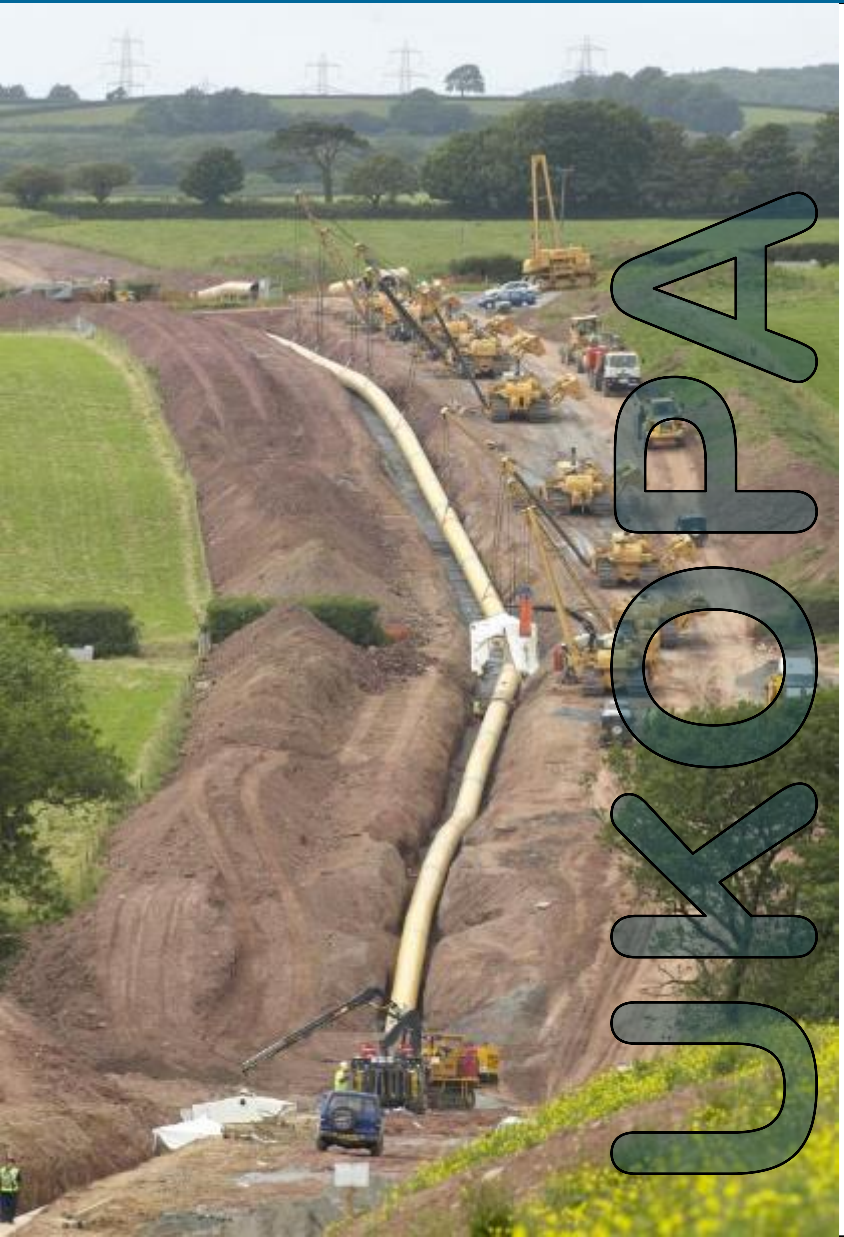
UKOPA

United Kingdom Onshore Pipeline Operators' Association



UKOPA Weld Quality Project

Technical Seminar May 2017

Overview

- Background & Introduction
  - Project:

  Graeme Pailor, SABIC, Chairman, PIWG
  - Technical:

  Tim Rudd (Senior Pipelines and Terminals Integrity Engineer) Valero
- Progress
  - Weld Inspection

    Kirsty McDermott (Welding Engineer) National Grid
  - Material Testing
  - Tim Rudd (Senior Pipelines and Terminals Integrity Engineer) Valero
- Interim Conclusions and Ongoing Work

    Graeme Pailor

Project Background & Introduction

Graeme Pailor

Background

- Pipelines are long life assets (+ 60 years)
- Safe operations requires integrity assessment
- The PIWG has and is developing methods for integrity assessment of operating pipelines:
  - Management of construction dents
  - Failure due to landsliding
  - Seismic assessment
  - Ground movement
- These methods require assessment of girth weld quality

Background

- In any integrity assessment, girth welds are a primary consideration as they may represent a weak point
- Weld quality has is a major input to integrity assessment, standards have changed
- Where records are not available, conservative assumptions must be made, which can lead to unnecessary remedial work/repair
- A programme of work to investigate the quality of girth welds on old pipelines is being undertaken

Introduction

- The weld quality project involved the evaluation of old girth welds cut from operating pipelines supplied by UKOPA members
- The scope involved full weld inspection, and destructive testing of weld samples
- The weld inspection (carried out by PMC Ambergate) has been managed and directed by Kirsty McDermott, National Grid
- The material investigation (carried out by Metamet Consultants) has been managed and directed by Tim Rudd, Valero

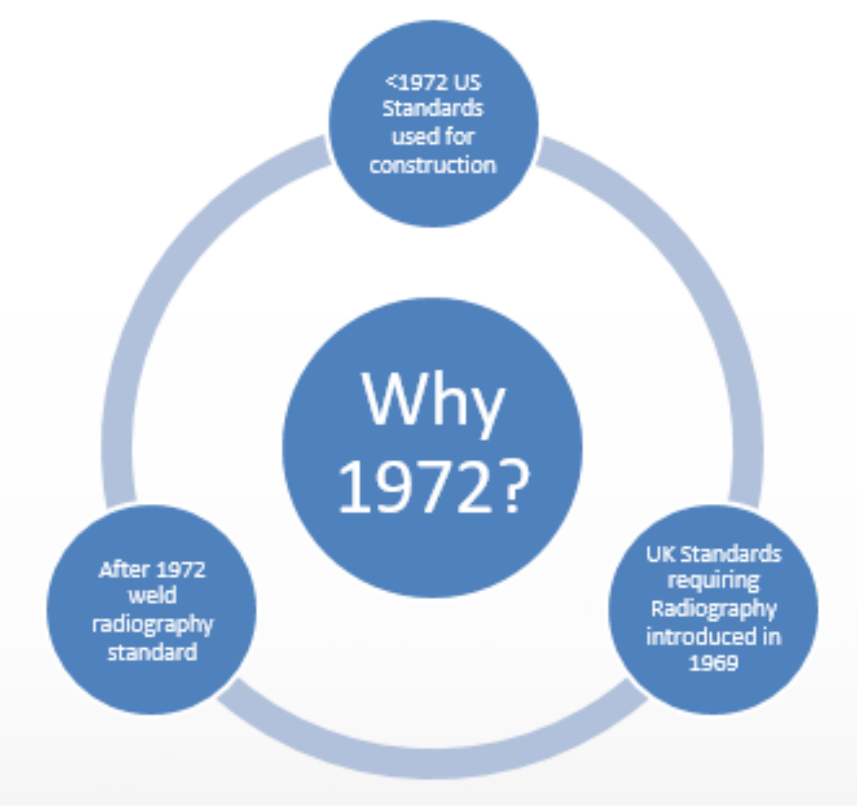
Technical Background

Tim Rudd

Background

- 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.
- Project was initiated to determine whether this was the case.
  - 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?

1972 – What is the significance?



- Pipeline girth welds constructed in the UK before 1972 were constructed using American construction companies using 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.

Sample Selection

- UK Pipeline Operators were asked to provide weld samples containing defects.
  - 28 samples provided.
  - 6” through to 36”.
  - Construction dates ranged from 1950’s through to 1970.
- Seventeen sample section selected for analysis.
- Samples containing flaws were selected, so that strength of flaw/defect could be assessed.
  - More conservative assessment than testing ‘good’ welds from this period.
  - Would allow assessment to be made of effect of similar defects that could be present on in-service pipelines.

Evaluation Process

Sample Selection

- Initial 28 samples reviewed and catalogued.
- 15 Samples initially selected for testing (another 2x added later), designed to provide cross-section of different pipeline ages, diameters, thicknesses, material grades and products carried.

Preliminary Inspection

- Selected samples inspected at Ambergate via Visual inspection and Radiography, interpretation of reports provided by qualified Weld Inspector.
- Defect types within samples noted, samples then cut down to pup-pieces for transport to Metamet.

Microscopy and Metallurgy

- Detailed visual inspection of all pipe samples. NDE carried out using ShearWave, internal defects noted and categorised. Most severe defects were identified and marked, then cut out for further assessment.
- Samples examined via microscopy and a full metallurgical assessment performed on the defect, weld, heat affected zone and parent material.

