US Department of Transportation
Pipeline and Hazardous Materials Safety Administration

Validation of Assessment Methods for Production Scale Girth Welding of High Strength Pipelines with Multiple Pipe Sources (DTPH56-07-T-0006)

Final Presentation by Troy Swankie

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Disclaimer

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THE PROJECT…….

Validation of Assessment Methods for Production Scale Girth Welding of High Strength Pipelines with Multiple Pipe Sources

Project: DTPH56-07-T-000006

Objectives:

1. To test a large set of girth welds produced under realistic conditions by a state of the art high productivity GMAW system
2. To demonstrate the effect of material variability between pipes, between heats and between pipe manufacturers
3. To validate current and proposed new weld defect assessment methods against the performance of a large set of welds made under field production conditions

INTRODUCTION…….

- There are a number of methods that are commonly used for developing defect acceptance criteria for pipeline girth welds
  - API 1104
  - CSA Z662
  - EPRG

  Pipeline specific

  - BS 7910
  - API 579-1 / ASME FFS-1

  Generic, but can be applied to a pipeline
- The applicability of these methods to girth welds in higher strength steel pipelines is not yet verified
- The work undertaken was aimed at investigating whether these methods could potentially be used for grade X100 pipelines

GIRTH WELDS FOR TESTING…..

The girth welds for testing were provided by BP from the X-100 full-scale operational field trial;

- Comprehensive overview of the construction of the pipeline was presented at IPC-2010 by Millwood *et al.*, (paper #31469)
- 800m of 1200mm diameter, 19.8mm nominal wall thickness pipe in 2 sections;
  - Section A – 600m in length
  - Section B – 200m in length
- Pipeline test sections designed to ASME B31.8 to a design factor of 0.8, with additional guidance taken from CSA Z662
- Two pipe mills produced the pipes from three plate suppliers
- The pipeline test sections were coated internally (flow coat) and externally (single layer FBE)

GIRTH WELDS FOR TESTING…..(continued)

- Arrangement of pipe joints in the test sections ensured that each pipe source was equally subjected to all the pipeline test conditions
- Section A – constructed to good pipelining practice to simulate a pipeline in normal service with a normal cathodic protection (CP) level maintained along its length
- Section B – incorporated numerous instances of pipeline damage and defects, and the CP level was varied along its length;
  - The first third of the section had no CP
  - The middle third had CP applied at an intermediate potential of -850 to -950mV
  - The final third had CP applied at a high potential of -1,200 to -1,300mV
- The pipeline sections were pressure tested on commission as per ASME B31.8; test pressure of 225 Barg, equivalent to 1.25 times the design pressure of 180 Barg
- The pipeline sections were then subjected to accelerated pressure cycling for a 2 year period to simulate a 40 year design life plus 20% life extension (48 years)

MATERIALS TEST PROGRAM…..

- Materials test program developed to;
  - Satisfy, as near as possible, the testing requirements of the different assessment methods, where specified
  - Investigate the range of applicability of the different assessment methods in relation to parameters such as defect size and material strength
- All testing undertaken by Professor Rudi Denys and his colleagues at the University of Gent, Laboratorium Soete

MATERIALS TEST PROGRAM…..

- BP provided 10 girth welds for testing. These were selected by the project team based on the following criteria;
  - Weld type (mainline or tie-in)
  - Strength mismatch between the weld and abutting pipes
  - Pipe supplier and pipe heat number
- BP provided the project with the following information to enable the team to identify the preferred welds for testing;
  - As-built weld map
  - Line pipe mechanical properties (Mill certificates)
  - Weld procedure qualification test data
  - Close-out inspection report comparing X-radiography and AUT inspections undertaken

MATERIALS TEST PROGRAM…..

- As an aside to the mechanical testing, the DoT agreed to additional testing of the adhesion properties of the field joint coatings
- Traditionally, the cut off temperature for the heating coil typically ranges from 232 to 239°C for line pipe grades X65 to X80
- However, the project specification for the field trial limited the cut-off temperature to 220°C to avoid the possibility of strain ageing the X100 material
- The scope of work agreed with the DoT involved;
  - Visual inspection and photographic record of each joint
  - Survey to assess the adhesion of the FBE field joint coating, and its intercoat adhesion with the mainline coating
  - Holiday detection to locate areas of coating damage
  - Assessment of the cathodic disbonding at areas of coating damage

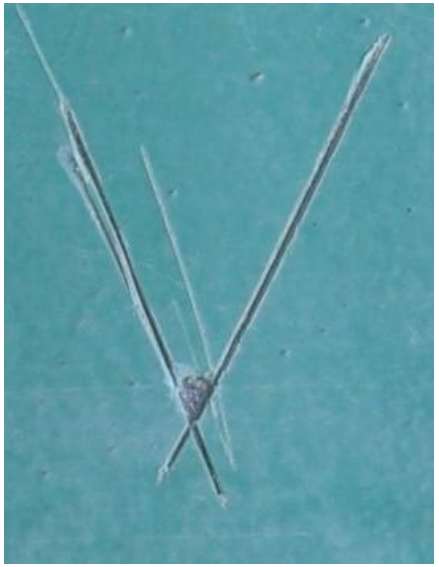
COATINGS TEST PROGRAM…..

- Adhesion test;
  - The tests were undertaken as soon as practicable following excavation of the field joint coatings
  - Adhesion of the FBE coating was at the 03:00, 06:00, 09:00 and 12:00 locations, as coated and positioned in the ditch, allowing the team to establish any circumferential variation in the wet adhesion of the field joint coating
  - Method;
    - Using a knife, make two incisions through the coating, approximately 13mm long to form a V with an angle approximately 30 - 40° at the intersection
    - At the intersection, attempts were then made to remove the coating
    - The adhesion results were assessed according to the ratings in NACE RP 0394-2002

NACE RATINGS…..(RP 0394-2002)

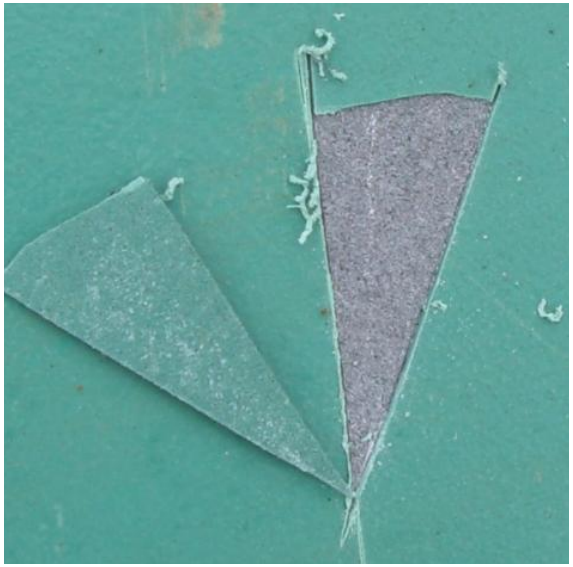
PASS	
Rating 1	The coating pieces removed are the same size as, or smaller than, the size of the inserted knife point.
Rating 2	Coating can be removed in chips that are slightly larger than the inserted knife point. Coating remains on 50% or more of the scribed area. In areas where coating has been removed by chipping, partial coating fragments may remain firmly attached to the steel surface and shall be counted as part of the 50% or more with coating.
Rating 3	Coating can be removed in chips larger than the inserted knife point. Coating remains on 20% or more of the scribed area. In areas where the coating has been removed by chipping, partial coating fragments may remain firmly attached to the steel surface and shall be counted as part of the 20% or more of coating.
FAIL	
Rating 4	The coating can be easily removed in strips or large chips considerably larger than the inserted knife point and coating remains on less than 20% of the scribed area.
Rating 5	The coating can be completely removed as a single piece or in a few large chips with little effort.

NACE RATINGS…..(RP 0394-2002)



Rating ‘1’

Rating ‘4’



Rating ‘5’

COATINGS TEST PROGRAM…..(Results Summary)

- Field joint coating to steel substrate;
  - Significant variation in coating adhesion around the circumference of a number of field joints inspected; 9 joints from 17 failed at the 12:00
    - Four of these also failed at the 03:00, 06:00 and 09:00 positions
- Intercoat adhesion between the field joint and mainline coatings;
  - Excellent intercoat adhesion
- No coating damage detected when the pipe was ditched and backfilled (hence, unable to comment on the cathodic disbonding resistance of the field joint coating)
- CP did not have an influence on the general adhesion of the field joint coatings during the trial; those subjected to high CP retained good adhesion

COATINGS TEST PROGRAM…..(Results Summary)

- Deterioration in adhesion of a number of the coatings was attributed to;
  - The low application temperature
  - Circumferential temperature variations around large diameter field joints, even with well set up coils
  - Circumferential temperature variations exacerbated by non-concentricity between the induction coil and the pipe

COATINGS TEST PROGRAM…..(Recommendations)

- Evaluate the performance of low temperature curing FBE powders to determine whether they are capable of achieving the required coating performance at a minimum temperature of 220°C
- Investigate whether there are any non-chromate based pre-treatments (e.g., siloxanes) that could be used in the field to enhance the wet adhesion of standard powders when applied at the low end of their recommended application range
- More detailed study of coating condition and performance; 28 days cathodic disbonding and elevated temperature water soak testing, Impact and flexibility testing and macrosectioning
- Perform a similar study on liquid coatings for the protection of field joints on X100 line pipe

GIRTH WELDS SELECTED FOR TESTING…..

Weld ID	Weld Type	Source	Mill	Plate	Heat
A06	Mainline	B to B	✓	✓	✓
A17	Tie-in	C to C	✓	✓	✓
A33	Mainline	B to A	✓		
A44	Mainline	C to B			
A46	Mainline	C to C	✓	✓	
A50	Mainline	B to B	✓	✓	
B03	Mainline	C to C	✓	✓	
B06	Mainline	A to B	✓		
B08	Mainline	C to C	✓	✓	
B10	Mainline	A to C			

SUMMARY OF TESTS UNDERTAKEN…..

