UKOPA
Weld Quality Project

Technical Seminar May 2018

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ATCO

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Swansea University Prifysgol Abertawe

Overview

- Background & Introduction
- Overview of previous work
- Discussion of ongoing projects
  - University of Strathclyde
  - Swansea University
  - ATCO
- Interim Conclusions and Ongoing Work
- Questions & discussion

UKOPA

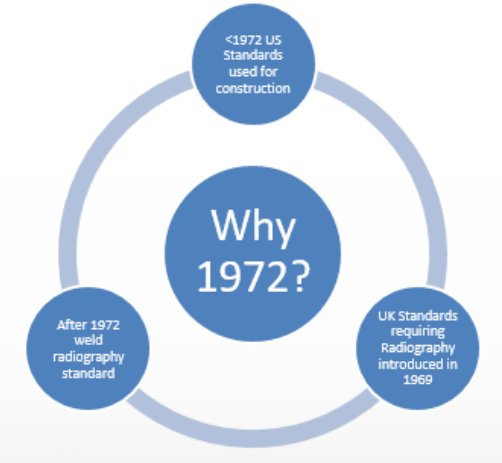
United Kingdom
Onshore Pipeline Operators' Association

Project Background & Introduction

Background – current situation

- Over 50% of UK pipelines were built before 1972.
  - Original construction records often not available.
  - Lower weld inspection requirements for pipelines built before this date.
  - Condition/quality of historical welds not known.
- Current, ‘simple’ assessment is to assume that girth welds in pre-1972 pipelines are of poor quality, unless data available to prove otherwise.
  - This impacts integrity and remaining life assessments for dents, fatigue and ground movement.
  - Requires many digs, NDE and destructive testing of samples to ascertain weld condition. Expensive and time-consuming for operators.

1972 – What is the significance?



- Pipeline girth welds constructed in the UK before 1972 were constructed using American construction companies, following American standards.
- The primary international welding workmanship standard, API 1104 was implemented in 1953. This US standard effectively set the quality of pipeline field girth welds internationally.

- In the UK, the formal requirement for 100% radiographic inspection of girth welds was introduced in 1969, with full implementation of this requirement generally taken as 1972.
- This requirement is accepted as resulting in the change in weld quality to current standards, and girth welds fabricated post 1972 are considered to be good quality.

Background – Desired Outcome

- Is the assumption that all pre-1972 welds are of poor quality justified?
- Was there evidence of in-service fatigue growth?
- What kind of defects can be found?
  - Do these defects mean the joint cannot be considered fit for service?
- Is current conservatism justified?
- Are current fatigue curves applicable?
- Should we be doing anything differently?

Background & Introduction

- Initial/Phase 1 work in 2016/2017 focused on static Mechanical Testing of samples obtained from UKOPA operators
  - Results presented at Technical Seminar last year and issued to PIWG as research report
    - Thanks to K. McDermott, J. Haswell and G. Pailor for their assistanc
  - No obvious evidence of systemic issues with historical welds
    - Strength, Toughness and Ductility of older welds generally OK
  - Older welds found to contain defects that would not be acceptable in new construction, but these did not appear to have a significant adverse impact on performance
- Low failure rate of welds in UKOPA database seemed to indicate that there were no signs of systemic issues

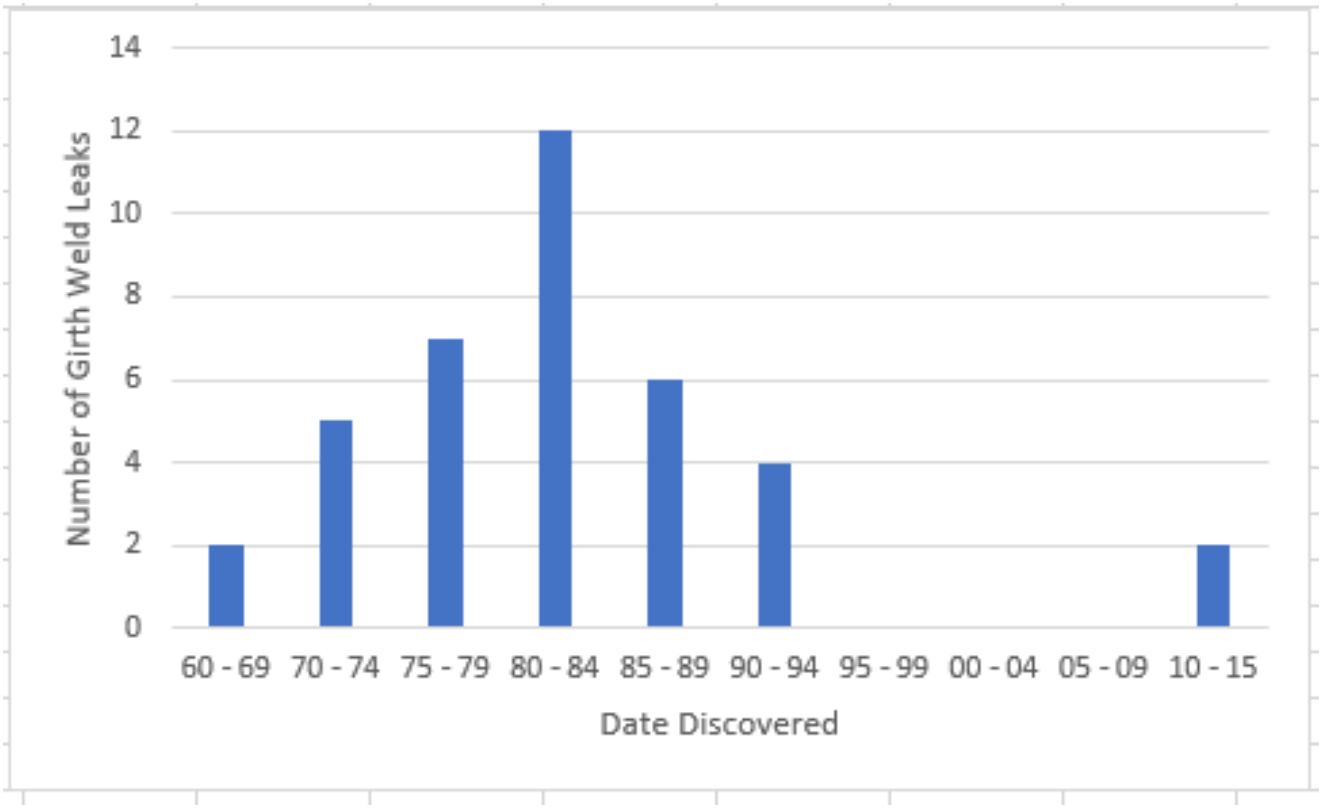
UKOPA Girth Weld Fault and Failure Data

Classification	Faults	Leaks
All	3640	196
Girth Welds	217	39
Girth Welds – pre 1972 pipelines	195 (90%)	37 (97%)

Classification	Faults	Leaks
Girth welds (corrected)	159	28
Girth welds pre -1972	148 (93%)	27 (96%)

