

RAILECT

“Development of an ultrasonic technique, sensors and systems for the volumetric examination of aluminothermic welds”

IoRW Seminar – 1st December 2010

Tamara Colombier

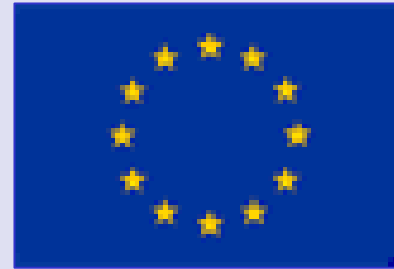
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European Project – “Research for SMEs”



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<http://ec.europa.eu/research/rea> ([FP7/2007-2013] [FP7/2007-2011] under grant agreement no [FP7-SME-2007-1-222425])



RAILECT Consortium



- 8 Beneficiaries from 4 different European countries
- SMEs Beneficiaries
 - Optel (Poland)
 - Vermon (France)
 - Spree (UK)
 - KCC (UK)
- RTD Beneficiaries
 - TWI (UK)
 - KTU (Lithuania)
 - UNUT (UK)
- Other Beneficiaries
 - Previously Jarvis and recently Network Rail UK



Aluminothermic Welds in the Railway Industry



- The majority of field welding is carried out using aluminothermic welding. This casting method is :
 - widely used for in-track welding during re-rail and defect replacement
 - an effective, highly mobile and cost effective
- In the UK :
 - 65,000 new welds per year produced by Network Rail and up to 2% rejection rate
 - 1.5 million welds already on the main line railways
- In Europe:
 - 300,000 to 400,000 new welds made per year
 - 11 million welds estimated to be on track
 - 20% of all rail failures estimated to be caused by weld failures



Rail Failures



- Effect of early failure:
 - Risk of derailment
 - Cost of track possession for repair
 - Cost of repair of good welds rejected on second inspection (track possession)
- Need for a rapid and reliable system of inspection:
 - To improve rail safety
 - To minimise track possession
 - To reduce costs and resources
- The system could be used straight after the welding, once the weld has cooled down sufficiently



Welding Defects



- The most common volumetric defects for AT welding are:

Porosity



Lack of fusion



Shrinkage



- These defects can cause welds to fail in months rather than years resulting in risk to safe operation and track closures for repairs

Current Techniques of Inspection



- Visual Inspection
 - Most of the time, only visual inspection is performed
 - Surface and geometric flaws only are assessed
 - Reliability? Performance? Assessment?
- Ultrasonics
 - Manual ultrasonic procedure for inspection of rail welds:
EN 14730-1:2006 Annex C
 - **Full inspection is time consuming and requires qualified operators**
- Radiography
 - Disadvantage of the exposure time and exclusion zone (especially for main line track)
 - **Full inspection is time consuming and requires qualified operators**



Need for new system of inspection

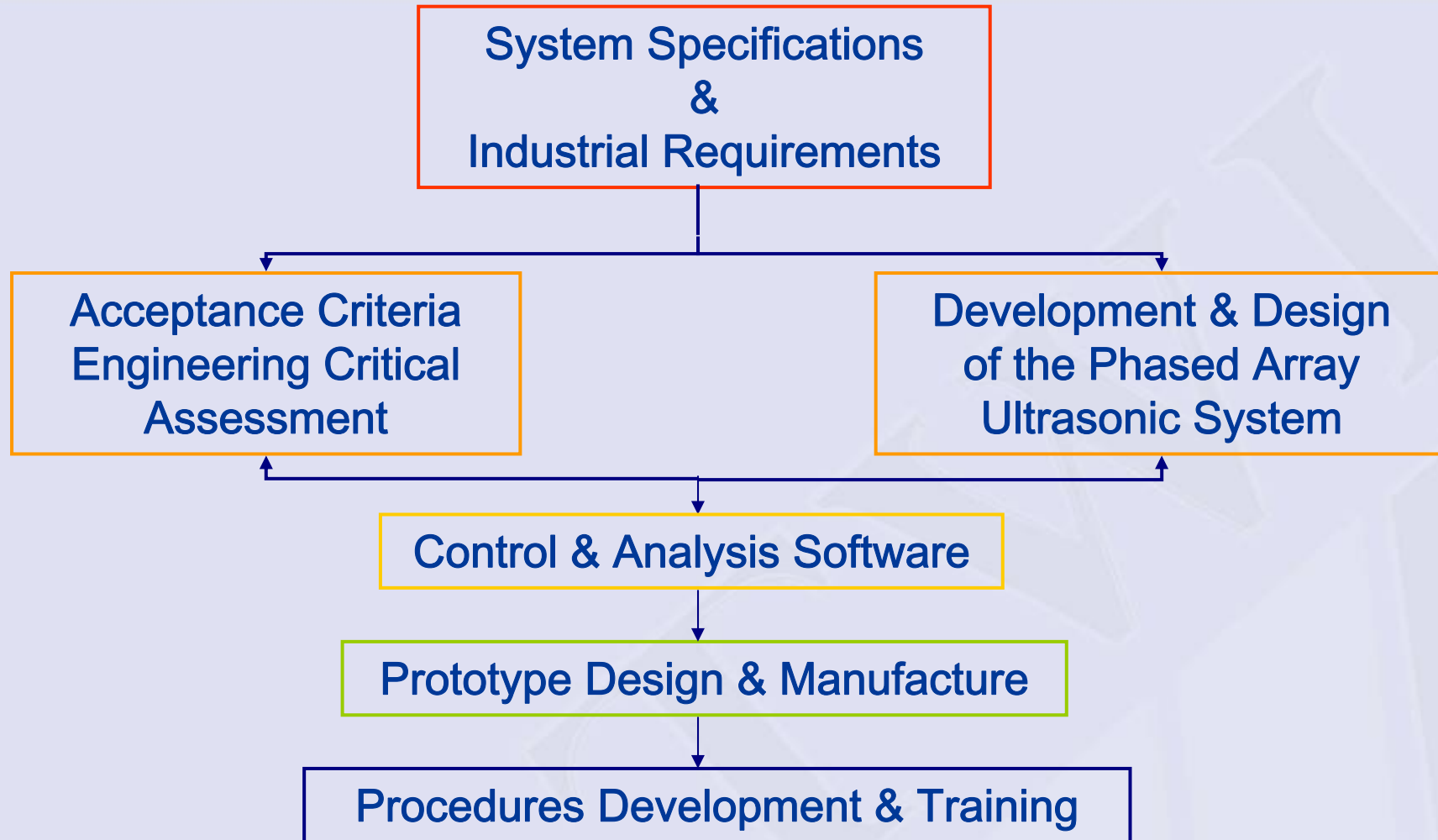
Project Objective



- **Development of an advanced and automated PA ultrasonic technique and equipment to inspect aluminothermic rail welds volumetrically**
- **The system features are:**
 - Rapid clamp on system – Automatically deployed
 - Quick interpretation of data and rapid analysis
 - Classification of welds with criteria for a go / no go decision
- **The project required:**
 - Knowledge of performance of AT welds
 - Development and validation of ultrasonic PA models
 - Development of an analysis software and output display



