UKOPA

United Kingdom Onshore Pipeline Operators' Association

Mechanical Properties and Weld Quality of Vintage Seam-Welded Pipe

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Academic Supervisor: Dr Elizabeth Sackett, Swansea University

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Prifysgol Abertawe
Swansea University

y Gyfadran Gwyddoniaeth a Pheirianneg
Faculty of Science and Engineering
Materials and Manufacturing Research Institute

Valero

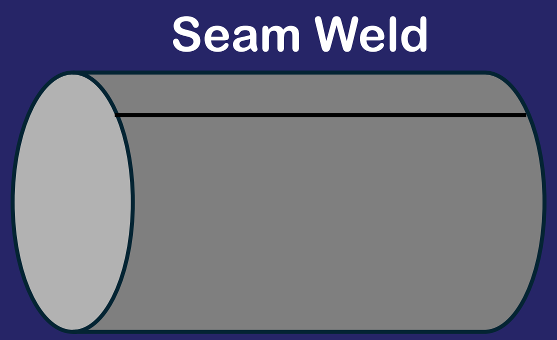
Background

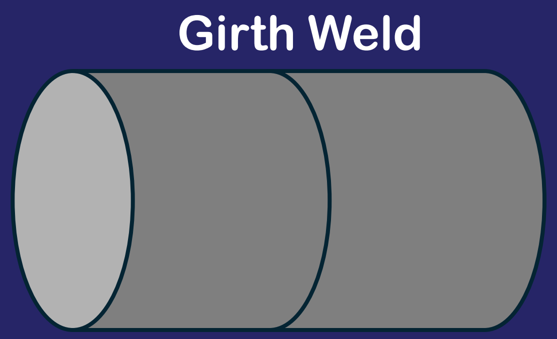
- Vintage – pre-1972
- Seam welds – longitudinal

Girth weld project (2017)[1]:

36 of 38[2] girth weld leakages were vintage

- Findings:
  - Numerous weld defects.
  - External defects have greater impact on fatigue life.
  - High safety factors "potentially excessive and unnecessarily conservative".
  - Adequate quality.





1. *Y-F, Joe. (2017). Fatigue Assessment of Historic Welds in Pipelines.*
2. *Goodfellow GD, Lyons CJ. UKOPA Pipeline Fault Database - Product Loss Incidents and Faults Report (1962-2021). UKOPA; 2023.*

Introduction

- 3 of 206 leakages between 1962-2021 occurred in seam welds (2).

Determine:

- Weld quality
- Mechanical properties
- Remaining lifetime

Product Loss Cause	No. of Incidents	%age of Total
External Corrosion	42	20.4
External Interference	44	21.4
Girth Weld Defect	38	18.4
Ground Movement	7	3.4
Internal Corrosion	2	1.0
Internal SCC	30	14.6
Lightning Strike	1	0.5
Original Construction Damage	1	0.5
Pipe Defect	13	6.3
Seam Weld Defect	3	1.5
Other[5]	16	7.8
Unknown	9	4.4
TOTAL	**206**	**100**

Product loss incidents (2)

2. Goodfellow GD, Lyons CJ. UKOPA Pipeline Fault Database - Product Loss Incidents and Faults Report (1962-2021). UKOPA; 2023.

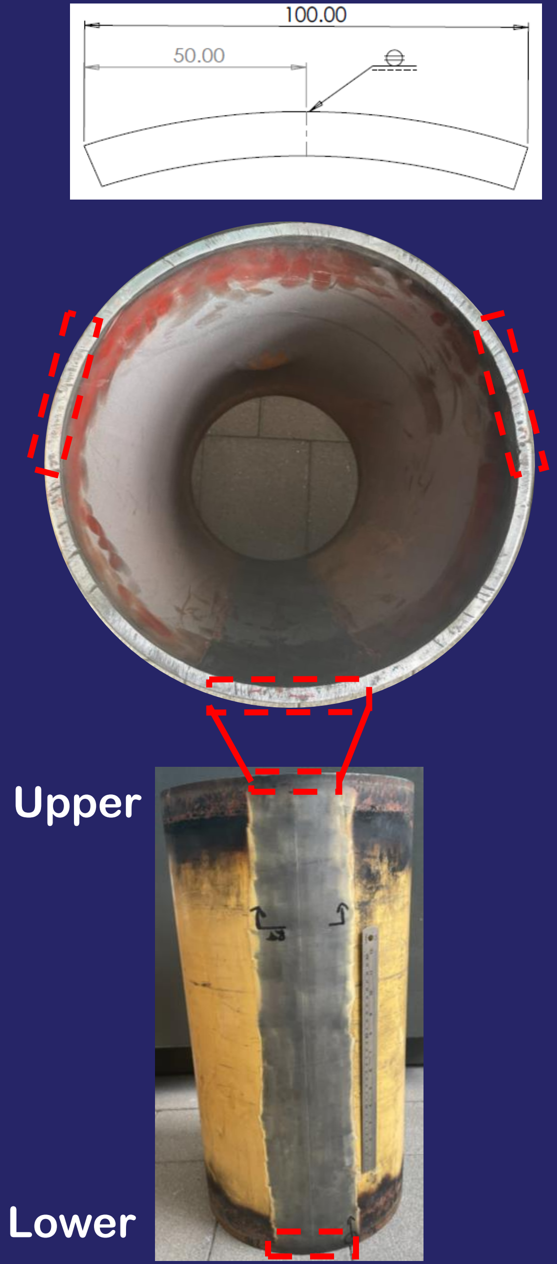
Experimental

Preparation:

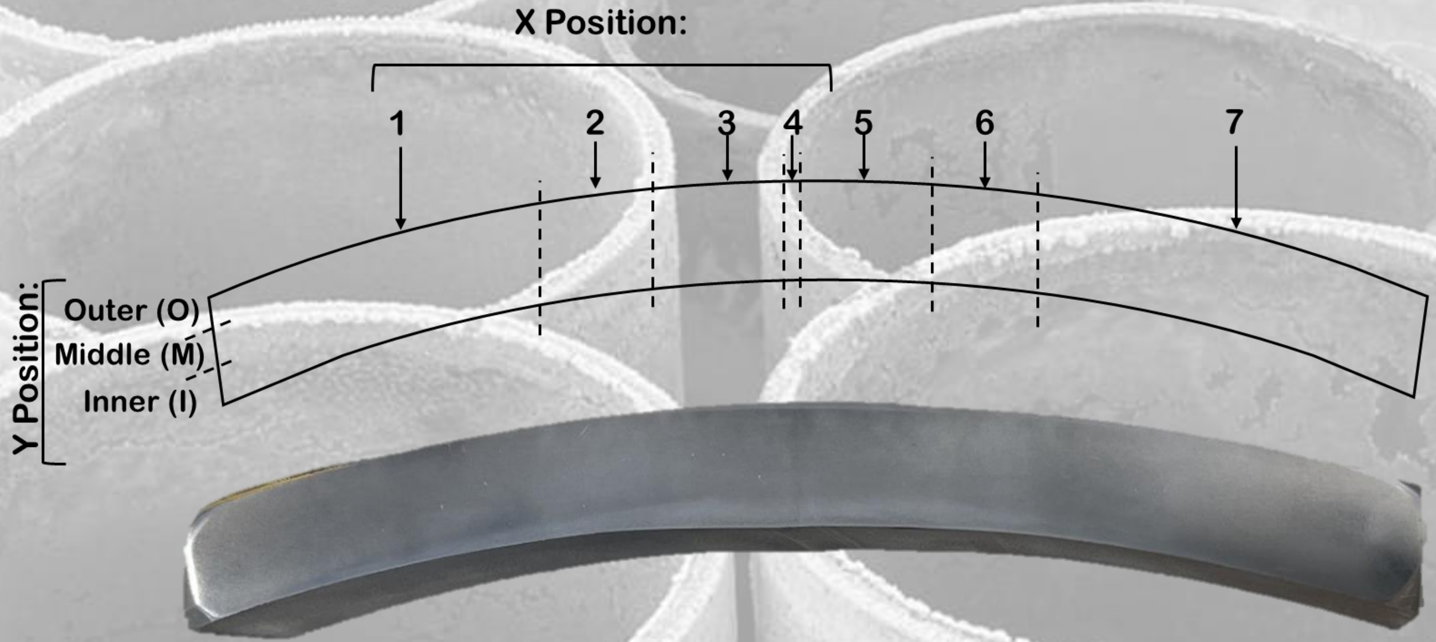
- Extraction of samples from 5, 7, 12’o’clock
  - Upper – 10mm x 15mm x 100mm
  - Lower – 10mm x 30mm x 155mm

Tests:

- Upper:
  - Optical microscopy & grain size analysis
  - Profilometry-based Indentation Plastometry (PIP)
  - Microhardness
  - Nanohardness
- Lower:
  - 4-point bend test
- Other:
  - Simulation
  - Phased Array Ultrasonic Testing (PAUT)



What do the labels mean?