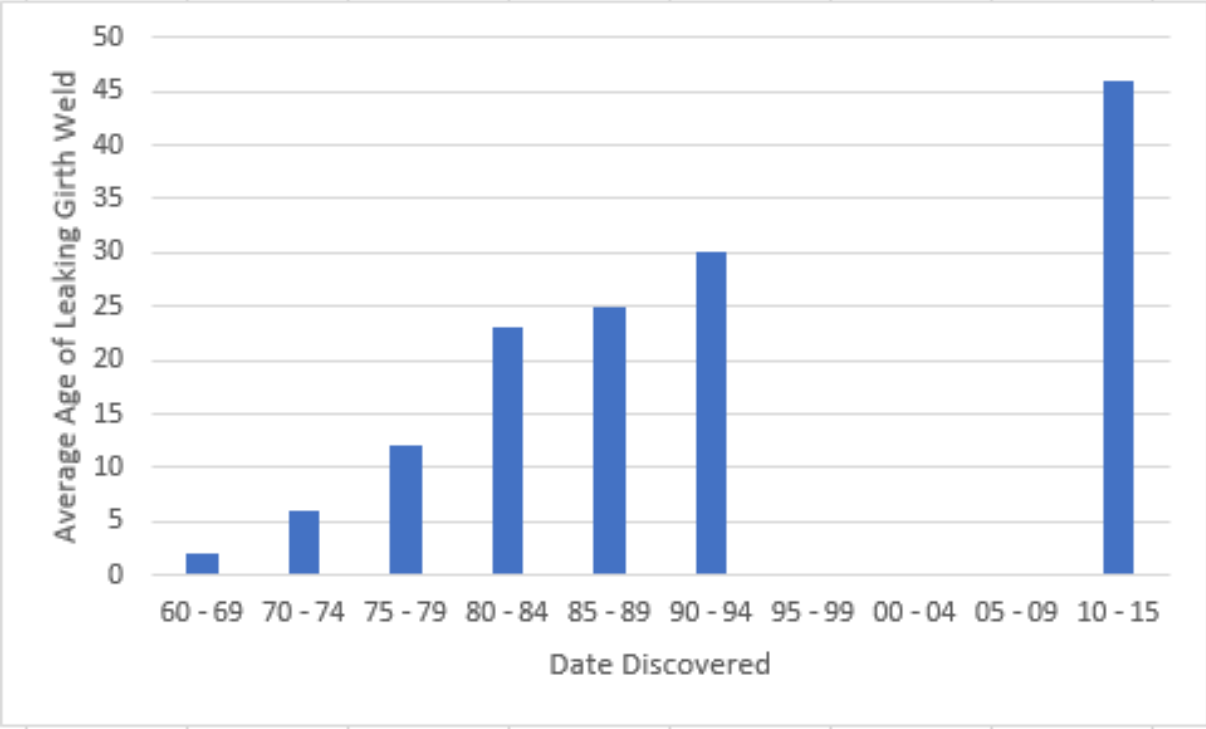
Of the 131 non leaking girth welds, 86 (66%) are recorded as severe
All of the leaks occurred before 1993

UKOPA Girth Weld Fault and Failure Data



Numbers of girth weld leaks in period 1964 – 2016
"Uncorrected" data – so includes failures at GW that were not due to defects in the weld itself

UKOPA Girth Weld Fault and Failure Data



Average age of leaking girth welds vs date discovered

Background & Introduction

- Study expanded in 2017/2018 to encompass static Mechanical Testing of additional samples from Canadian operator (ATCO)
  - Same test method followed as on UKOPA research
    - Only significant difference – impact tests done at -10 deg C rather than at ambient, to get information more relevant for Canadian operators.
    - ATCO samples collected more hardness samples and did greater number of impact tests than original UKOPA work
- Additional university led research commissioned, focusing on Fatigue Performance
    - Strathclyde University – Fatigue testing of samples, comparison to TD1 and BS 7608 (overseen by J. Haswell)
    - Swansea University – Ongoing MSc project looking at UKOPA Samples (overseen by T. Rudd)

Overview of previous work

Sample Selection

- UK Pipeline Operators were asked to provide weld samples containing defects.
  - Seventeen sample sections selected for analysis.
- Samples containing flaws were selected, so that strength of flaw/defect could be assessed.
- ATCO obtained news of research and offered to participate
  - Offered to provide additional fourteen sample sections for analysis
  - To date, test results received on six samples
  - Remainder of tests will be completed later in 2018, when cut-out program permits
- At end of study should have 31 datasets
  - NOT statistically significant
  - However, can be used to draw inferences

Examples of Samples Received

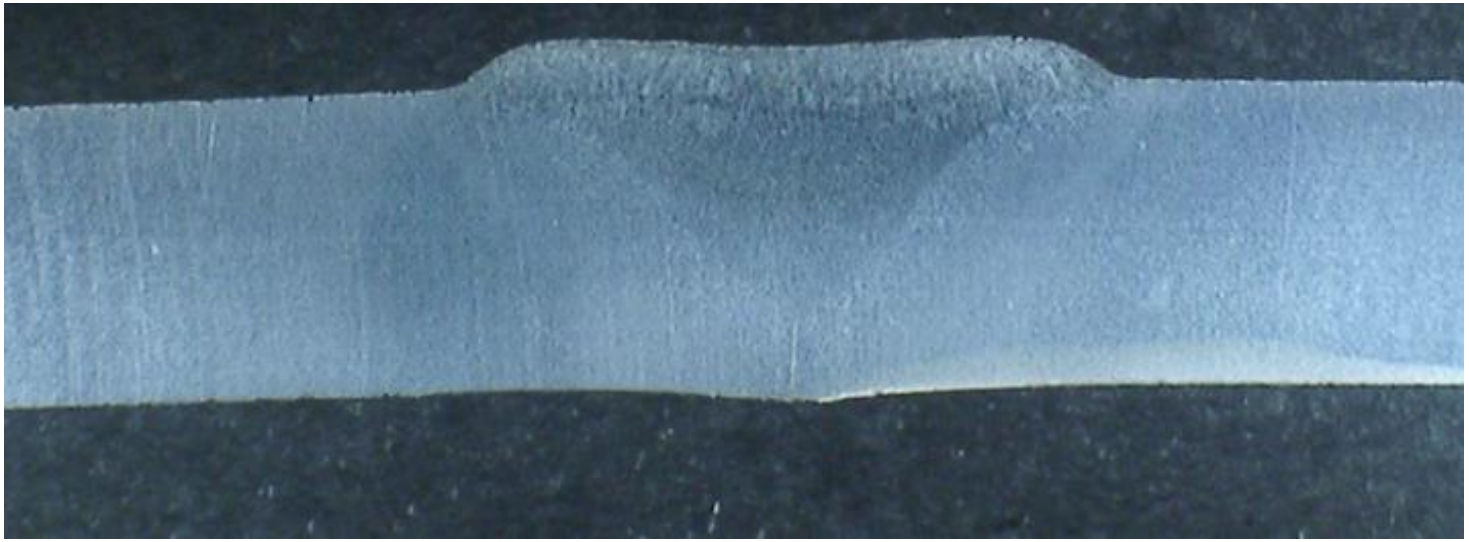
Why expand to ATCO?