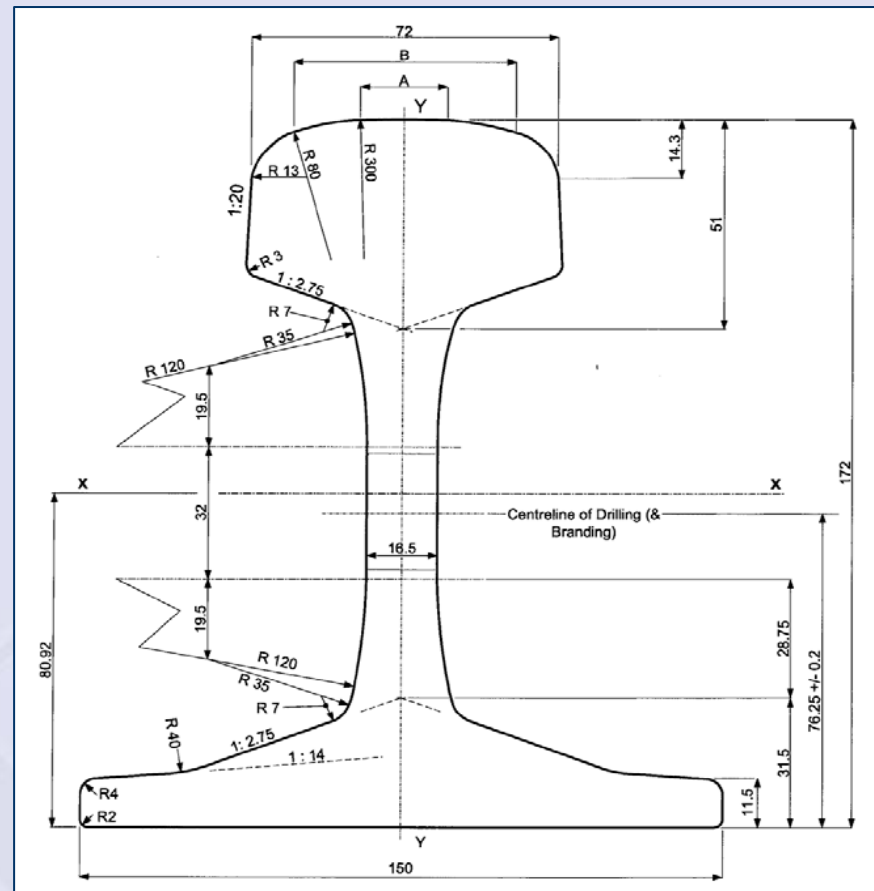
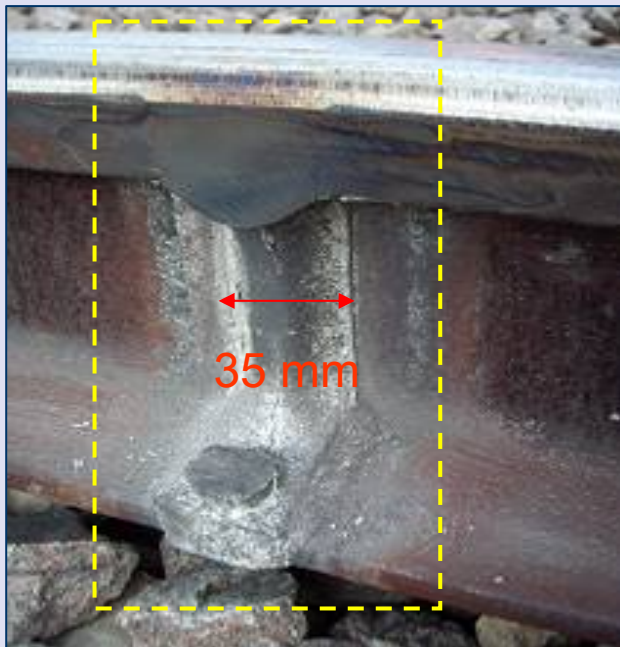
Project Organisation



System Scope



- Inspection of AT welds
 - CEN 60E1 or CEN 60E2 rail profiles
 - Finished cast width of 35 mm



Design & Manufacture of Samples



4 Categories of Rail Weld Samples

Non defective welds

Welds with porosity defect

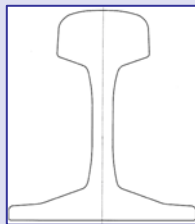
Welds with LOF defect

Welds with shrinkage defect (lower body)

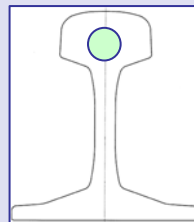


Production supervised by Jarvis

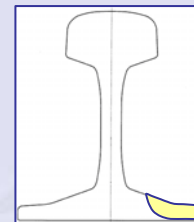
Production supervised by TWI



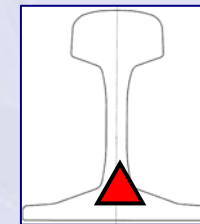
Good



Porosity



LOF



Shrinkage

- 3 samples for each type of weld were used for fatigue testing
- Some samples were used for tensile, hardness and fracture toughness testing (ECA calculations)
- 1 or 2 samples for each type of weld were used for PA inspection
- Many difficulties to produce LoF samples (with LoF in the rail foot)





