Weld Restoration Technologies to Enhance Life & Performance of Rails

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RAILSOLUTIONS ltd.

Innovations through research & design

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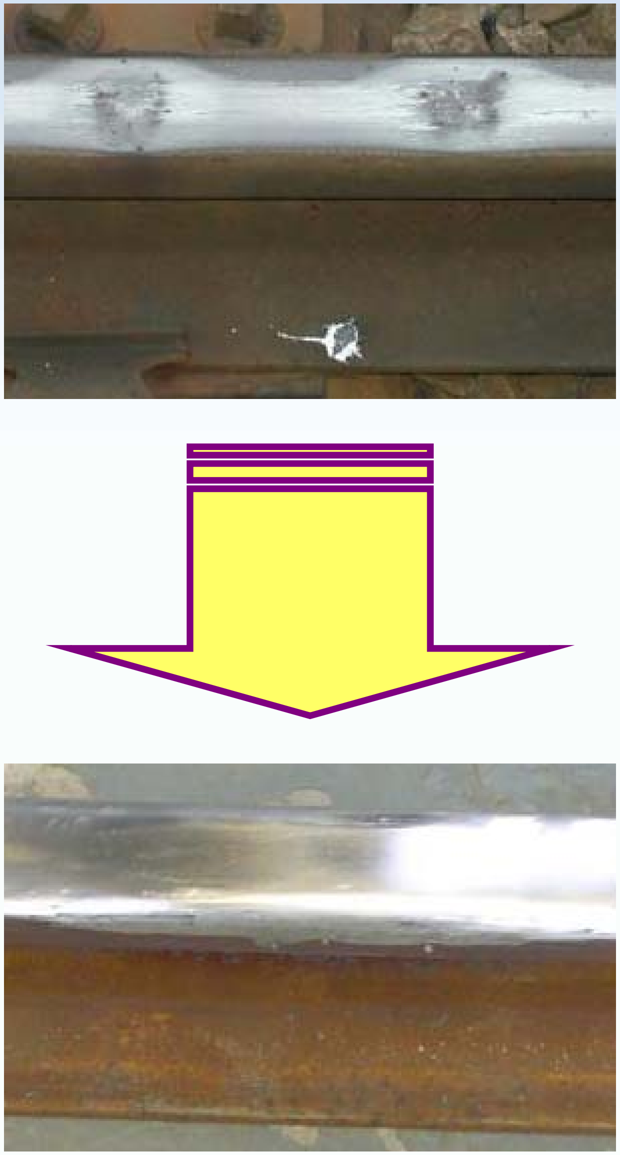

- **Background**
  - Key Rail degradation Mechanisms
  - Solutions on offer
  - Some specific Challenges
- **Novel process to restore discrete defects –**
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  - Key Innovations & Status
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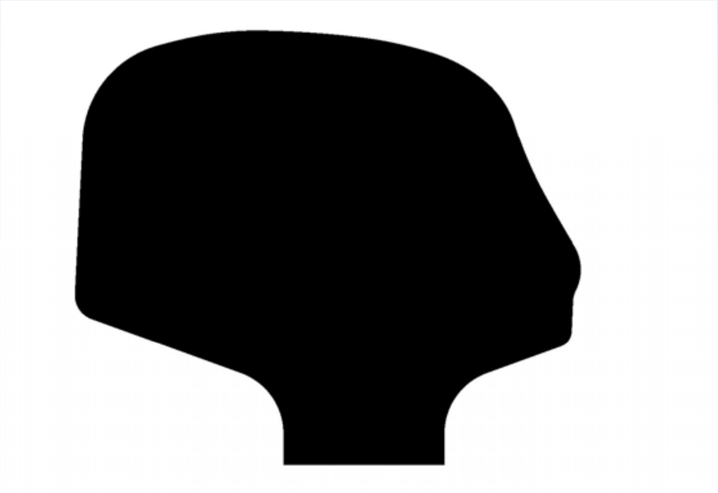
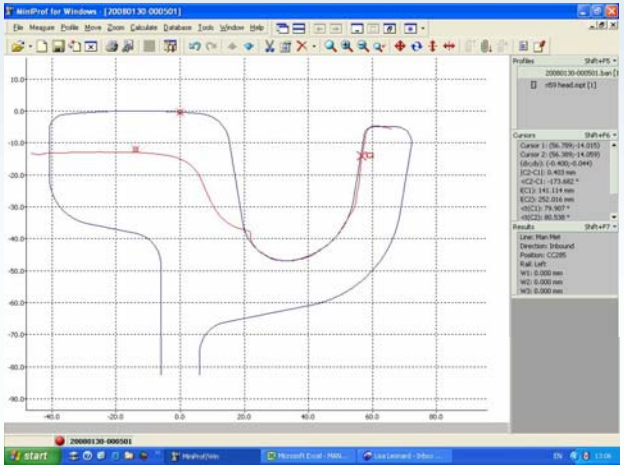
- **Summary**

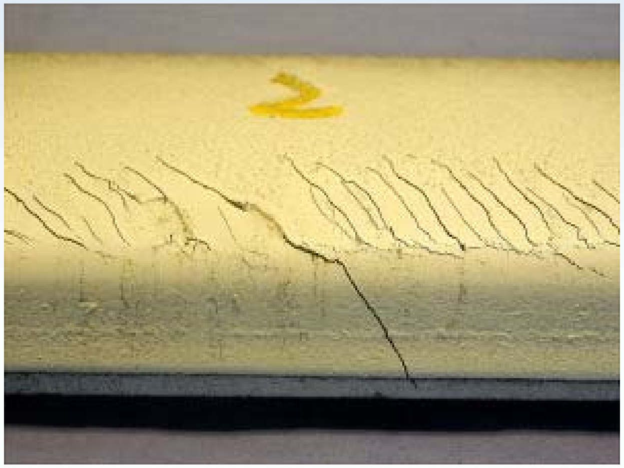
Key Rail Degradation Mechanisms





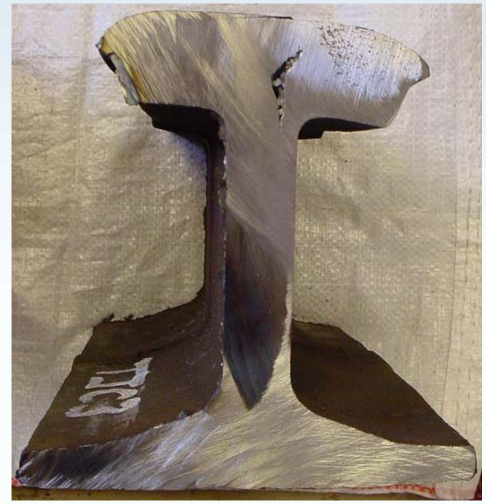
- Rail Wear & Plastic Deformation
  - Even at maximum permissible wear limit, only ~20% of the original section weight has been consumed
  - What proportion of rails replaced annually have reached the wear limit?