Test type	Weld number									
	A06	A17	A33	A44	A46	A50	B03	B06	B08	B10
Macro	3	4	3	2	3	3	3	3	3	11
HV survey	3	3	3	2	3	3	3	3	3	11
Tensile tests										
AWM-cap	4	4	4	2	4	4	4	4	4	11
AWM-mid	-	-	-	-	-	-	-	-	-	11
AWM-root	2	2	2	1	2	2	2	2	2	11
AWM-pris	-	-	-	-	-	-	-	-	-	11
Pipe-L-FT	10	10	10	6	10	10	10	10	10	-
Pipe-T-FT	2	2	2	2	2	2	2	2	2	-
Pipe-T-RB	4	6	4	2	4	4	4	4	4	-
Cross weld	2	2	2	2	2	2	2	2	2	-

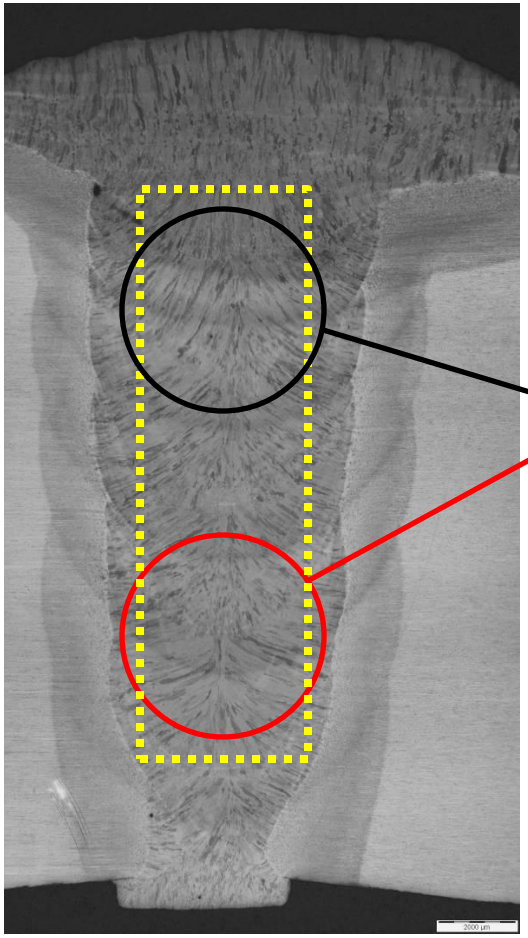
SUMMARY OF TESTS UNDERTAKEN…..

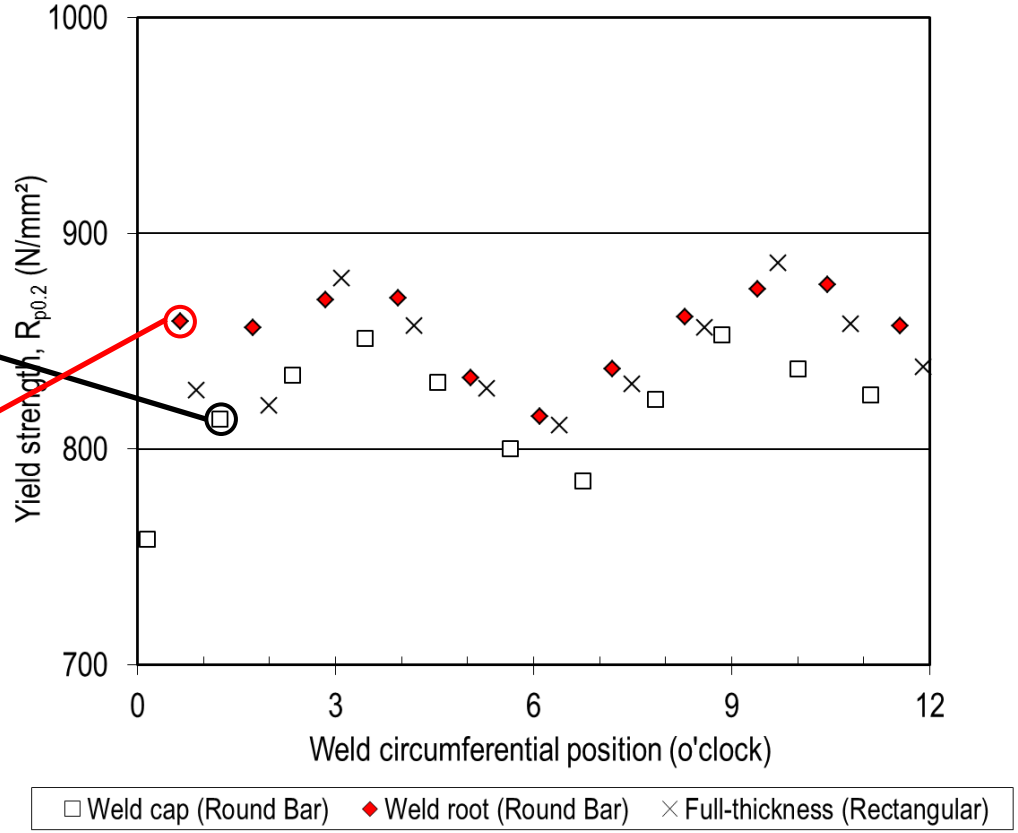
Test type	Weld number									
	A06	A17	A33	A44	A46	A50	B03	B06	B08	B10
Charpy Impact tests (sets of 3 specimens)										
HAZ/FL	2	2	2	2	2	2	2	2	2	-
AWM	2	2	2	2	2	2	2	2	2	-
Fracture mechanics (CTOD) toughness tests (sets of 3 specimens)										
HAZ/FL	1	1	1	1	1	1	1	1	1	-
AWM	1	1	1	1	1	1	1	1	1	-
Curved wide plate tests										
HAZ/FL	3	3	3	-	3	2	-	-	-	-
AWM	1	1	1	-	1	1	-	-	-	-
Nat/Delib	-	-	-	-	-	-	4	4	3	-

CIRCUMFERENTIAL VARIATION IN WM STRENGTH

- Previous test results have shown that the weld metal strength can vary significantly around the weld circumference, as can the position of maximum and minimum strength;
  - Y-Y Wang *et al.,* Portugal, 2007
  - R M Denys, Japan, 2008
  - E Osterby *et al.,* Canada, 2008
- Hence, an initial series of tensile tests were undertaken to determine the through-thickness variation in weld metal strength around the weld circumference; Weld B10 was selected for these tests

WELD B10 - AWM CIRCUMFERENTIAL VARIATION

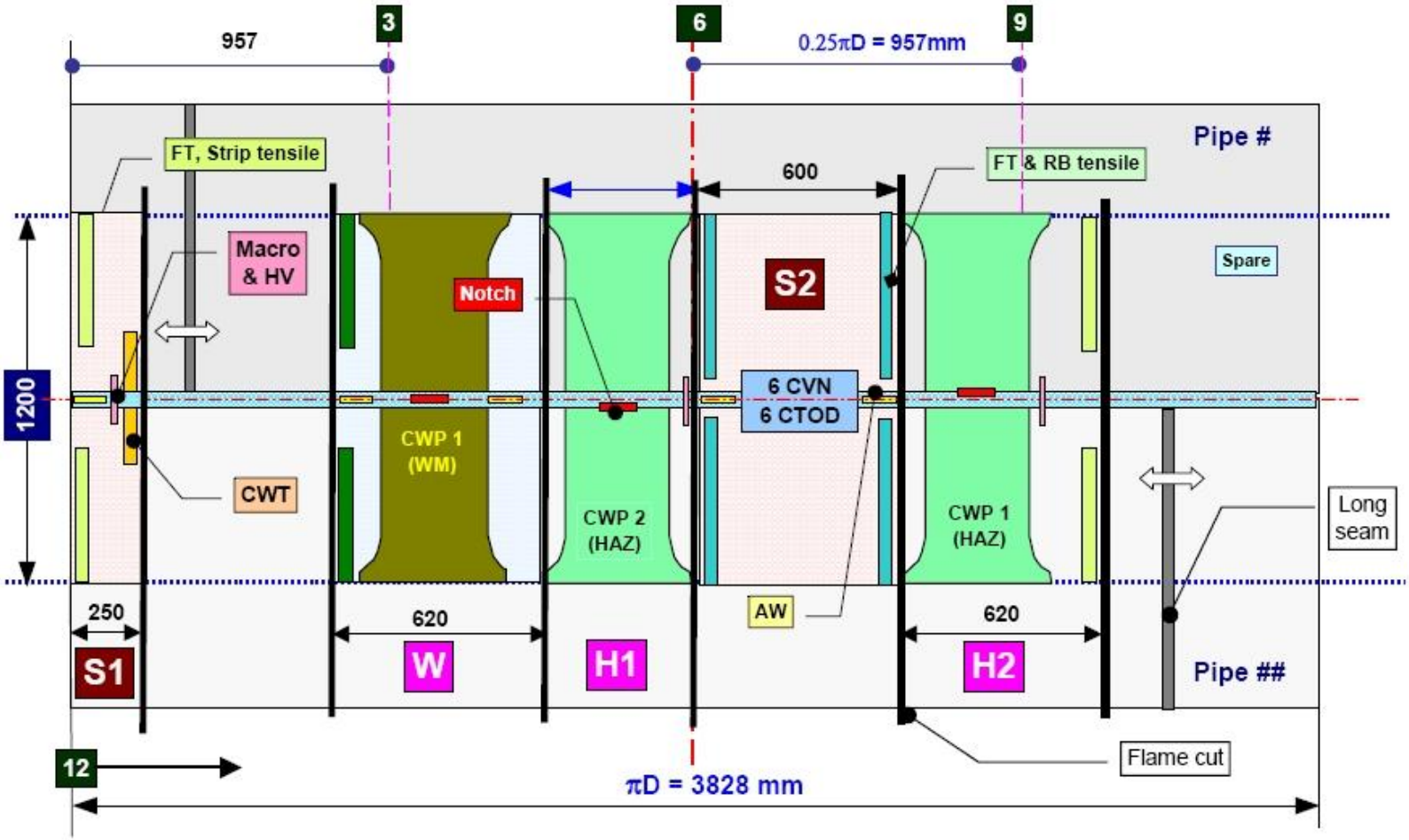




TEST PROGRAM

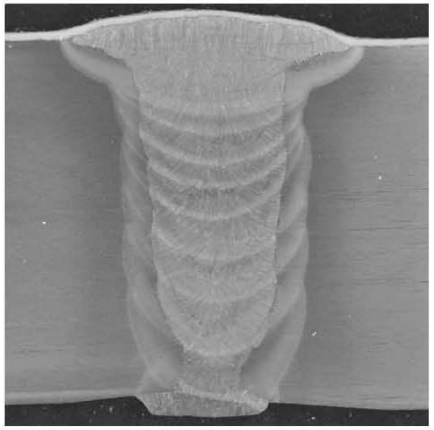
- The type, position (around the pipe circumference) and number of tests undertaken was not the same for each weld
- Depending on the results of some of the initial tensile tests undertaken, either 3 or 4 CWP specimens were extracted from a weld