Project Results

Conventional Inspection



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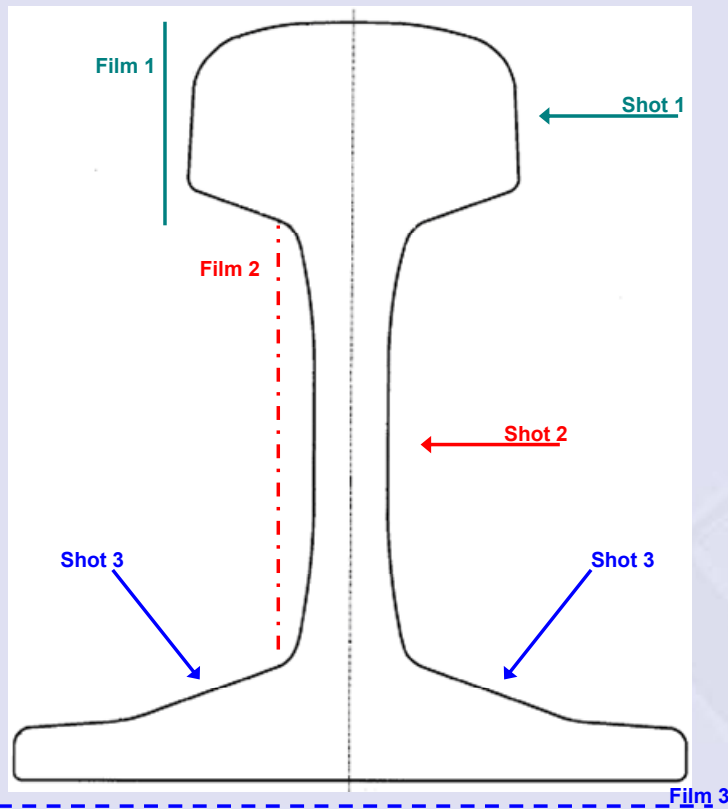


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Radiographic Inspection of Welds



- Procedure for rail CEN60 E1
 - Associated document BS EN 1435 : 1997



In total, 3 shots:

Shot 1: Head

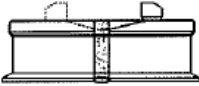
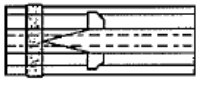
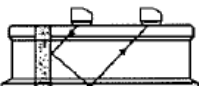
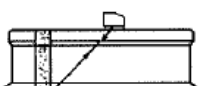
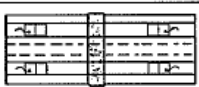
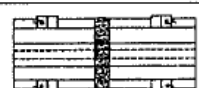
Shot 2: Web

Shot 3: Foot

Conventional Manual UT of Welds



- Procedure for rail CEN60 E1
 - Associated document BS EN 14730-1:2006 Annex C

Summary of test			
1	Test of head for non-planar defects		One 70° double crystal probe from both sides
2	Test of head for planar defects		Two 70° single crystal probes (TX & RX)
3	Test of web for planar defects		Two 45° single crystal probes in tandem with a positioning rig
4	Test of middle of foot		One 45° single crystal probe from both sides
5	Test of ankles		One 70° single crystal probe
6	Test of toes		One 70° single crystal probe
Total number of probes required:		6 or 7	

2 MHz transducer

2 MHz transducers (X2)

2 MHz transducers (X2)

2 or 4 MHz transducer

2 or 4 MHz transducer

2 or 4 MHz transducer



Comparison of the Results (UT/X-rays)



Sample	Defect	Radiography	Coventional Manual UT
RPS001	Non defective	Gas pores	No indications
RPS003	Non defective	Gas pores	No indications
RPS004	Non defective	Gas pores	1 indication in the web
RPS005	Porosity	Detected	Detected
RPS006	Porosity	Detected	No indications
RPS007	Porosity	Detected	No indications
RPS008	Porosity	Detected	Detected
RPS009	Porosity	Detected	Detected
RPS010	Porosity	Detected	Detected
RPS011	LoF	Gas pores detected	1 indication in the web
RPS012	LoF	Large gas pores detected	1 indication in the web
RPS013	LoF	Large and gross gas pores	No indications
RPS014	LoF	Large and small gas pores	No indications
RPS018 (S10)	Shrinkage	Detected	Detected
RPS019 (S11)	Shrinkage	Detected	Detected
RPS020 (S12)	Shrinkage	Detected	Detected
RPS021 (1RE)	Second batch of LoF	LoF along full length of web	No indications

- Results not consistent when the two techniques are compared
- Performance of radiography technique > performance of conv.manual UT
- Standard BS EN 14730-1:2006 Annex C not adapted?
- LoF difficult to detect using conventional manual UT



Project Results Mechanical Testing



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Mechanical Testing



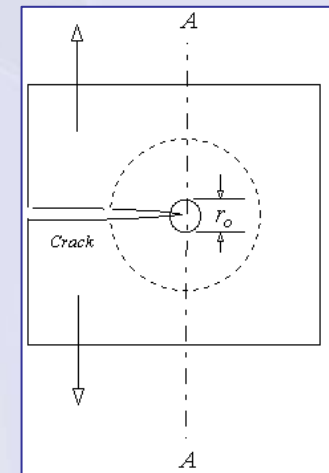
- Fatigue testing of non defective and defective welds
- Evaluation of the weld rail properties for ECA calculations
 - Tensile testing (parent, HAZ and weld)
 - Hardness testing
 - Fracture toughness testing
- ECA will be used to determine the acceptance criteria