Key Rail Degradation Mechanisms



- Rolling Contact Fatigue:
  - Many manifestations - GCC, Head Checks, Squats, Sub-surface
  - A major cause of increased Life Cycle Cost

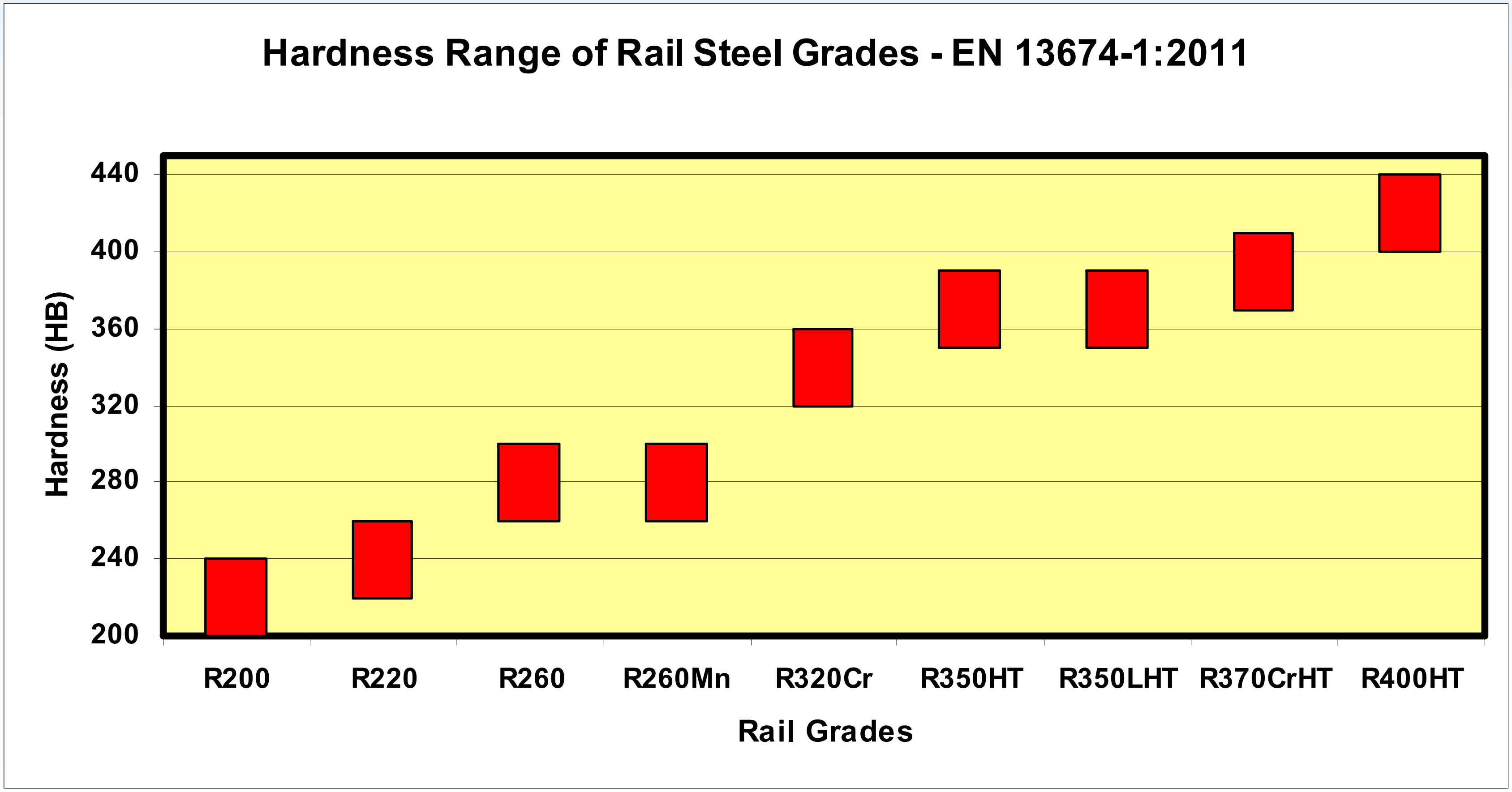
Key Rail Degradation Mechanisms



- Plastic Deformation
  - Increasing freight traffic on routes designed for higher speed passenger
  - Contact conditions on low rail of highly canted curves

Metallurgical Solutions on Offer

Range of Available Rail Steels



Metallurgical Solutions on Offer

New Rail Steel Grades

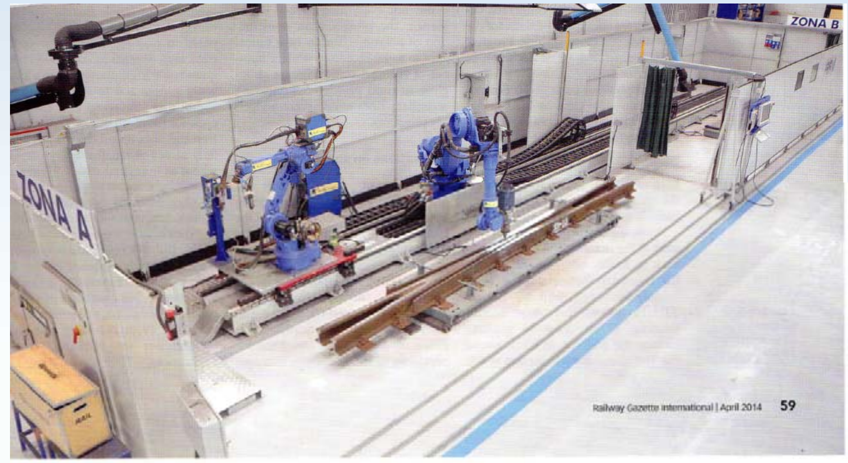
New Steel Grades	Description	Hardness HB
HP335	Alloyed (C-Si-Mn-V) Non-Heat treated	335 minimum
B320	Low carbon carbide-free bainitic	320 to 340
B360	Low carbon carbide-free bainitic	360 to 390
DOBAIN	High carbon Heat treated bainitic	430

