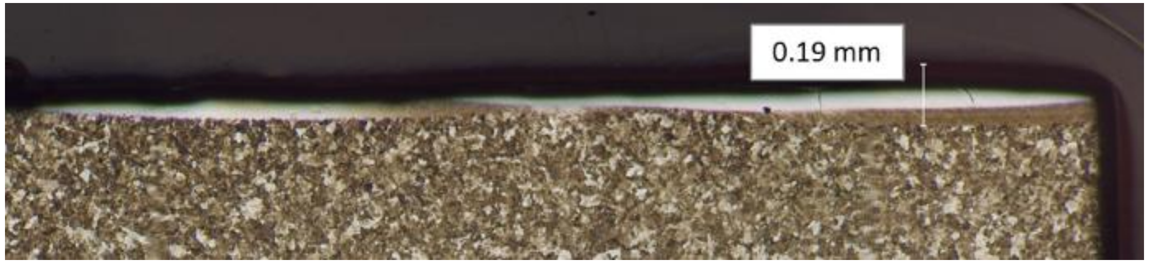
- NRC/ARM report results on metallurgy, martensite, hardness, crack characteristics

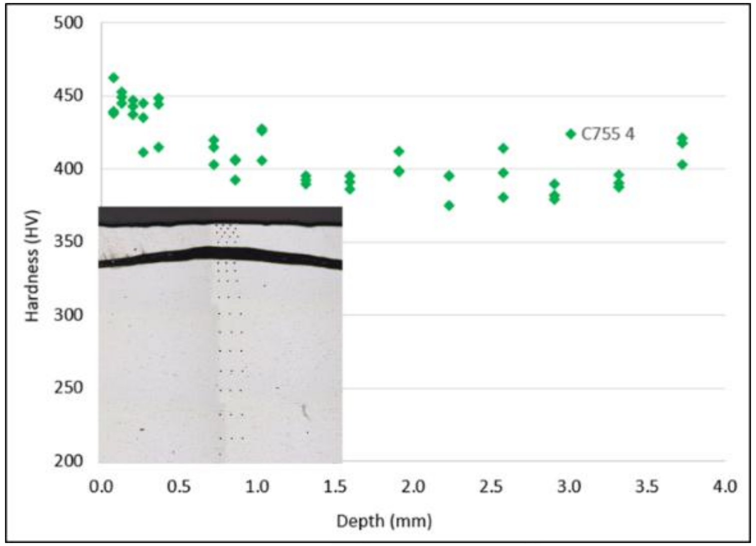


Root Cause Analysis









Element	C755-3	C755-4	IJ-3	SB-1	ER-3	AREMA Standard [23]	AREMA Intermediate [23]
Al	<0.005	<0.005	<0.005	<0.005	<0.005	max 0.005	
C	0.84	0.82	0.80	0.91	0.91	0.72 - 0.82	
Co	0.008	0.008	0.008	0.01	0.009	-	
Cr	0.22	0.22	0.2	0.22	0.22	0.25 - 0.40	0.40 - 0.70
Cu	0.24	0.24	0.2	0.21	0.21	max 0.4	
Mn	1.01	1.01	0.99	1.07	1.06	0.80 - 1.10	0.70 - 1.25
Mo	0.02	0.02	0.01	0.03	0.03	max 0.05	
Nb	<0.005	<0.005	<0.005	<0.005	<0.005	-	
Ni	0.09	0.08	0.08	0.09	0.09	max 0.15	
P	0.011	0.011	0.014	0.017	0.017	max 0.020	
S	0.01	0.011	0.012	0.009	0.009	max 0.020	
Si	0.31	0.31	0.32	0.32	0.31	0.10 - 0.50	0.10 – 1.00
Ti	0.016	0.016	0.018	0.016	0.015	-	
V	<0.005	<0.005	<0.005	<0.005	<0.005	max 0.01	

Ongoing Monitoring

- Ongoing monitoring for the hunt for incipient studs
- Search for early/shallow martensitic layers or other indicators