Mechanical Testing

- Destructive tests carried out on samples containing flaws/defects, and on the parent metal and HAZ.
- Tensile Tests (Strength and Ductility), Impact Tests (Toughness), Hardness Tests and Chemical Analysis carried out .

Interpretati on

- Report generated by Metamet detailing results from Metallurgical examinations.
- Interpretive report produced by PIWG members evaluating Metamet results and discussing effects on in-service pipelines.

Progress

Weld Inspection

Kirsty McDermott

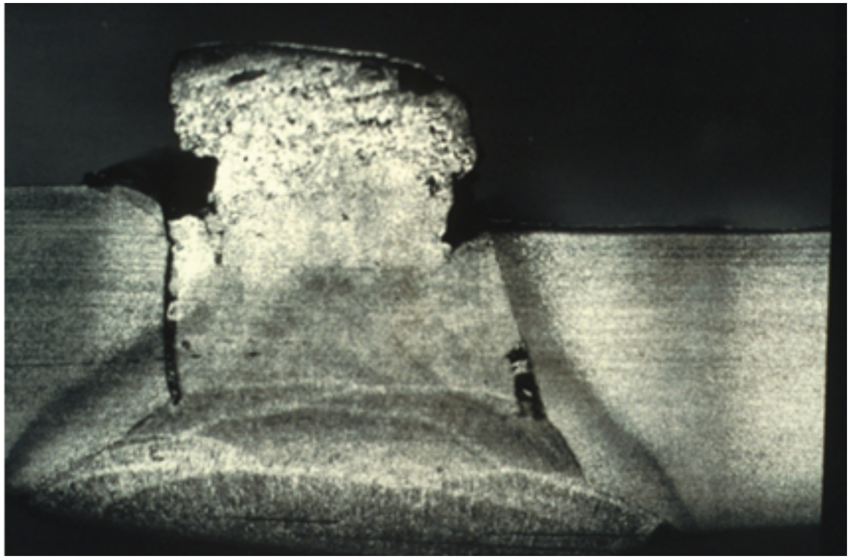
Weld Inspection Overview

- Scope of Work
  - Inspection of pipe weld samples from operators taken from pipelines constructed in 1970s and earlier
  - Confirm weld quality against i) weld standard in place at time of construction and ii) current standard (BS 4515)
  - Material investigation and destructive material tests on small scale samples to obtain weld material properties
  - Project report

Management of Girth Weld Quality in the UK Gas Industry

P18 Procedure

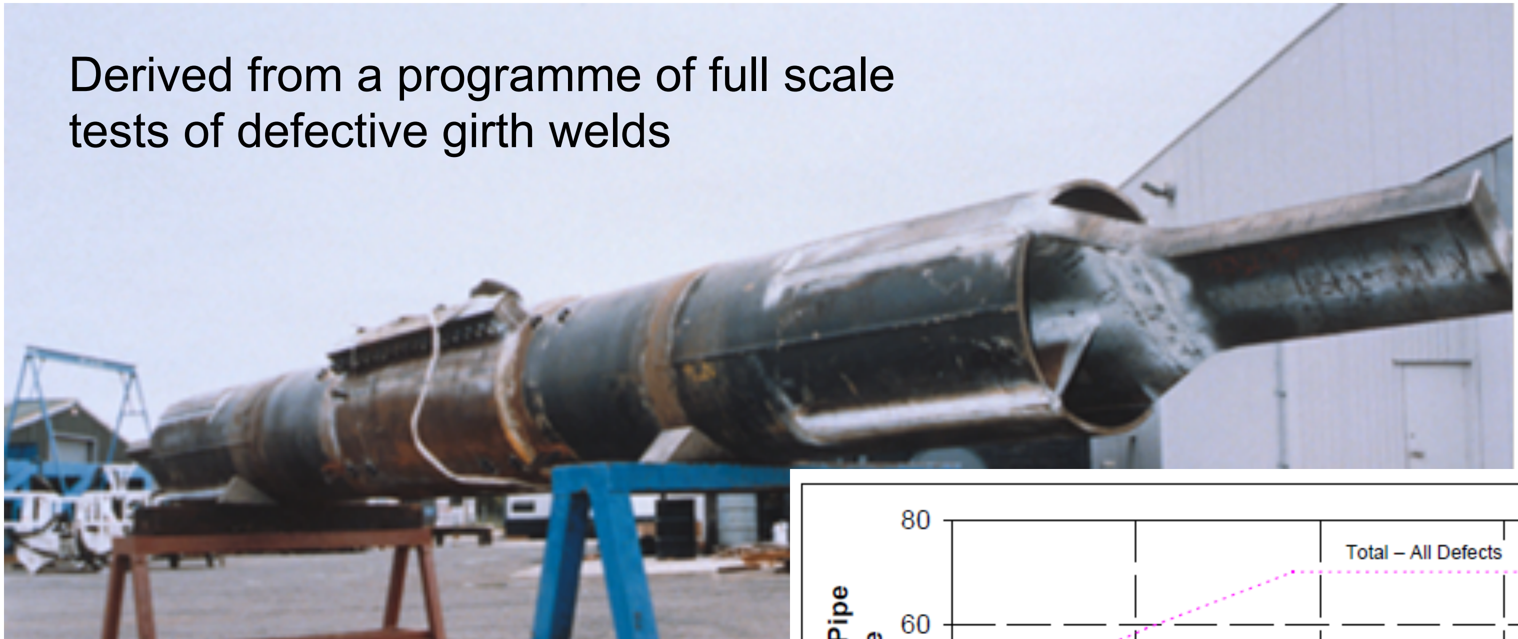
- Procedure for working on pipelines containing defective girth welds or girth welds of unknown quality

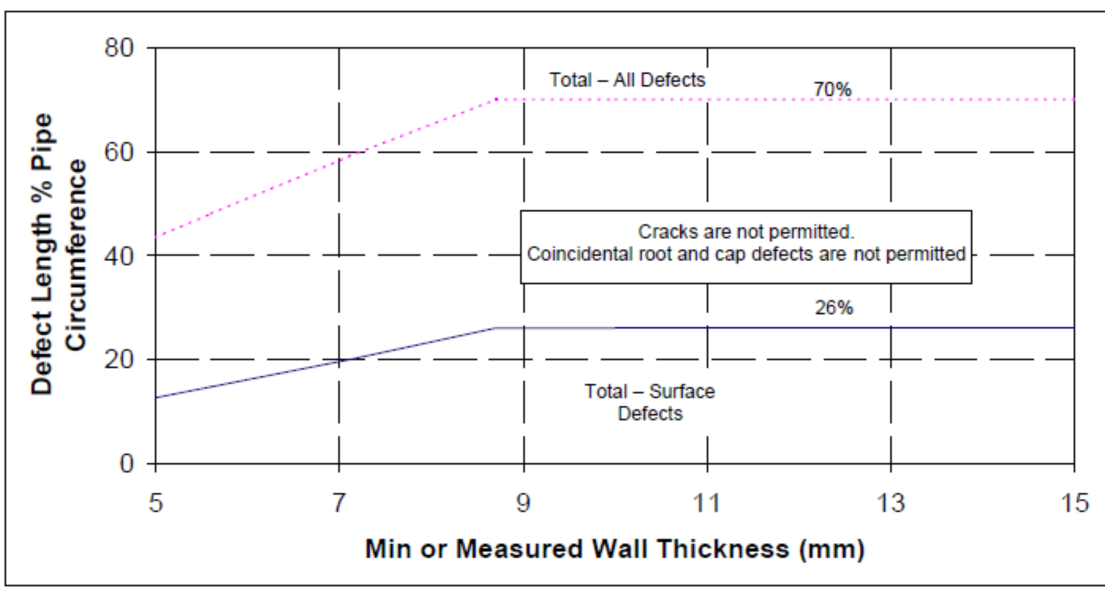


- Requires that no increase in load on the pipeline occurs until the girth weld has been inspected and if required repaired before work is carried out

P18 Weld Defect Criteria

Derived from a programme of full scale tests of defective girth welds





Operator Samples Received

Operator	Pipe Samples	Pipeline	Material Grade	Commission date
UKT	24" x 3	No 2 Feeder Tirley AGI	X52	1970
UKT	36" x 2	No 4 Feeder Bacton	X60 & X65	1970
UKT	36" x 1	Feeder 4	X60	1968
UKD	10" x 3	Peel Hill - Thornton	X52	1969
UKD	12" x 1	White Lund - Slyne	X46	1965
NGN	6" x 3	Thrintoft Catterick	X42	1971
SGN	12" x 3	Newlands North Pit	X52	1970
SGN	12" x 3	Aberdeen	X52	1970
SABIC	8" x 2	TPEP	X42	1968
CLH	12" x 3		X42	1950s - 1960s
CLH	8" x 1		B	1950s - 1960s
WWU	18" x 2	Gilwern - Hafodrynys	X46	1970
BPA	12" x 1		X52	1965 - 1968