- **Increased resistance to degradation mechanisms but the essential maintenance requirement of regular grinding remains for most grades**
- **Judicious selection and deployment of steel grades is essential**

Other Challenges Remain

- **Discrete defects such as Squats and wheel burns**
- **Damage at Crossing nose**
- **Squeal noise at complex junctions**

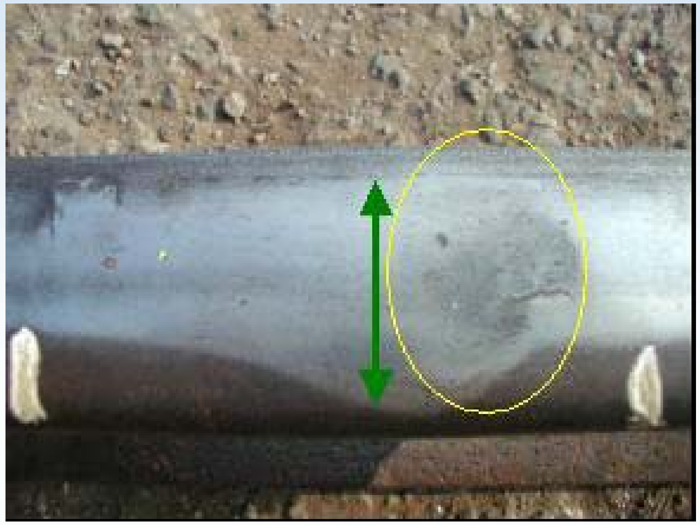
Weld Restoration – A Solution



- **Weld restoration technology has been available**
  - **From Manual Metal Arc to Factory Robotic Welding**
- **Further development was required for:**
  - **Much lower preheat temperature**
  - **Automated in-situ repair process**
  - **Deposition of degradation resistant materials on basic rail steels**

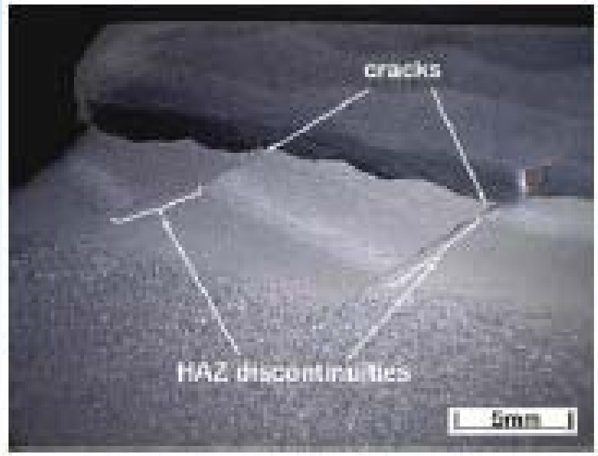
Novel Weld Restoration Process for Repair of Discrete Defects

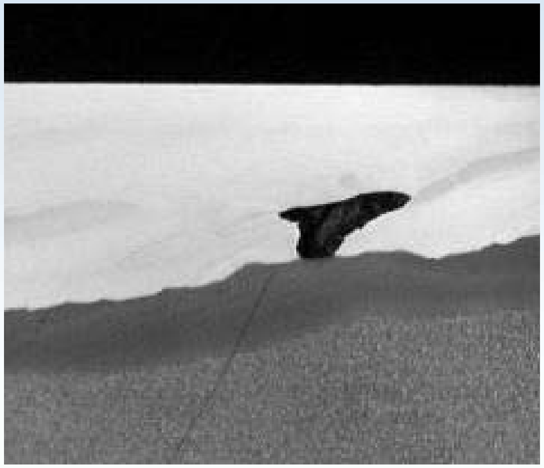
The Drivers for Innovation (1)



- **Complex Contact Conditions: even the best maintained railway networks develop discrete defects – wheel burns, squats, ….**
- **NR Assessment: ~10,000 squats/wheelburns removed annually - ~6000 weld repairable**
  - **Average cost of replacement estimated at ~£2.5k per defect or ~£15 million annual expenditure**

The Drivers for Innovation (2)