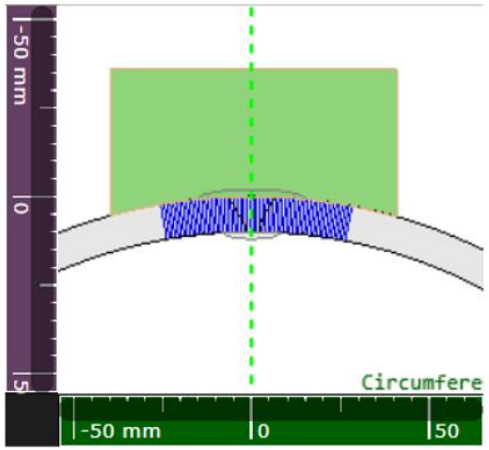
1&7
2&6
3&5
should have similar microstructures

e.g. W-XPos1-YPosI = Welded Sample in X-axis Position 1 and Y Position Inner

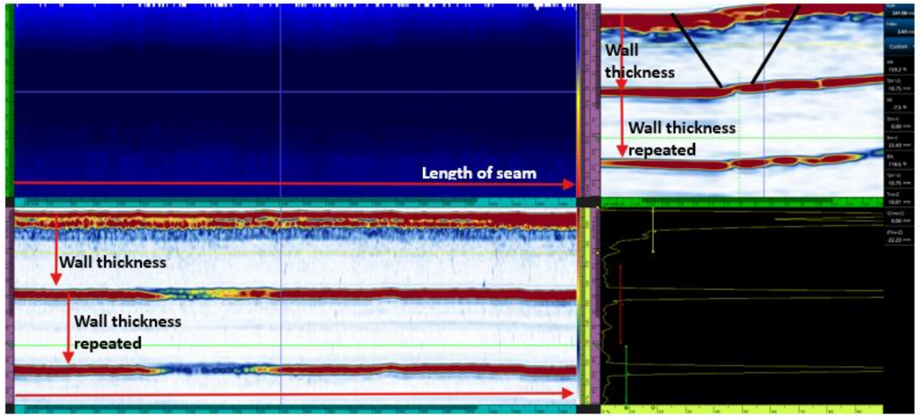
Phased array ultrasonic testing PAUT (Oceaneering, Swansea)

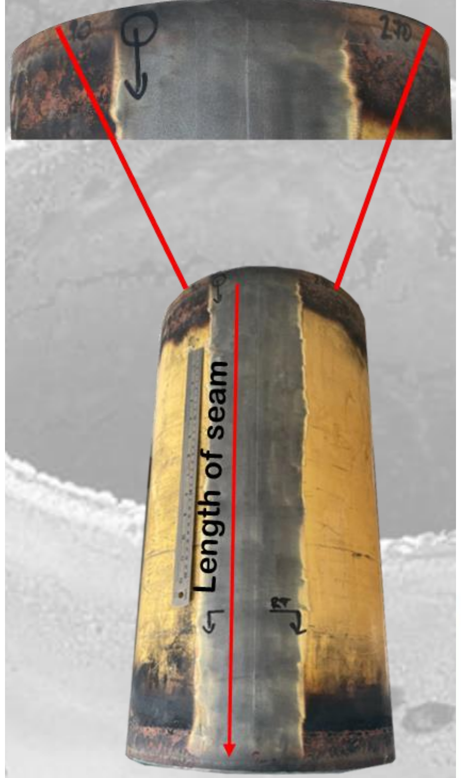
https://www.oceaneering.com/

0 Degree Phased Array Mapping Scan Plan

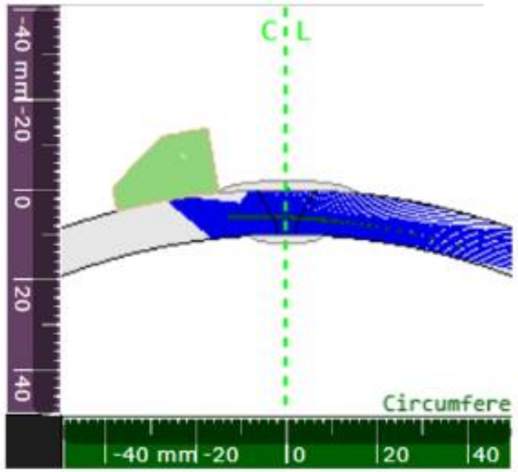


0 Degree Phased Array Data

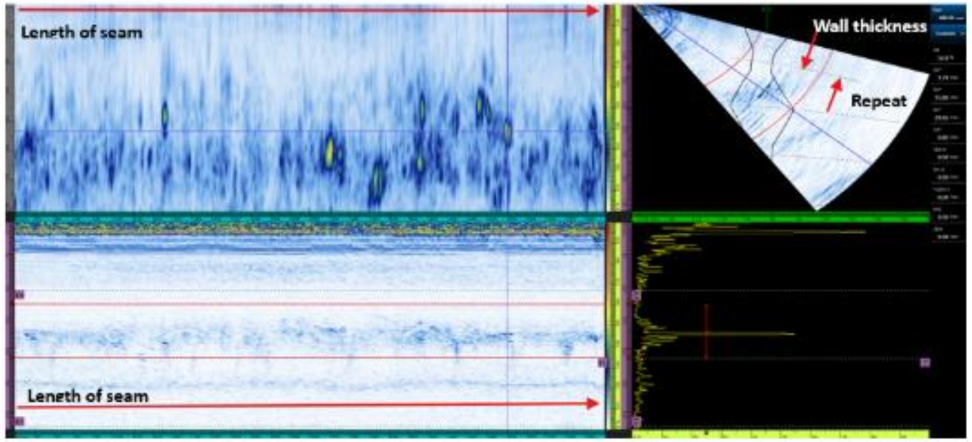




Shear Wave Phased Array Scan Plan



Shear Wave Phased Array Data



No notable defects found using PAUT

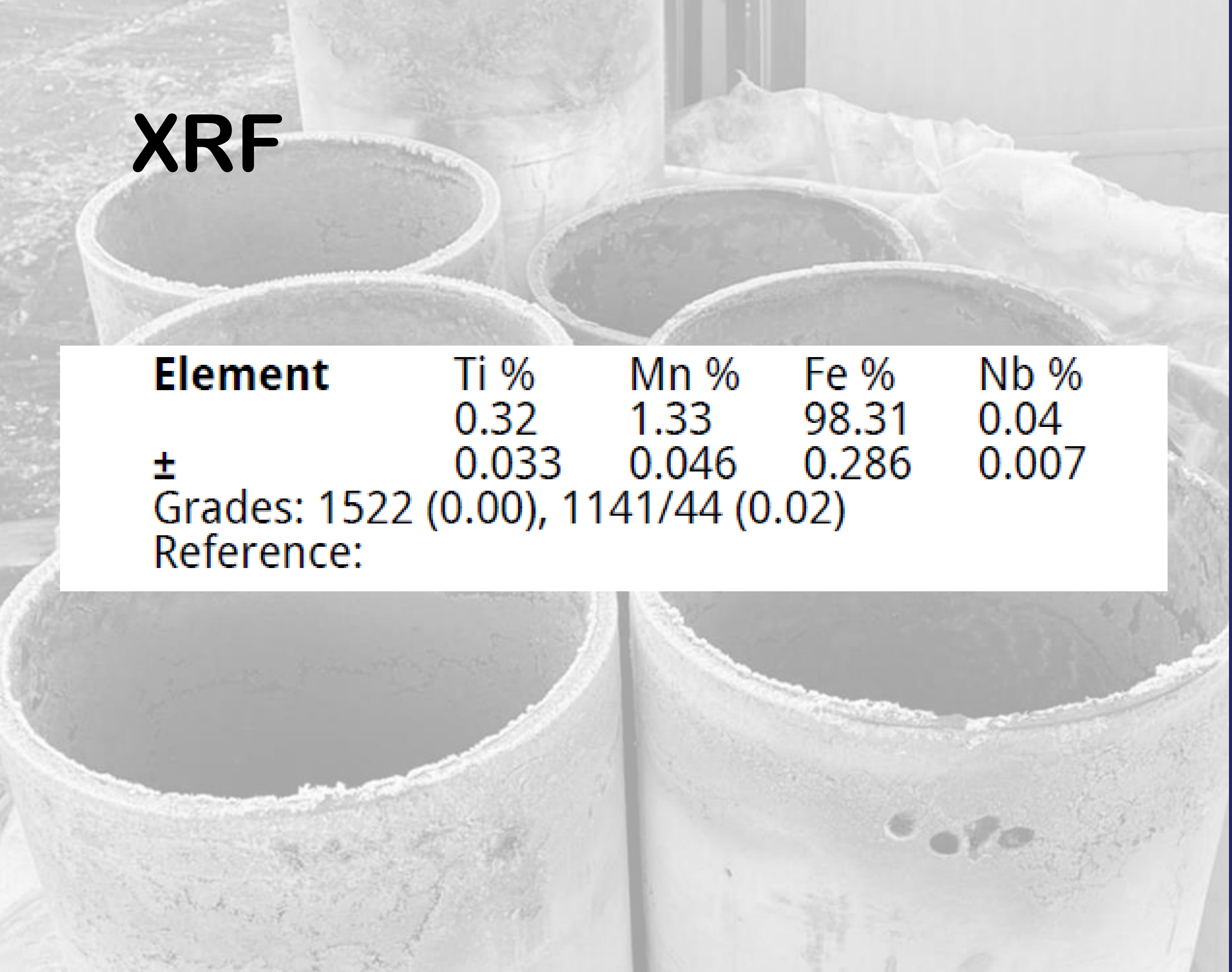
X-ray

Brightness -40%
Contrast +40%

Brightness ±0%
Contrast +40%

No notable defects found using X-ray radiography

XRF



Element	Ti %	Mn %	Fe %	Nb %
	0.32	1.33	98.31	0.04
±	0.033	0.046	0.286	0.007

Grades: 1522 (0.00), 1141/44 (0.02)
Reference:

Expected grade (based on girth weld project and other data): API 5L ~X52 Pipeline Steel

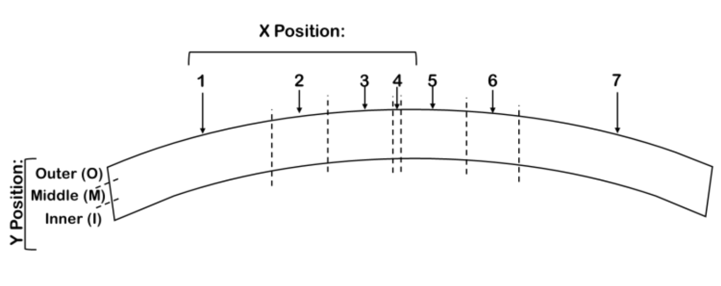
Estimated grade (based on XRF data): AISI 1522 or AISI 1141/44