Total of 28 samples received
including 3 where sleeves had been removed from SGN

Examples of Samples Received

Weld Inspection

- All samples had Visual Inspection
- Radiography carried out on all welds
- MPI on defective welds for further detail

Weld Quality Standards

- 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

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

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Simple Comparison of Weld Quality Standards

For 324 mm diameter pipe:

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

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Weld Inspection Results

Operator	Sample Ref	Comments	Quality
1	12" W2	Lack of root fusion, repaired burnthrough noted	weld would meet T/SP/P2
1	8" dia.	Cap undercut noted	weld would meet T/SP/P2
2	12" Sample 1	Hollow bead noted	weld would meet T/SP/P2
2	Sample 1 (Sleeve Removed)	No root penetration.	weld would not meet T/SP/P18
2	Sample 2 (Sleeve Removed)	No root penetration.	weld would not meet T/SP/P18
2	Sample 3 (Sleeve Removed)	No root penetration.	weld would not meet T/SP/P18
3	8" W5	Nothing to note	weld would meet T/SP/P2
4	10" Peelhill to Thornton	5mm burnthrough noted	weld would meet T/SP/P2
4	10"A160 Diversion	Lack of root penetration, slag inclusion noted	weld would meet T/SP/P2
4	12" Sample 1 W1	No root penetration.	weld does not meet T/SP/P18
5	6" Catterick W7	Nothing to note	weld would meet T/SP/P2
6	Tirley W2	Nothing to note	weld would meet T/SP/P2
7	Sample 1 P/P	Root Concavity, Cap undercut, Slag Inclusions noted	weld would meet T/SP/P2
7	Sample 2 W1 P/B	Corrosion noted, linear Indication.	weld meet T/SP/P18
7	Sample 2 W2 P/B	Excessive penetration, some root undercut & corrosion noted	weld would meet T/SP/P2
8	12" Sample	Some lack of root penetration and undercut noted	weld would meet T/SP/P2

SABIC 8”

1968

Nothing to note

Meets T/SP/P2 (1980)

UKT Tirley 24”

Pre 1972

Nothing to note

Meets P2 (1980)

CLH 12” & 8”

12”

1960s

Lack of root fusion
Repaired burn through

Meets P2 (1980)

8”

1960s

Cap undercut noted

Meets P2 (1980)

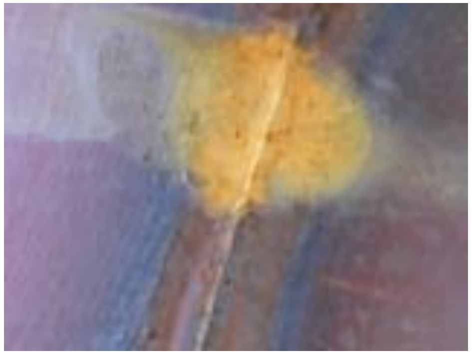
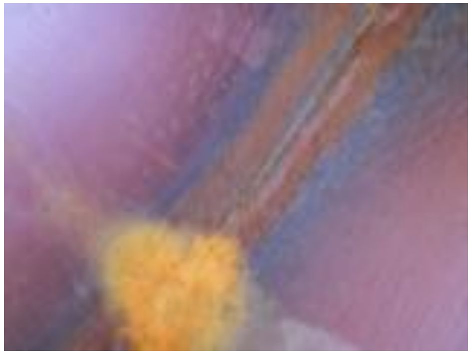
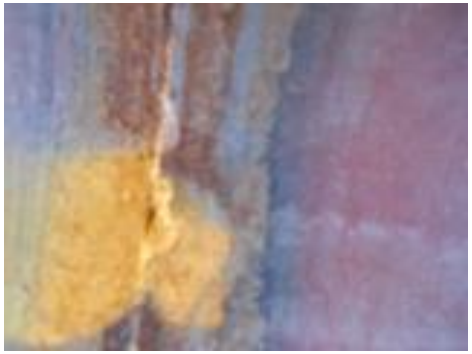
UKT 36”

1968

Nothing to note

Meets P2 (1980)

SGN 12”

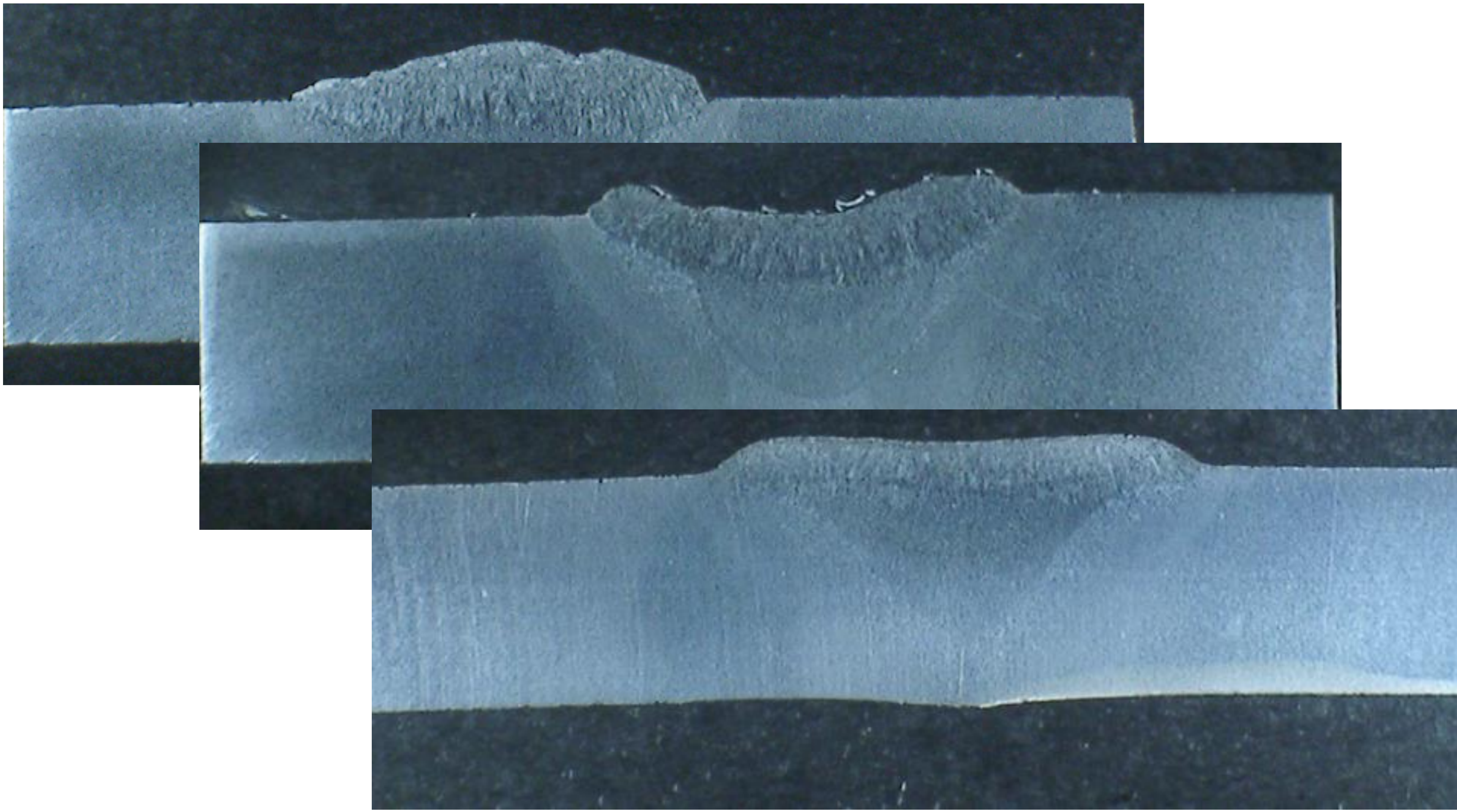
Pre 1972

No root penetration (P13 standard)