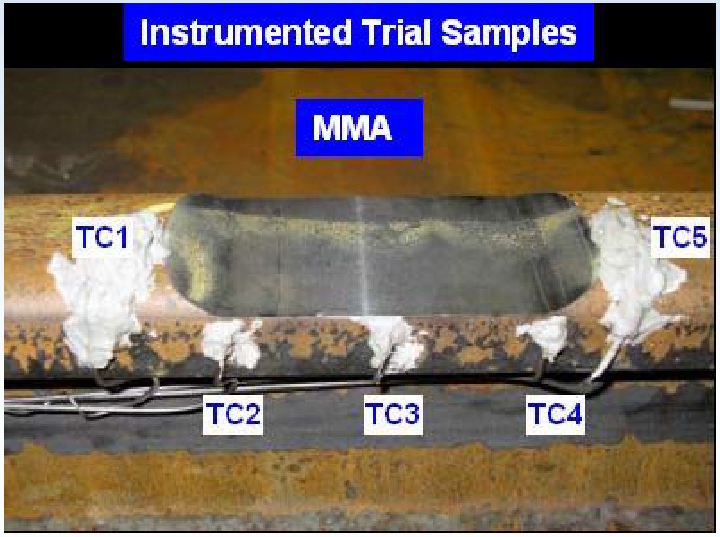


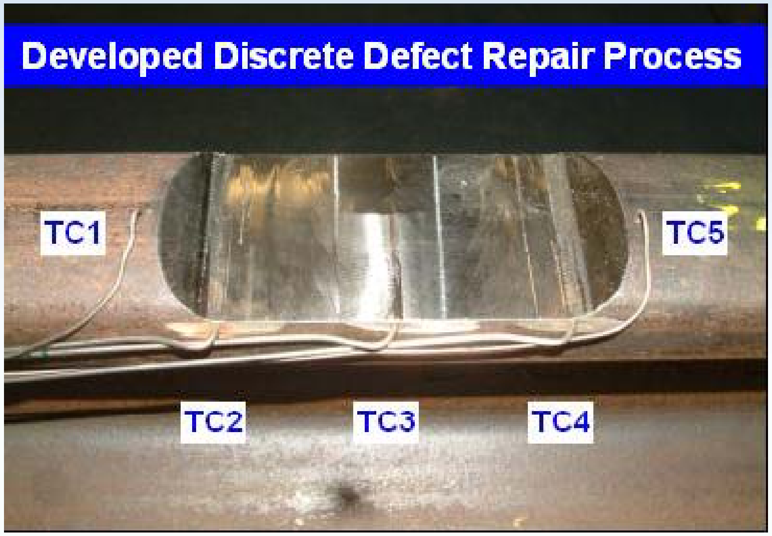
Pictures from Welding Lines

- **Current remedial measures:**
  - **“5m Closure Rail”:** Introduces 2 new AT welds, geometry changes, re-stressing,
  - **Wide gap AT welds:** Limited to shorter length, differential wear, increases the number of AT welds in network
  - **MMA repair:** requirement of high preheat, inconsistent results and high perceived failure rate, availability of skills
  - **Thermit Rail Head Repair:** Cast material on running surface?, integrity of cast – wrought steel interface under cyclic loading

The Developed Process: Metallurgical Foundations

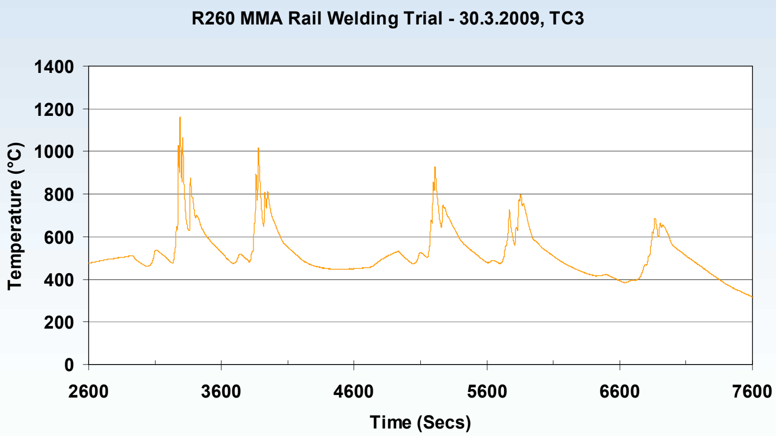
The Metallurgical Foundations

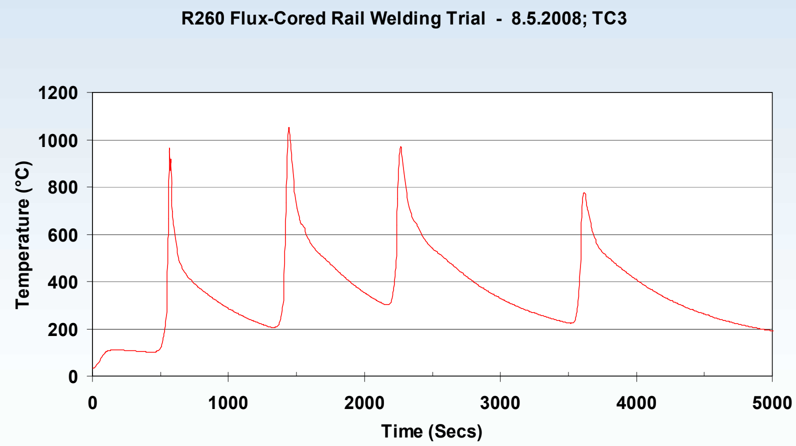




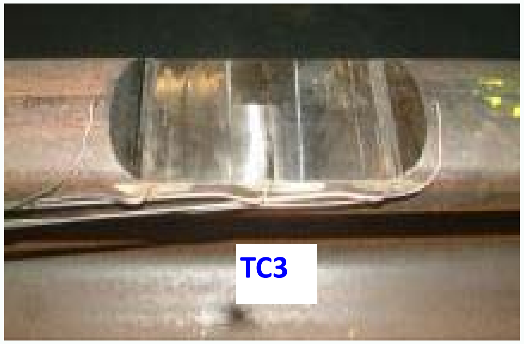
- **The key factor influencing HAZ microstructure & integrity is the thermal history it undergoes.**
- **Comparative instrumented thermocouple trials have been undertaken for:**
  – **MMA repair**
  – **Developed Discrete Defect Repair (DDR) process**
  – **Thermocouples in five locations surrounding the excavated cavity at ~2-3mm from edge**