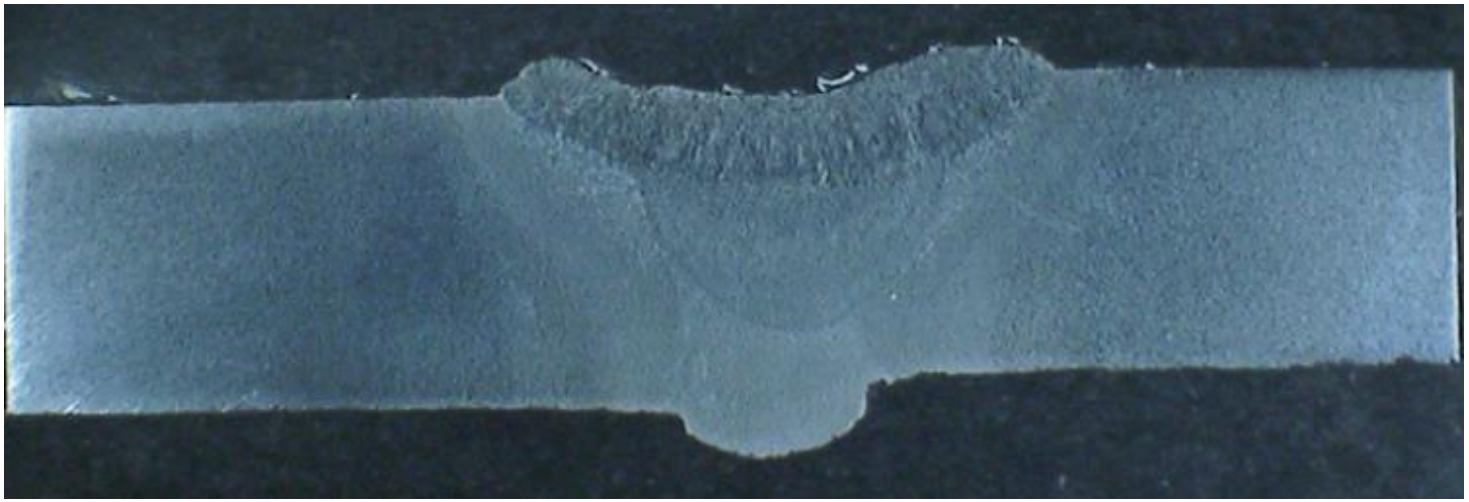
- Similar vintages
  - Pre-1970's
- Similar construction methodology
  - Welded to API 1104 by US contractors
- Large base of liquid lines
- More severe weather conditions
  - Greater temperature fluctuations
  - Colder winters – more risk of brittle fracture
- Opportunity to expand knowledge base and re-affirm conclusions
- Determine whether weld quality/performance varies in different areas of the world

Weld Defect Types

- Welding inspection done at Ambergate, under direction of K. McDermott
  - Similar activity performed for ATCO by consultants
- External & internal profile
- Porosity, burn-through, inclusions
- Lack of fusion (inter-run, side wall), hollow bead, slag, cap undercut
- Inadequate penetration, incomplete root fusion, root undercut
- Cracks

Macro Results





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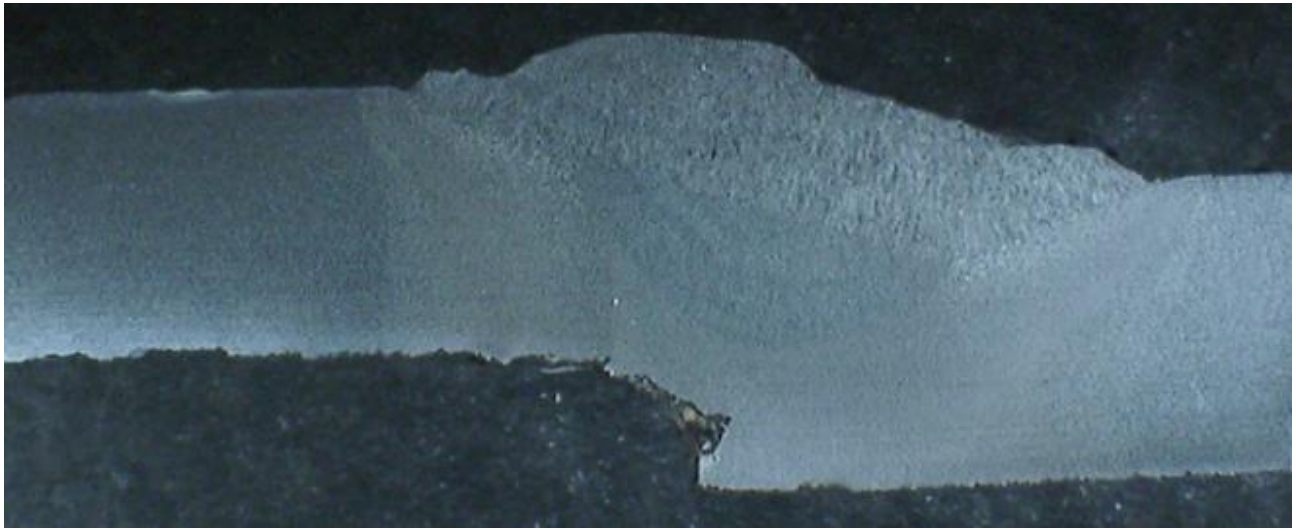

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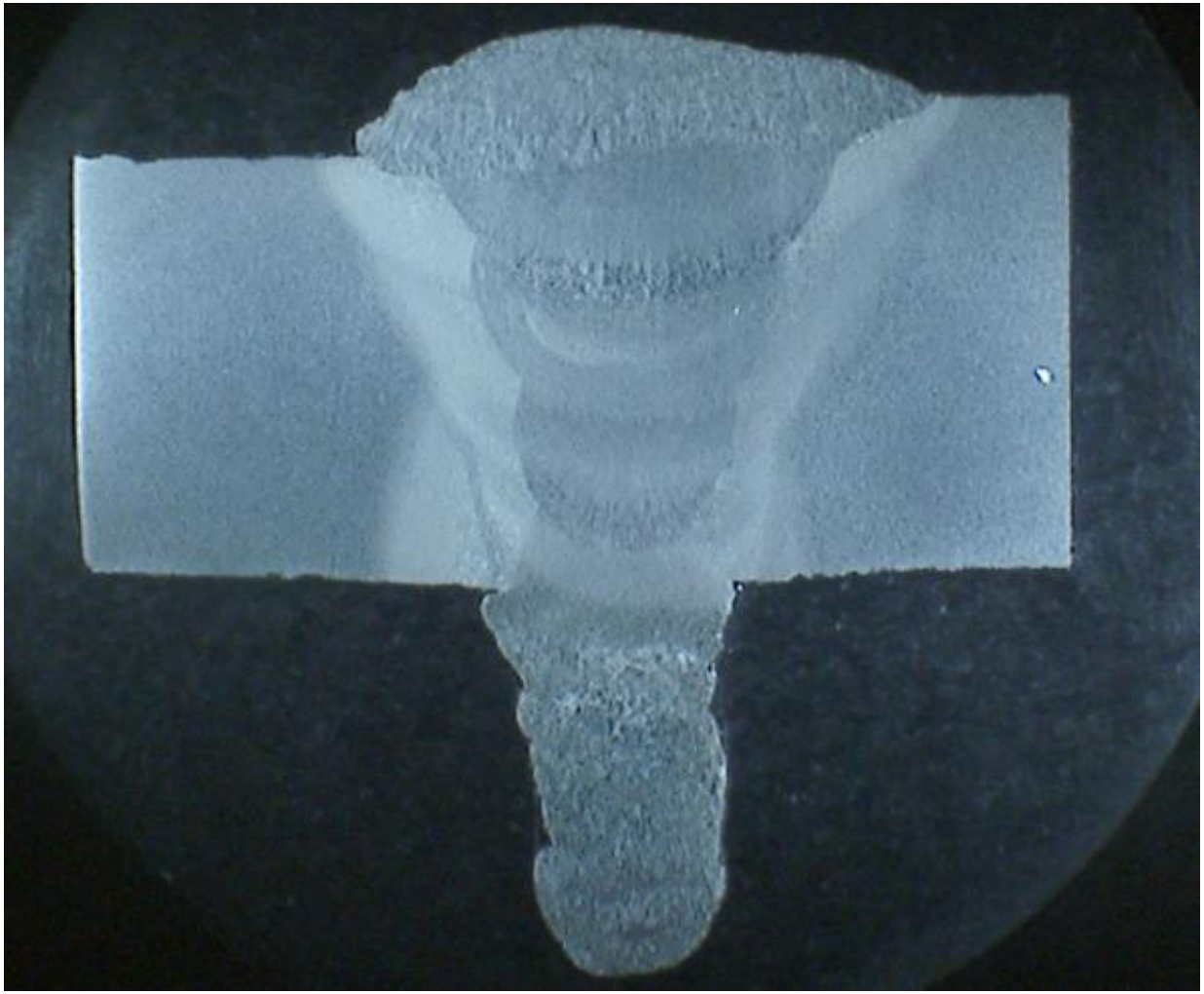