Does not meet P2 (1980) or P18

P13 weld

Macro Results



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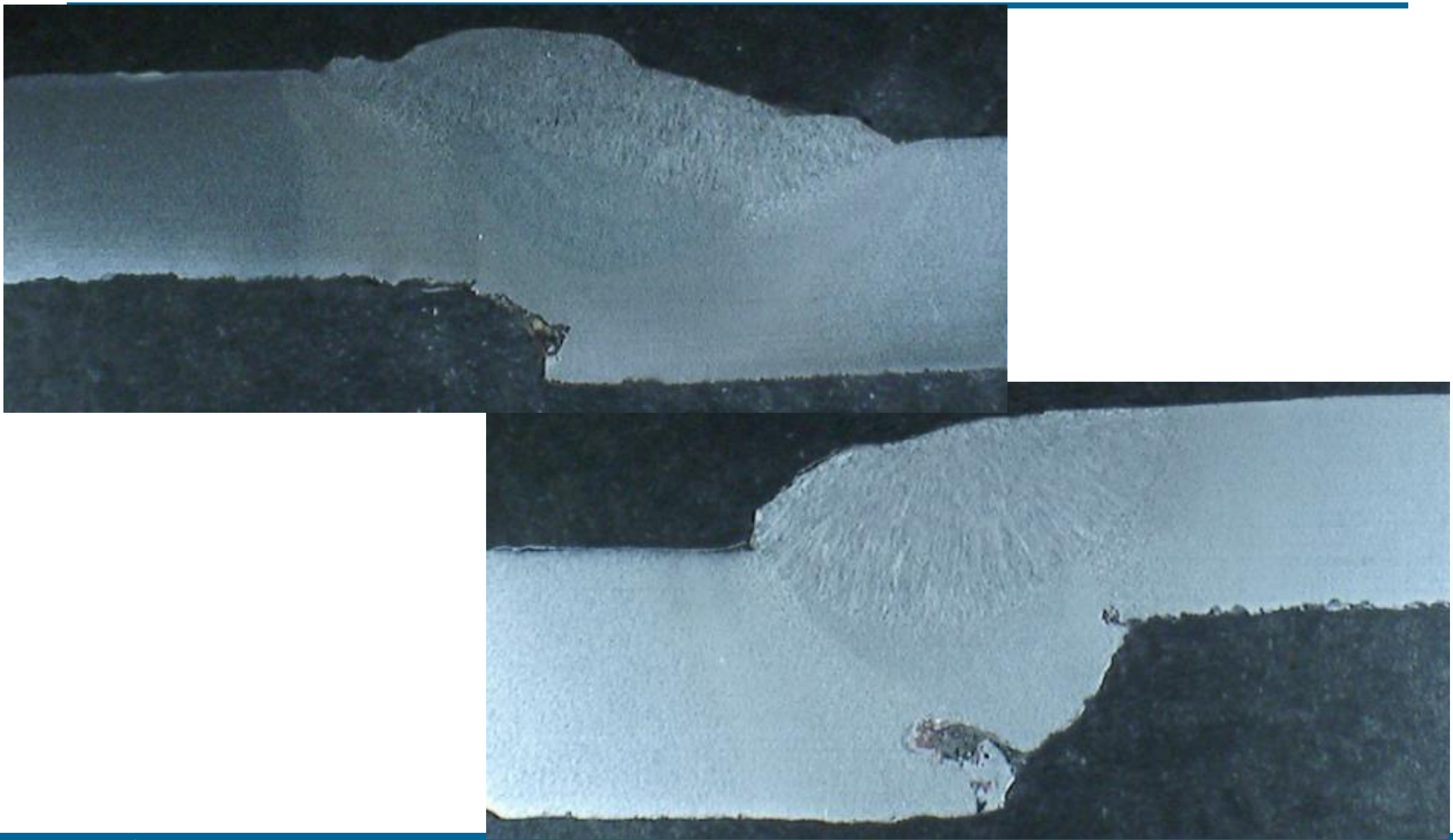
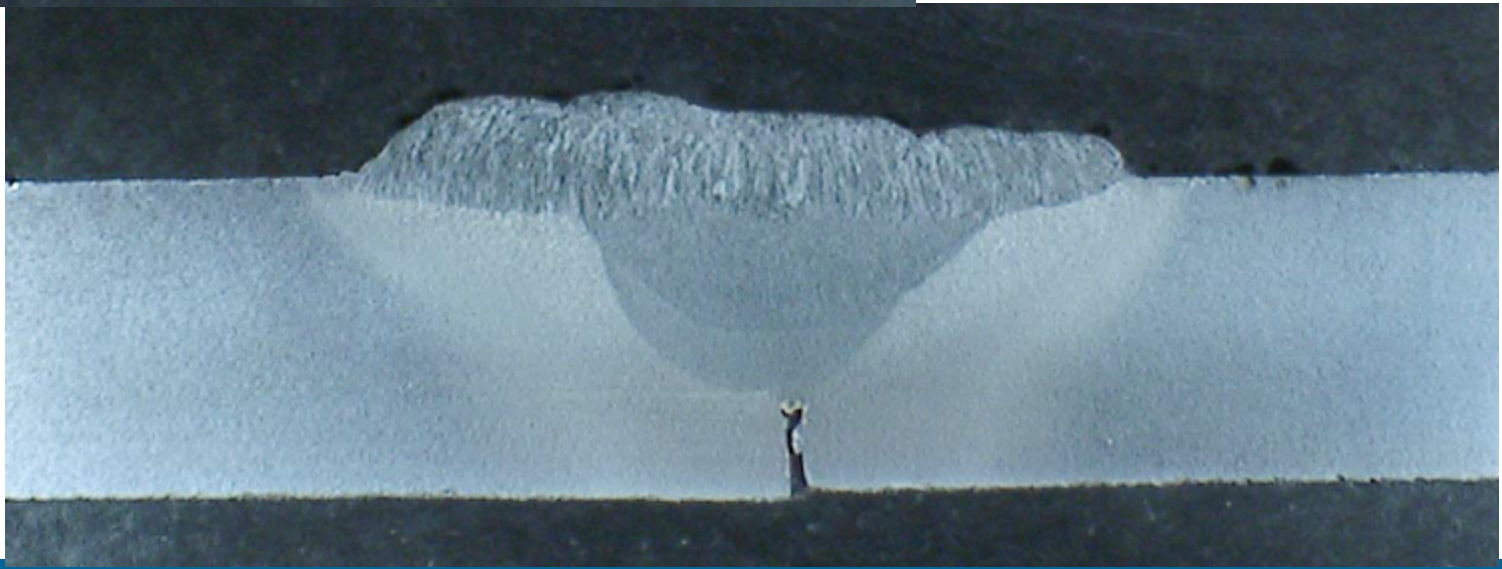


Weld Macros



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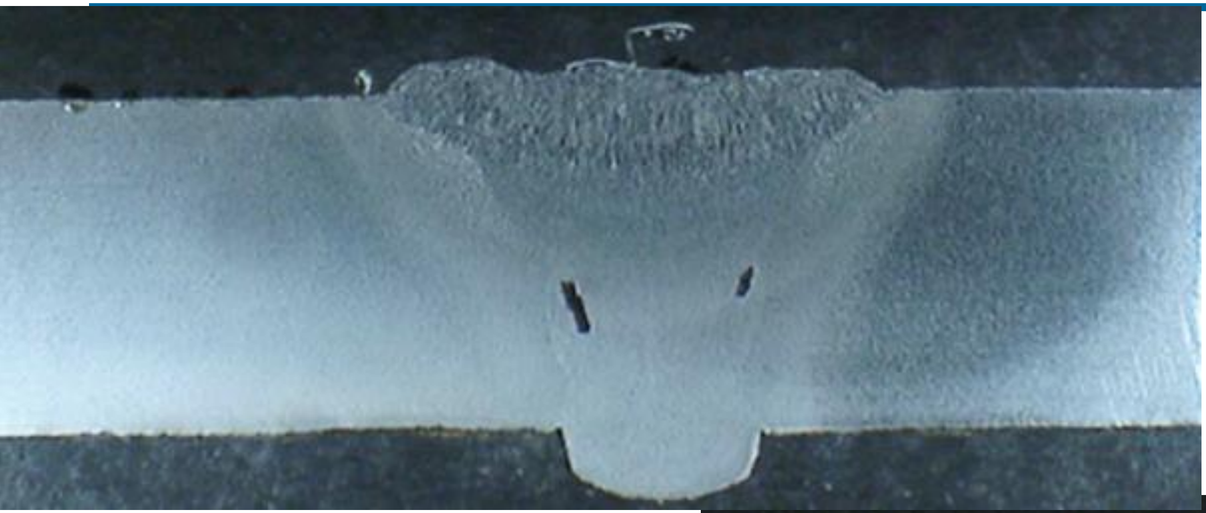