The Thermal History



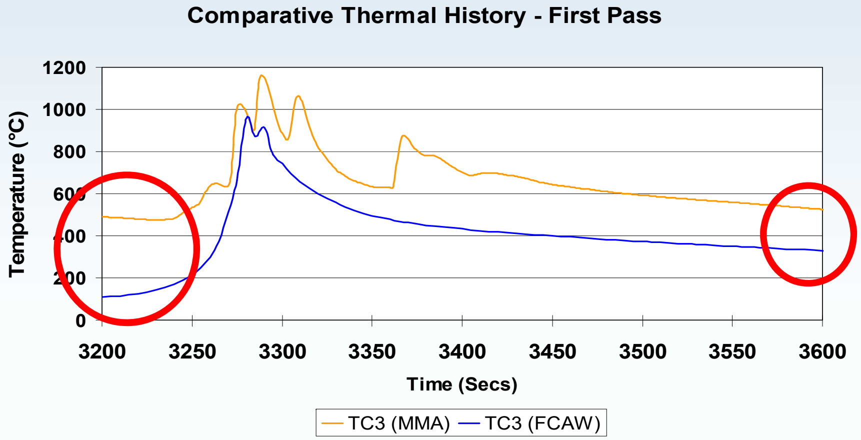


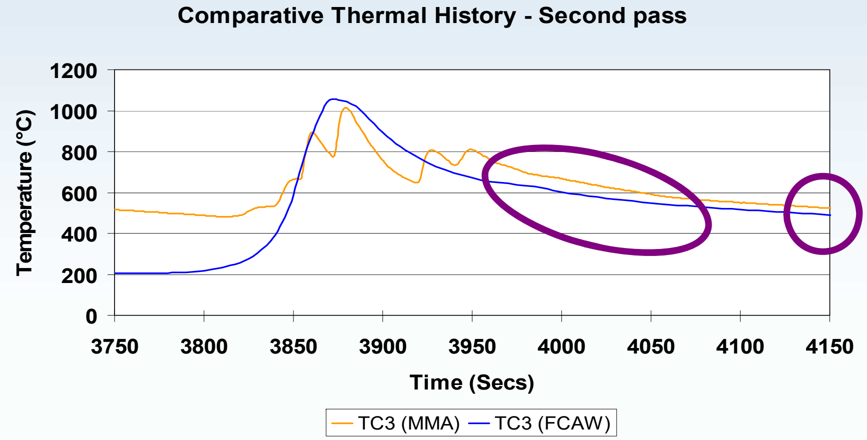
Parameter	MMA	Developed Process
No of passes	5	4
Preheat Temperature, ^{0}C	350	80
Cooling Rates, ^{0}C/s (800^{0}C - 500^{0}C)		
Pass 1	1.1	5.2
Pass 2	1.3	1.3
Pass 3	0.9	1.0
Pass 4	1.1	1.5

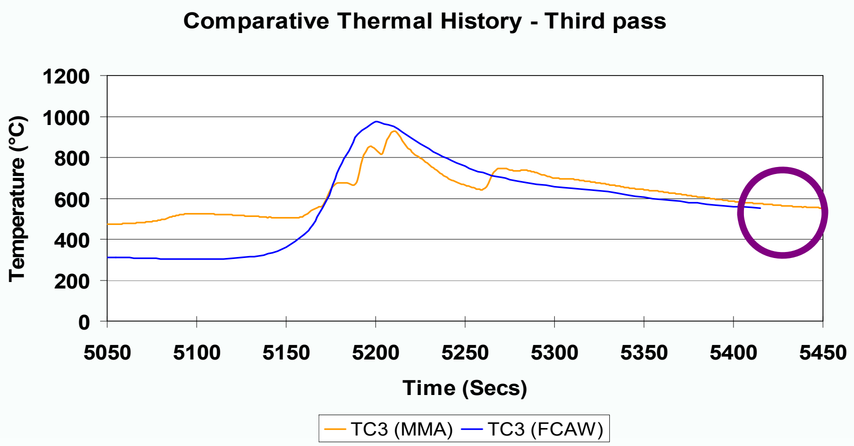


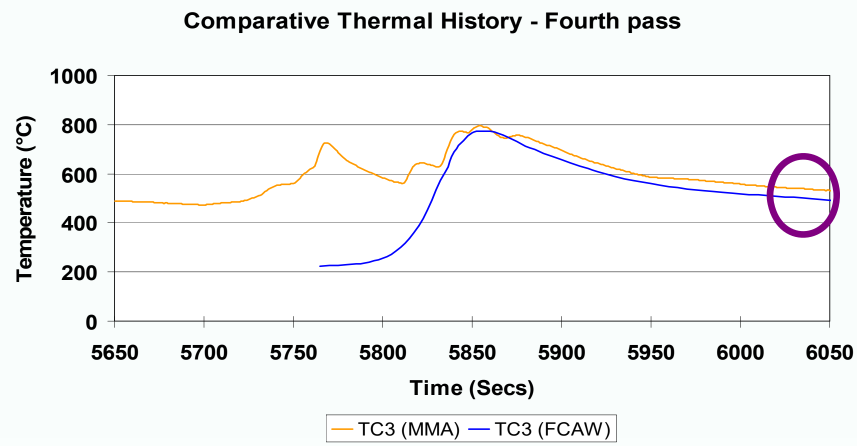
- Despite the very significant preheat temperature differences, the cooling rates for all but the first are almost identical. **The fastest C.R. of 5.2^{0}C/s in Pass 1 has also resulted in pearlitic transformation.** Note the consistency of the thermal history in the developed process

Comparative Thermal History: Passes 1- 4









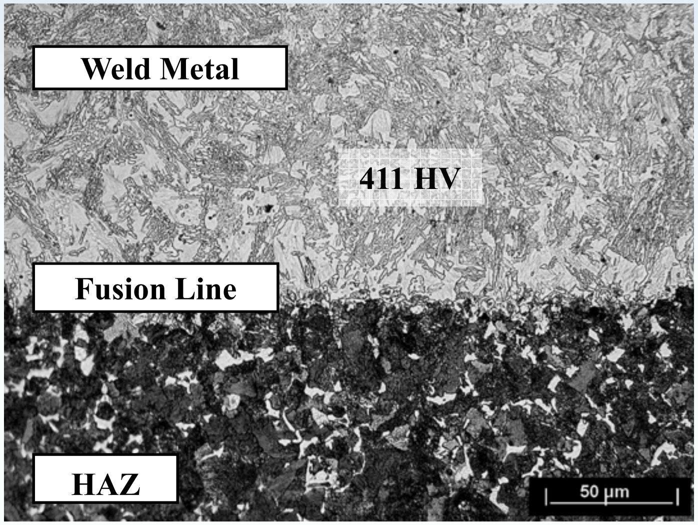
Metallurgical Foundations

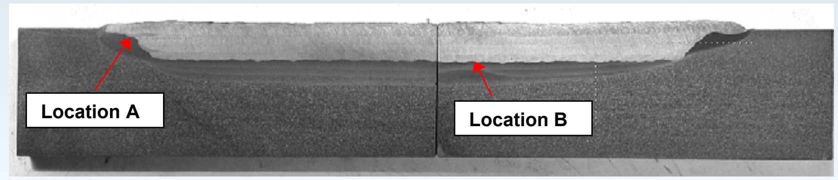
- **Key Conclusions**
  - Fastest cooling rate = 5.6^{0}C/s - well below the critical rate for non-pearlitic transformation – Previous BR Research has concluded rates of >10^{0}C/s result in martensite in the microstructure
  - Lowest temperature achieved for each weld deposit is above 200^{0}C/s – i.e. above M_s temperature of ~160 ^{0}C – Consequently there is no possibility of forming martensite even if the cooling rate was much faster
  - The maximum temperatures & cooling rates closer to the fusion line are not expected to affect the overall integrity of the repair.