TYPICAL PLAN…..(3 CWPs)

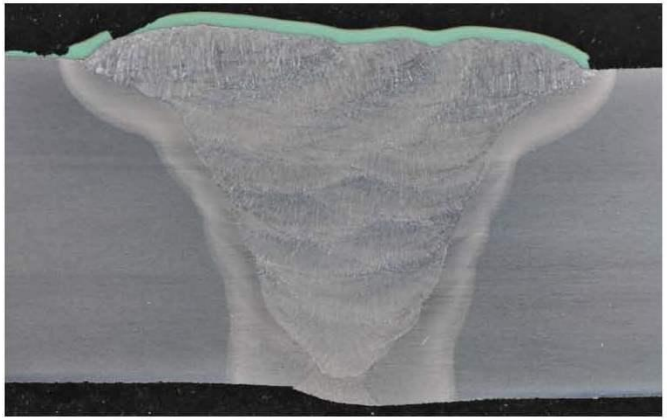


WELD MACRO-SECTIONS

- Weld macro-sections:
  - Transverse sections generally taken from the weld 12, 3 and 6 o'clock positions



(a) Mainline weld A33

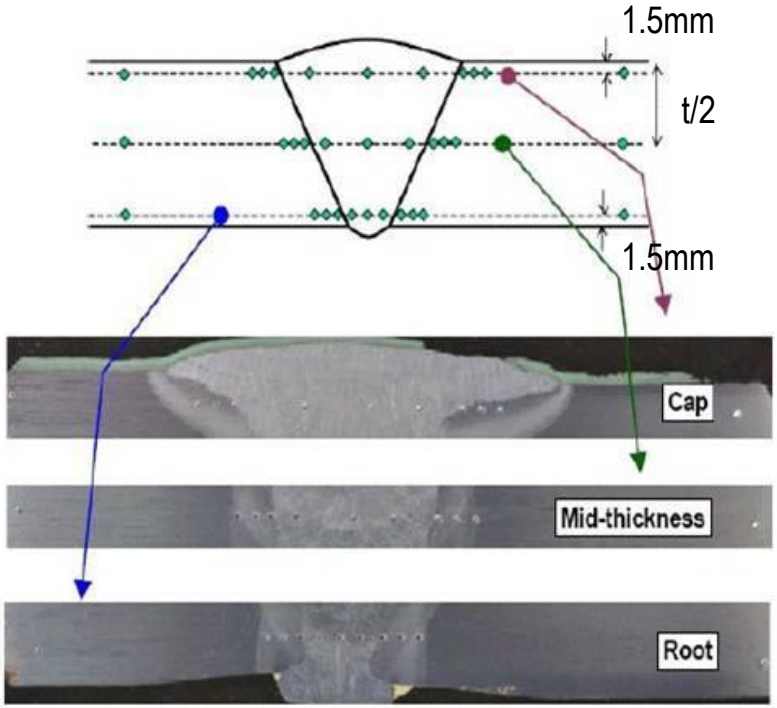


(b) Tie-in weld A17

  - Weld B10: transverse sections were taken at 11 equi-spaced positions around the weld circumference

HARDNESS SURVEYS

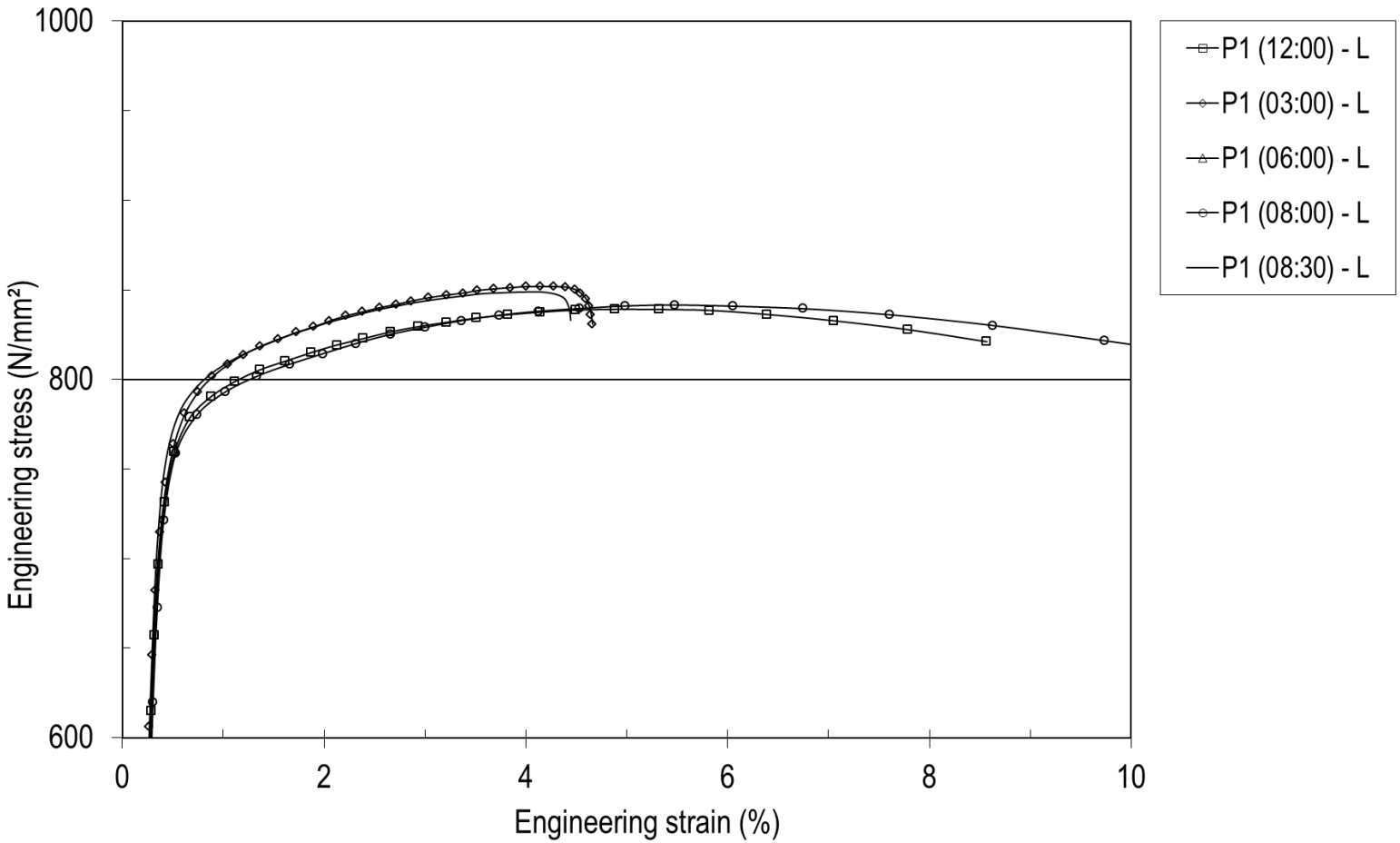
- Vickers hardness surveys
  - 3 traverses per weld macro-section; 1.5mm below weld cap, at the pipe mid-wall thickness, 1.5mm up from the weld root



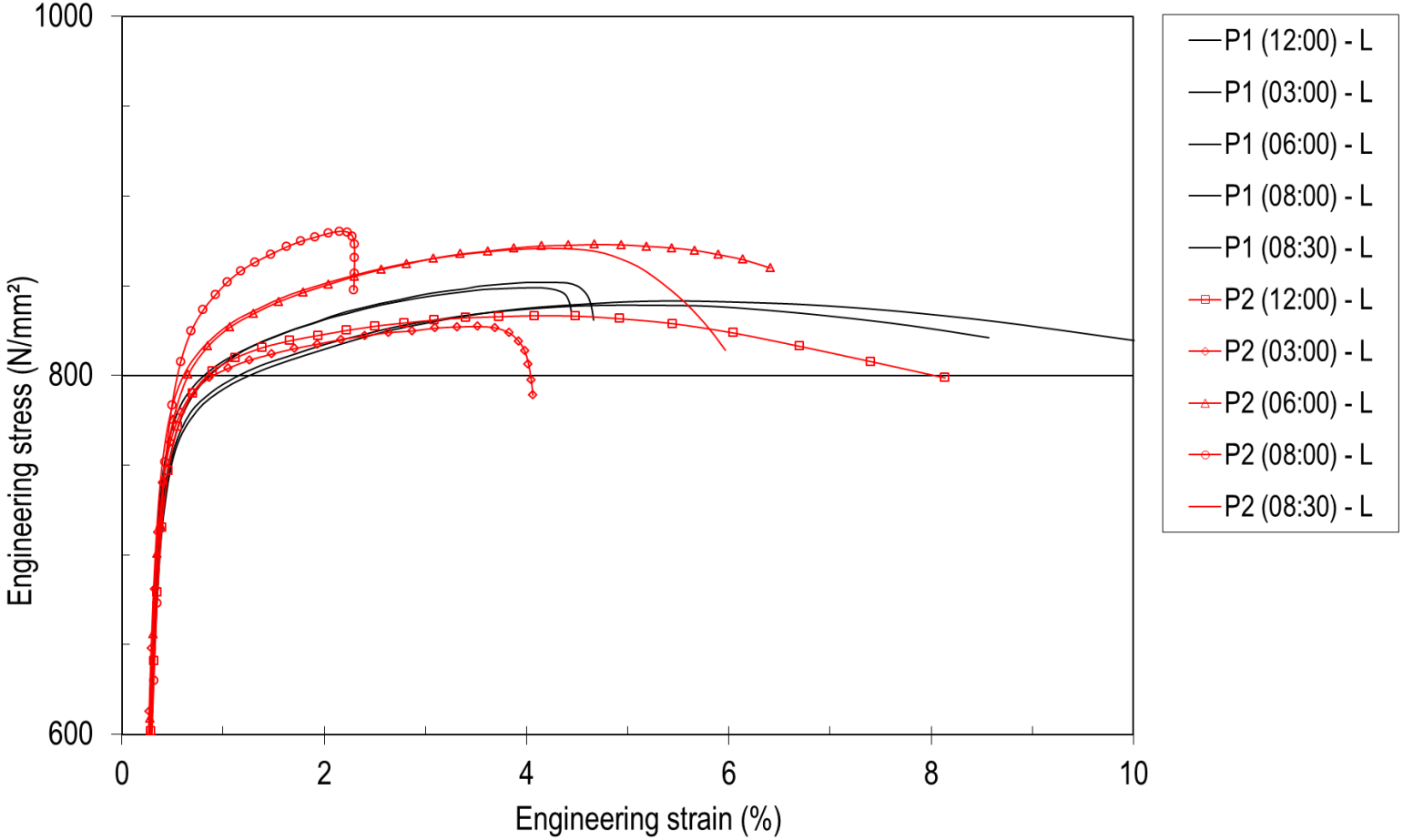
TENSILE TESTS…..