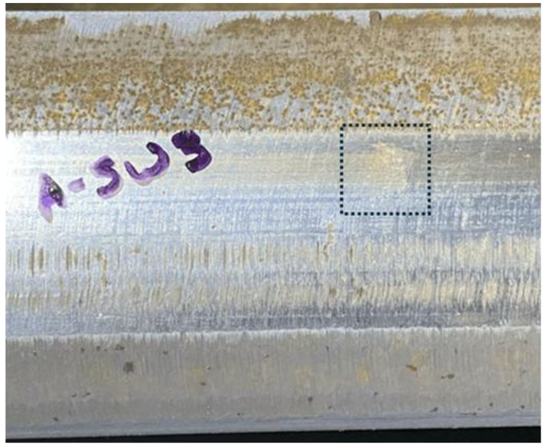
Ongoing Monitoring

30JUL24

23JAN25

10JUL25

Ongoing Monitoring



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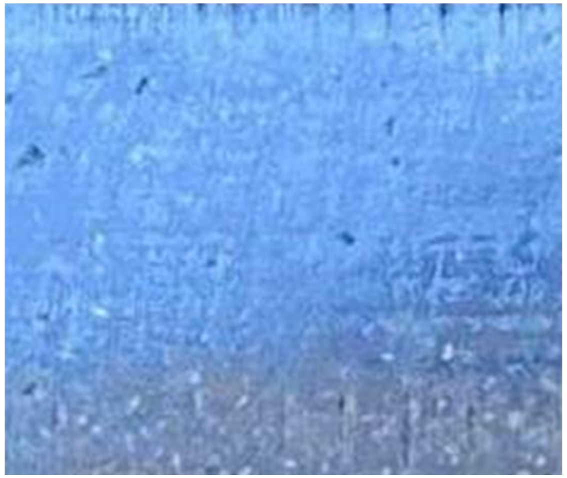

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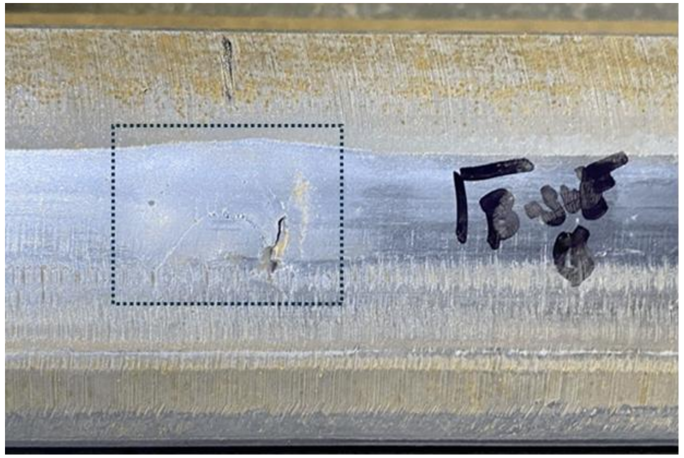
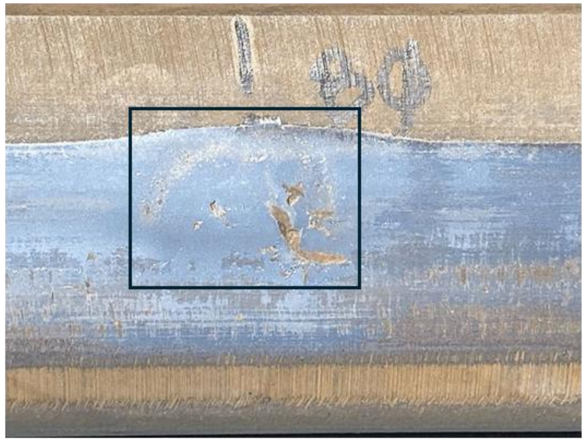
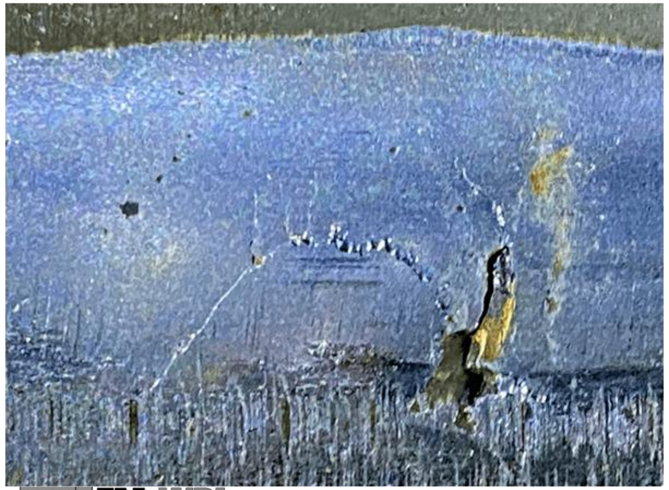
Ongoing Monitoring