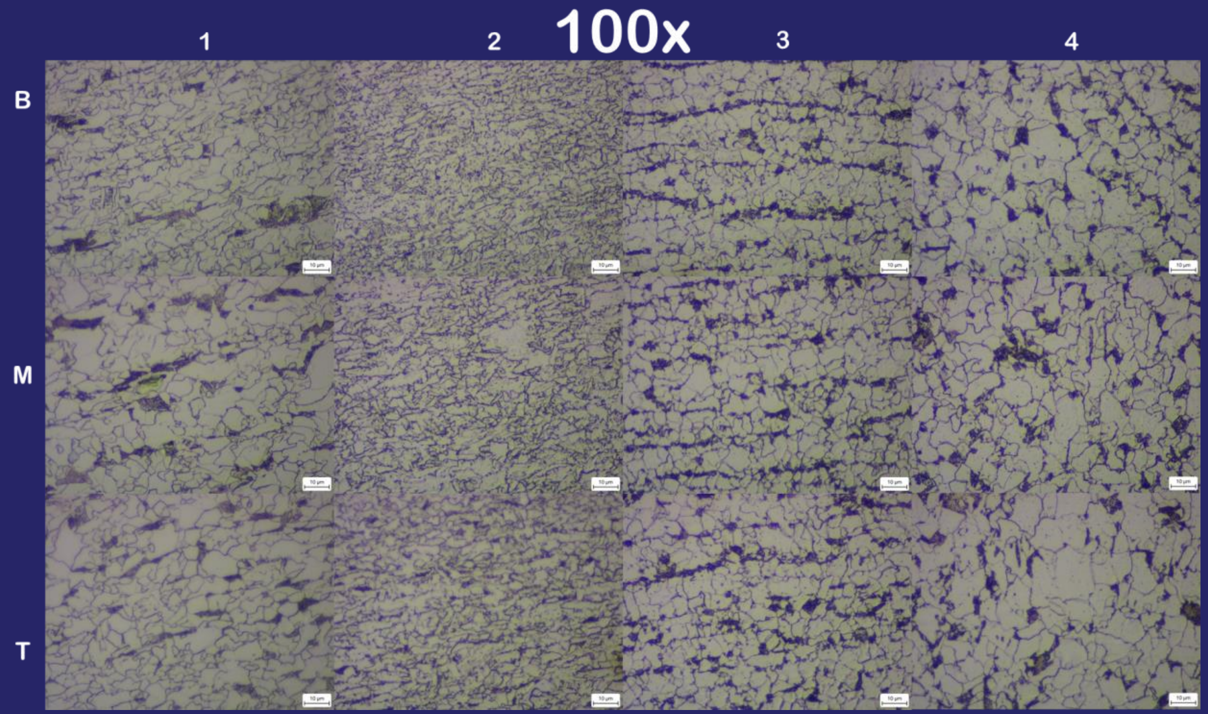
Grain size analysis

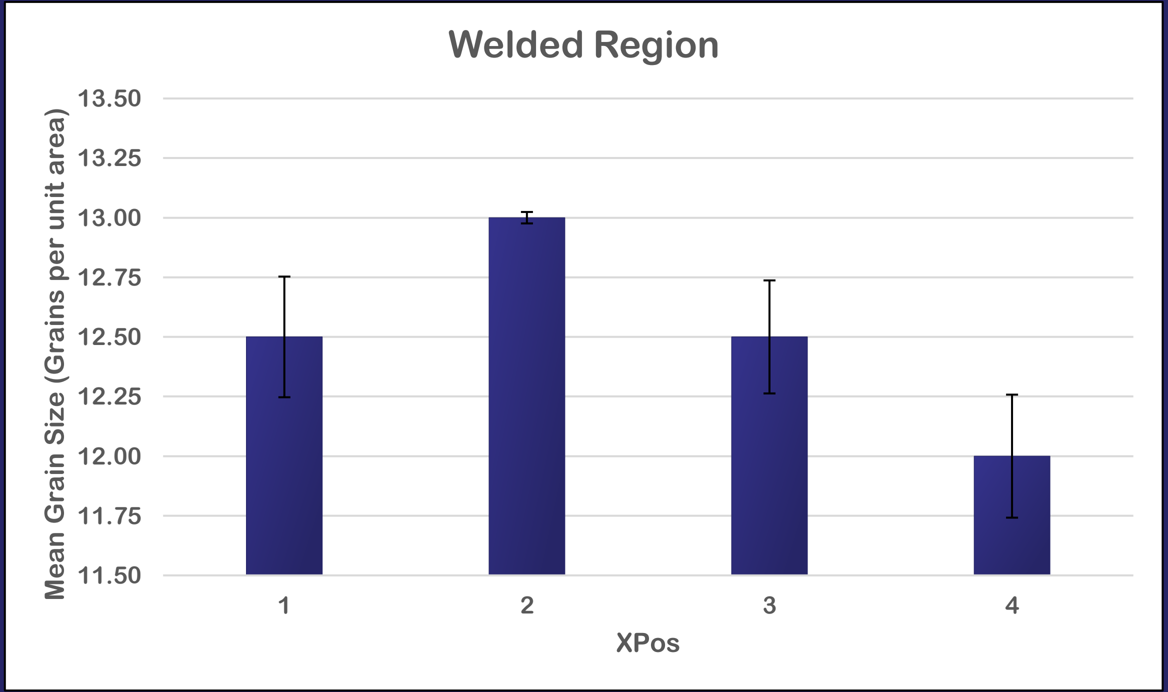
Grain size was calculated using MLI with standard ASTM E 112-13 on Zeiss ZENcore software

Identified:

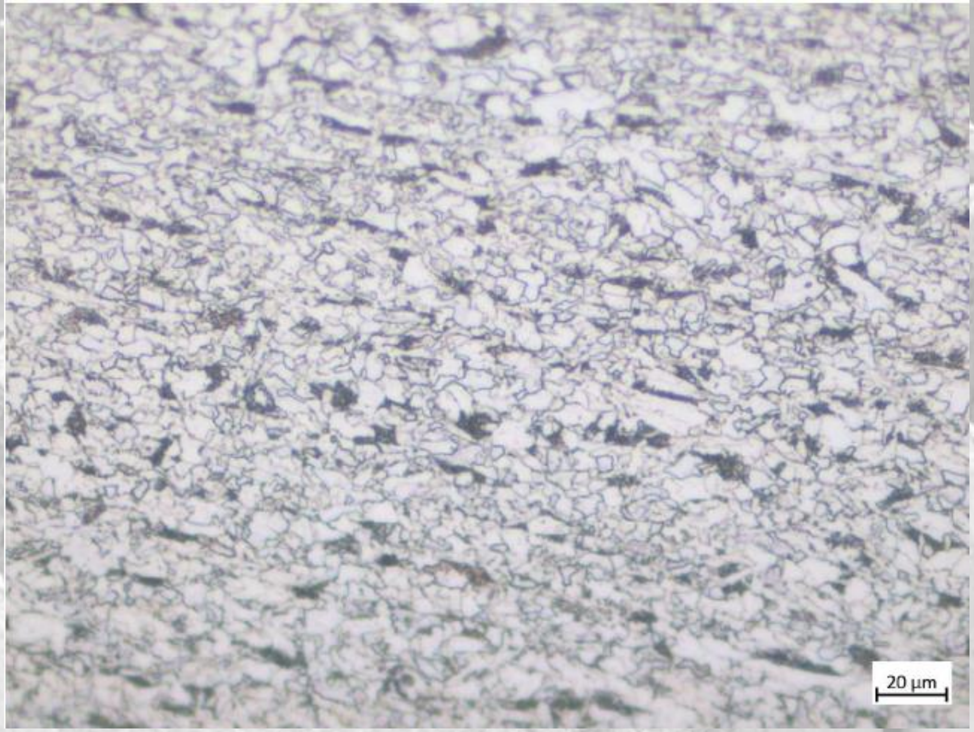
1. Parent metal
2. Fine grain HAZ
3. Coarse grain HAZ
4. Weld