Evaluation of the Properties of the Rail Welds for ECA Calculations



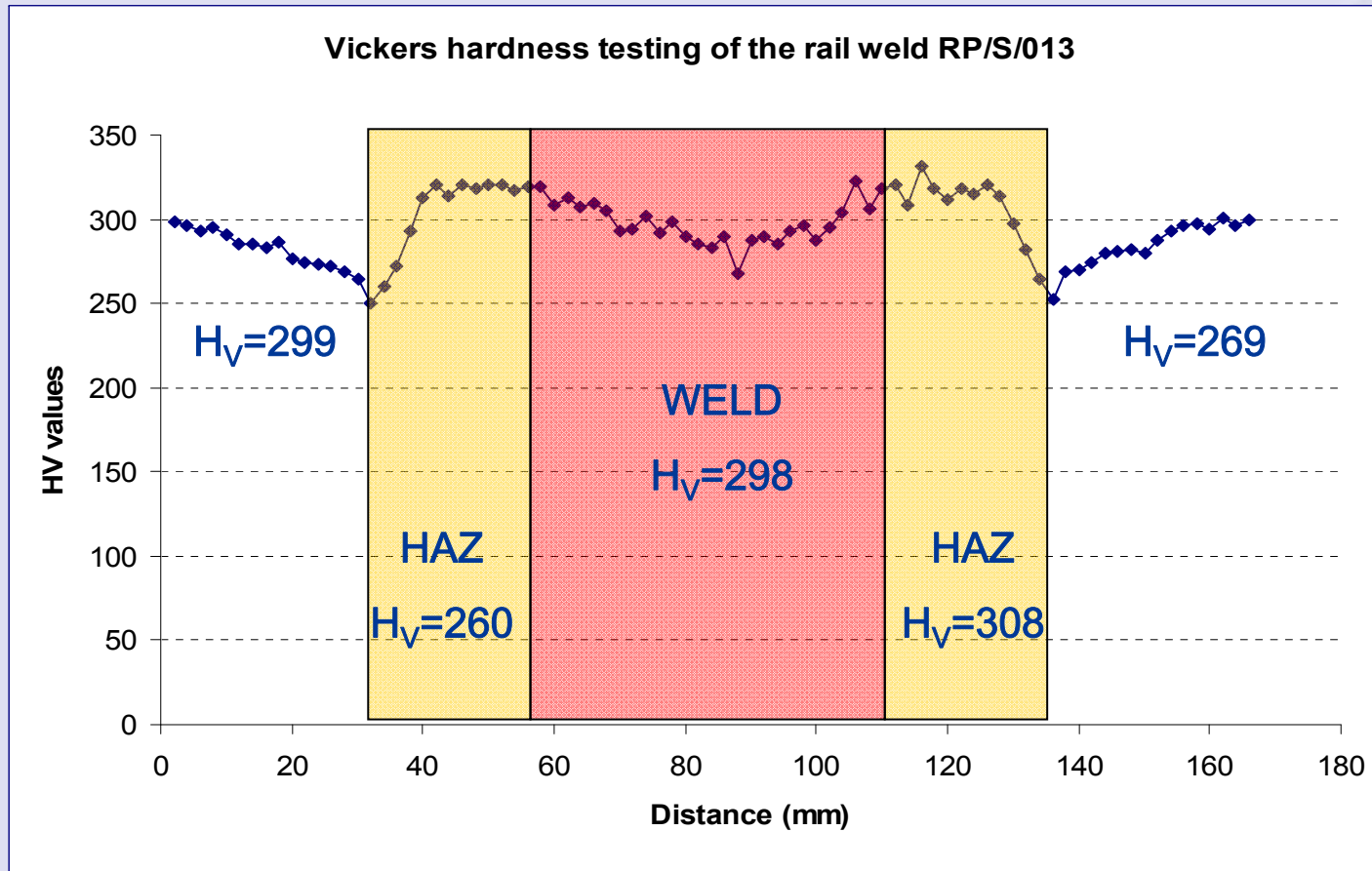
- Testing carried out:
 - Hardness measurements of the parent material, HAZ and weld metal
 - Brinell hardness measurements EN ISO 6506-1
 - Vickers hardness measurements EN ISO 6507-1
 - Tensile testing
 - 2 specimens from the base metal BS EN 10002-1
 - Fracture toughness testing
 - CTOD tests BS 7448-1
 - 3 specimens for each welding condition (parent material, HAZ and weld metal)



Hardness Testing



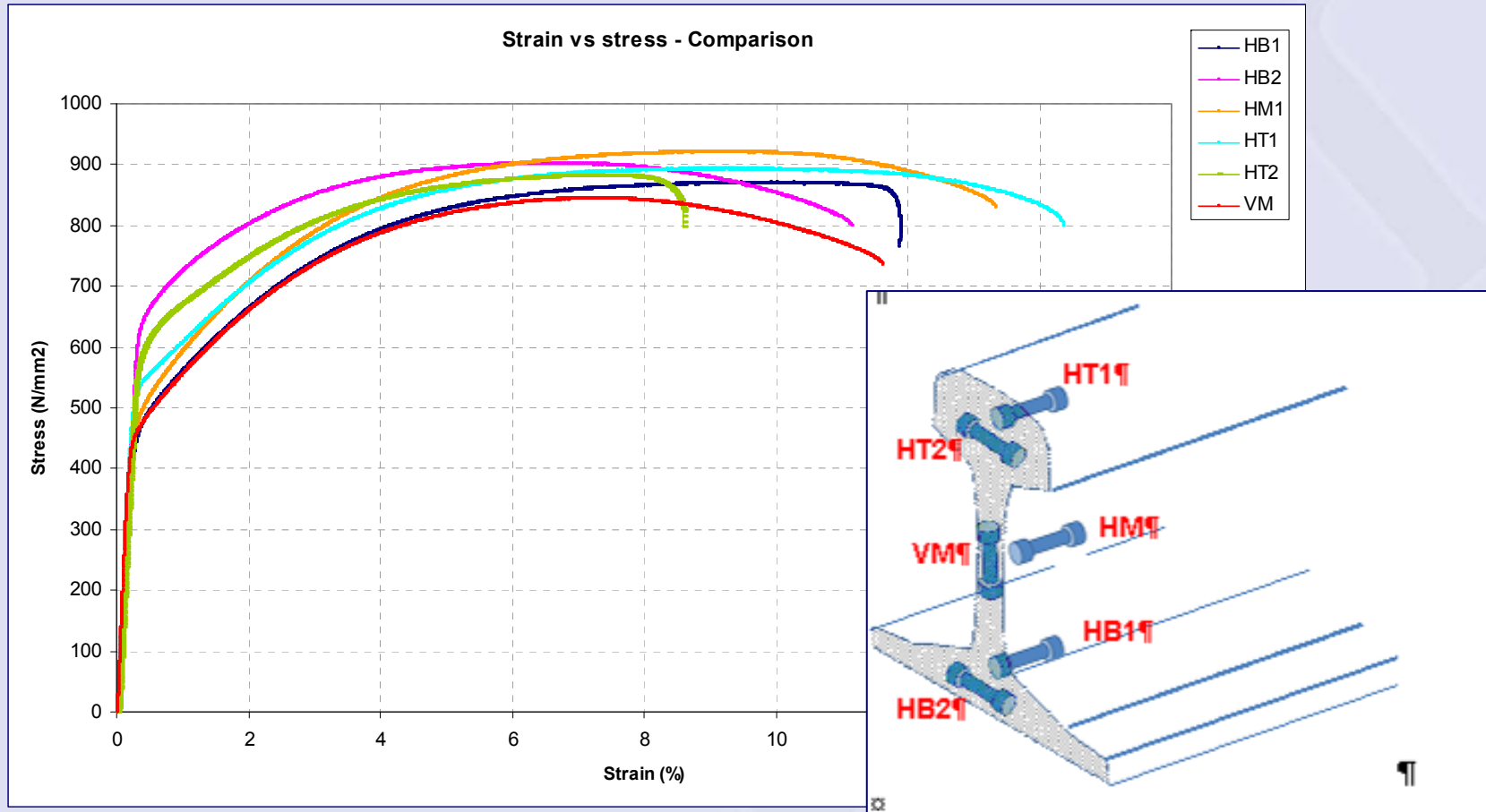
- Test results (RP/S/013)