Weld Quality Standards

- BS 4515 – Specification for welding of steel pipelines on land and offshore
- P2 – Specification for Welding of land pipelines and installations designed to operate at pressures greater than 7 bar (supplementary to BS 4515)
- P18 – Specification for welding on pipelines containing defective girth welds or girth welds of unknown quality
- API 1104 – Welding of Pipelines and Related Facilities

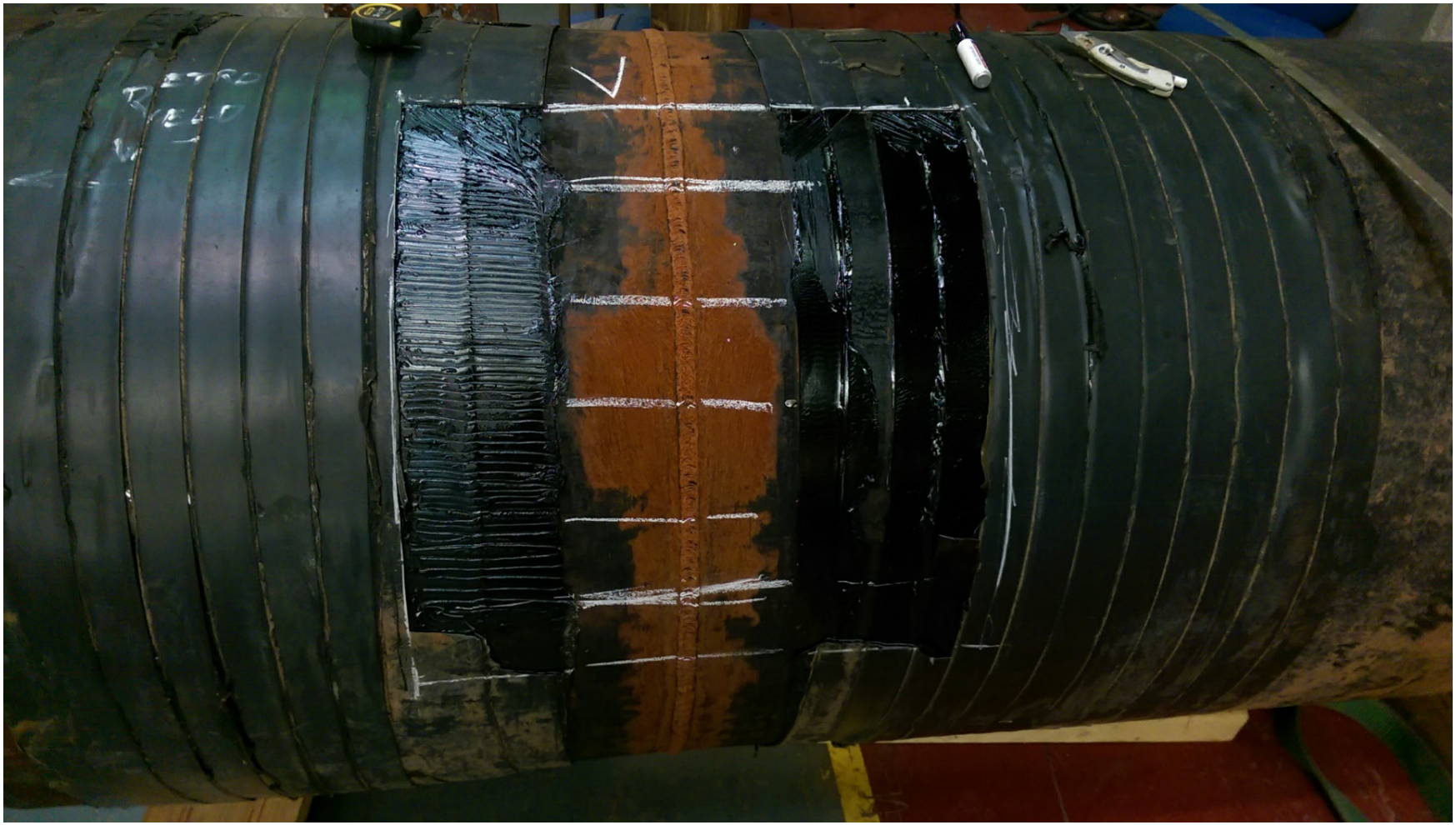
Defect	P18	P2 (1980)	BS 4515	API 1104
Cracks	Not allowed	Not allowed	Not allowed	Not allowed
General defects	75mm in 300 mm	50 mm in 300 mm	25 mm in 300 mm	25 mm in 300 mm

Figures quoted above are for 324 mm diameter pipe:

Ongoing Work - Fatigue testing of girth welds at University of Strathclyde

Dr. Julia Race

Sections taken from 36” pipe – 16mm wt



Fatigue samples machined from 36” pipe – 16mm wt

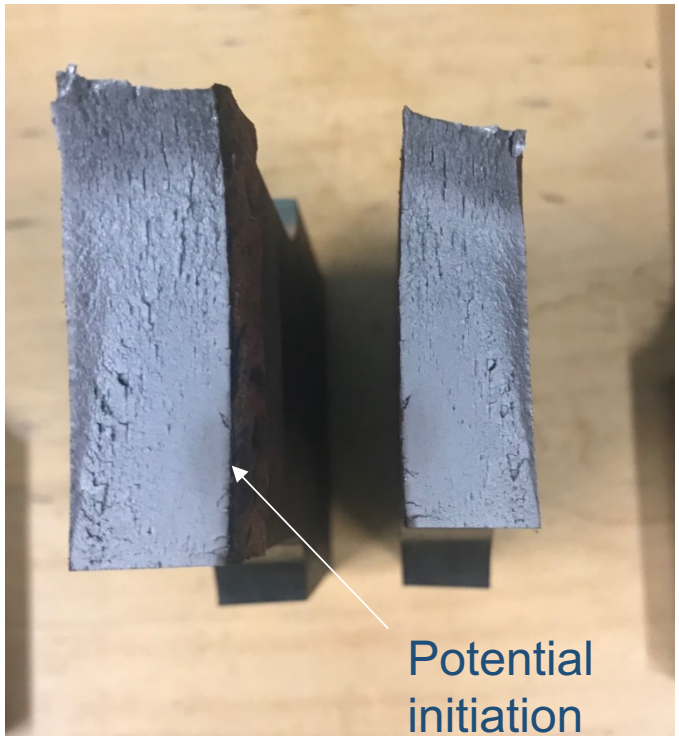
Notes:
The UTS of the 16mm pipe was measured to be ~550MPa on the 440kN Tinius Olsen instrument (Sample 1 in the photo).

Please note that this instrument was not calibrated and the measurement should be taken just as indicative.

Fatigue testing of 16mm pipe – Test 1

Sections taken from 24” pipe – 12mm wt

Test 2 – Results



Notes:
Test failed after 1,117,048 cycles

Fatigue crack initiated at weld cap from visual inspection and propagated from one corner to the other.

Picture shows the back side of the specimen with the weld root

Test 3 – Results

Potential initiation site

Notes:
Test failed after 602660 cycles

Fatigue crack initiated at weld cap from visual inspection and propagated from one corner to the other – as for test 2.