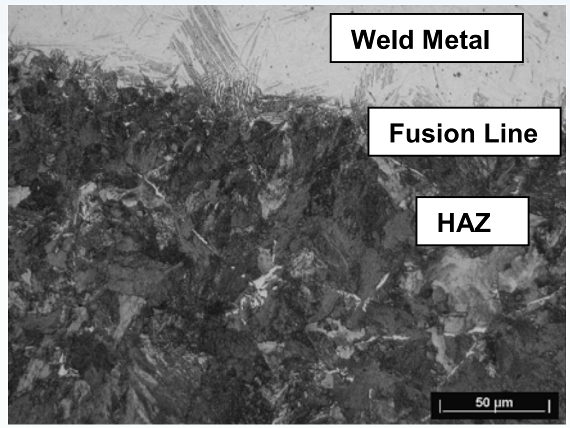
The Developed Process:

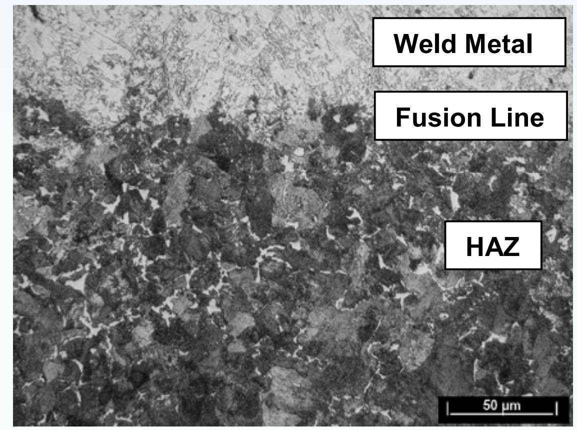
Metallographic Confirmation of Integrity