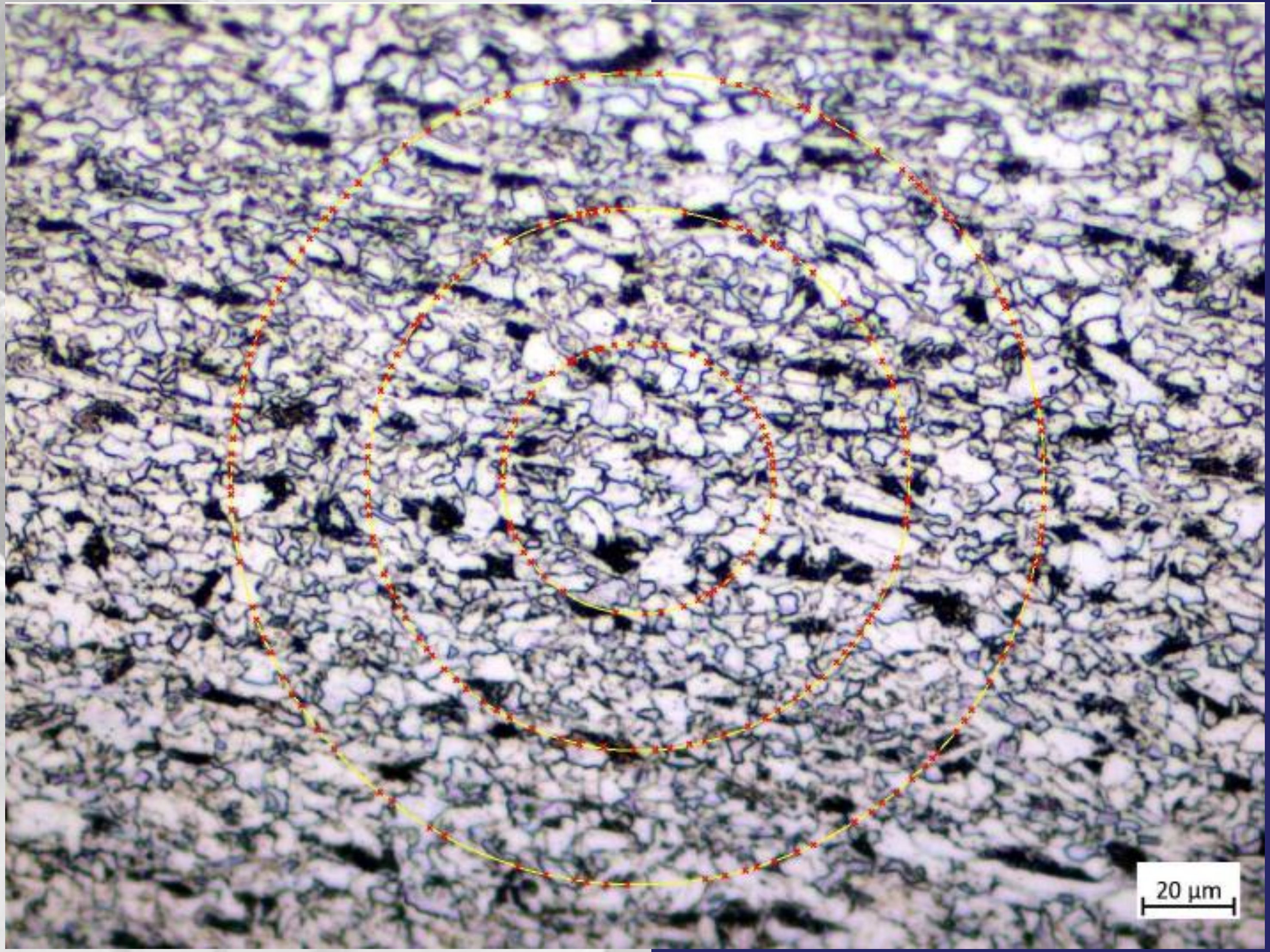






Grain size analysis





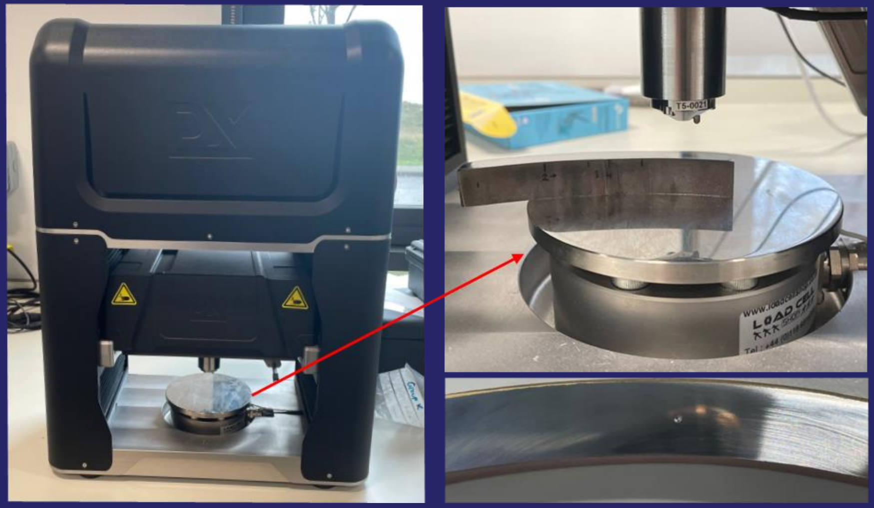
PIP

“Profilometry-based indentation plastometry”

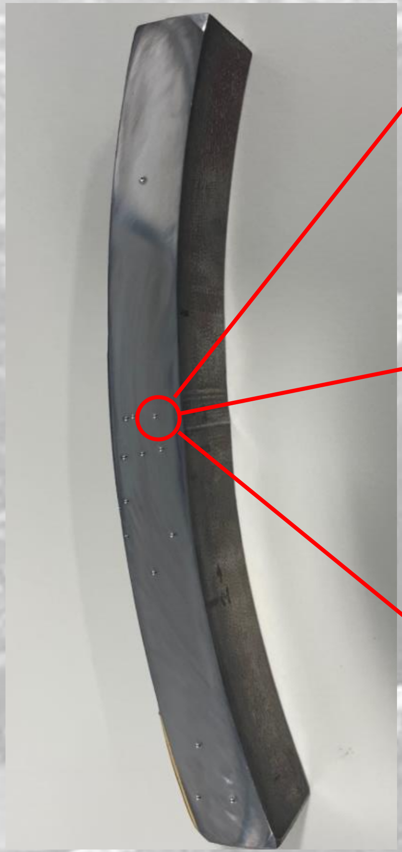
Capabilities:

- Test diagnostics – e.g. surface roughness, tilt, target and measured load
- Work hardening detection
- Residual Indent
- Load-displacement
- Stress-Strain
  (including YS, UTS, Elongation)
- Anisotropy check
- Profilometer Alignment Check
- Brinell Hardness
- Generate reports

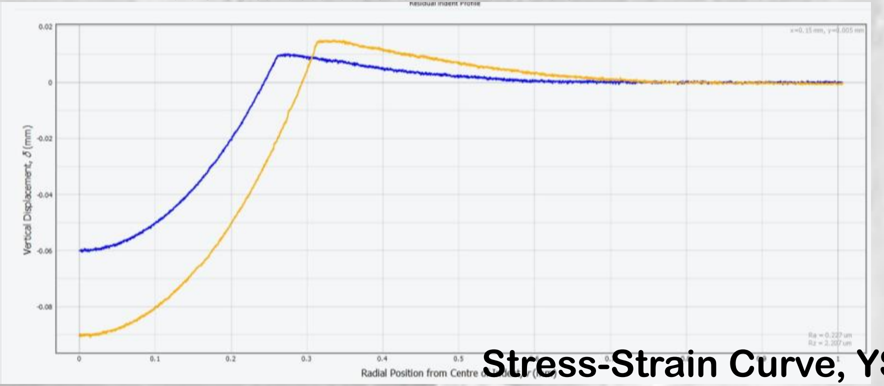
https://plastometrex.com/



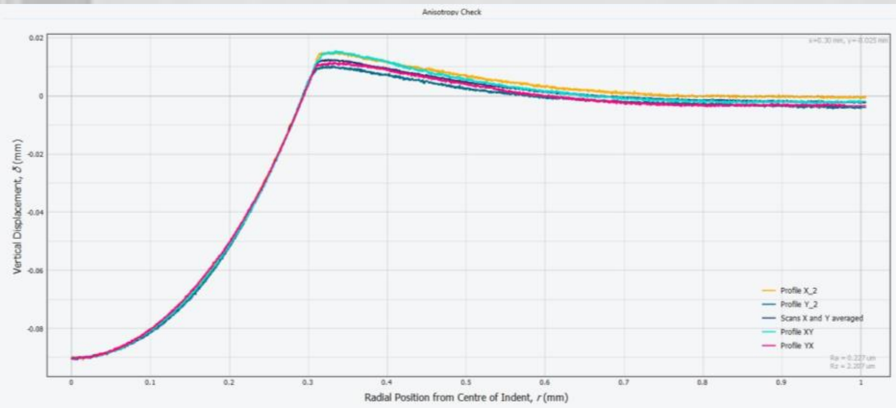
PIP



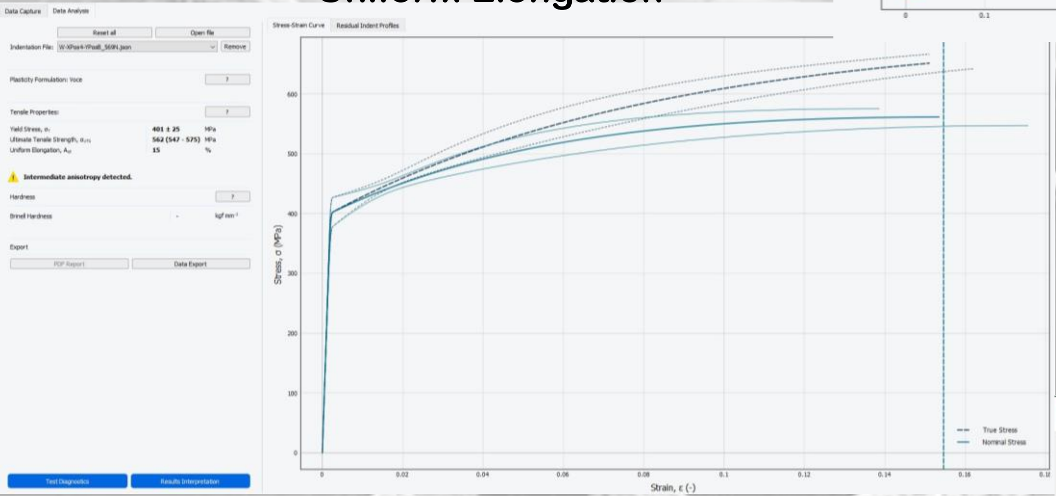
Residual Indent Profile



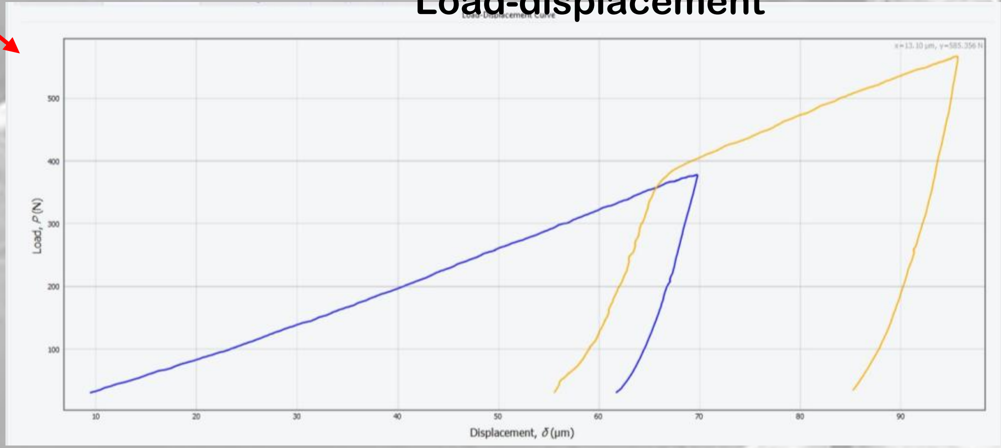
Anisotropy Check



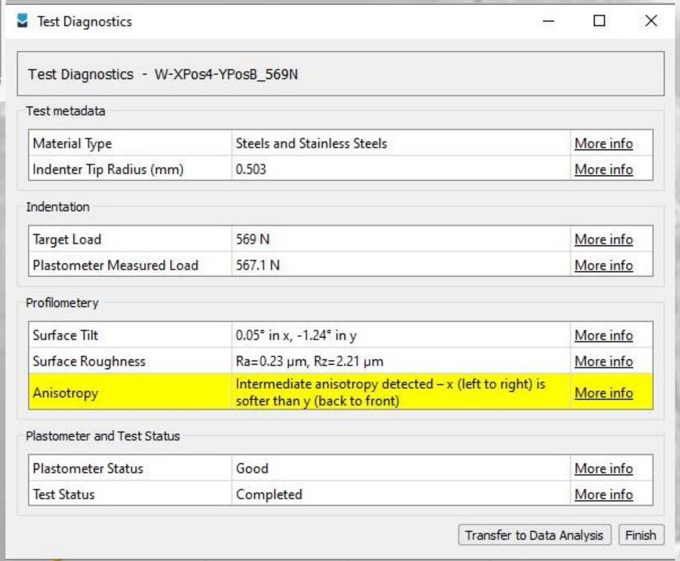
Stress-Strain Curve, YS, UTS, Uniform Elongation