Updated test programme 11.10.17

Notes:
Test 1 complete. Specimen did not fail after ~9x10^6 cycles and test was stopped

16mm Pipe			
t		16	(mm)
Width		50	(mm)
A		800	(mm^2)

Test 1	Required stress	125	(MPa)
	Stress (%SMYS)	35	%
	Load	100	(kN)
	Yield stress	358	(MPa)
	Fatigue life (mean E curve)	1.68E+06	cycles
Test 1	Experimental test	9000000	cycles

Test 2&3	**Required fatigue life**	1.00E+06	cycles
	Stress (mean E curve)	148.71	(MPa)
	Load (mean E curve)	119	(kN)
	Stress (%SMYS)	42	%
Test 2	Experimental test	1117048	cycles
Test 3	Experimental test	602660	cycles

Test 4 & 5	**Required fatigue life**	5.00E+05	cycles
	Stress (mean E curve)	187.37	(MPa)
	Load (mean E curve)	150	(kN)
	Stress (%SMYS)	52	%
Test 4	Experimental test	388163	cycles
Test 5	Experimental test	397097	cycles

12.1mm Pipe			
t		12.1	(mm)
Width		36.33	(mm)
A		439.23	(mm^2)

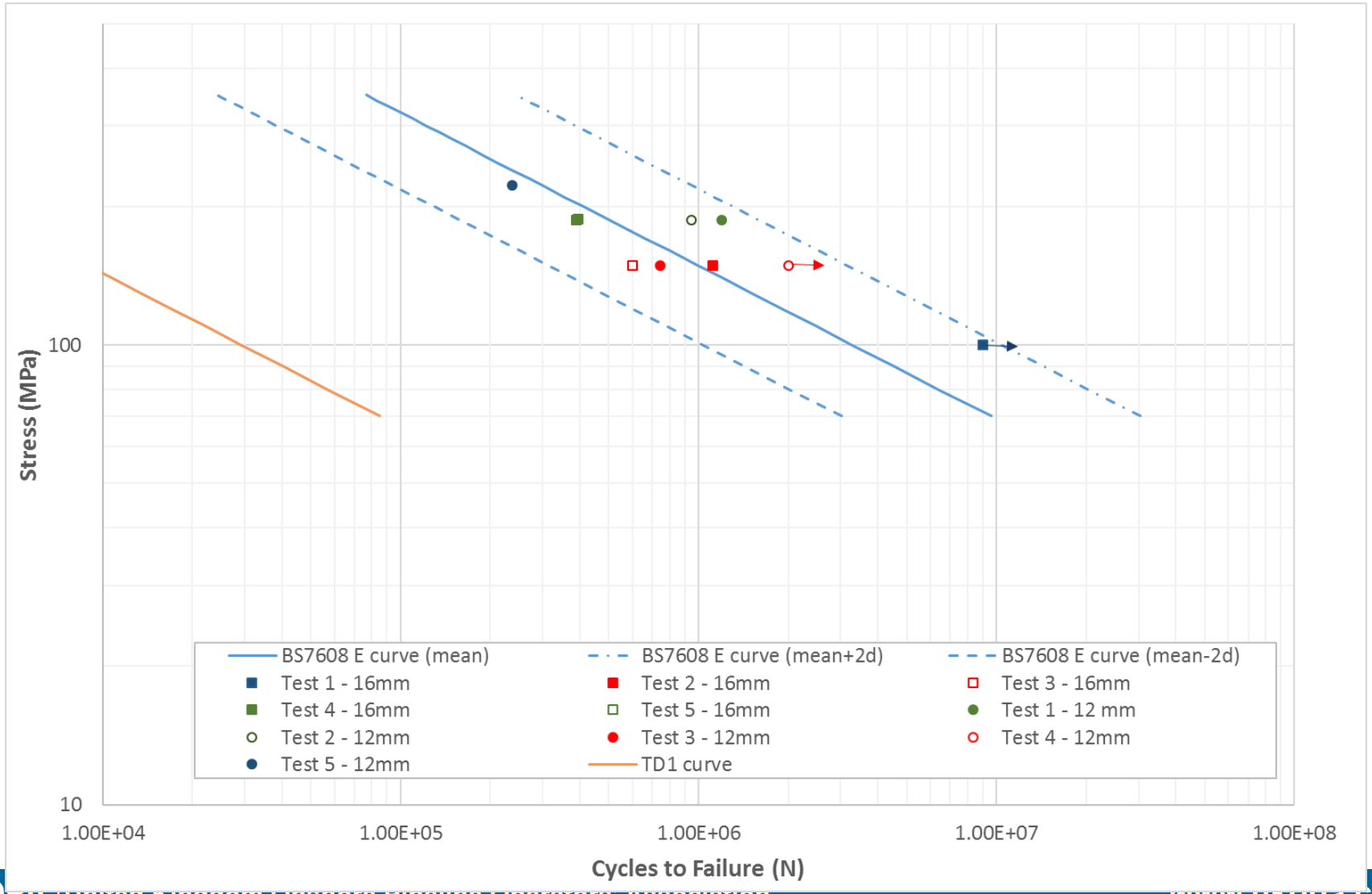
Test 5	Required fatigue life	3.00E+05	cycles
	Stress (%SMYS)	222	(MPa)
	Load	98	(kN)
	Stress (%SMYS)	62	%
Test 5	Experimental test	237060	cycles

Test 3 & 4	**Required fatigue life**	1.00E+06	cycles
	Stress (mean E curve)	148.71	(MPa)
	Load (mean E curve)	65	(kN)
	Stress (%SMYS)	240	%
Test 3	Experimental test	741380	cycles
Test 4	Experimental test	2000000	cycles

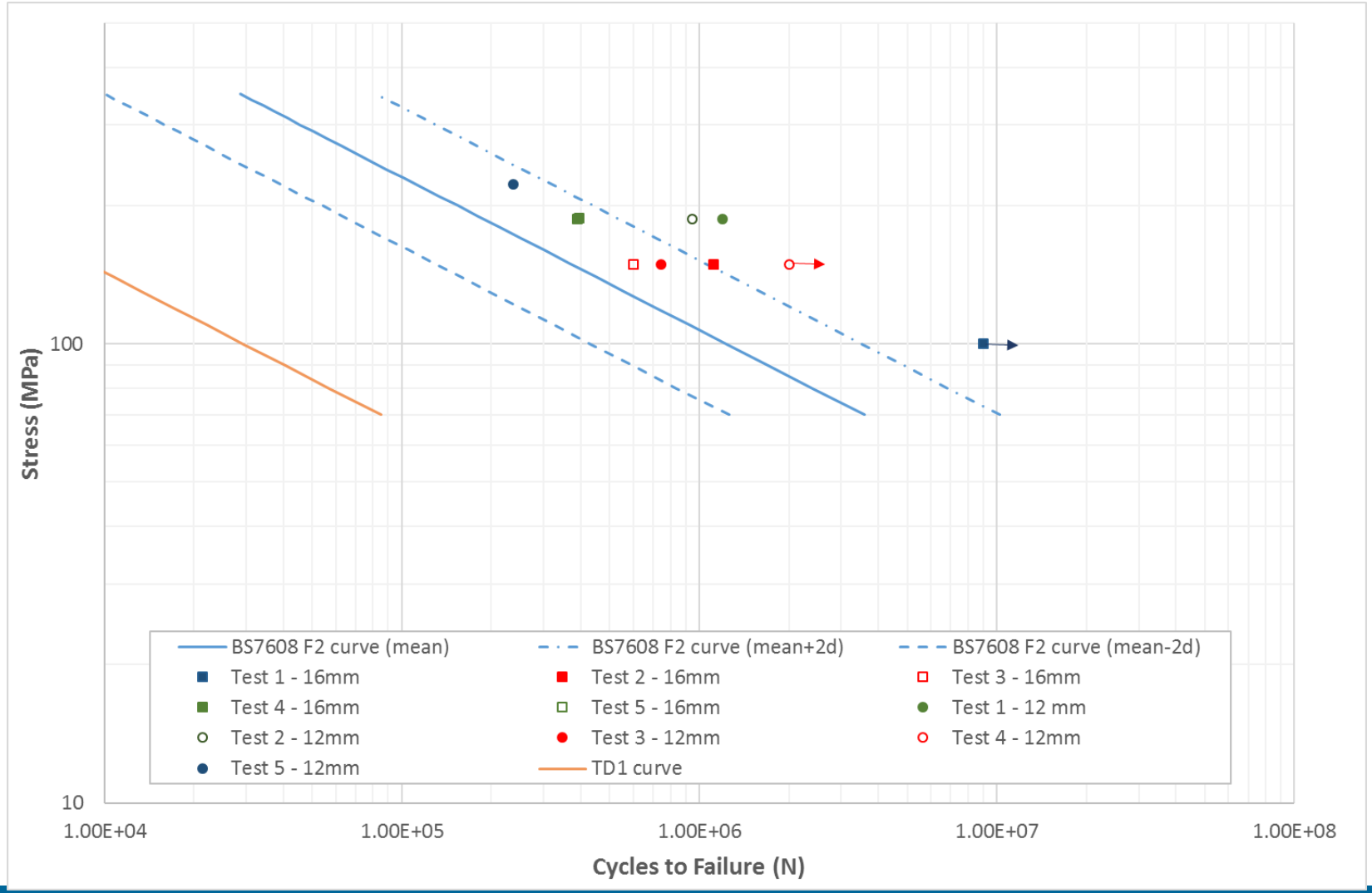
Test 1 & 2	**Required fatigue life**	5.00E+05	cycles
	Stress (mean E curve)	187.37	(MPa)
	Load (mean E curve)	82	(kN)
	Stress (%SMYS)	302	%
Test 1	Experimental test	1193262	cycles
Test 2	Experimental test	947012	cycles