- For each pipe, tests were undertaken using round bar and full-thickness flat strip tensile specimens in both the pipe longitudinal and circumferential directions
- All weld metal tests were undertaken using round bar specimens, sampling the weld root and weld cap regions
- For each test the stress-strain response was measured, and the corresponding values of yield and tensile strength, Y/T and uEL were determined
- Cross weld tests were also undertaken using full-thickness flat strip specimens to identify the weakest part of the weldment and corresponding failure stress
- Excluding the test undertaken on weld B10, a total of 209 tensile tests were undertaken on the remaining 9 welds;
  - 140 pipe metal tests
  - 51 all weld metal tests
  - 18 cross weld tests

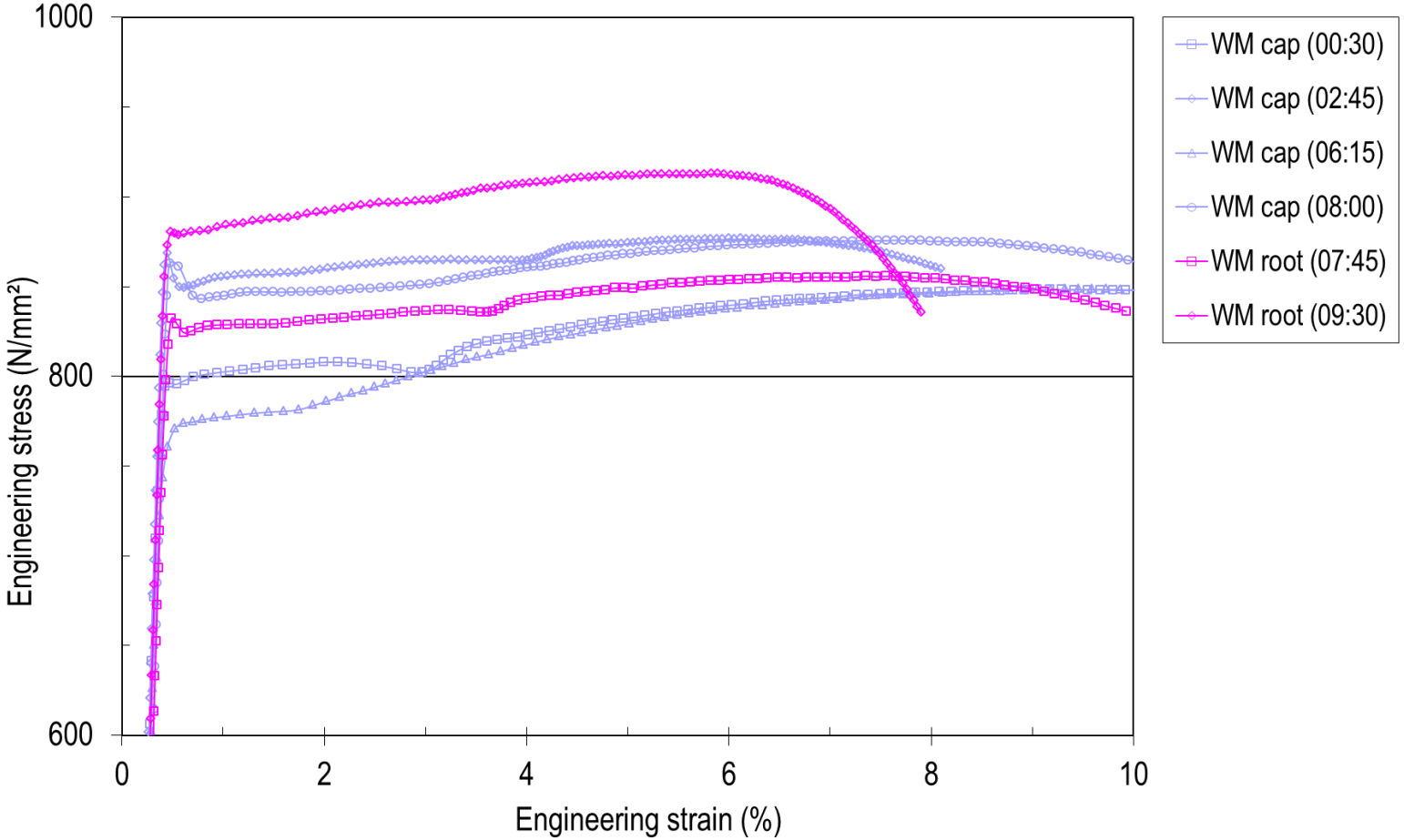
TENSILE TESTS…..(Weld A06, Pipe 1)



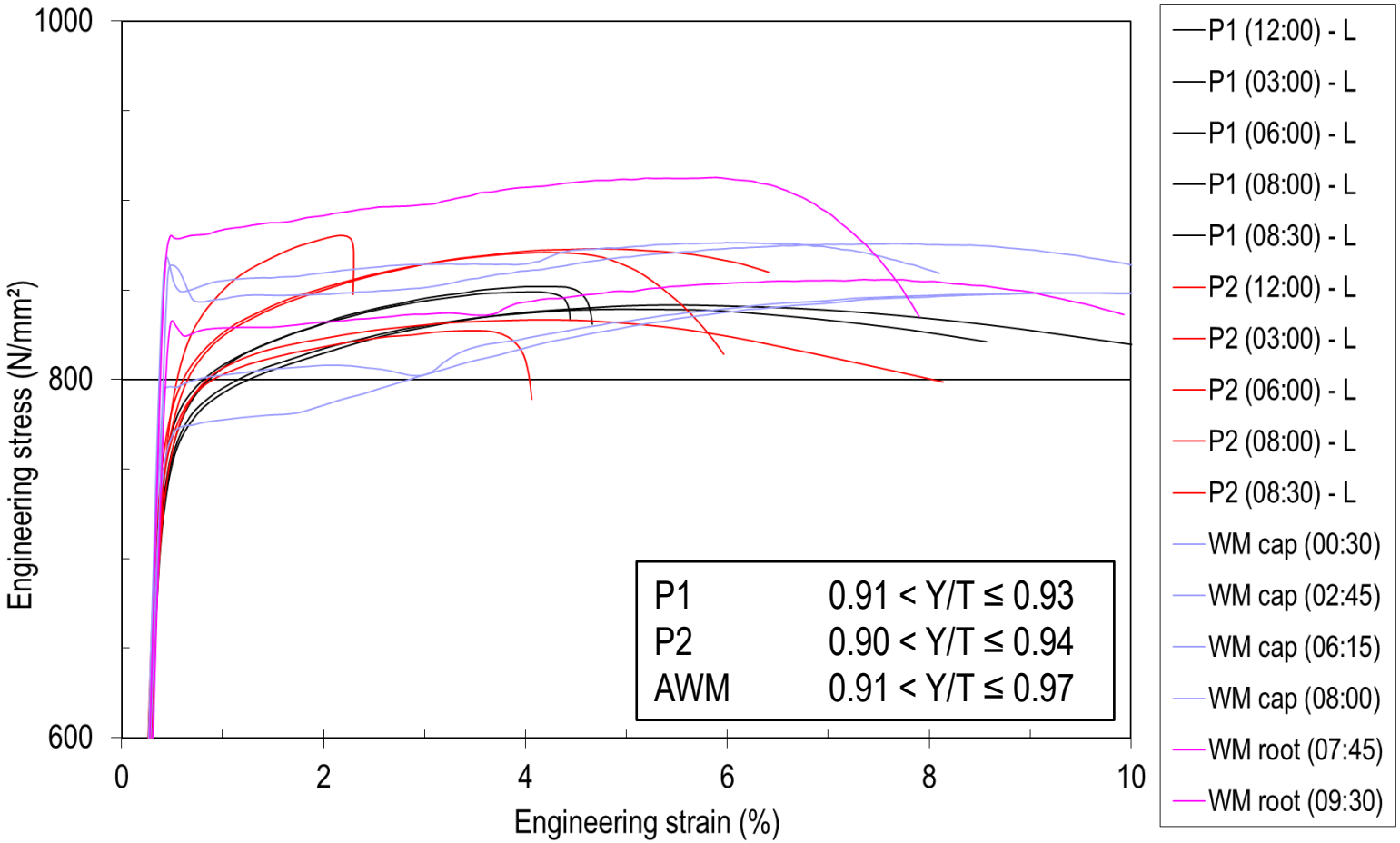
TENSILE TESTS…..(Weld A06, Pipes 1 and 2)