Load-displacement



Test diagnostics



Test Diagnostics

Test Diagnostics - W-XPos4-YPosB_569N

Test metadata

Material Type	Steels and Stainless Steels	More info
Indenter Tip Radius (mm)	0.503	More info

Indentation

Target Load	569 N	More info
Plastometer Measured Load	567.1 N	More info

Profilometery

Surface Tilt	0.05° in x, -1.24° in y	More info
Surface Roughness	Ra=0.23 μm, Rz=2.21 μm	More info
Anisotropy	Intermediate anisotropy detected – x (left to right) is softer than y (back to front)	More info

Plastometer and Test Status

Plastometer Status	Good	More info
Test Status	Completed	More info

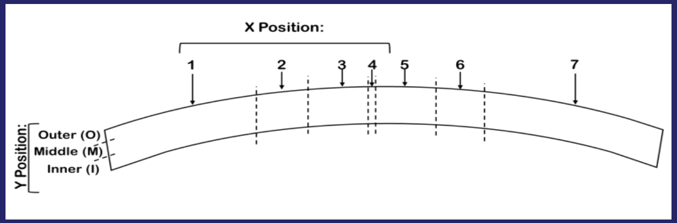
Transfer to Data Analysis | Finish

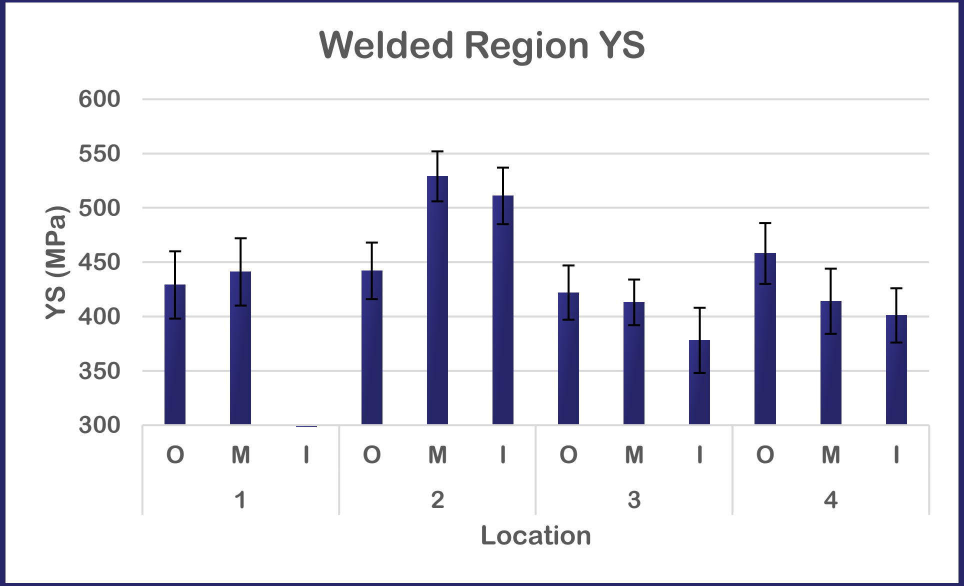
PIP

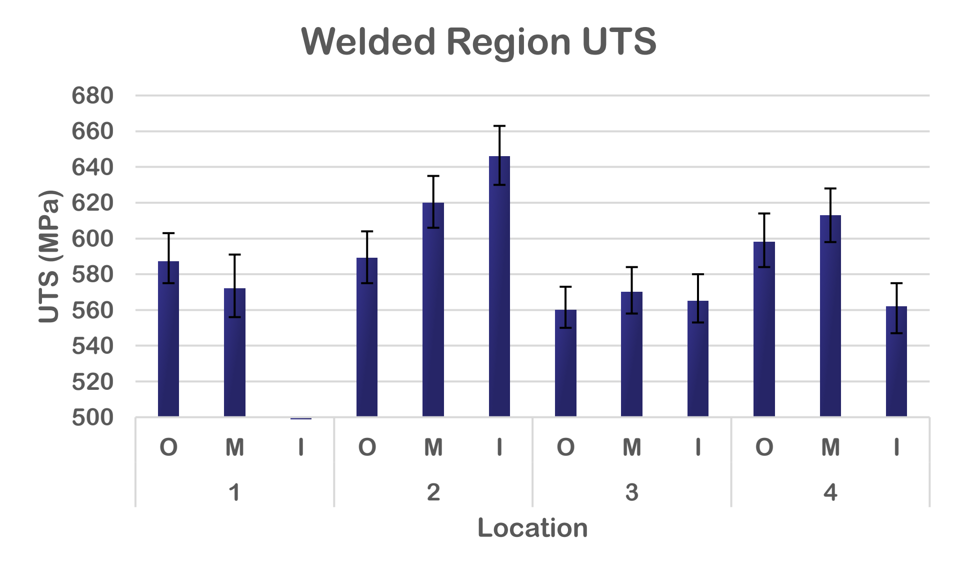
Test diagnostics indicate intermediate and severe anisotropy.

When severe anisotropy is detected, stress-strain data is not given for that data point.

Sample	XPos	YPos	Yield Stress (MPa)	YS Uncertainty	UTS (MPa)	UTS Min (MPa)	UTS Max (MPa)	Elongation %
W	1	O	429	31	587	575	603	15
		M	441	31	572	556	591	14
		I	-	-	-	-	-	-
	2	O	442	26	589	575	604	15
		M	529	23	620	606	635	13
		I	511	26	646	630	663	14
	3	O	422	25	560	550	573	15
		M	413	21	570	558	584	17
		I	378	30	565	553	580	16
	4	O	458	28	598	584	614	14
		M	414	30	613	598	628	14
		I	401	25	562	547	575	15







PIP

Plastometrex have developed a portable tester.

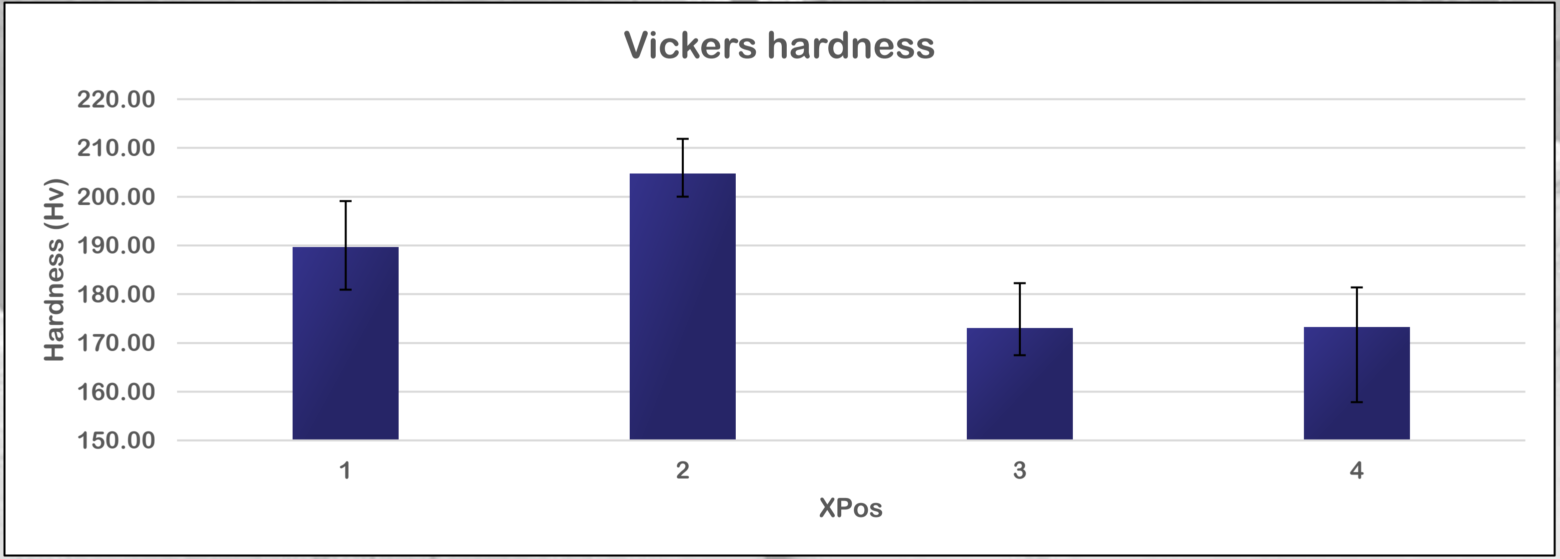
“**[…]** PLX-Portable delivers reliable **stress-strain** results **quickly**, **non-destructively**, and **in-situ**, with report-ready pipeline material verification data available **immediately**[…]”[3]

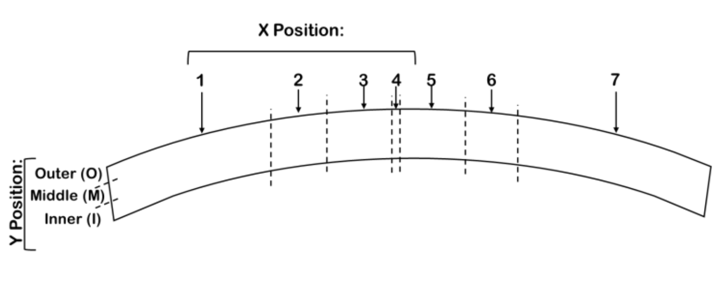
Pipeline PIP

3. PIP testing for Pipeline Inspection. PIP Testing for Pipeline Inspection. (n.d.). https://plastometrex-6034553.hs-sites.com/pip-testing-for-pipeline-inspection