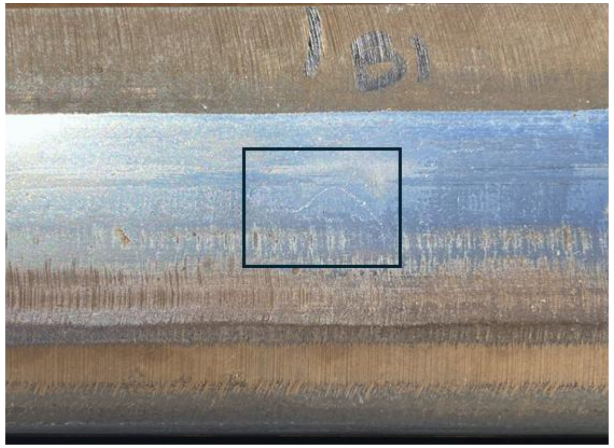




30JUL24 **23JAN25** **10JUL25**



Ongoing Monitoring



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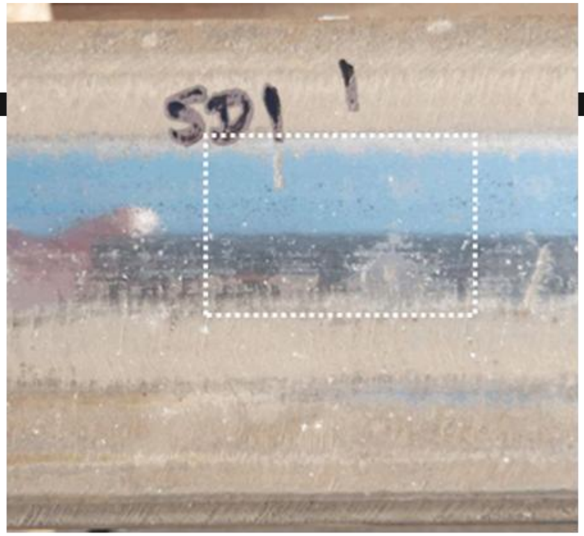
Ongoing Monitoring

30JUL24 | 23JAN25 | 10JUL25

Ongoing Monitoring

- Sight ground a month or two before inspection in July 2025



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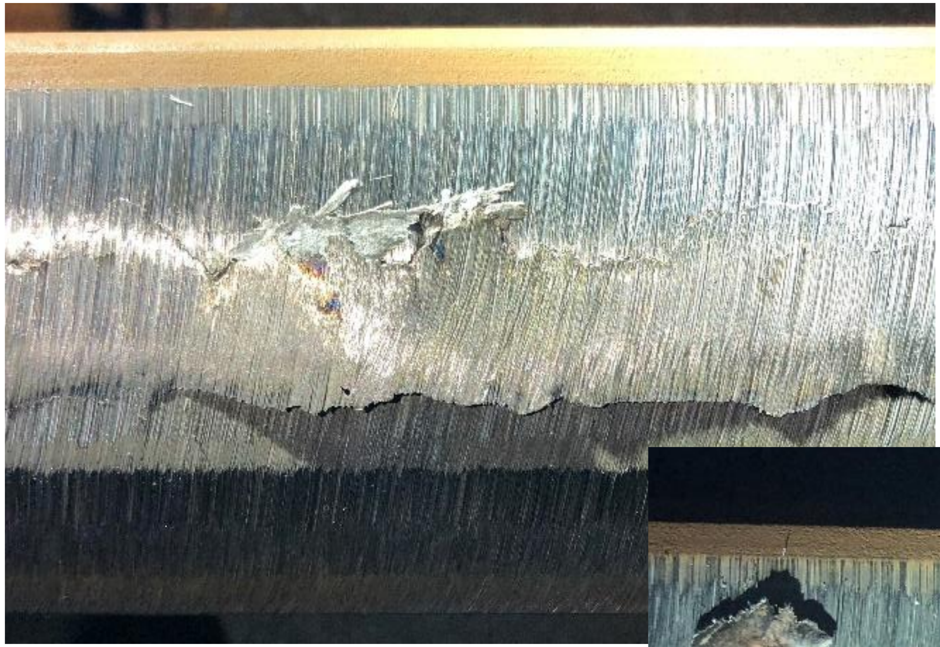
Maintenance Strategies