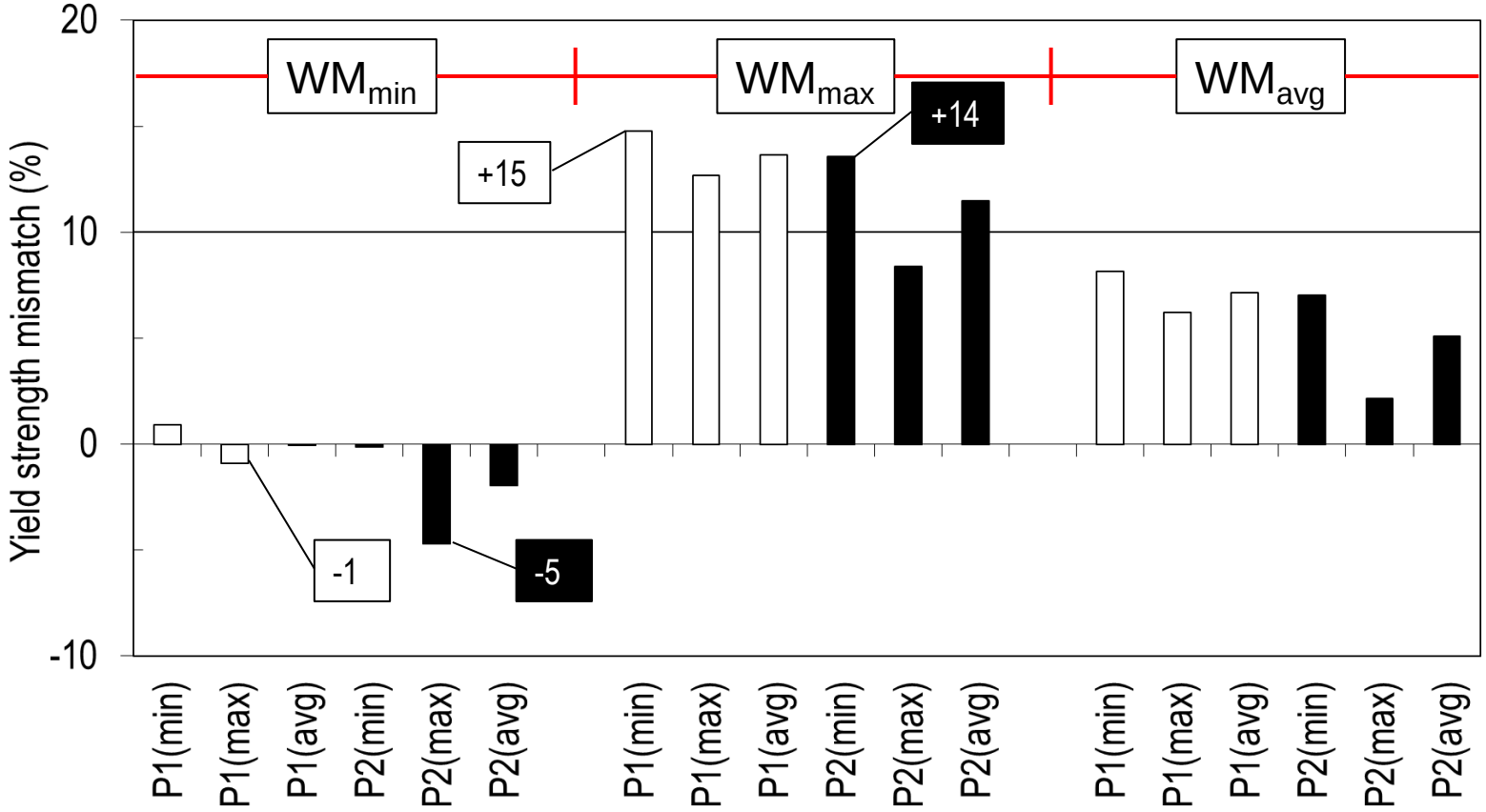
TENSILE TESTS…..(Weld A06, AWM)



TENSILE TESTS…..(Weld A06, all data)



TENSILE TESTS…..(Weld A06)



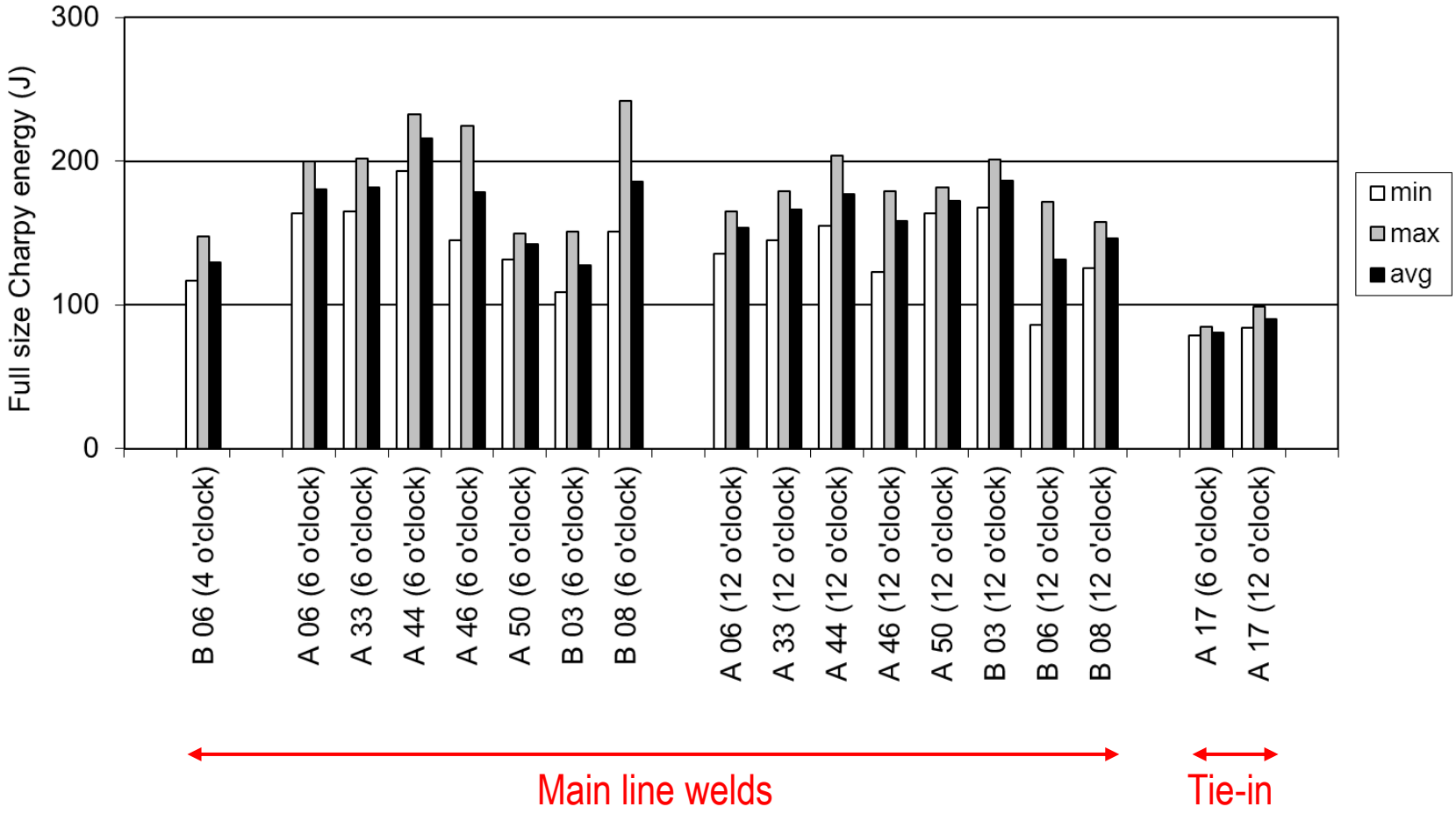
TENSILE TESTS…..Summary of all Welds

- All pipe achieved the strength requirements of ANSI/API 5L
- Stress-strain response of the pipe in the longitudinal direction was similar, but the post yield behaviour in the transverse direction varied considerably
- The tensile properties and yielding behaviour were found to vary significantly depending on test specimen type (round bar compared with flat strip)
- The properties of the weld metal varied significantly around the pipe circumference (maximum at near 3 and 9 o'clock, minimum at near 12 and 6 o'clock) and through the weld thickness (weld cap had the lowest strength, compared with the weld root and mid thickness regions which were similar)
- The properties of the pipe varied greatly between pipe manufacturer and plate source, although not one consistently achieved the highest yield or tensile strength, Y/T or uEL
- The variation in strength resulted in a wide range of weld metal strength mismatch, ranging from -11% (under-matching) to +26% (over-matching)

CHARPY IMPACT TESTS…..

- The tests were undertaken using full size (10x10mm) specimens, orientated transverse to the weld and notched in the through thickness direction, parallel to the weld
- A total of 108 tests were undertaken, 4 sets of 3 specimens extracted from the 9 girth welds;
  - 54 specimens notched at the weld metal centre line
  - 54 specimens notched at the fusion line sampling 50% weld metal and 50% HAZ
- All tests were undertaken at -20°C
- Both the impact energy and percentage shear area was measured for each specimen tested

CHARPY IMPACT TESTS.....(AWM)



CHARPY IMPACT TESTS.....(HAZ 50/50)

	Source A		Source B		Source C*	
	(6 specimens)		(21 specimens)		(27 specimens)	
	min	max	min	max	min	max
4 o'clock			48 J	193 J		
6 o'clock	45 J	239 J	69 J	256 J	85 J	234 J
12 o'clock	45 J	117 J	60 J	279 J	92 J	241 J
SA_{min}	45 %		50 %		55 %	