Microhardness

XPos1 Parent Metal					XPos2 Fine Grain HAZ					XPos3 Coarse Grain HAZ					XPos4 Weld Metal				
183.40	189.28	180.92	187.26	188.40	201.75	202.04	202.43	202.77	200.97	178.38	173.64	237.31	182.26	180.56	178.38	180.90	180.60	177.67	176.92
186.42	186.31	186.50	191.49	187.20	204.06	205.41	206.01	207.71	203.04	170.34	171.38	173.76	175.83	177.46	209.65	174.77	181.39	173.73	174.81
190.46	183.88	188.53	188.41	192.96	202.13	204.59	200.00	209.70	200.83	169.98	172.67	168.00	172.95	167.48	175.47	180.27	170.51	173.63	172.89
189.49	191.61	190.81	193.07	191.93	209.03	237.02	211.87	202.39	204.01	172.97	168.70	177.77	177.13	173.32	175.61	175.94	168.59	157.85	166.70
194.24	191.86	193.23	199.10	194.38	210.11	202.02	204.26	207.83	207.13	170.79	169.91	169.51	170.19	168.38	172.48	167.28	165.48	166.19	169.17

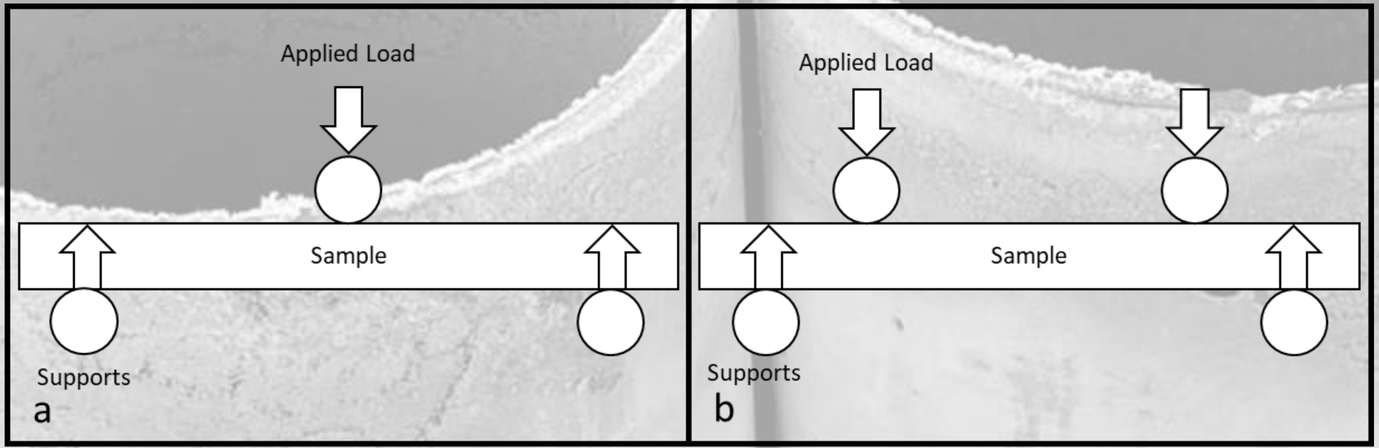




Each zone was tested in a 5x5 array with 1mm separation

Fatigue

- SolidWorks model
  - Estimation of roller spacing
  - Behaviour prediction
- 4-point bend test
  - Test curved sample
  - Stress distribution similar to hoop stress



Gripped sample damage

Poor gripping

Tab damage

Neutral zone extraction

Future work

- Fatigue testing:
  - 4-point bend test
- Failure characterisation


SINGLETON
PARK CAMPUS

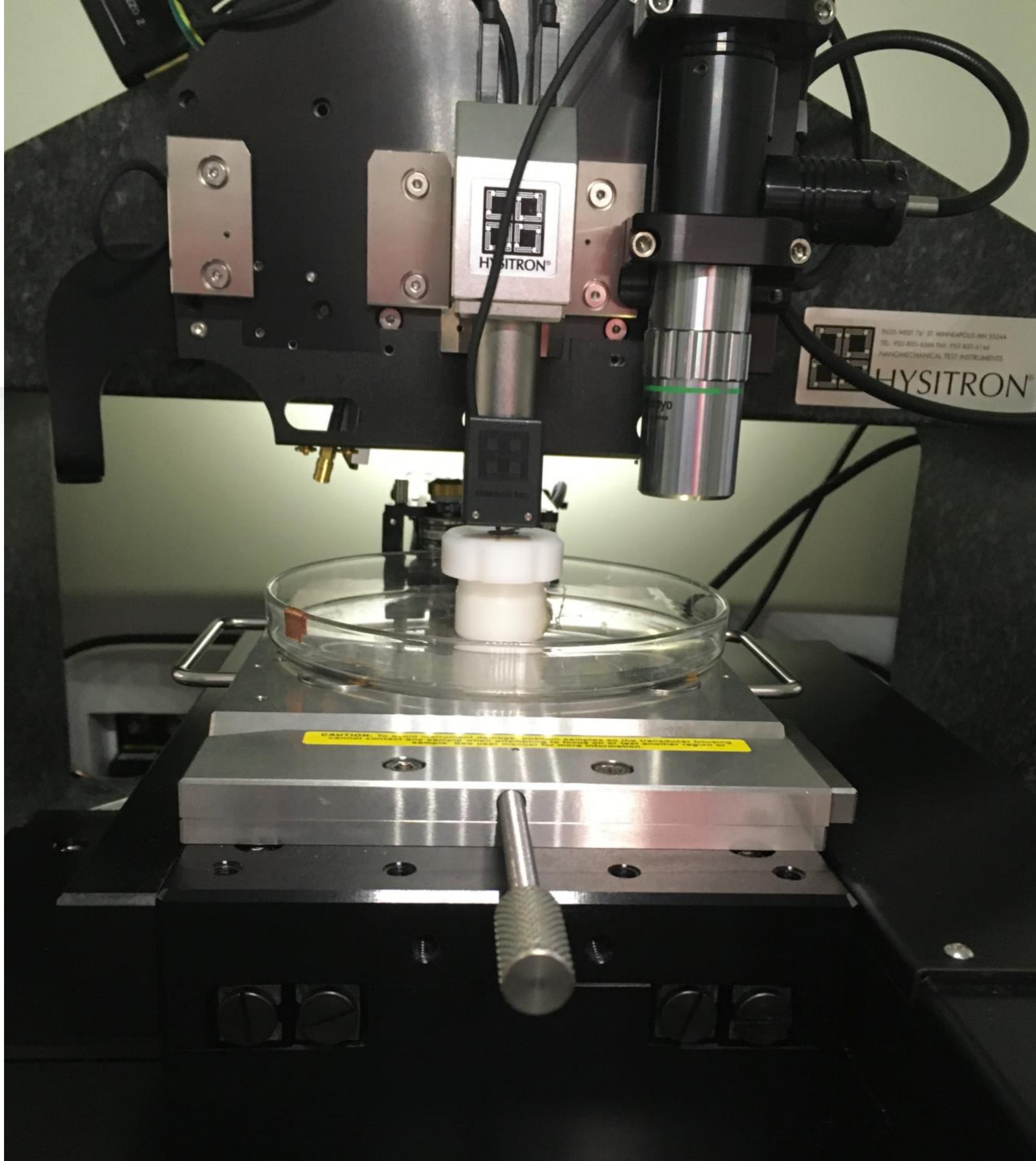

BAY CAMPUS

Advanced Imaging of Materials

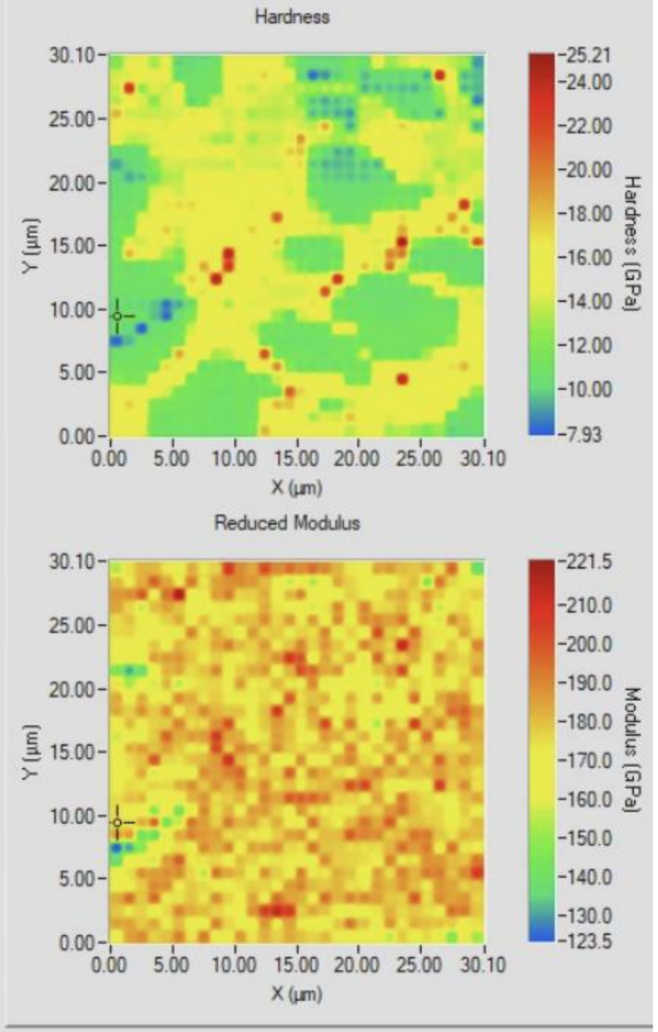
- Transmission Electron Microscopy (TEM),
- Scanning electron Microscopy (SEM), EDS, EBSD, WDS
- Focussed Ion Beam (FIB) nano-fabrication,
- X-ray Diffraction (XRD),
- X-ray Photoelectron Spectroscopy (XPS),
- micro and nano X-ray computed tomography (microCT).