- Rail head weld repairs – abandoned
- Rail Grinding
  - Corrective – abandoned, made things “worse”
  - Preventive – acoustic approach, maintain profiles, natural wear
- Rail Milling
  - Corrective – Various success
  - Preventive – minimum removal, but what’s the timing, what’s the cost, and what is the depth required
- Friction Management
  - TORFM be a reasonable approach for next step?

Rail Grinding



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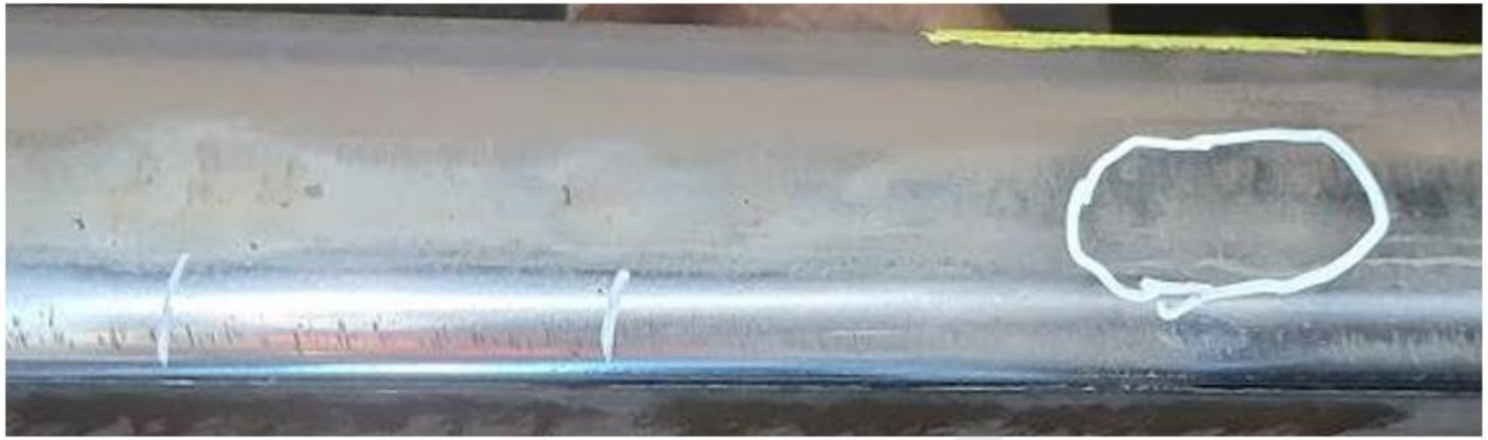
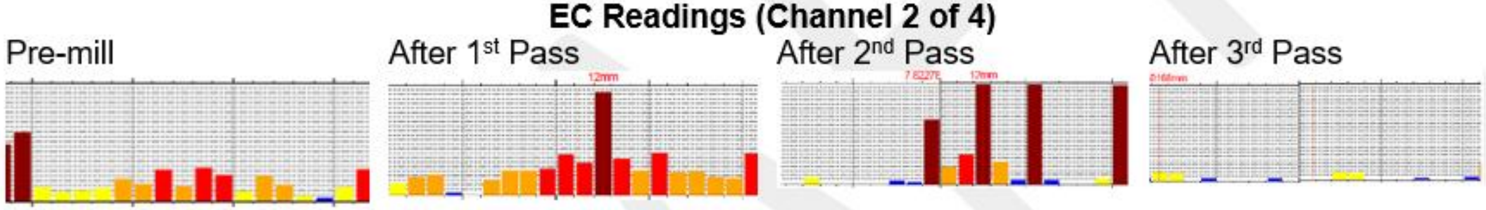
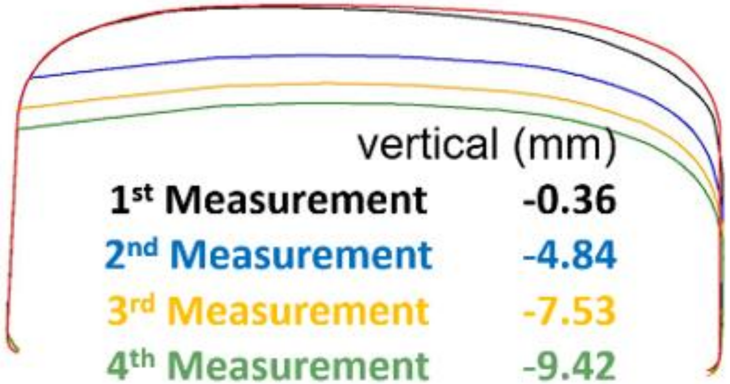
Rail Milling