Notes:
Test 4 did not fail and was stopped

Test results – BS7608 **E** curve comparison



Test results – BS7608 **F2** curve comparison



Ongoing Work

Swansea University

Joe York-Fisher

MSc Update 14/05/2018

FATIGUE ASSESSMENT OF HISTORIC WELDS IN PIPELINES

Joe York-Fisher

Supervisors: R. Johnston, E. Sackett, T. Rudd

Sample Complications

- Received 1st batch of samples 12/02/18
- Oceaneering X-Rayed, and supplied labelled films of weld defects
- University Workshop machine dog-bone specimens

- Consolidated all known data from my samples, UKOPA report samples, and METAMET samples

Sample Complications

- Many thin samples had weld line off-centre, meaning dog-bone not possible
- Instron 8802 (250kN) used in previous project
- University's 8801 (100kN) cannot test thicker pipes

- Remainder of samples collected 30/04/18
- 8801 booked throughout July

- Potential option for Dr Race to test larger samples in Strathclyde; Time/Cost?

Current Status

- Oceaneering to quote for new batch
- New samples ≤8mm, 8801 use confirmed

- Simplification of project:
  - Previous samples will not be used, except a small batch (this week) to calibrate Instron
  - Out of the new batch; all samples selected are of the same grade, and only carried gas
  - Selected samples also have the most complete database from the previous reports
- More conservative, reduces variables, allows project to focus on defect effects

Current Status

- This week:
  - Testing selection of previous batch
  - Non-standard dog-bone dimensions, due to pipe section size
- Rig untested on metal at high frequency
- Test parameters; conservative, based on MLP hoop stress at Waterston location:
  - Sine wave
  - Stress max= 180MPa (approx. 30-36kN*)
  - Stress min= 80MPa (approx. 10-16kN*)
  - R-Ratio= 0.44
  - Frequency= 15Hz
  - No-fail cut-off= $2x10^6$ cycles (approx. 2days)

*depending on thickness of sample

Future

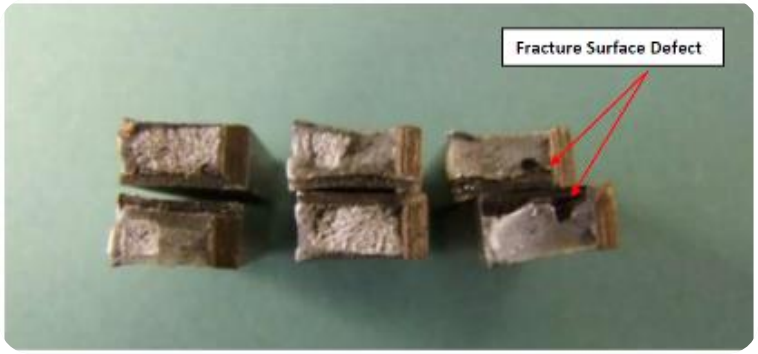
- Keep project focused;
  - No complex wave testing
  - Ensure maximum (concise) data is acquired
- Later, focusing on intricacies of defect effects on crack propagation:
  - Small non-standard samples
  - Stop-start analysis testing
  - Mixture of CT-Scans and Dragonfly analysis