Hydrogen Embrittlement

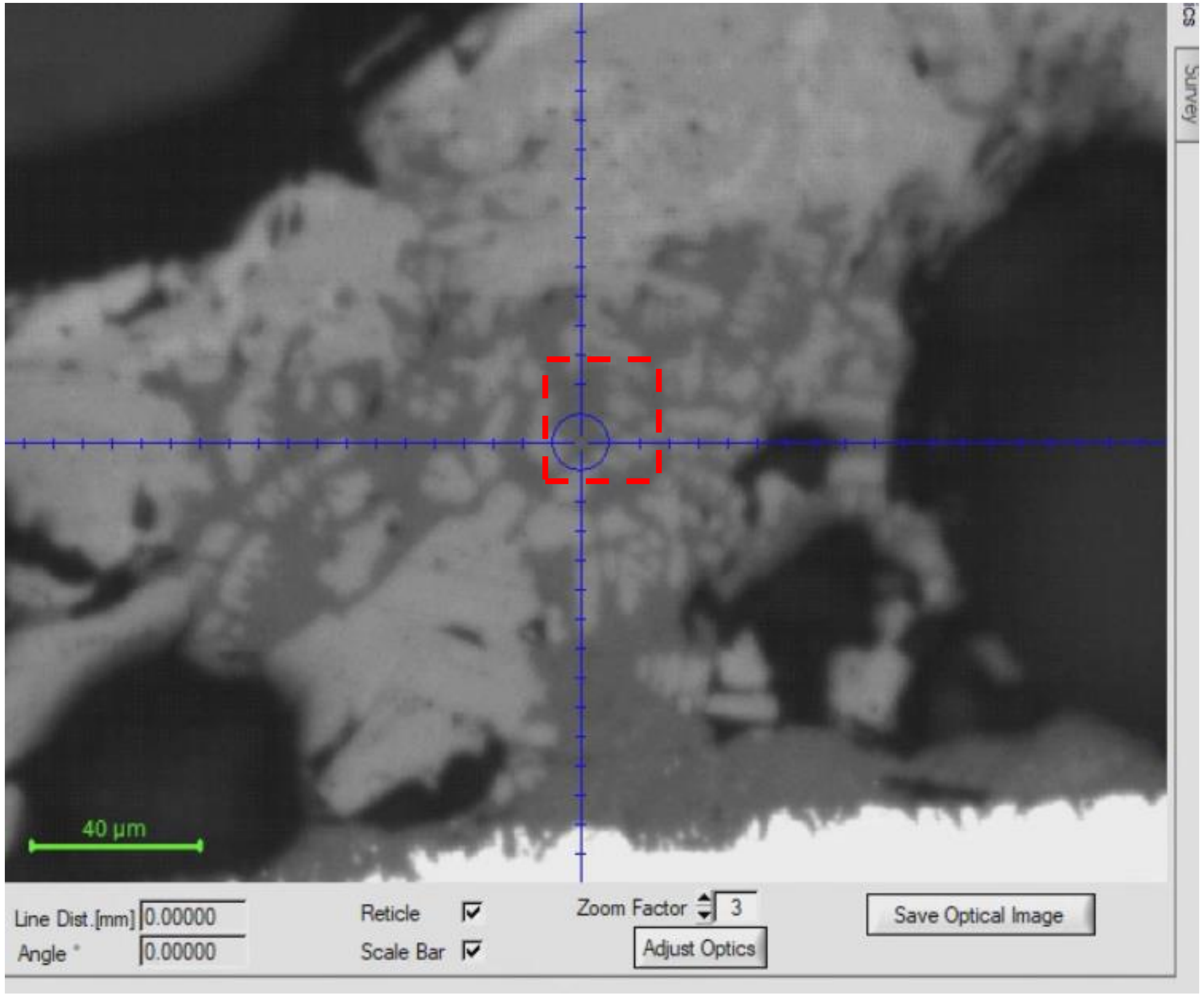
- Modified charging cell
  - ElectroChemically charge samples in-situ
  - Issues with compliance
- Correct trends observed in comparison to tensile data
- Pre-charged samples also investigated
  - Good correlation to tensile data



Variations in mechanical Properties - Oxide



	Average	Std. Deviation
Hardness (GPa)	13.32	2.70
Reduced Modulus (GPa)	178.13	11.62
Contact Depth (nm)	74.4	12.9

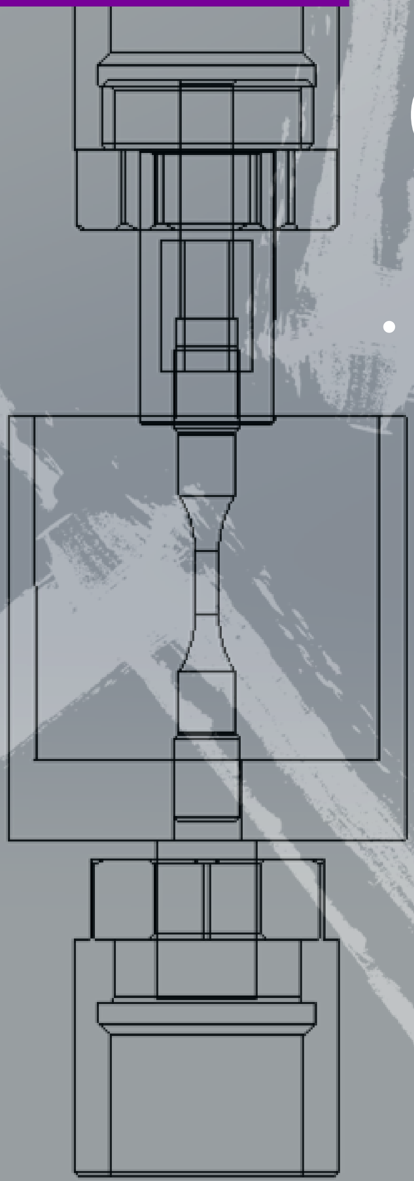


R Dewfall 2021

SMaRT Swansea Materials Research & Testing Ltd

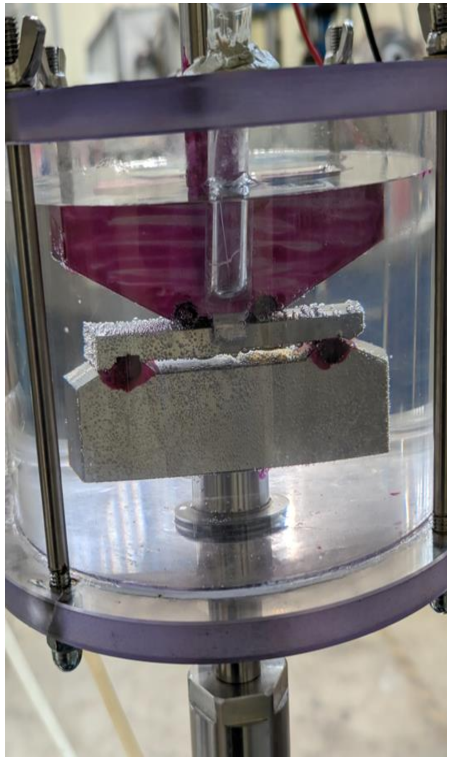
Cryogenic Testing

- -160C, at lowest temps hold for about 6-8hrs.
- At these temps; tensile, LCF, crack prop, strain control L
- Submerged in liquid nitrogen