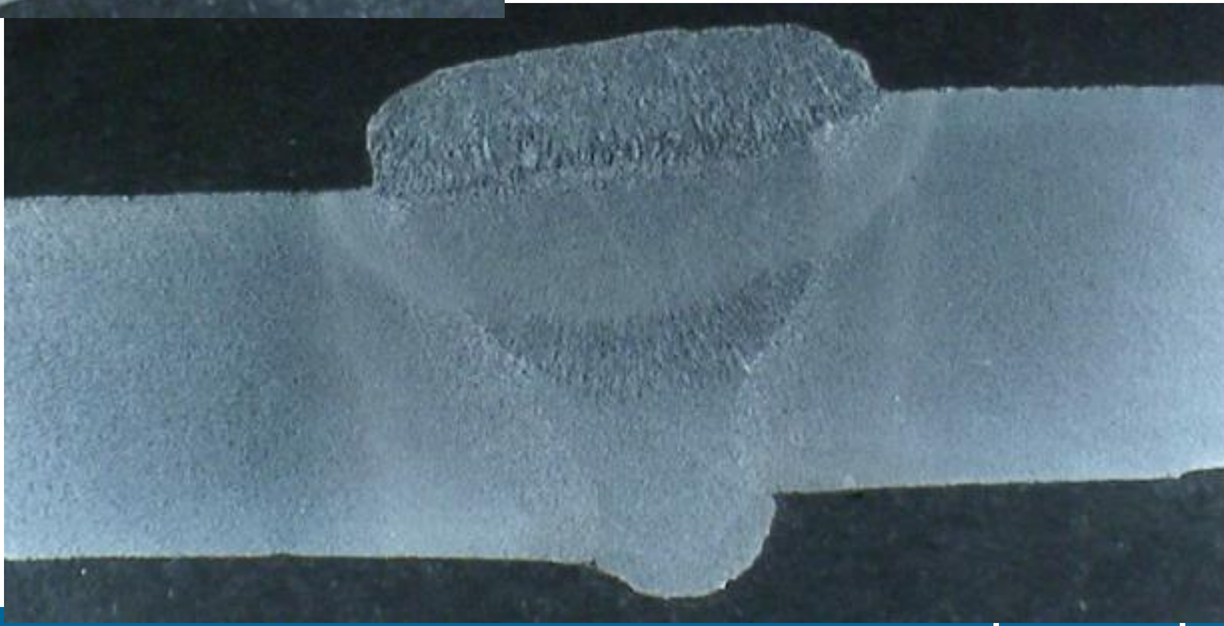

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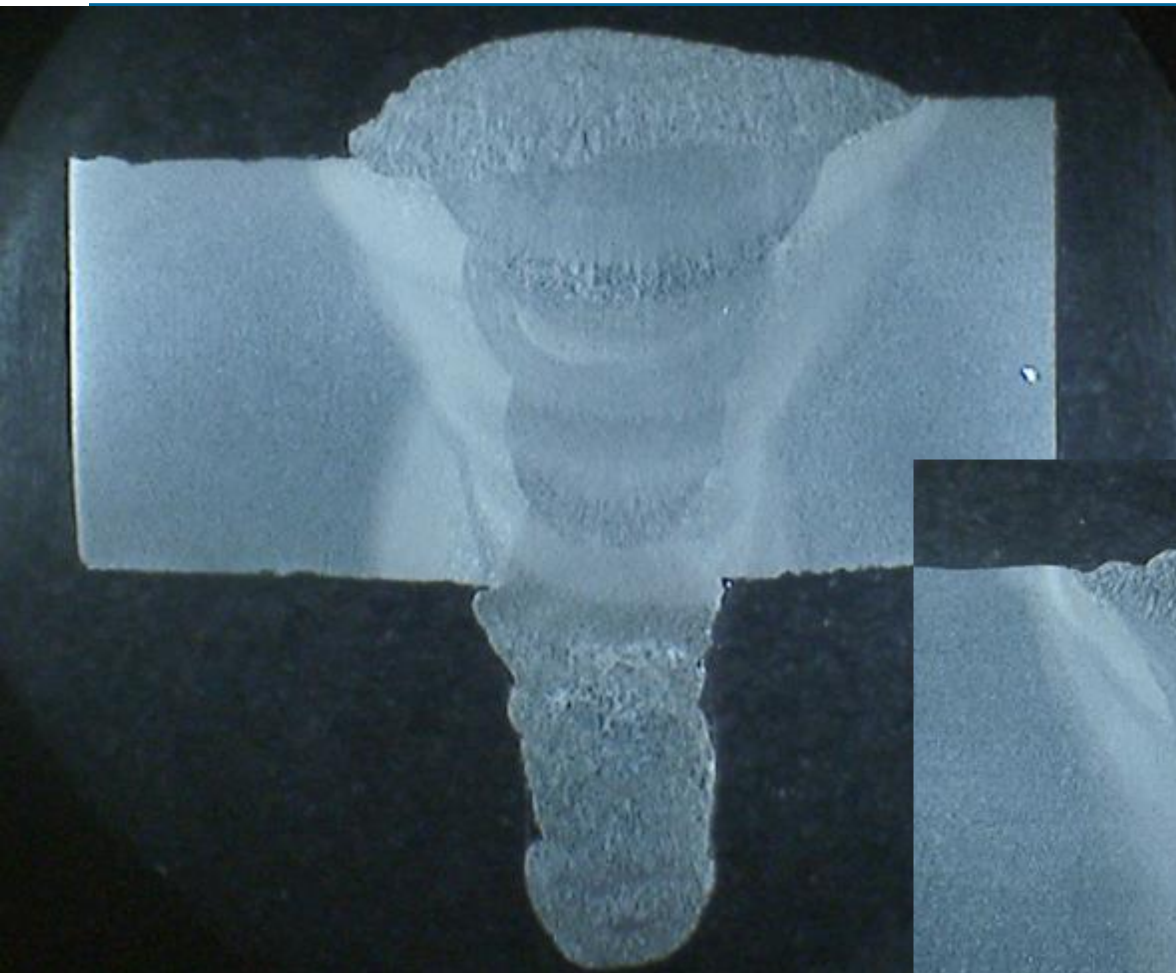
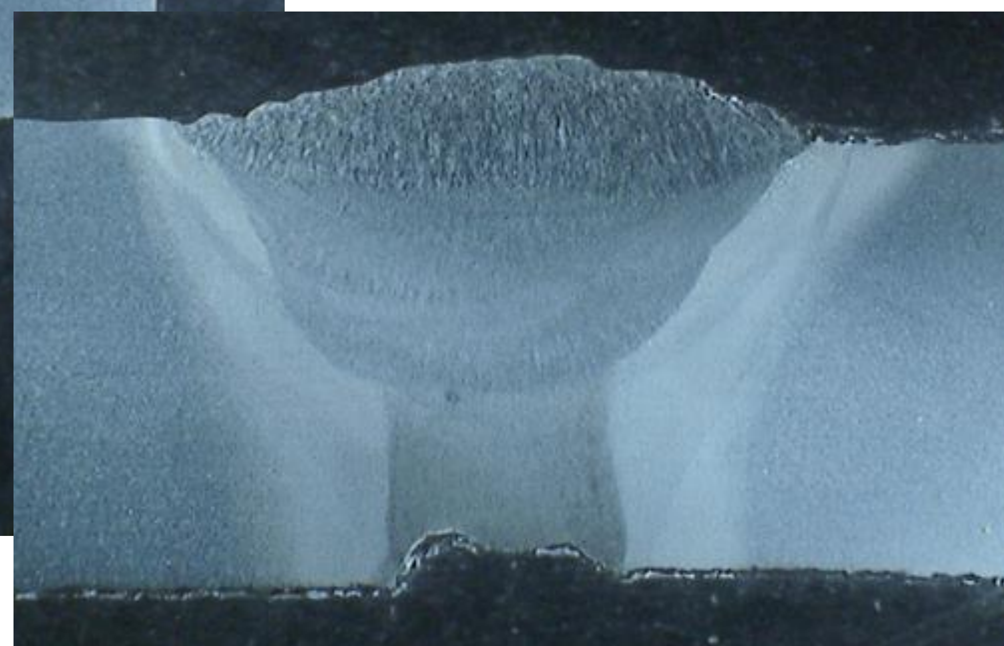




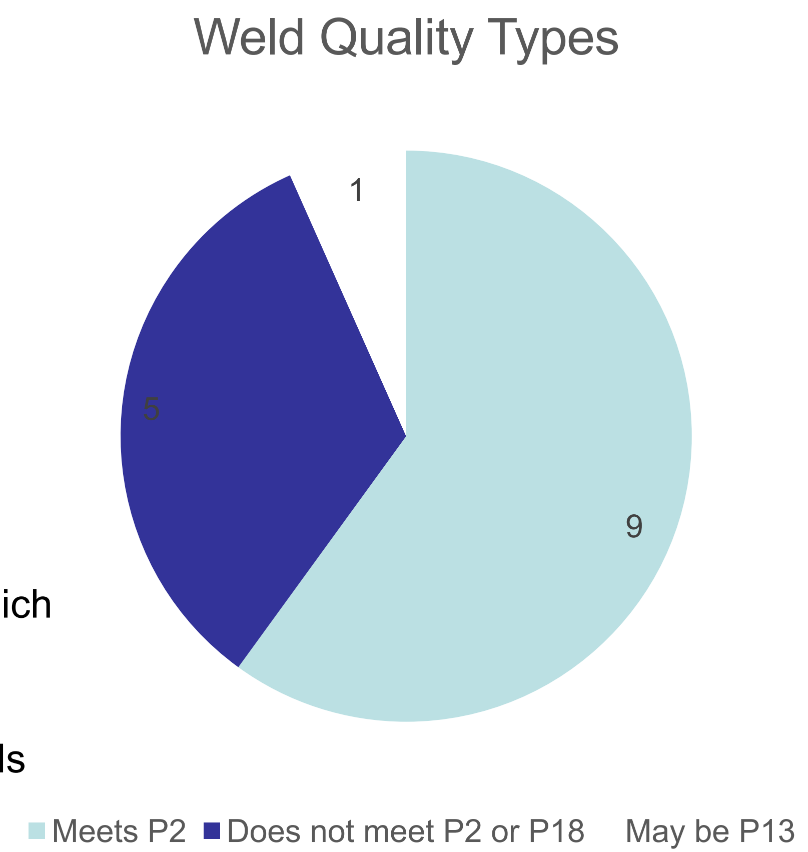
Progress

Material Testing

Tim Rudd

Results – Weld Inspection

- The 15 initial samples were inspected in Ambergate and compared to current code standards.
  - 9 met P2 standard.
  - 1 potentially met P13 standard.
  - 5 didn't meet either P2 or P18.
- This is despite 12 of the 15 sample welds containing flaws.
- Findings indicate that many older welds containing defects would NOT meet modern standards.
  - Pre-1972 welds may contain flaws which would not meet current standards.
  - Investigation needed to determine whether these flaws would mean welds need to be treated as being of "poor quality".
- Presence of flaws or indications does not necessarily mean weld is unfit for service.