Ongoing Work

ATCO

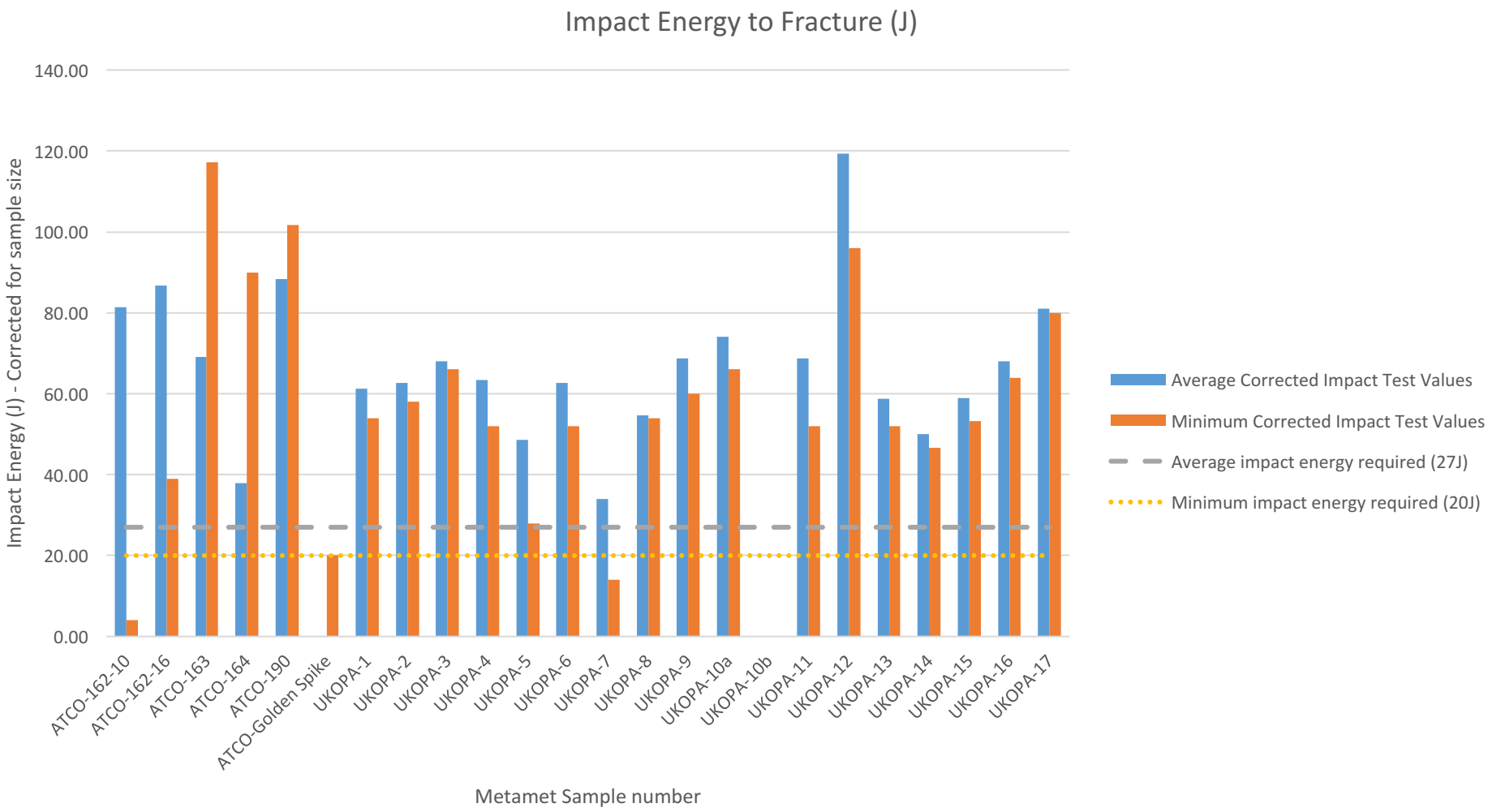
Results – Impact Testing

- 23 Sets of samples had impact testing.
  - All 17 UKOPA samples passed the ‘average’ impact value (>27J).
  - One UKOPA sample failed on an individual test (>20J) due to the presence of a large defect

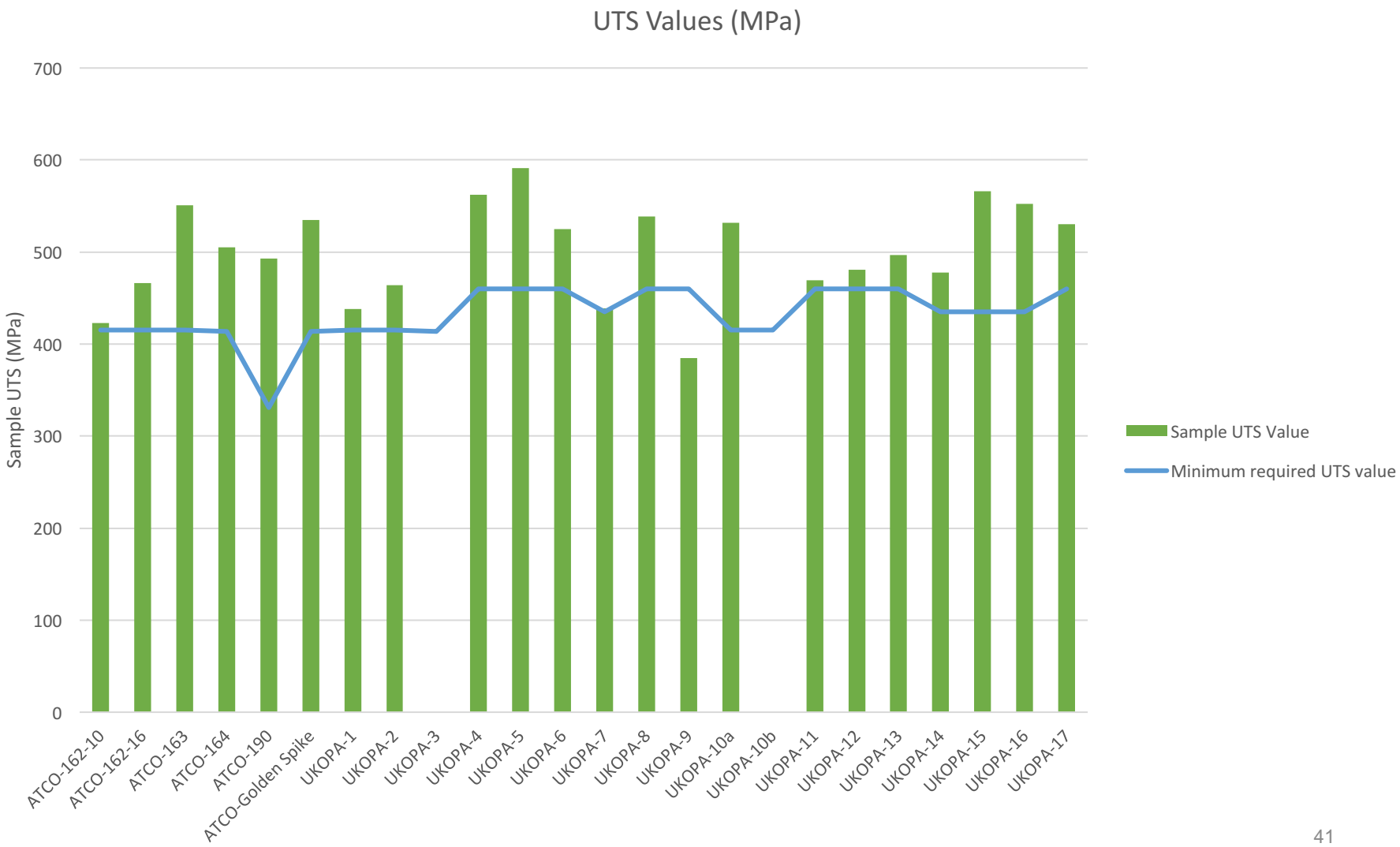


- ATCO tests done at lower temperature (-10 °C), required toughness is 18J
  - All ATCO tests passed WELD metal impact testing, but some issues with pipe values
  - Readings of 4J on one spool – poor quality PARENT metal
- Conclusion – impact toughness of historical welds appears acceptable, impact energy of weld is not less than that of pipe