Tensile Testing



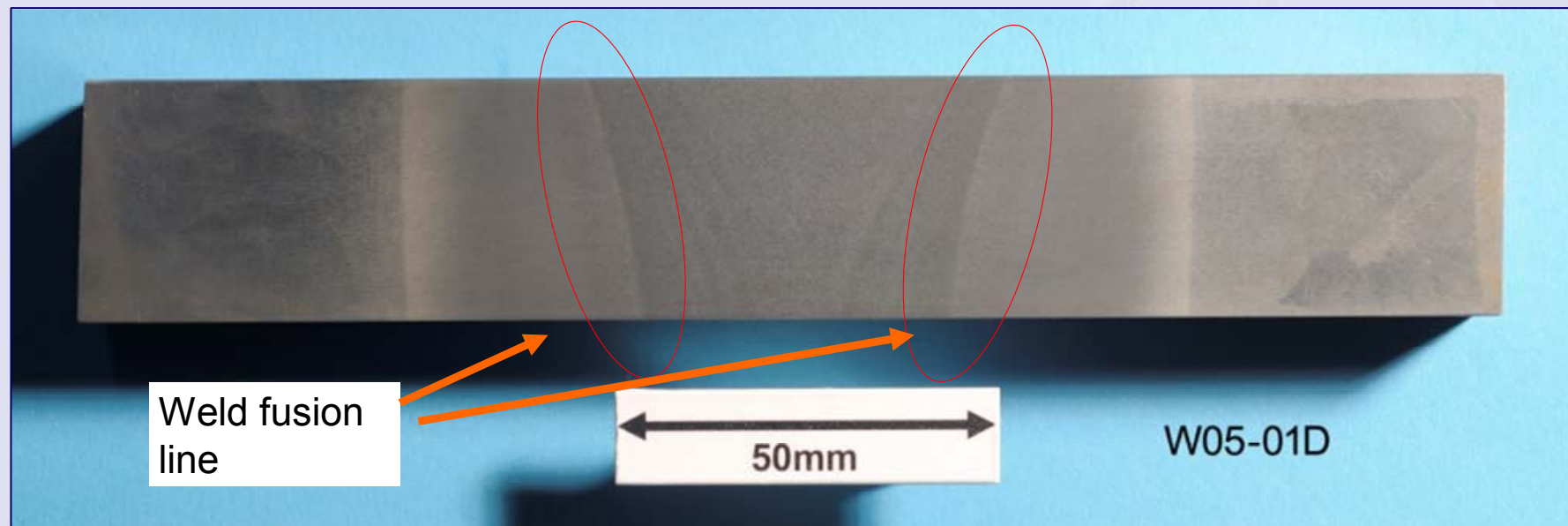
- Test results



Fracture Toughness Testing



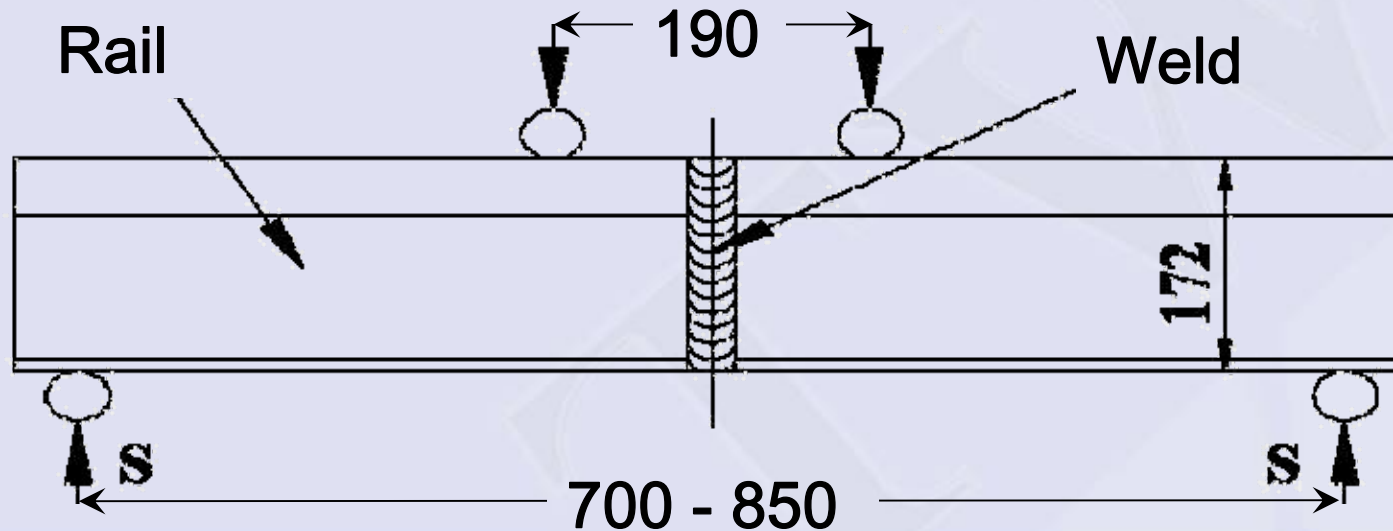
- Test results
 - All specimens failed in brittle fashion and displayed a low fracture toughness value
 - Failure mode is not a single event brittle fracture. A sequence of various cleavage propagation and arrest events seemed to occur.