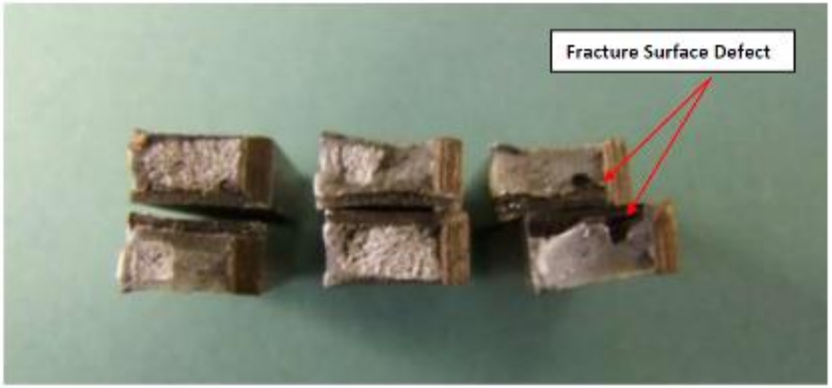


Results – Weld Inspection

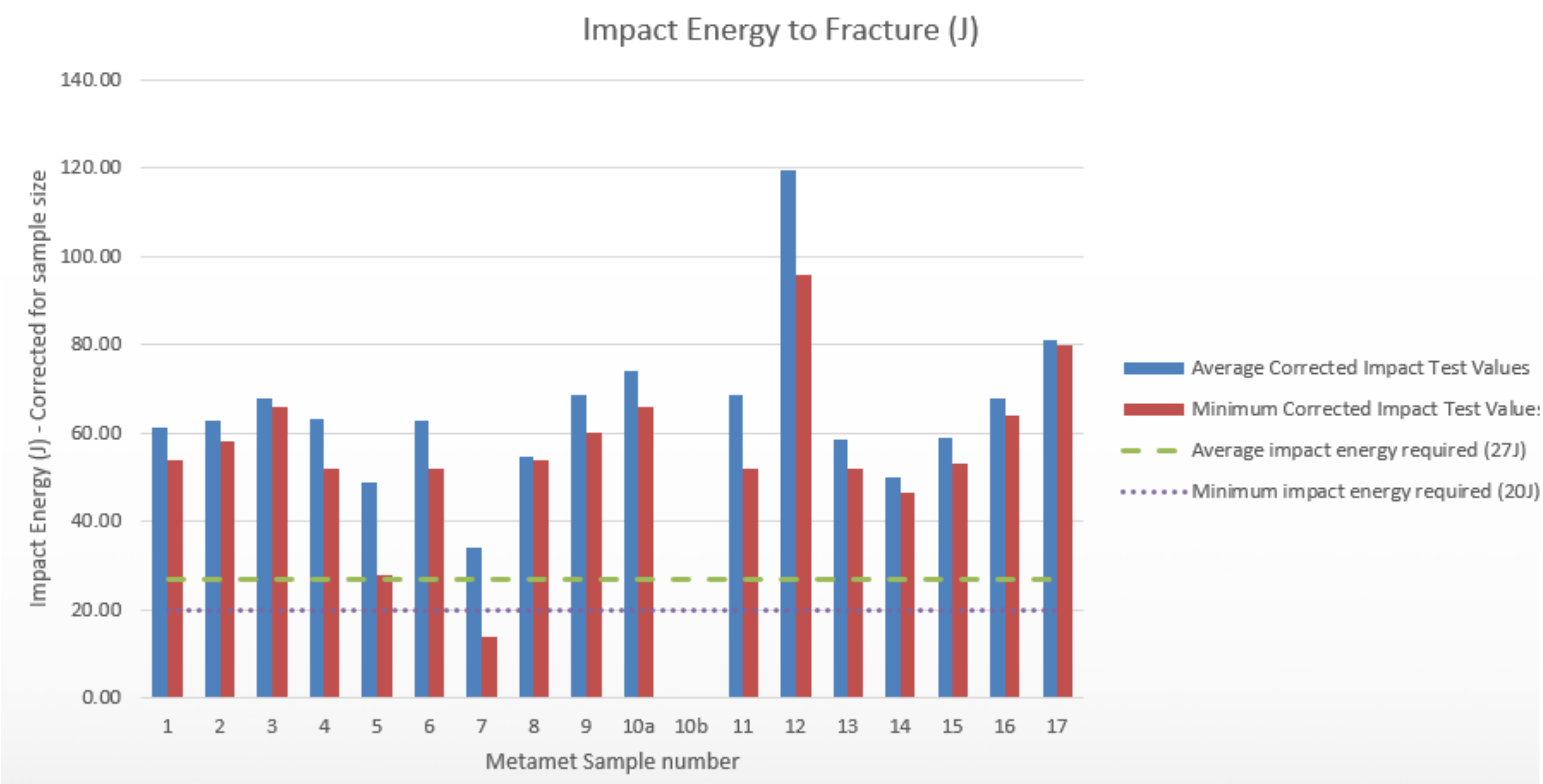
Sample ID	Comments	Weld Quality
A	Lack of Root Fusion, repaired Burnthrough noted	Weld would meet T/SP/P2
B	Cap undercut noted	Weld would meet T/SP/P2
C	Hollow Bead noted	Weld would meet T/SP/P2
D	Nothing to note	Weld would meet T/SP/P2
E	5mm Burnthrough noted	Weld would meet T/SP/P2
F	Lack of Root Penetration, Slag Inclusion noted	Weld would meet T/SP/P2
G	No root penetration.	Weld does not meet P/2 nor P/18. Potentially a P/13 weld.
H	Nothing to note	Weld would meet T/SP/P2
I	Nothing to note	Weld would meet T/SP/P2
J	Root Concavity, Cap undercut, Slag Inclusions noted	Weld would meet T/SP/P2
K	Corrosion noted 15-27, 40-45. Linear Indication 72-73 cm area checked with UT and confirmed.	Weld may not meet T/SP/P2.
L	Excessive Penetration, Root Undercut noted. Corrosion noted 65-100	Weld would not meet T/SP/P2 or T/SP/P18
M	No root penetration.	Weld would not meet T/SP/P2 or T/SP/P18
N	No root penetration.	Weld would not meet T/SP/P2 or T/SP/P18
O	No root penetration.	Weld would not meet T/SP/P2 or T/SP/P18

Results – Impact Testing

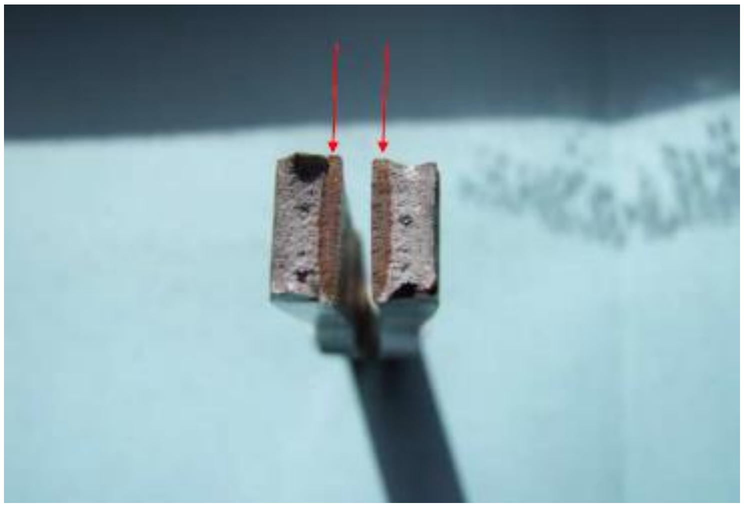
- 17 Sets of samples had impact testing.
  - All 17 samples passed the 'average' impact value (>27J).
  - One sample failed on an individual test (>20J) but this was due to the presence of a large defect in the sample.
  - A local defect such as this would not cause the impact toughness of the entire joint to be unsatisfactory.
- Conclusion – impact toughness of historical welds acceptable.