Results – Impact testing



Results – Ultimate Tensile Strength



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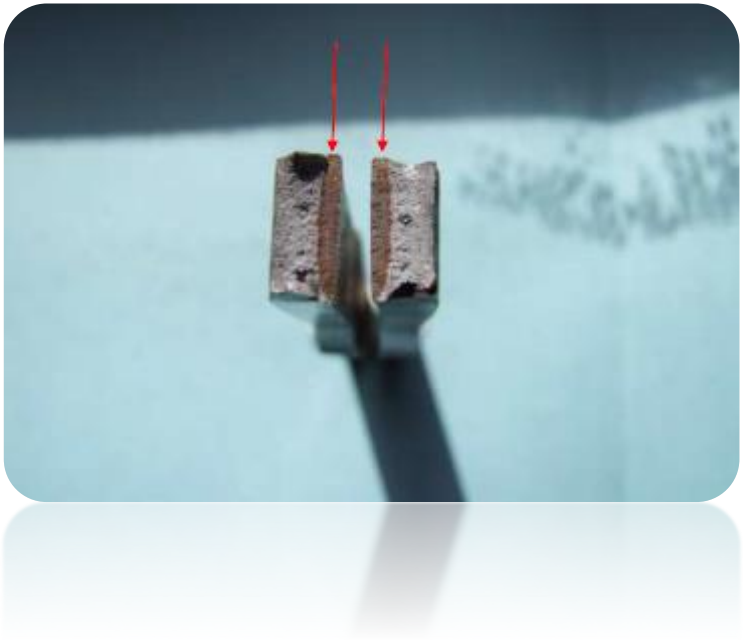
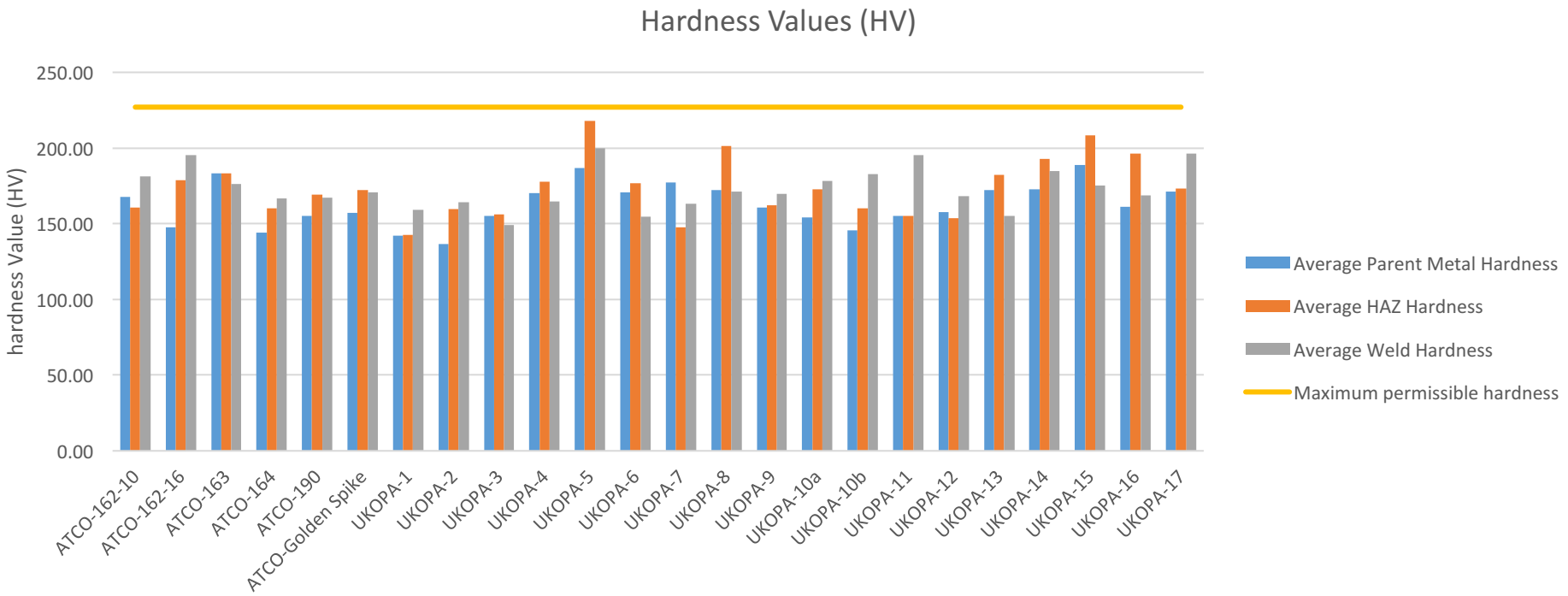


- Low UTS values in tests appear to be generally due to large defects in the tensile specimen.
- UKOPA sample 9 is an example - failure stress of this defect was at an equivalent stress ratio of 0.837, so in service this would not have been reached
- In the actual GW the stress would have been carried by the whole weld (not just the small section containing defect)

- On average samples failed at a stress significantly in excess of the required minimum, for both UKOPA and ATCO samples
- Conclusion – strength of historical welded joints acceptable, despite presence of defects.

Results – Hardness Testing



- All hardness values acceptable.
  - Welds and HAZ were on average slightly harder than parent metal.
  - All values well below the 227 HV threshold that could indicate a propensity for cracking.
- Conclusion – Hardness values of historical welded joints are acceptable.

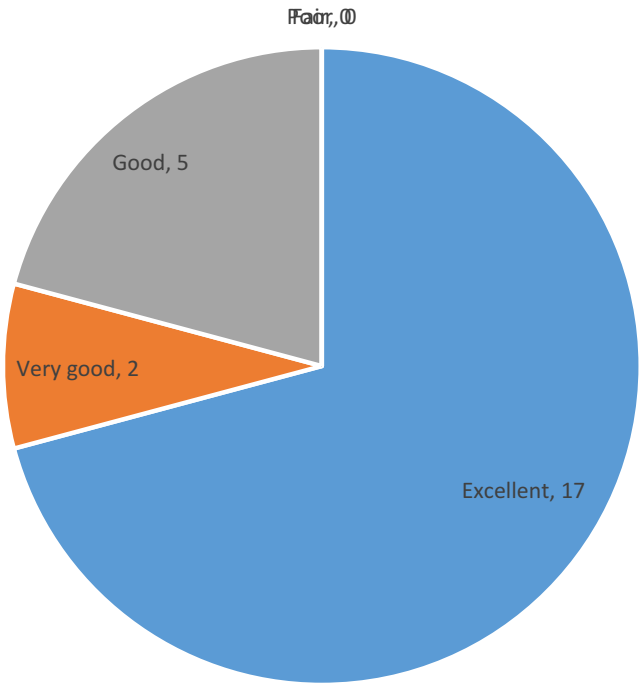
Results – Compositional Analysis

- All parent metal and weld samples had acceptable Carbon Equivalents.
  - CE of Welds less than Parent Metals.
- Composition of all materials consistent with expected grades.
  - Slightly high Sulphur levels in 6 samples, but only marginally so.
  - Low Molybdenum levels in 5
    - Likely due to poor historical control of steel melt composition.
    - High sulphur can cause reduction in toughness, but impact test results show this was not the case.
- Conclusion – historical weld and parent metal composition acceptable.

Results - Weldability

$$CE_{\mathrm{IIW}} = C + \frac{Mn + Si}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15}$$

Carbon equivalent (CE)	Weldability
Up to 0.35	Excellent
0.36–0.40	Very good
0.41–0.45	Good
0.46–0.50	Fair
Over 0.50	Poor



Results - Microscopy

- Grain structure of materials was indicative of a low-carbon steel.
- Parent metal microstructure predominantly Ferrite and Pearlite.
  - Typical microstructure for slow-cooled low carbon steel.
- Weld microstructure different to parent material - due to different composition and different cooling rates
  - Weld microstructures were Bainitic (no Martensite present) indicating that weld cooling was faster than parent material, but not too rapid.
- HAZ microstructure was a bridge between parent and weld material.
  - Contained combination of Ferrite, Pearlite and Bainite.
- Microstructures indicative of tough, relatively strong material.
- Conclusion – Historical welds and parent metal have acceptable microstructures, that do not differ significantly from those expected today.

Interim Conclusions

Interim Conclusions

- Welds constructed to pre-1972 standards appear to be of good quality
- Cracks were not and are not allowed
  - Historical welds may contain defects that would not meet modern construction standards.
- Other allowable defect limits have reduced, this is unlikely to affect the strength of the joint
- Material properties in pre 1972 welds are acceptable
- Metallurgical and mechanical tests show despite these defects welds would be fit for continued service.
  - Samples met or exceed required properties.
    - Anomalous results in some samples are due to test configuration or localised defects that would not govern material behaviour over the entire joint.
  - Welds were ‘overmatched’.
  - No evidence of in-service fatigue.

Conclusions

- Primary concern is fatigue performance
  - TD1 curve appears conservative (from limited sample tests)
  - BS 7608 ‘E’ curve appears best fit
  - BS 7608 ‘F’ curve fits well, but appears slightly conservative
- Need larger sample sizes to draw definite conclusions about fatigue curves
- Samples examined to date not are showing signs of fatigue flaw growth.
- So far, additional results from ATCO in Canada appear to show similar results to UKOPA samples
- UKOPA Fault Database doesn’t show particularly high failure rates for older pipes.
  - No failure of pre-1972 girth welds since 1993.
- PIWG has requested the FARWG to include weld inspection data in the pipeline fault database

Questions