Fatigue Test Configuration



- Technique used
 - Four point bend fatigue testing (BS EN 14730-1:2006)
 - Spans
 - Upper = 190mm,
 - $700\text{mm} < \text{Lower span} < 850\text{ mm}$ depending on sample length



Fatigue Test Results

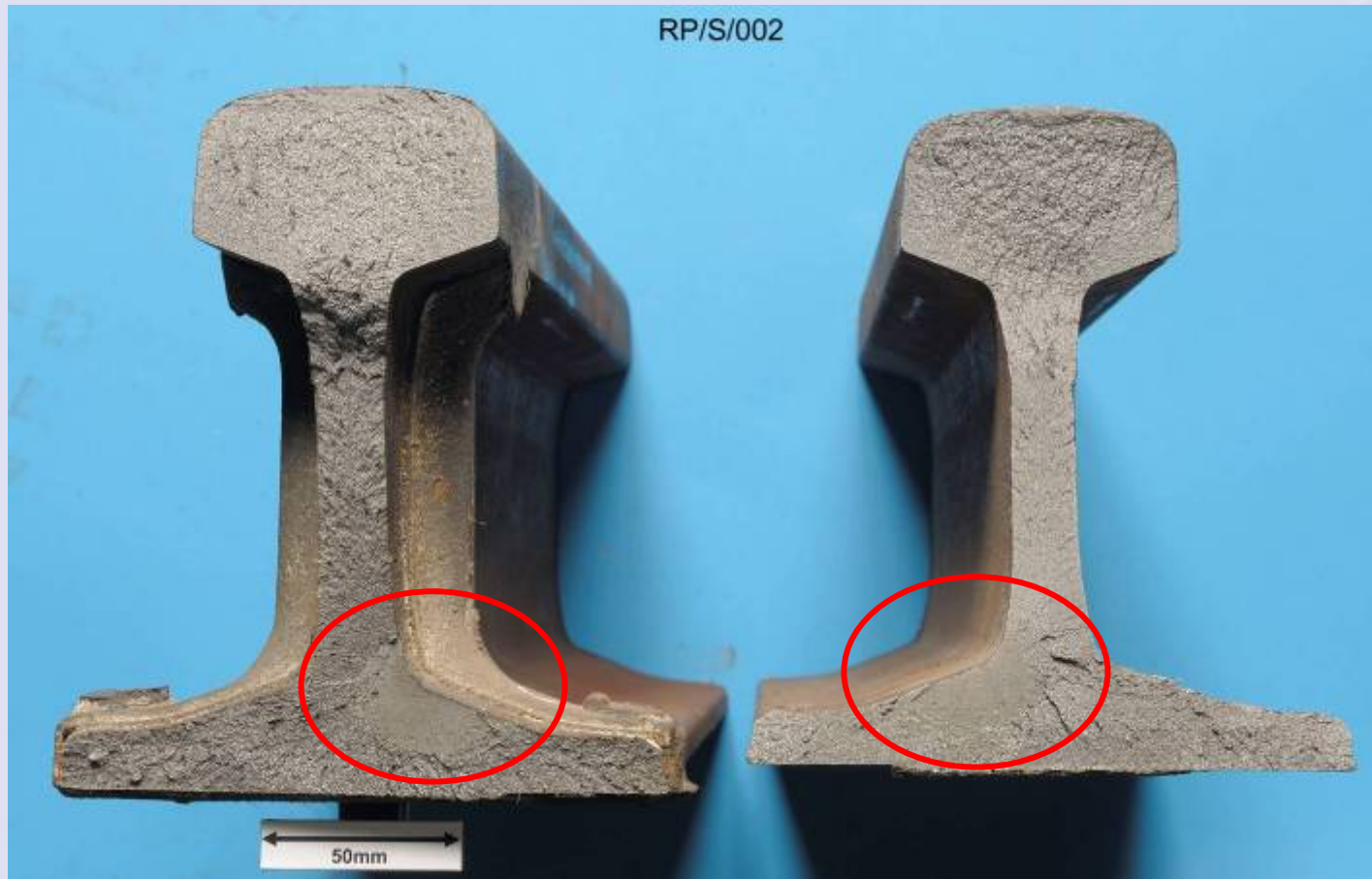


Sample Number	Frequency (Hz)	Stress ratio	Maximum stress (Mpa)	Minimum stress (Mpa)	Maximum load (kN)	State	Failure mode	No of cycles performed	Preliminary NDT
Production Welds									
RP/S/001	2	0.08	229	19	488	Runout	-	2.09E+06	R: indications UT: NRD
RP/S/002	5	0.07	245	17	582	Failed	In HAZ	1.48E+06	-
RP/S/003	2	0.09	221	20	469	Runout	-	2.00E+06	R: indications UT: NRD
Porosity in Rail Head									
RP/S/006	2	0.08	226	20	619	Runout	-	2.00E+06	R: indications UT: NRD
RP/S/007	2	0.10	254	26	615	Failed	In the weld	2.85E+05	R: indications UT: NRD
RP/S/010	1	0.08	238	20	586	Failed	In the weld	7.63E+03	R: indications UT: Indications
First Batch LoF									
RP/S/011	1	0.07	233	16	522	Runout	Parent material crack in the foot	7.73E+06	R: indications UT: Indications
RP/S/012	2	0.07	225	14	552	Runout	In HAZ	2.00E+06	R: indications UT: indications
Shrinkage Rail Foot									
S6	1.35	0.08	224	18	606	Failed	In the weld	3.17E+05	R: indications UT: indications
S8	1.6	0.09	222	21	515	Failed	In the weld	1.60E+06	R: NDR UT: indications
S9	1.5	0.08	225	19	529	Runout	-	4.26E+06	R: NDR UT: indications
Second Batch LoF									
1RE	0.5	0.08	239	21	380	Failed	In the weld	2.08E+05	R: indications UT: NRD
2RE	0.5	0.09	240	22	378	Failed	In the weld	4.07E+05	R: indications UT: indications