* The results for Source C include the results from the Tie-in weld, A17

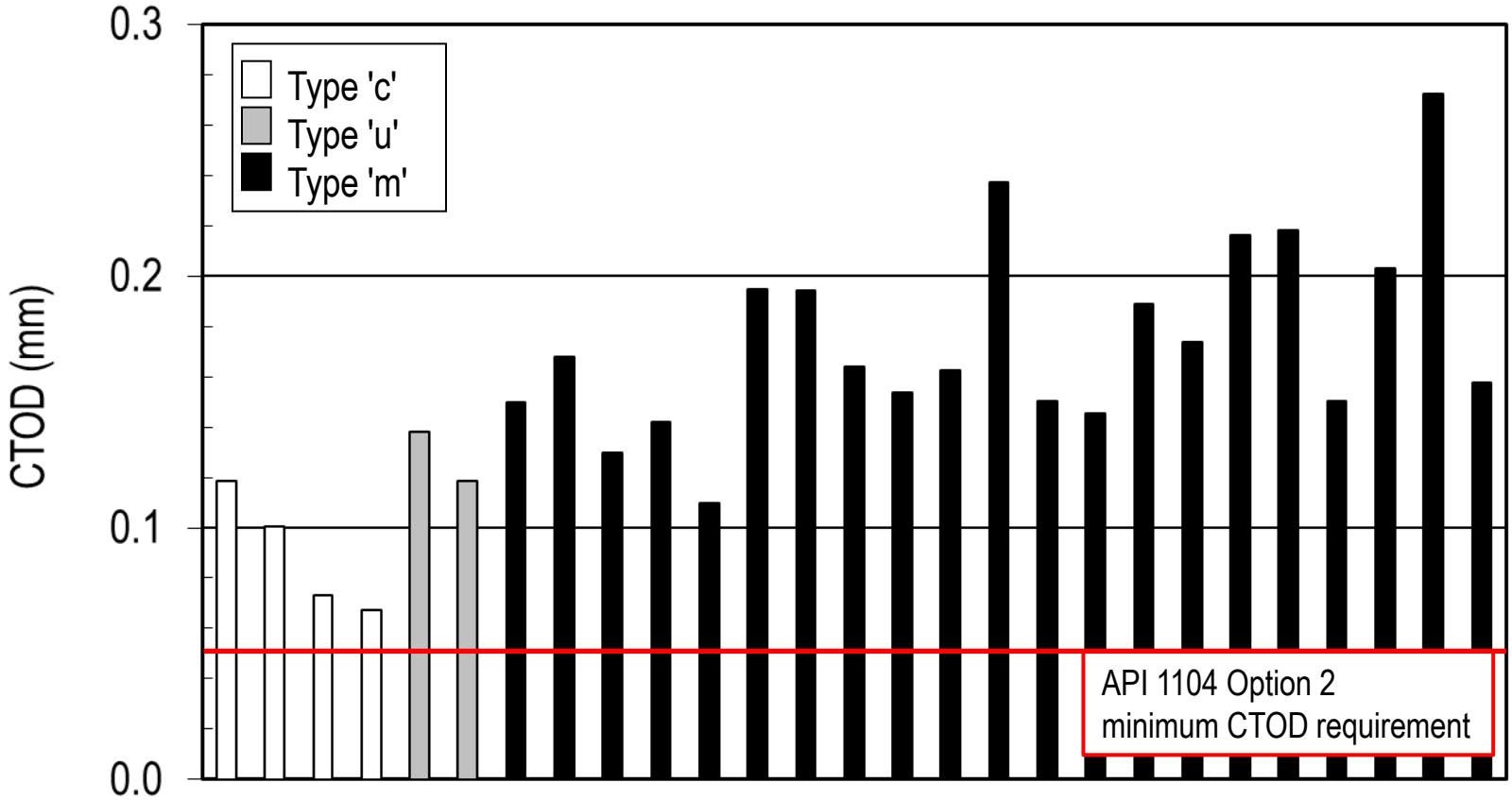
CHARPY IMPACT TESTS…..Summary

- Each girth weld tested achieved the performance criterion specified in API 1104, CSA Z662 and EPRG of 30J minimum, 40J average
  - CSA Z662 specifies 40J, but does not state whether this is a minimum or average value
- Although not a requirement of CSA Z662 and EPRG, API 1104 requires that the shear area should be greater than 50%
  - Only 1 of the 108 specimens tested failed this criterion with an estimated shear area of 45%

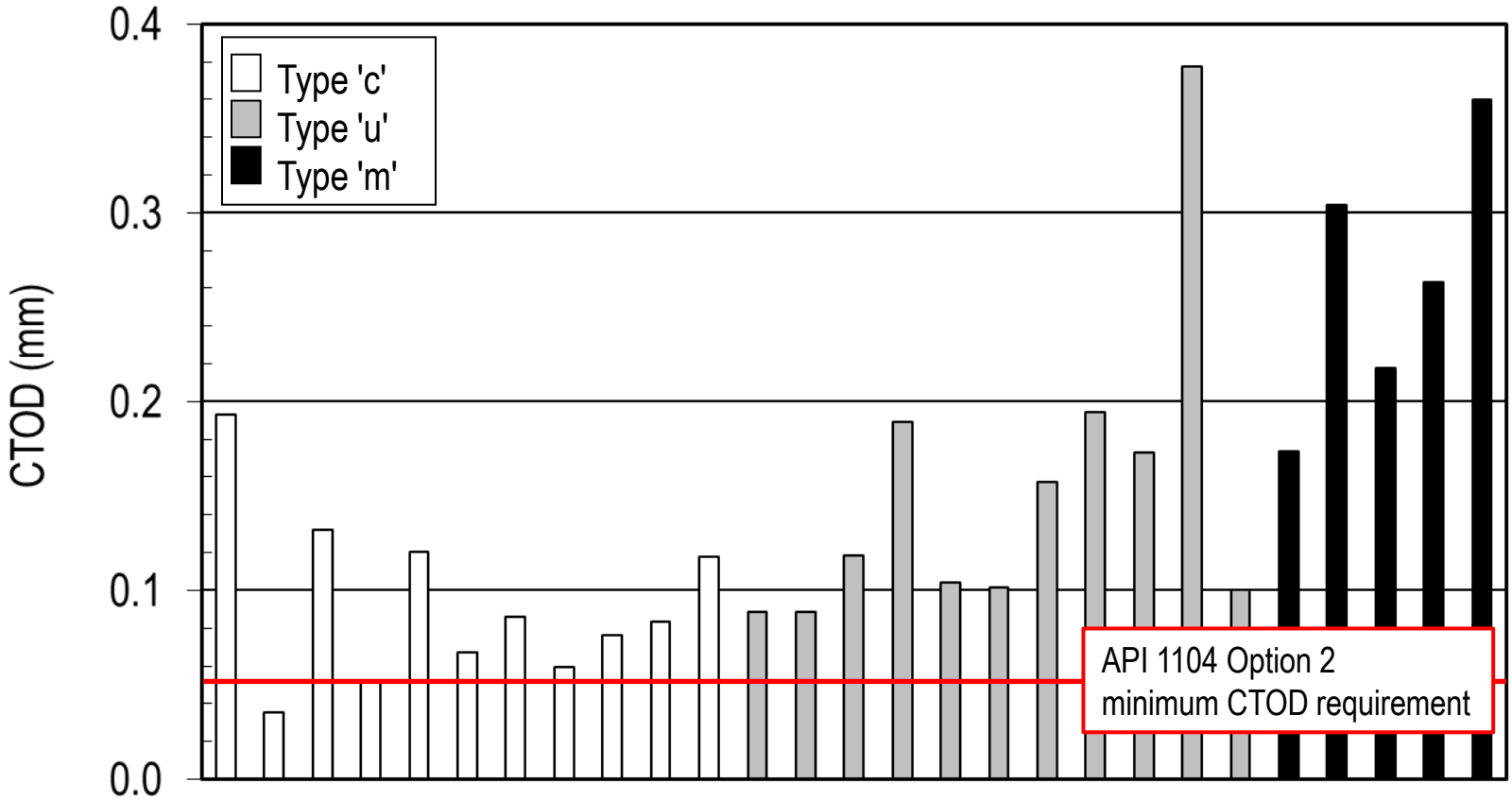
FRACTURE MECHANICS TESTS…..

- The tests were undertaken using ‘standard’ rectangular, Bx2B single edge notch bend (SENB) specimens, orientated transverse to the weld and notched in the through thickness direction, parallel to the weld
- Each specimen was locally compressed after notching, and fatigue pre-cracked at ambient laboratory temperature to produce a sharp crack of depth equal to half the specimen thickness ($a/W \approx 0.5$)
- A total of 54 tests were undertaken, 2 sets of 3 specimens extracted from the 9 girth welds;
  - 27 specimens notched at the weld metal centre line
  - 27 specimens notched at the fusion line sampling 50% weld metal and 50% HAZ
- All specimens were tested in three-point-bend loading at -20°C
- Single point values of fracture toughness (CTOD, J and K) were calculated for each specimen tested

FRACTURE MECHANICS TESTS…..(AWM)



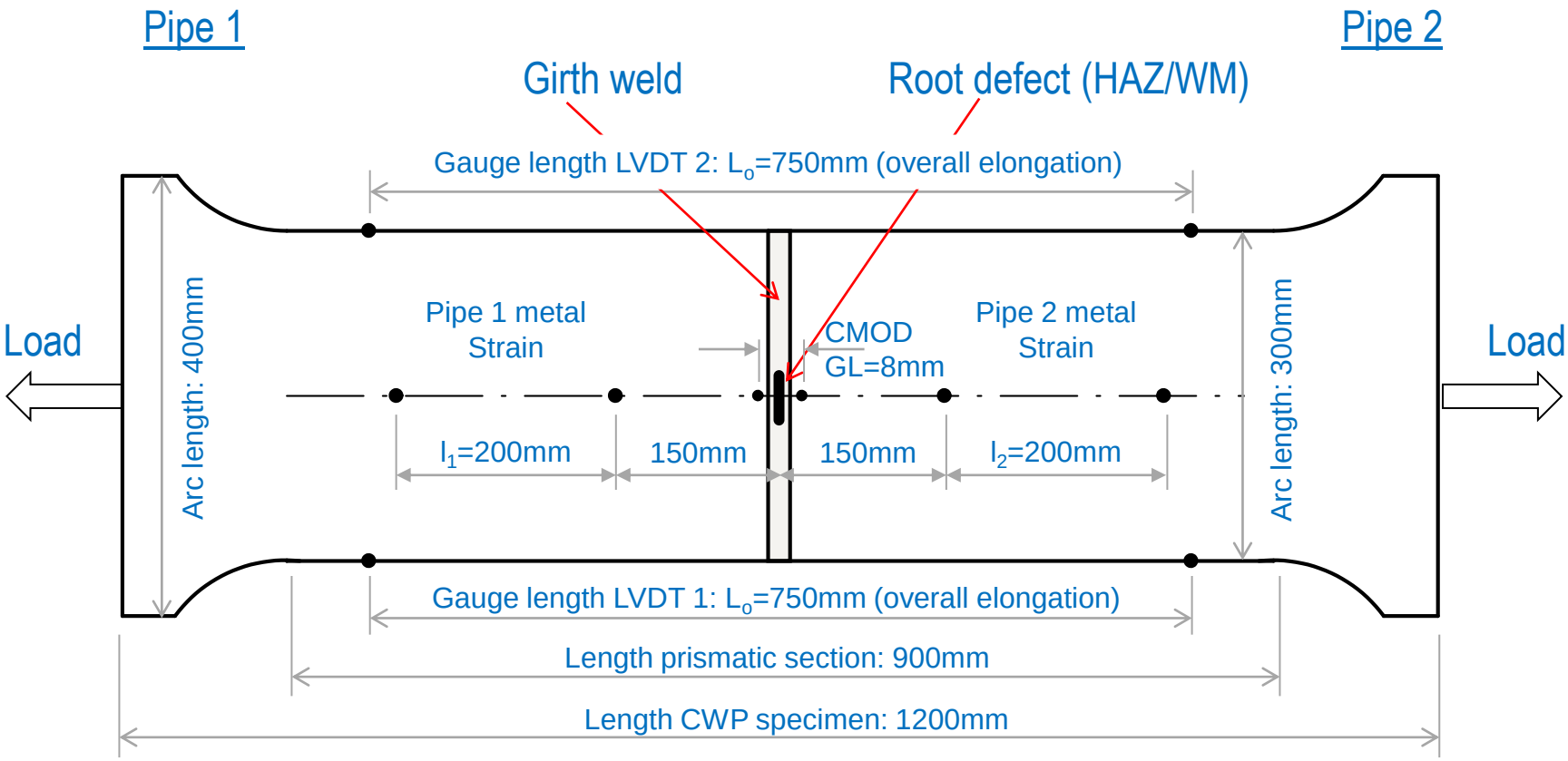
FRACTURE MECHANICS TESTS…..(HAZ 50/50)