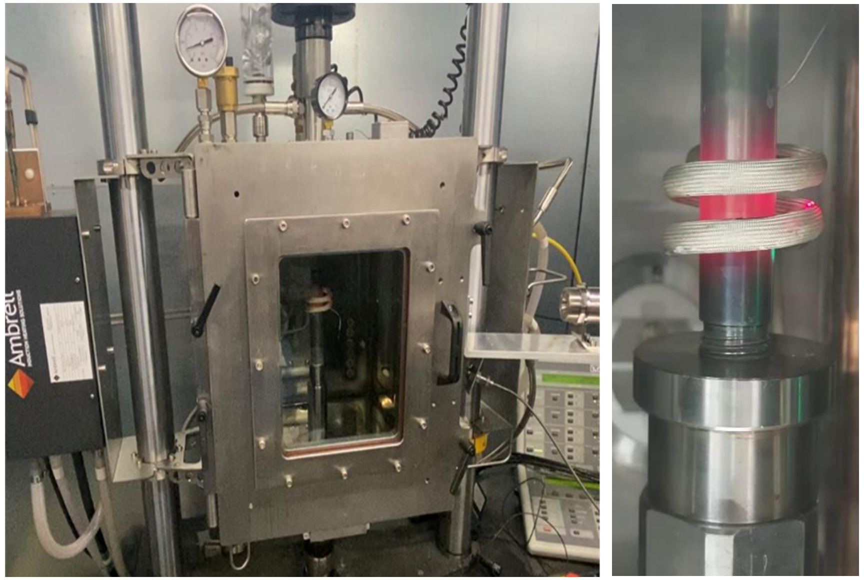


Swansea University
Prifysgol Abertawe

Steel and Metals Institute
Sefydliad Dur a Metelau



Electrochemical Hydrogen Cell

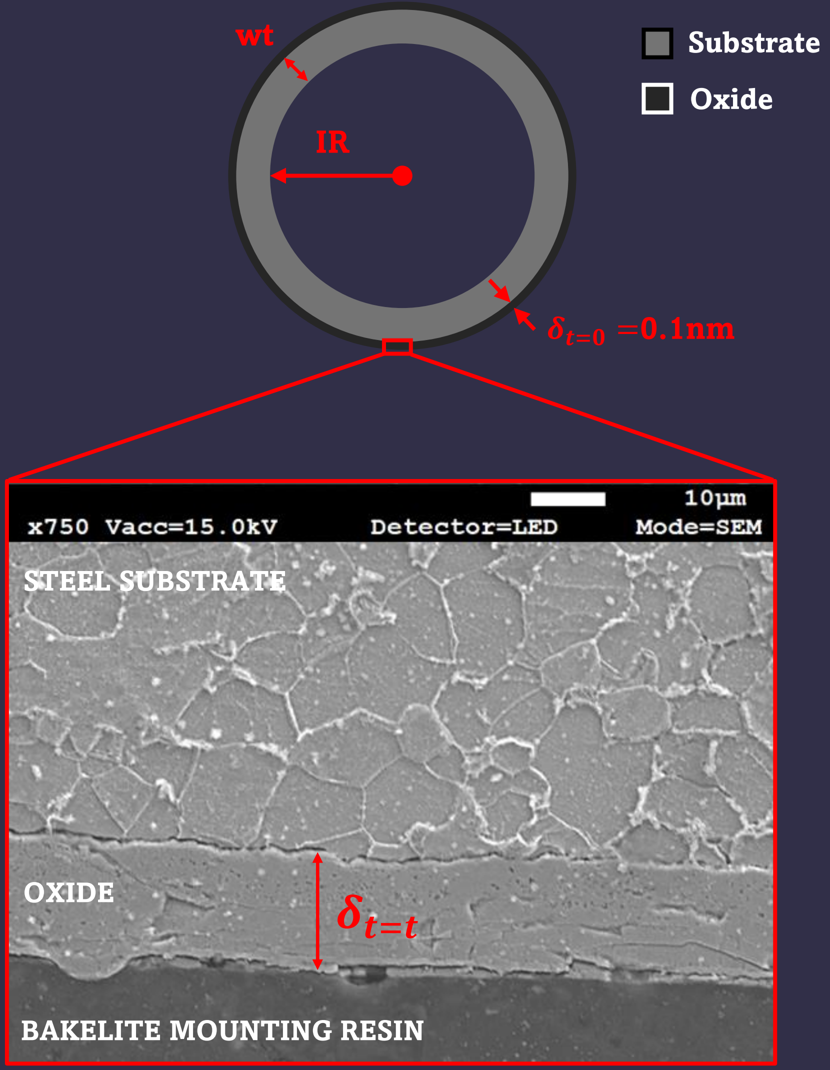


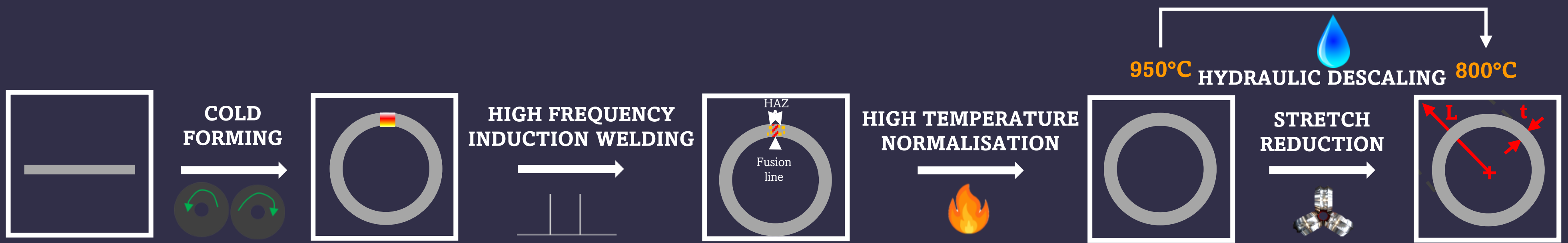
High temperature capability via induction heating

Gaseous hydrogen environments including high pressure (150 bar hollow samples),

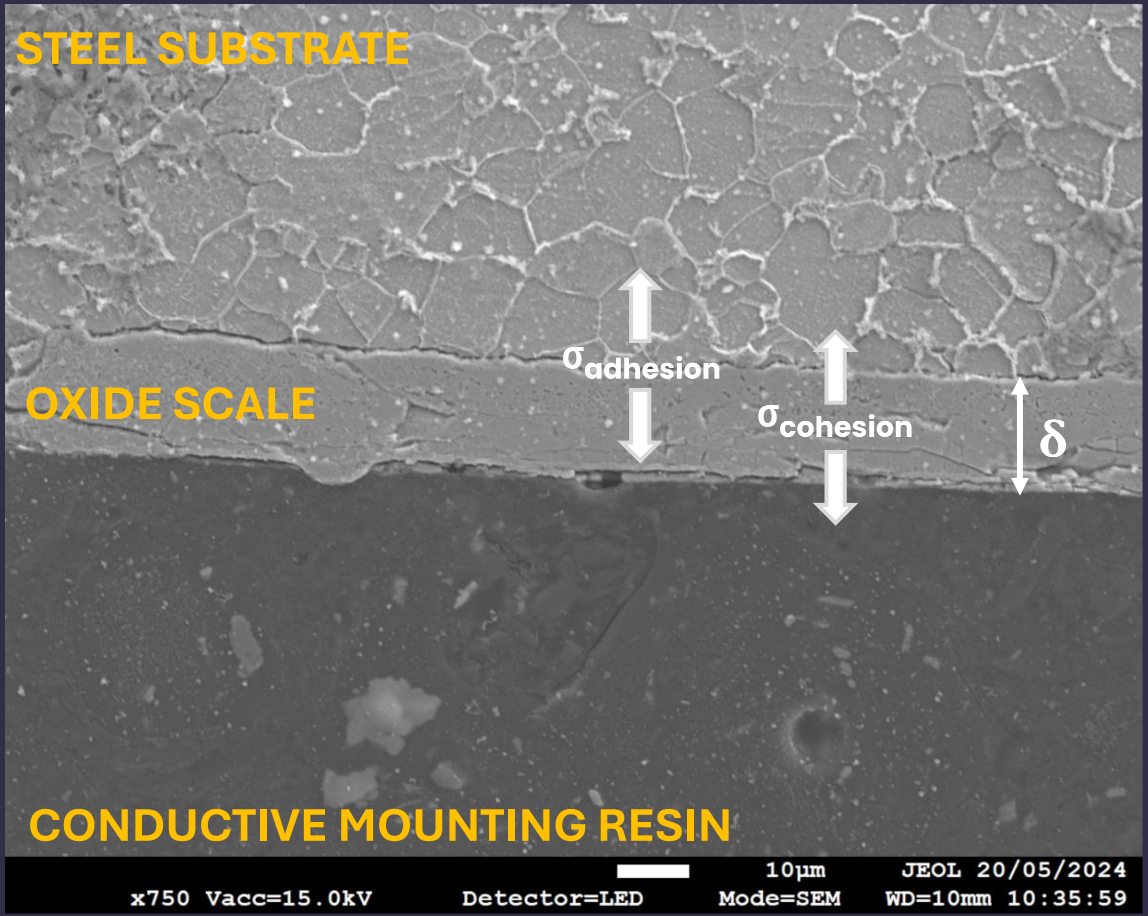
Project Background

- **Oxide scale** growth on surface during high temperature processing
  - Yield loss – **1.5-3% total feedstock lost** due to scale
  - Surface **defects**
  - Premature **failure** (manufacture, installation and service)
  - Aesthetics – customer **product rejection**





Project Background



- Tube-specific aim: **Reduction of scale** (adhesion is secondary factor)
  - **Reduced** plant **damage** and **contamination**
- Key scale parameters
  - Thermodynamic – **thickness, δ**
  - Mechanical – adhesive/cohesive **strength, $\sigma_{adhesion/cohesion}$**

Proactive scale management

\+

Computational thermodynamics

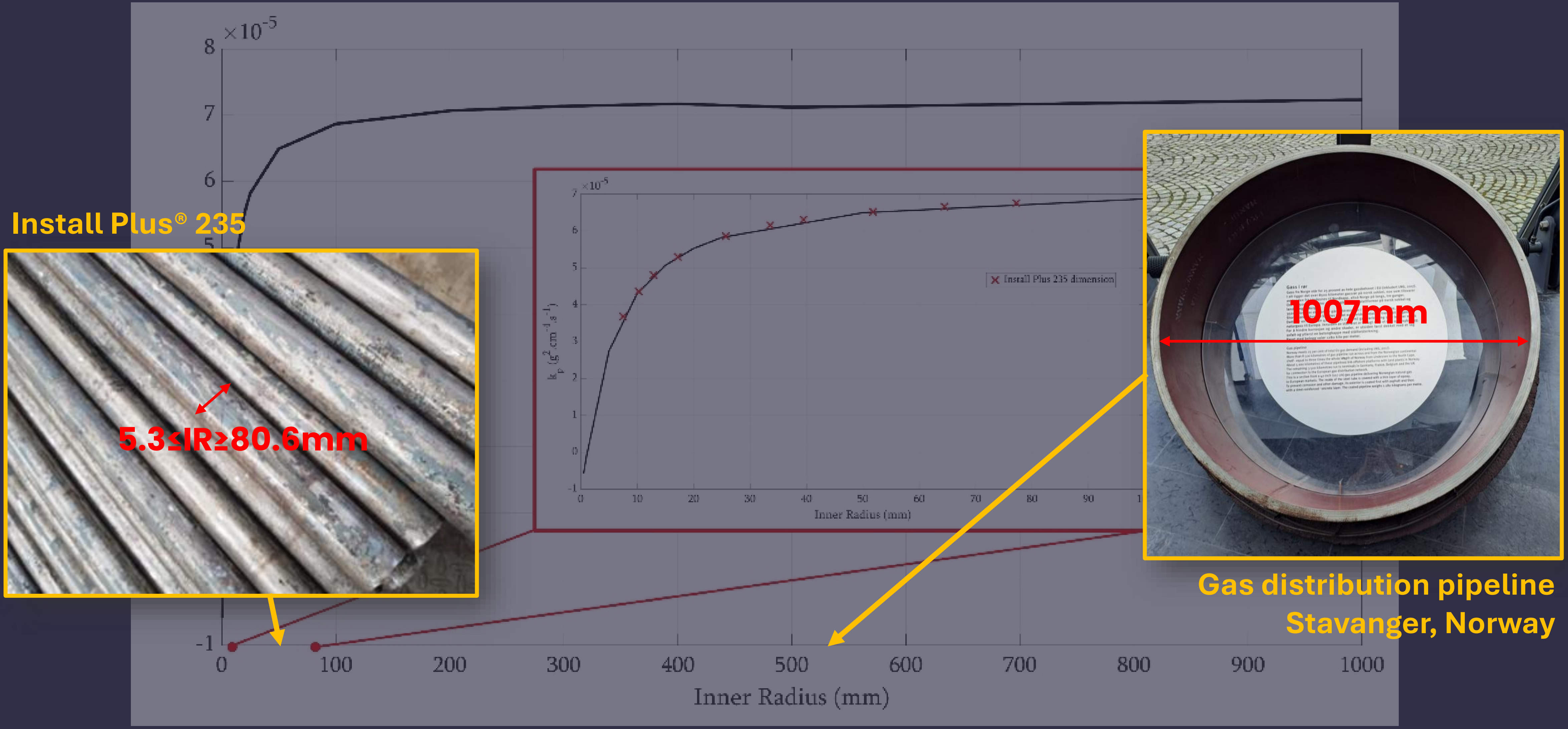
=

Increased manufacturing **agility**

$$Oxidation = f\left(\begin{matrix} Wall\ thickness, Chemistry, Thermal\ Cycle, \\ Furnace\ Environment, Heating\ Approach, Geometry \end{matrix}\right)$$

M.Kendall 2024

Computational Methodology



Fatigue performance of dented pipes (PhD starting Oct 2024)

Valero®

UKOPA
United Kingdom Onshore Pipeline Operators' Association

Thanks for listening

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