Results – Impact testing



Results – Ultimate Tensile Strength



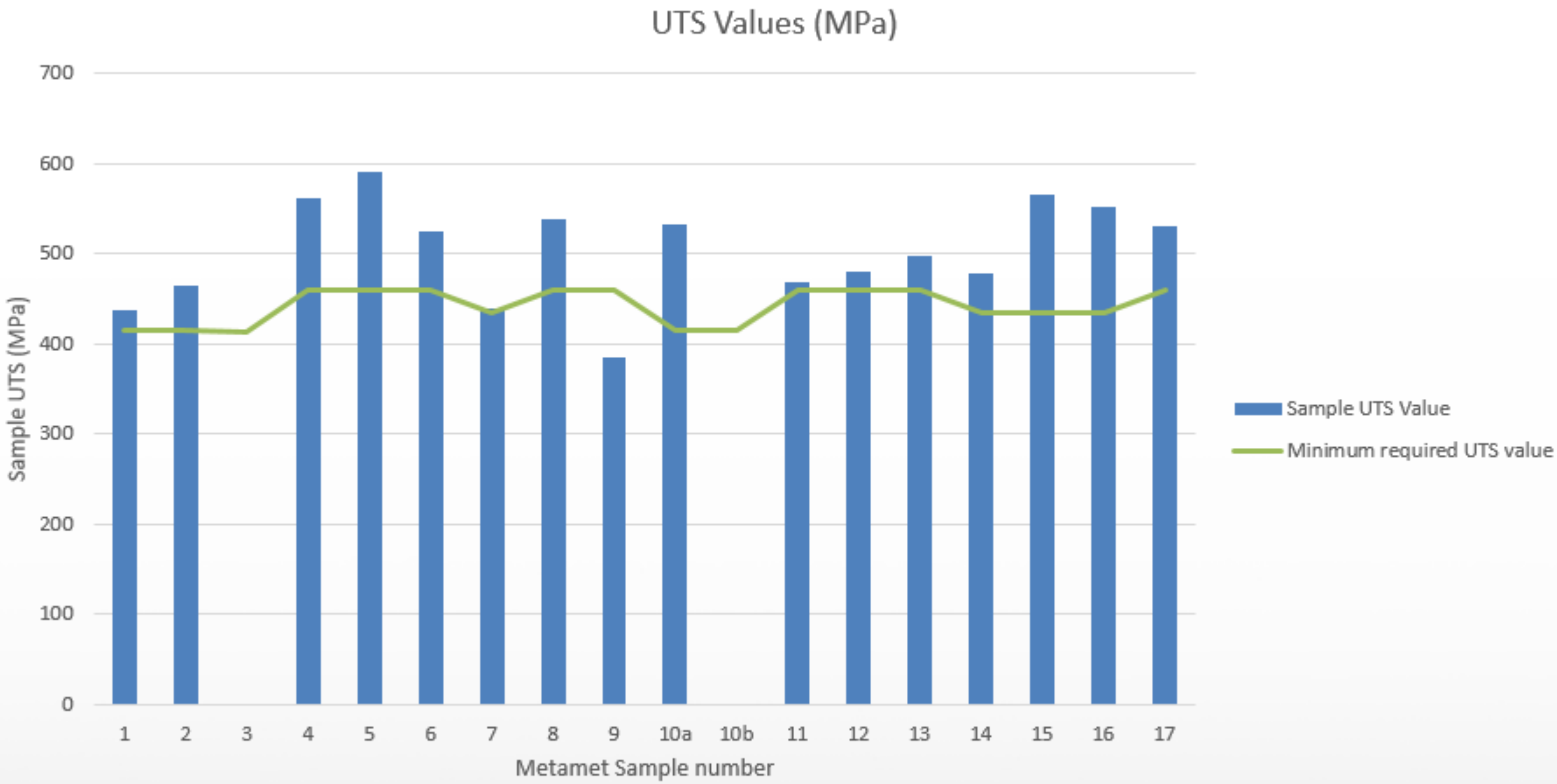
Material Grade	Specified UTS	Observed UTS	Ratio
API Grade B	331 MPa	414 MPa	125%
API 5L-X42	415 MPa	478 MPa	115%
API 5L-X46	435 MPa	508.8 MPa	117%
API 5L-X52	460 MPa	508.8 MPa	111%

- Tensile tests were performed on 15 of the 17 samples.
  - All bar sample 9 passed.
  - Failure at sample 9 was down to presence of a large defect in the tensile specimen.
    - Failure stress of this defect was at an equivalent stress ratio of 0.837, so in service this would not have been reached (maximum design factor of 0.72 used in codes).
    - In the actual GW the stress would have been carried by the whole weld (not just the small section containing defect) so the failure at the lower stress would not have been seen.

On average samples failed at a stress significantly in excess of the required minimum.

Conclusion – strength of historical welded joints acceptable, despite presence of defects.

Results – Ultimate Tensile Strength



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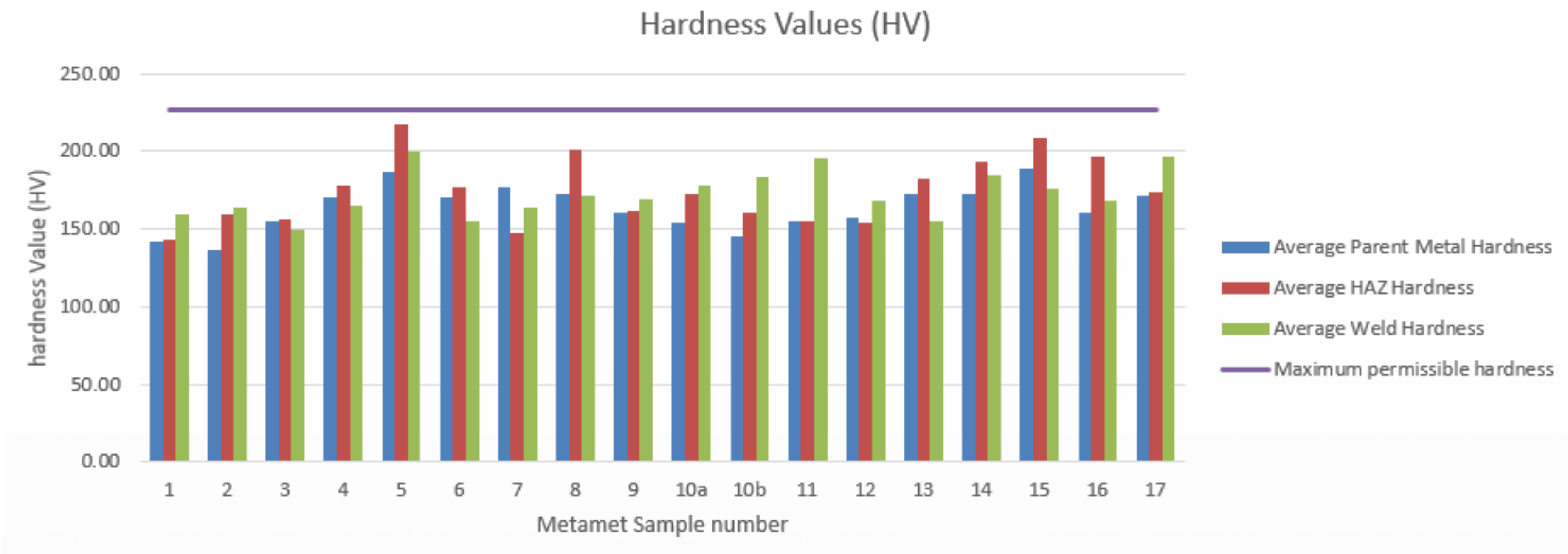
Results – Elongation to Failure

- Samples 7 and 9 contained major defects within tensile specimen, so failed at defects.
  - No elongation or ductile behaviour observed.
  - Property of the artefact, not of the joint as a whole.
  - Not possible to determine elongation to failure for these samples.
- All other samples displayed adequate % elongation to failure.
  - Indicative of a ductile material.
- 50% of samples failed at weld, 50% in parent metal.
  - Elongation to failure higher for samples that failed in parent then in weld.
  - Indicates that weld defects cause samples to fail at lower elongation then otherwise the case.
  - Load-bearing capacity of joints not affected (as shown by UTS values earlier).
- Results show that weld defects can affect the ductility of the joint.
  - As the failures only occur above the YS of a material this would not affect performance of the joint in the field.
- Conclusion - % elongation to failure (ductility) of historical materials and welded joints is acceptable

Sample ID	% Elongation to failure – in weld/defect	% Elongation to failure – in parent metal
1		20
2		15
3	-	-
4		23
5	9.5	
6		21
7	0	
8	5.5	
9	0	
10	-	-
11		20
12	15	
13	11	
14	9.5	
15		26
16		21
17	17.5	
Average	8.5	20.9

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 slightly less than Parent Metals.
- Composition of all materials consistent with expected grades.
  - Slightly high Sulphur levels in 5 samples, but only marginally so.
    - 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.