FRACTURE MECHANICS TESTS…..Summary

- API 1104 Option 2 method requires a minimum CTOD of 0.05mm
- CSA Z662 does not have a minimum requirement, the minimum measured value is used in the assessment
- EPRG does not require fracture mechanics testing to be undertaken
- 1 specimen (HAZ) had a CTOD < 0.05mm
- The specimens extracted from the tie-in weld failed in a fully ductile manner
- The scatter in HAZ results is likely due to the pipe being from 3 different pipe sources and/or production heats
- From the comparable data;
  - Source C ranged from 0.06 to 0.36mm (average of 0.18mm, STD of 0.09mm)
  - Source B ranged from 0.04 to 0.19mm (average of 0.10mm, STD of 0.05mm)

CURVED WIDE PLATE TEST SPECIMEN…..



CWP TESTS…..(Procedure)

- Each CWP specimen was subject to detailed metrology to catalogue the dimensions of the specimen and defect
- The specimen was then welded to ‘loading lugs’ to enable the specimen to be connected to the test machine. The lugs were aligned with the centroid of the CWP specimen to prevent out-of-plane bending of the cross section during loading
- The specimen was mounted into the test machine, and the instrumentation was fitted and verified
- The specimen was cooled to -20°C (refrigerated methanol), which was allowed to stabilise for 1 hour prior to loading
- The specimen was loaded under displacement control at a rate of 1mm/min. The test was stopped when either failure occurred or a maximum load was achieved

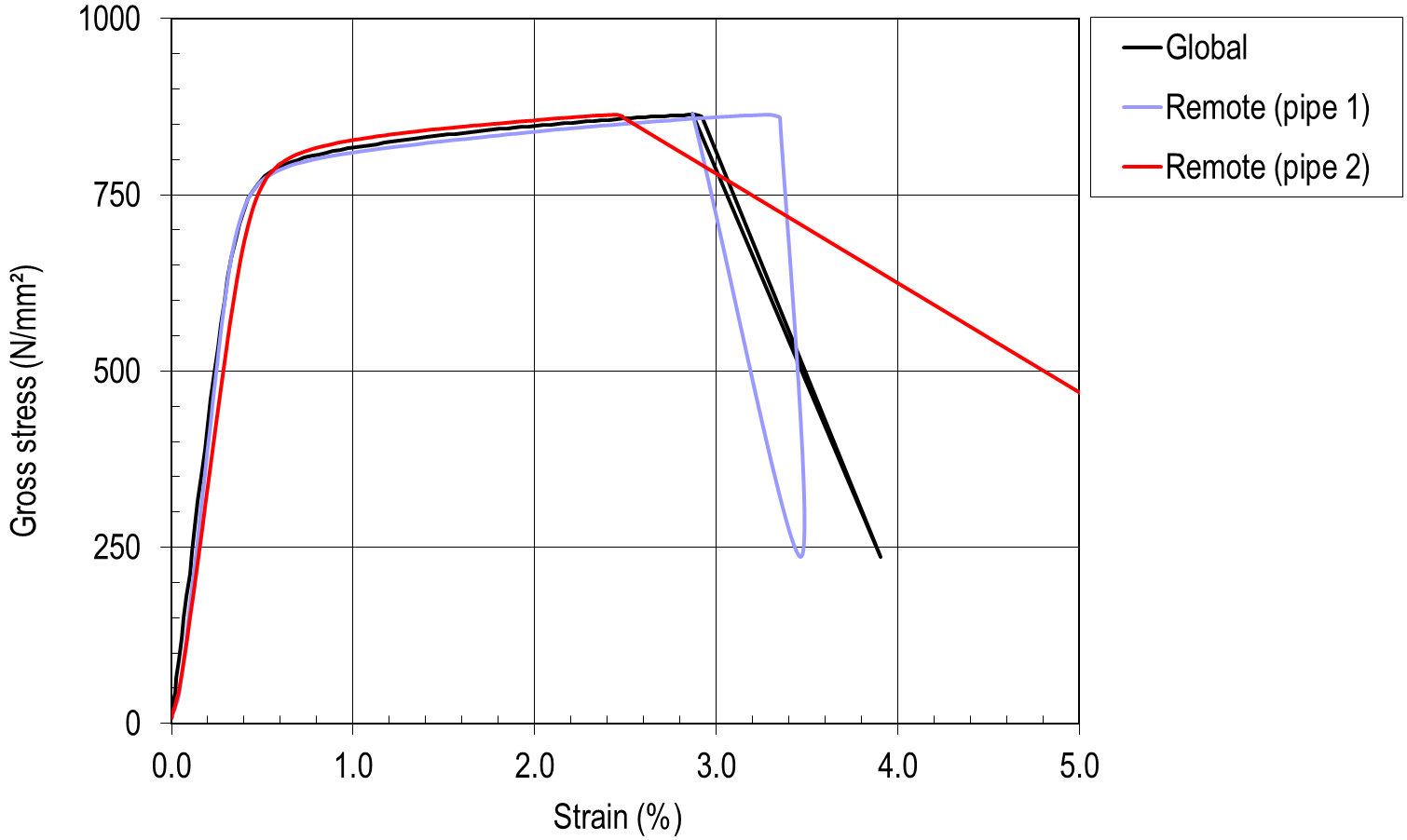
CWP TESTS…..(Procedure)

- On completion of the test;
  - Photographs taken of the tested specimen
  - Fracture surfaces cut from the specimen;
    - Photographed and defect dimensions measured (height and length)
  - For the CWP specimens that failed during the test;
    - Fracture initiation point OR deepest point of the notch was identified, as appropriate
    - Fracture surface sectioned at this point, perpendicular to the fracture surface to reveal the position of the notch in relation to the target location
    - Cross section was ground, polished and etched (2% Nital)
    - Photographed and measured (notch location relative to the fusion boundary)

CWP TESTS…..(Analysis)

- Plastic strain capacity and defect tolerance was quantified by means of the remote (pipe metal) failure strains;
  - A pipe metal failure strain of 0.5% was used as a performance requirement, i.e., the gross section yielding or pipe yielding criterion;
    - Local Collapse **LC** collapse of the remaining ligament below the surface breaking defect
    - Net Section Yield **NSY** collapse of the section containing the defect without significant straining of the parent material
    - Gross Section Yield **GSY** collapse by gross straining remote from the defect. A pipe metal strain of 0.5% is required to consider GSY has been achieved

CWP TESTS…..(Weld A06-WP-H1, example results)

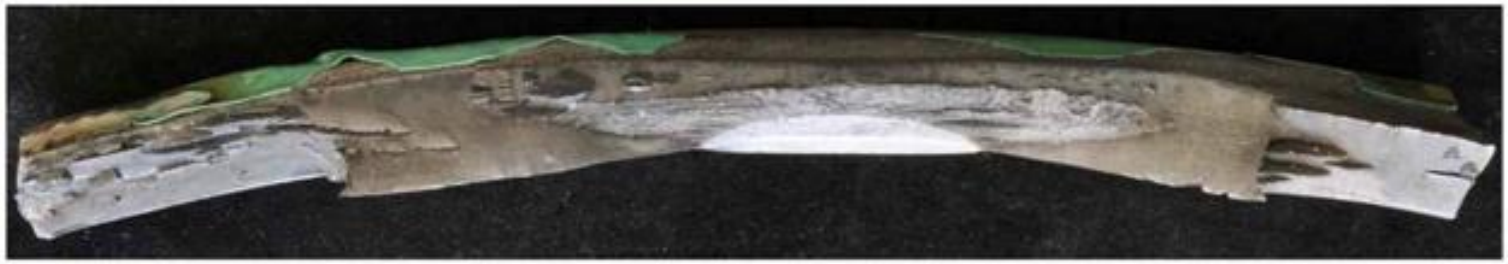


CWP TESTS…..(Weld A06-WP-H1, example results)

View: Weld root

View: Weld cap

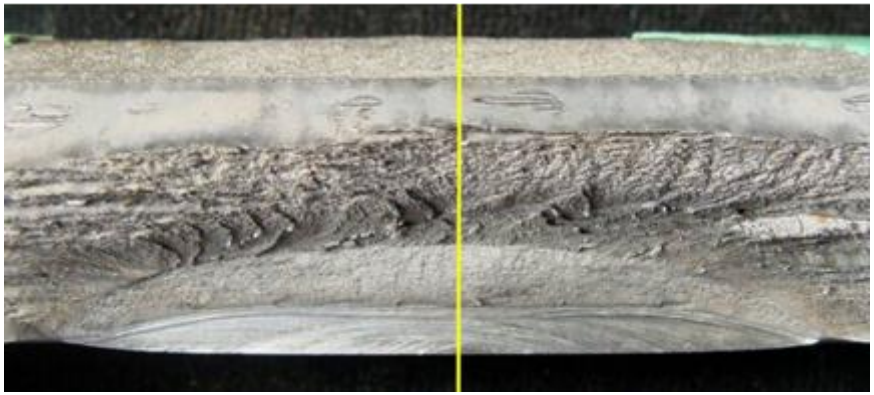
CWP TESTS…..(Weld A06-WP-H1, example results)