- Rail Milling program in one curve provide detailed analysis on metal removal, eddy current, and photos with dye penetrant
- Initial visual assessment and EC measurement did not typically match to expected level of effort

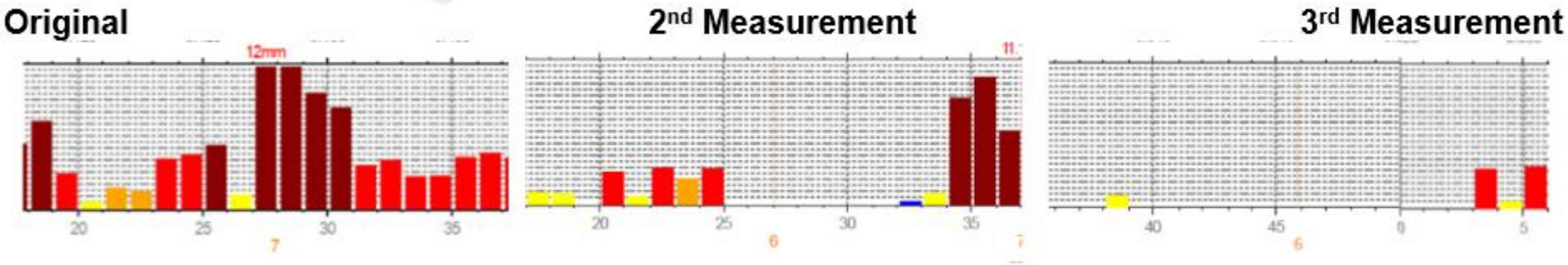




Rail Milling



EC Readings (Channel 2 of 4)



Summary

- Studs are an issue, possibly not a direct safety issue, but still a concern on performance and asset life
- We, and others, have not seen rail breaks directly from studs
  - Mixed review/reports from some other agencies
- So far nothing has reliably given us the incipient rail defect
  - Preventive maintenance to just follow 10 MGT? That is a lot of grinding… not a lot of metal removal but a lot of track time and resource allocation
- Milling has restored profiles and preventive grinding has slowed/prevented return and growth of defects
  - At large metal removal though

Knowledge Gaps

- Martensite – a buildup of martensite layers or single events, most vehicles or rogue incidents, maintenance equipment.
  - Thickness/depth is key? WEL and/or BEL?
- Crack growth – tonnage accumulation before detectable crack develops and what technology, if any, can find it early enough
- Role of contact patch size, contact stress?
- Preventive grinding adequate for control?
- Is corrugation a contributor to or result of studs?
- What role do harder steels play?

Next Steps

- Continue to monitor key locations and trend/track
  - What's a good inspection frequency and, visually, what are we looking for
- Non-destructive testing of martensite formation and depth
  - Track, time, and plan maintenance
  - Does technology exist? Magnetic Barkhausen Noise Analysis?
- Friction management (top of rail)
  - Control friction level and minimize stick/slip
  - Decreases the range in friction levels within a segment
- Track and monitor adhesion events
  - Data loggers from trains, map out severity/frequency in segments
- Other ideas?