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

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

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.
  - Grains typically equiaxed, so properties are likely to be fairly isotropic.
  - Samples showed slight evidence of banding.
    - Result of rolling process – not detrimental.
- Weld microstructure different to parent material.
  - To be expected, 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.

UKOPA Girth Weld Fault and Failure Data

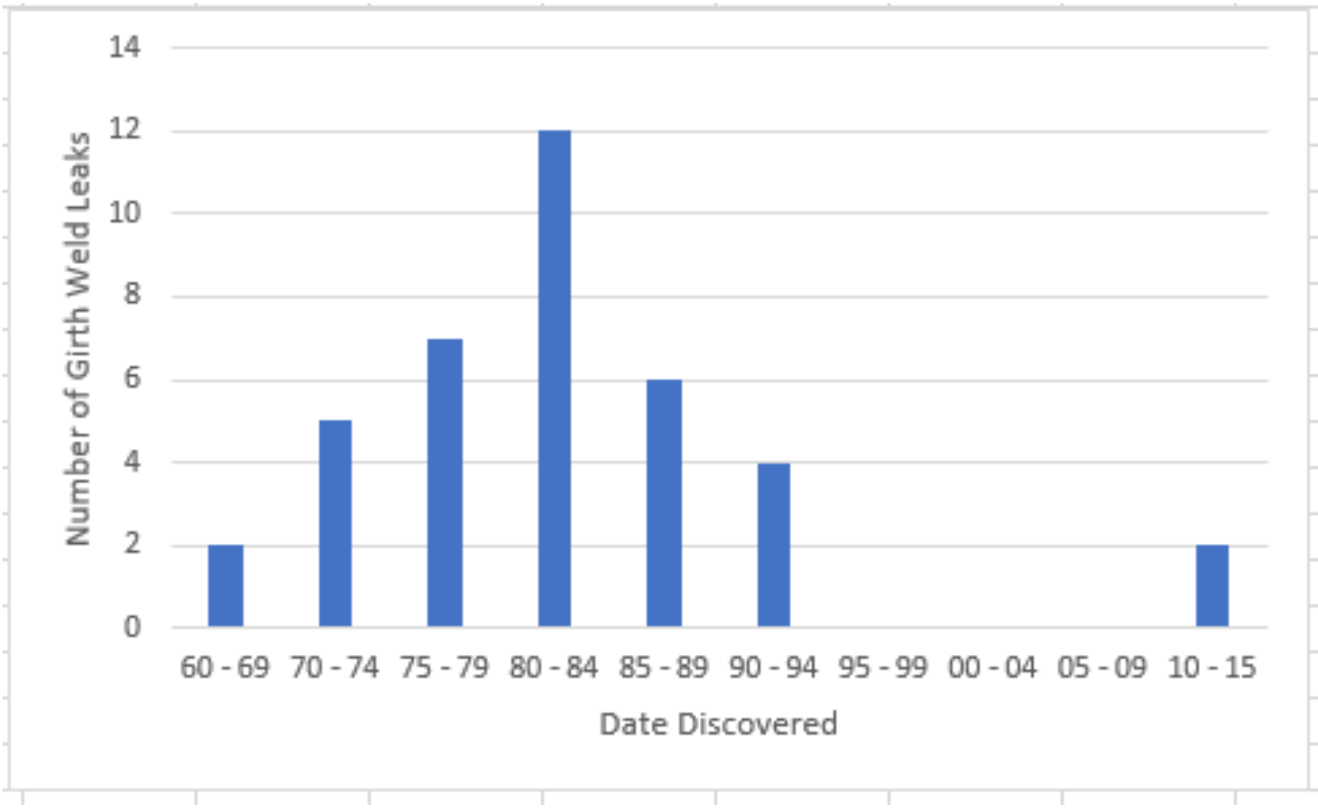
Classification	Faults	Leaks
All	3640	196
Girth Welds	217	39
Girth Welds – pre 1972 pipelines	195 (90%)	37 (97%)

UKOPA Girth Weld Fault and Failure Data

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

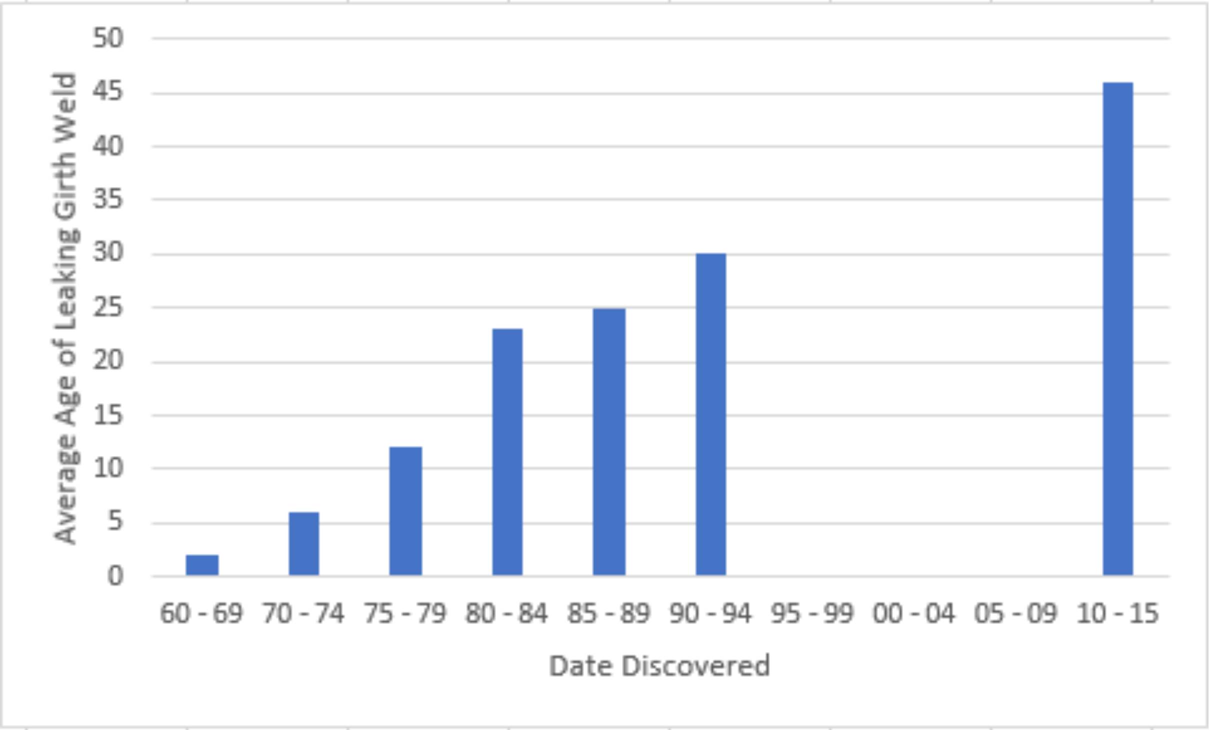
Of the 131 non leaking girth welds, 86 (66%) are recorded as severe
All of the leaks occurred before 1993

UKOPA Girth Weld Fault and Failure Data



Numbers of girth weld leaks in period 1964 - 2016

UKOPA Girth Weld Fault and Failure Data



Average age of leaking girth welds vs date discovered

Conclusions

- Historical welds may contain defects that would not meet modern construction standards.
- 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.
- UKOPA Fault Database doesn’t show particularly high failure rates for older pipes.
  - No failure of pre-1972 girth welds since 1993. Believed that any ‘critical’ flaws would have grown to failure by this time, implying remaining flaws are sub-critical.
  - Backed up by samples examined not showing signs of flaw growth.

Interim Conclusions & Ongoing Work

Graeme Pailor

Interim Conclusions

- Welds constructed to pre-1972 standards are good quality
- Cracks were not and are not allowed
- Other allowable defect limits have reduced, this is unlikely to affect the strength of the joint
- Material properties in pre 1972 welds are acceptable
- Primary concern is fatigue performance
- PIWG has requested the FARWG to include weld inspection data in the pipeline fault database

Further Research

- The Canadian operator ATCO is undertaking testing of weld samples taken from a vintage 1950s and 1960s pipeline for UKOPA
- This will compare similar vintage US and UK pipeline girth welds, will enable the US experience to be applied in the UK, and will support the conclusion that pre 1970's welds are good quality
- Fatigue testing of operator samples is to be undertaken at Strathclyde University
- Research into fatigue behaviour of typical weld defects at Swansea University

Questions