Fracture Surface



- Sample RP/S/002 (No defect)



Fracture Surface



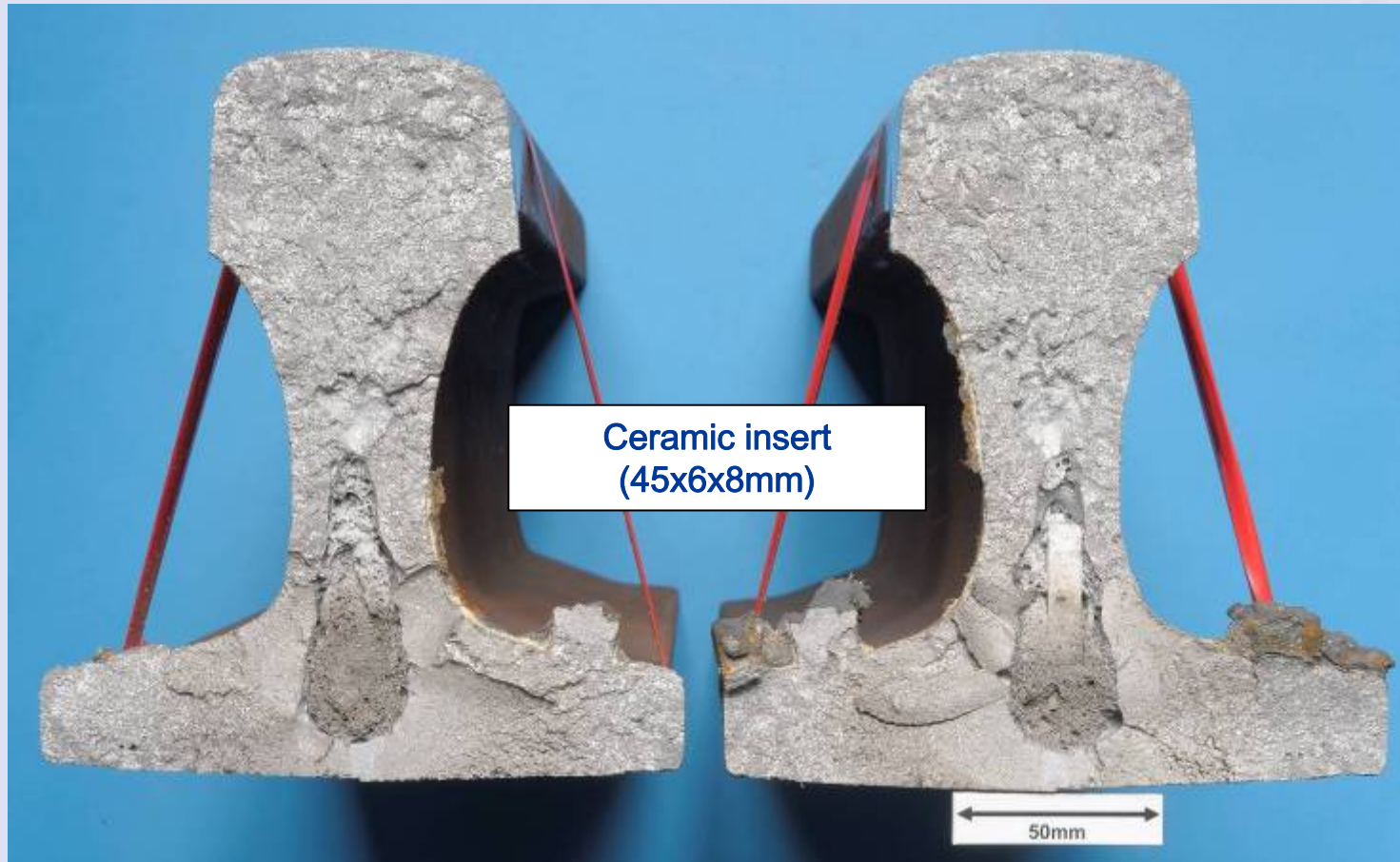
- Sample RP/S/010 (Porosity)



Fracture Surface



- Sample S6 (Shrinkage defect)



Fracture Surface



- Sample 2RE (Lack of fusion defect)





*Project Results
Railect Phased Array
Ultrasonic System of Inspection*



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Development Stages of the Railect System

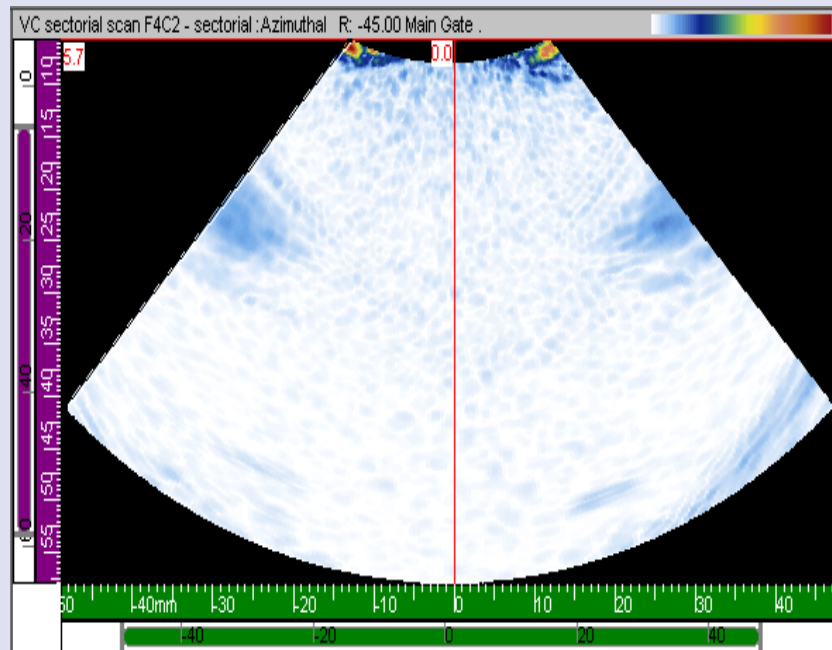


- Modelling
- Civa and ESBeamTool softwares
- Model Validation
- Experimental trials on welds
- Probe arrangements
- System mechanical design
- Data analysis and processing software developments
- System integration
- Laboratory trials to evaluate performance of the prototype
- Field trials to assess performance of the prototype on site in real outdoor conditions (railway environment and weather)