Microstructural Integrity of Deposit



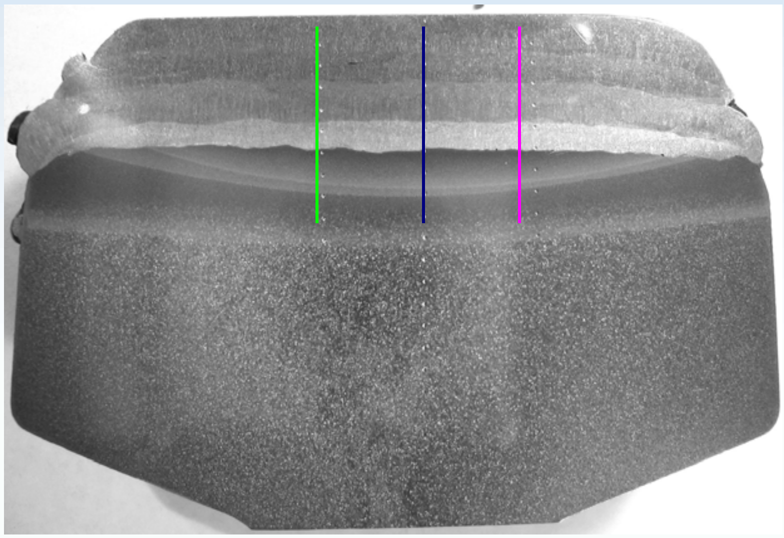


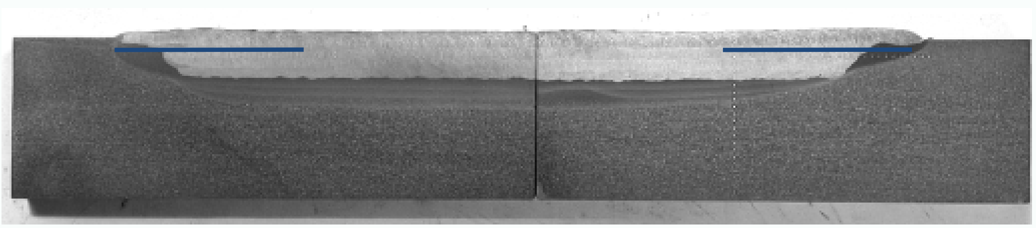


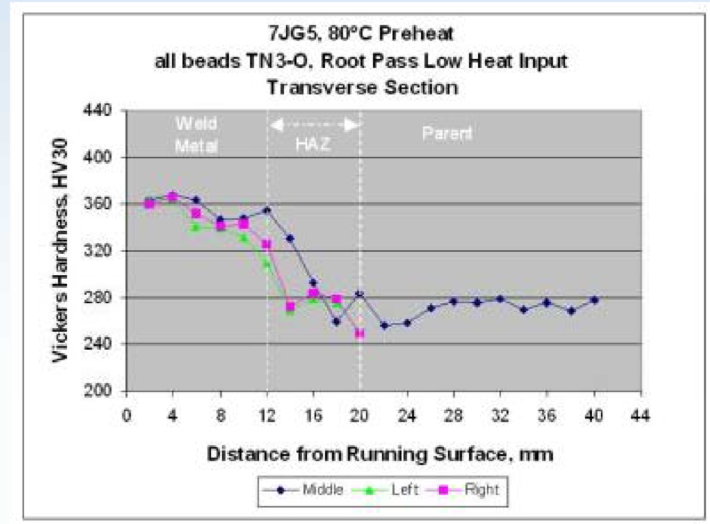


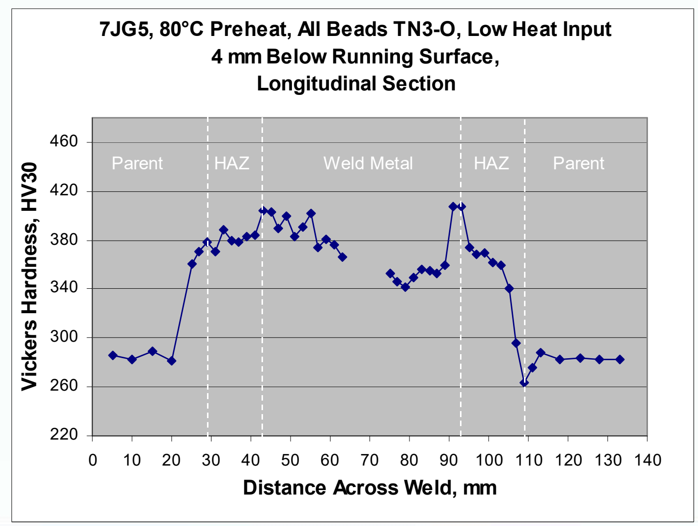
- **Crack Free Interface is apparent in all transverse and longitudinal slices**
- **HAZ microstructures are free from any martensite or bainite. Some ferrite at grain boundaries is a reflection of the carbon diffusion into the weld metal**
- **The weld metal microstructure is, as expected, bainitic with a high hardness in the root bead from the carbon pick up.**

Hardness Integrity





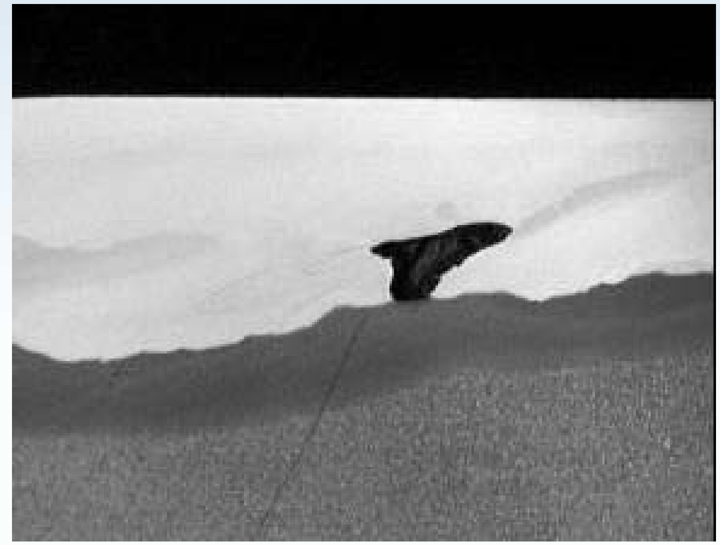




- **Weld deposit hardness of ~360HV at the surface = good wear resistance**
- **Relatively uniform hardness across longitudinal section**

<u>The Developed Process:</u>
Structural Integrity of Weld Repair

Fatigue Failure Resistance – MMA Repair



- **Failure mode often encountered with MMA repairs is fatigue initiated from flaws at the weld-parent metal interface.**
- **Such defects, like the classical Tache Ovale defects are not detected till they are sufficiently large leading to rail replacement.**
- **Statistical data for such failures is often inaccurate - mistaken for Tache Ovale or Vertical-Transverse breaks.**

Fatigue Failure Resistance – DDR Process

- **Fatigue Resistance: 4-point Bending Fatigue test with Rail Head in tension**
- **Stress range = 3 times expected service load – passed 5 million cycles**
- **Increased loading = ~ X 8 service load on same sample- further 4.3 million cycles**
- **Failure in service extremely unlikely**

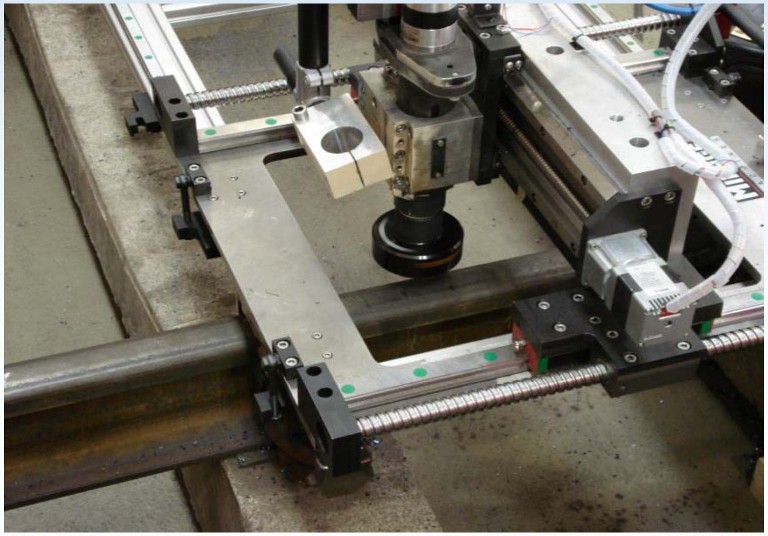
Cost Effective & Robust Repair of Discrete Defects

A Pictorial Walk Through the Developed Process

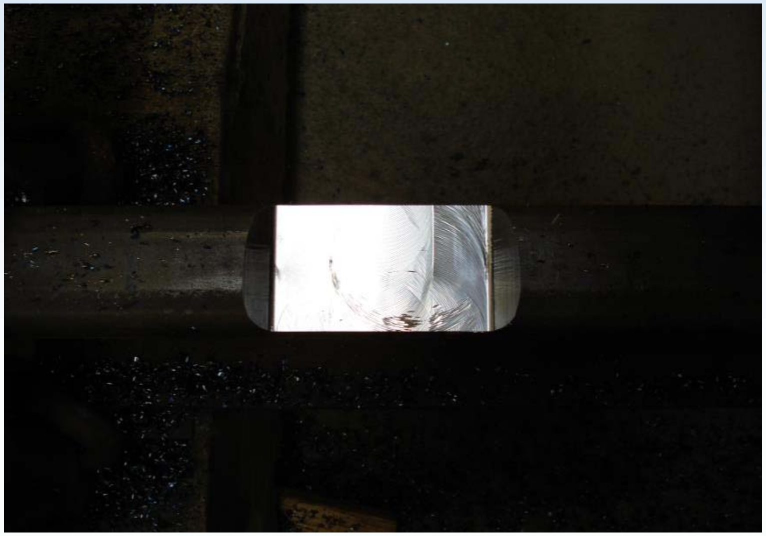
A Pictorial Walk Through the Process

- **DDR Machine transport to site to be as per approval of Network Manager**
- **Set up time on site = ~10 minutes**