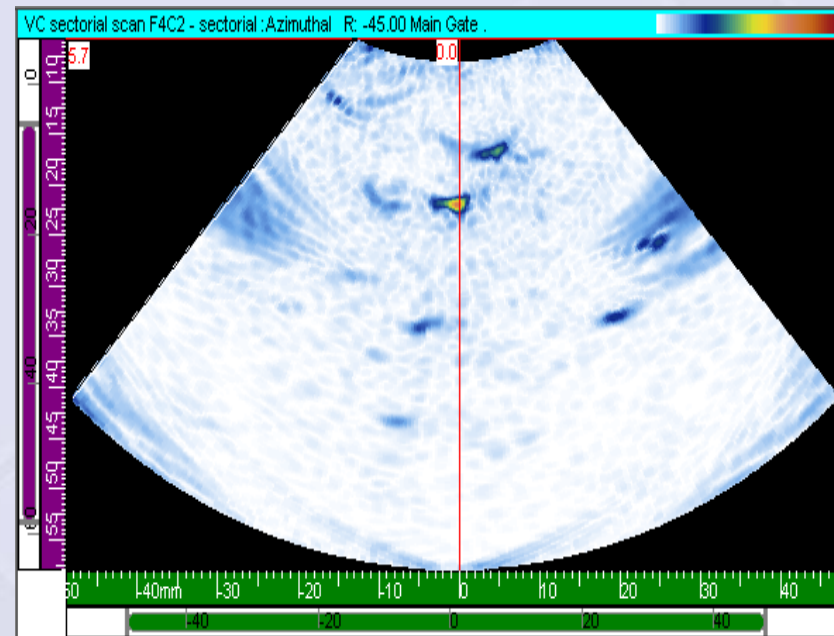
Detection of Defects in Head



Non defective rail head



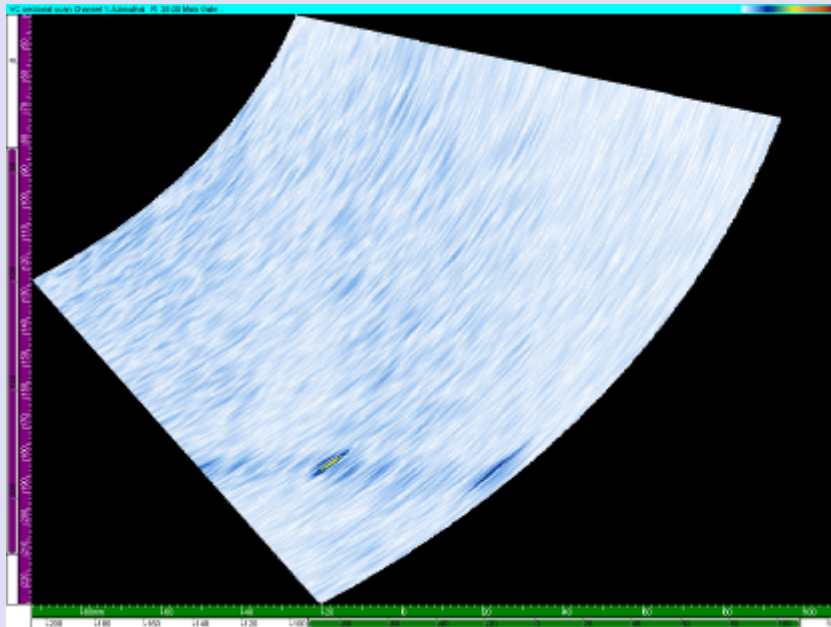
Porosity in the rail head



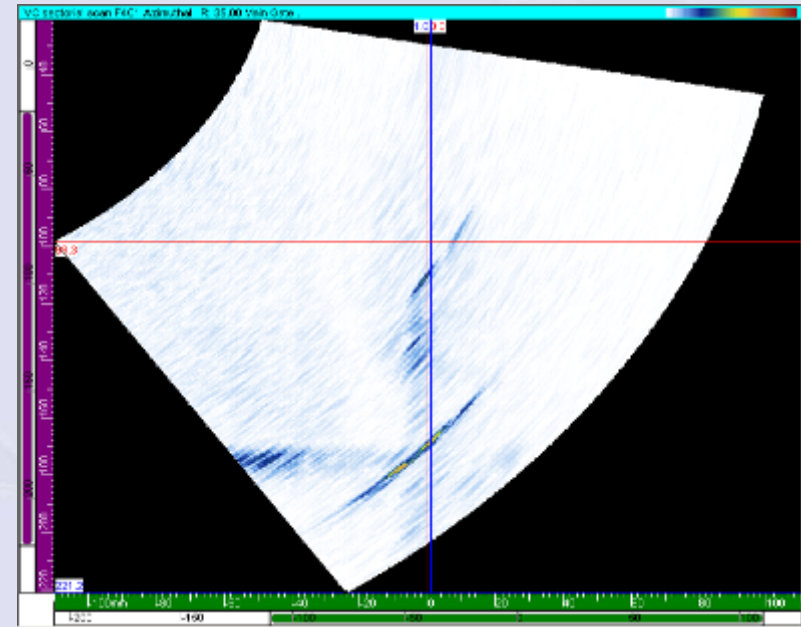
Detection of Defects in Weld Web



Non defective rail web



Shrinkage in the rail web



Conclusions



- System developed is a semi-automated system of inspection of rail welds
 - Full volumetric inspection in 15 minutes!
 - No equivalent system available on the market
 - Very efficient and operator friendly system that can save time and resources
- Next stage:
 - Commercialisation of the Railect system
 - Further funding to be applied for to turn prototype into production system and to push it into market



Final Field Trials



- Demonstration at Network Rail's test track, Rail Innovation and Development Centre, High Marnham, UK



Acknowledgements



- **Railect Consortium:**
 - Network Rail, UK
 - Joe Small , UK
 - TWI, UK
 - Newcastle University, UK
 - Kaunas University of Lithuania
 - Vermon (SME, France)
 - KCC (SME, UK)
 - Spree Engineering (SME, UK)
 - Optel (SME, Poland)
- **European Community's Seventh Framework Programme managed by REA-Research Executive Agency**