A Pictorial Walk Through the Process



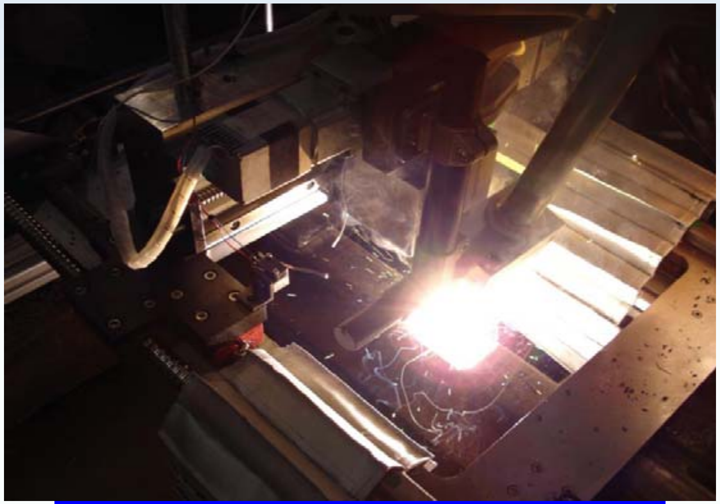
Milling Head in Place



Milled Cavity

- **Programmed milling to deliver cavity of prescribed dimensions**
  - **Full head width but several length and depth dimensions programmed**
- **Time for milling a cavity (100 (L) x 72 (W) x 10 (D) mm) = ~25 minutes**
- **Milling turnings collected to prevent contamination**

A Pictorial Walk Through the Process



Welding Head in Place

First Welded Layer

- **Detachable milling head replaced with welding gun ensuring identical control of movement**
- **Time for welding a cavity** (100 (L) x 72 (W) x 10 (D) mm) **= ~21 minutes**
- **Slag removal between layers using a pin gun**

A Pictorial Walk Through the Process

As-finished Weld Deposit

Finish Repaired Rail

- **Process requires a carefully positioned sacrificial layer to ensure the desired tough HAZ microstructure**
- **Finish profiling is using conventional grinders to permit blending with parent rail profiles on either side of repair.**

DDR Process – Key Innovations

- **Avoids high preheat** – recommended 60^0 – 80^0C only
- **Avoids restressing** – no through section cuts made
- **Avoids new welded joints** – only the area with defect repaired
- **Improved process consistency** – largely automated plc controlled process
- **Improved consistency of wear resistance** – approved consumables
- **Increased repair integrity** – fatigue failure under cyclic loading unlikely
- **Increased productivity** – 100mm (L) X 10mm (D) defect repaired <1 hr

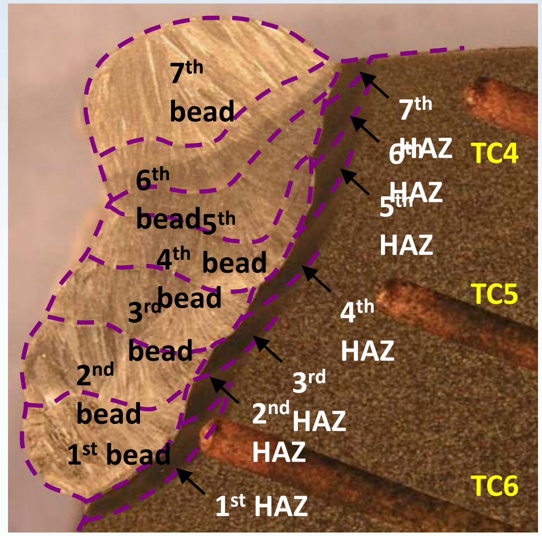
Development Status

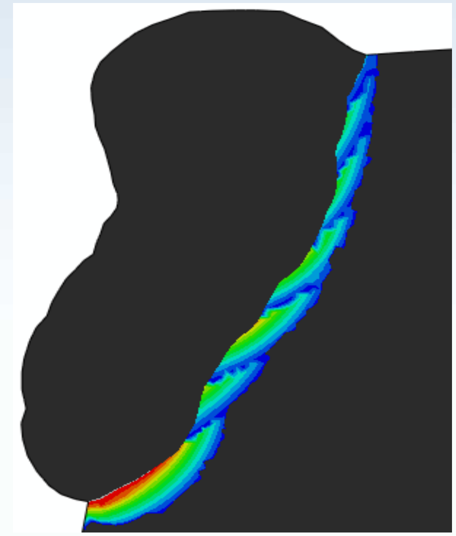
- **Prototype equipment available for live demonstration**
- **Process for R260 standard grade rail proven**
- **Detailed process approval document available**
- **Process selected for demonstration & further development within IN2Rail project**

WELD RESTORATION TECHNOLOGY

OTHER POTENTIAL APPLICATIONS

Minimising Squeal Noise





- **Process of gauge corner restoration well established in tramway sector**
- **Austenitic stainless deposit on R260 grade provides lower roughness growth & coefficient of friction**
- **Further weld deposit compositions with additional properties of very high resistance to wear & RCF developed and demonstrated**
- **Composite rails with specialist materials deposited on gauge corners offer a material solution for niche segments of track**

Crossings

- **Visible running bands on crossings show the areas that experience the demanding contact conditions and resultant degradation**
- **Metallurgical solution is deposition of specific materials more resistant to the degradation mechanisms**
- **Feasibility of milling of bespoke cavity in standard grade rails proven**
- **Feasibility of deposition of novel degradation resistant compositions proven**

Summary

- **Novel low preheat weld restoration process for high carbon rail steels offers many opportunities:**
  - **Largely automated repair of discrete defects such squats, wheel burns**
  - **Stainless cladding at gauge corner offers potential to reduce squeal noise**
  - **Cladding of crossings with materials that possess much higher resistance to plastic deformation, wear, and rolling contact fatigue**
- **Further work required to define the optimum dimensions of deposits and their in-service performance**

THANK YOU