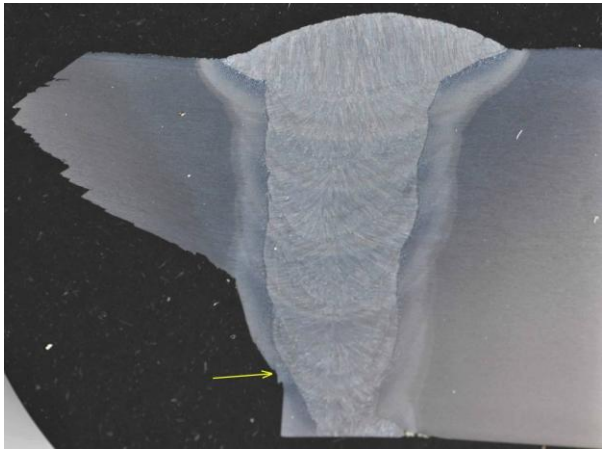
View: Weld

View: Pipe

CWP TESTS…..(Weld A06-WP-H1, example results)



- No clear initiation point
- sectioned midway along defect length



- Tip of defect 0.6mm from fusion boundary, in coarse/fine grained microstructure

CWP TESTS…..(Weld A06-WP-H1, example results)

- Defect located in the HAZ of pipe 1
- Defect dimensions: 3 x 50mm (2.46% of the specimen cross section area)
- Minimum measured strain at failure was 2.44% in pipe 2
- The gross stress at failure exceeded;
  - The *minimum* yield strength between the parent pipe and weld metal, *measured at the CWP location*. The weld metal matched the parent pipe
  - The *minimum* yield strength of the parent pipe and weld metal, *measured around the weld circumference*. The weld metal matched the parent pipe
  - The *average* yield strength of the parent pipe and weld metal, *measured around the weld circumference*. The weld metal overmatched the parent pipe
  - No clear fracture initiation point. The tip of the machined defect was +0.6mm from the fusion line, in coarse/fine grained HAZ microstructure
  - The CWP specimen failed by GSY

EVALUATION OF PERFORMANCE…..

- API 1104 - Option 2
- CSA Z662
- EPRG - Tier 2
- BS 7910
- API 579-1 / ASME FFS-1

API 1104 (Option 2)…..

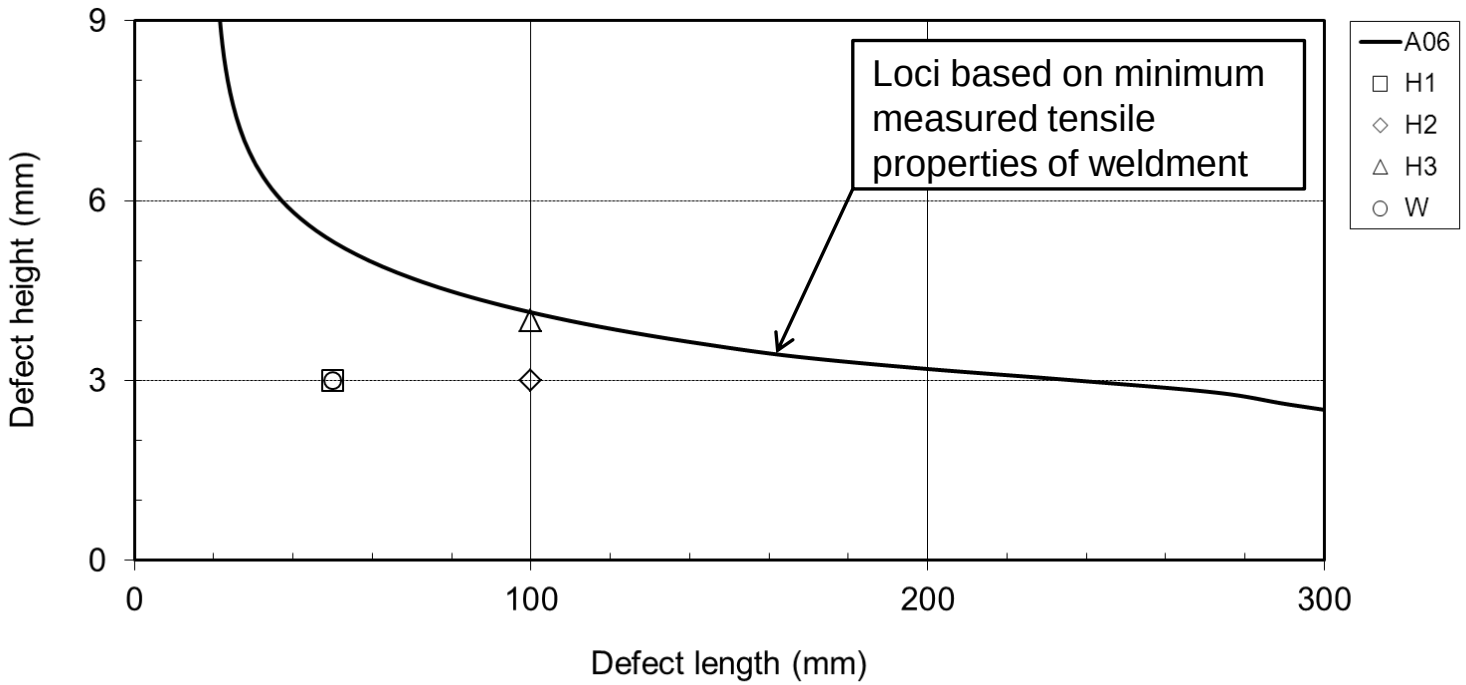
- Application of the procedure is dependent on;
  - Weld metal strength is not less than the strength of the line pipe, which must not be less than SMYS
  - The minimum CTOD is not less than 0.05mm
  - The applied longitudinal stress is not greater than SMYS
  - The applied longitudinal strain is not greater than 0.5%

API 1104 (Option 2)…..

- Only Welds A06 and A17 exhibited weld metal yield strength undermatching
- Only 1 fracture specimen failed the minimum CTOD requirement
- The following analyses were undertaken;

1. Construct loci of critical defect height as a function of defect length specific to each weld. Compare this with the defects tested. Each locus was constructed using the minimum tensile properties and fracture toughness of the weld, with an applied longitudinal stress equal to SMYS

API 1104 (Option 2)…..(Example: Weld A06)



API 1104 (Option 2)…..

- Only Welds A06 and A17 exhibited weld metal yield strength undermatching
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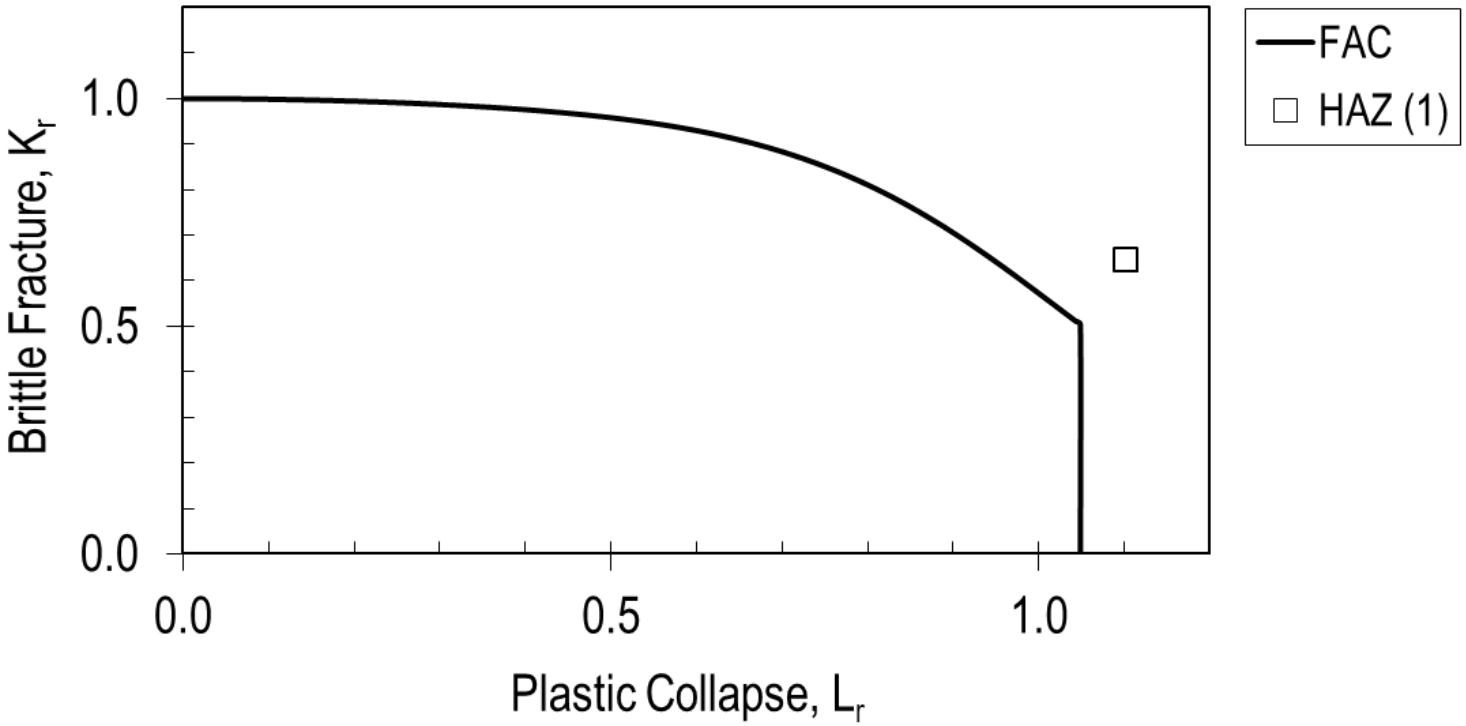
- The following analyses were undertaken;

1. Construct loci of critical defect height as a function of defect length specific to each weld. Compare this with the defects tested. Each locus was constructed using the minimum tensile properties and fracture toughness of the weld, with an applied longitudinal stress equal to SMYS
2. Construct a material specific FAD for the weldment. Determine the failure assessment point (K_r, L_r) and compare this with the FAC

API 1104 (Option 2)….. (Example: A06-WP-H1)

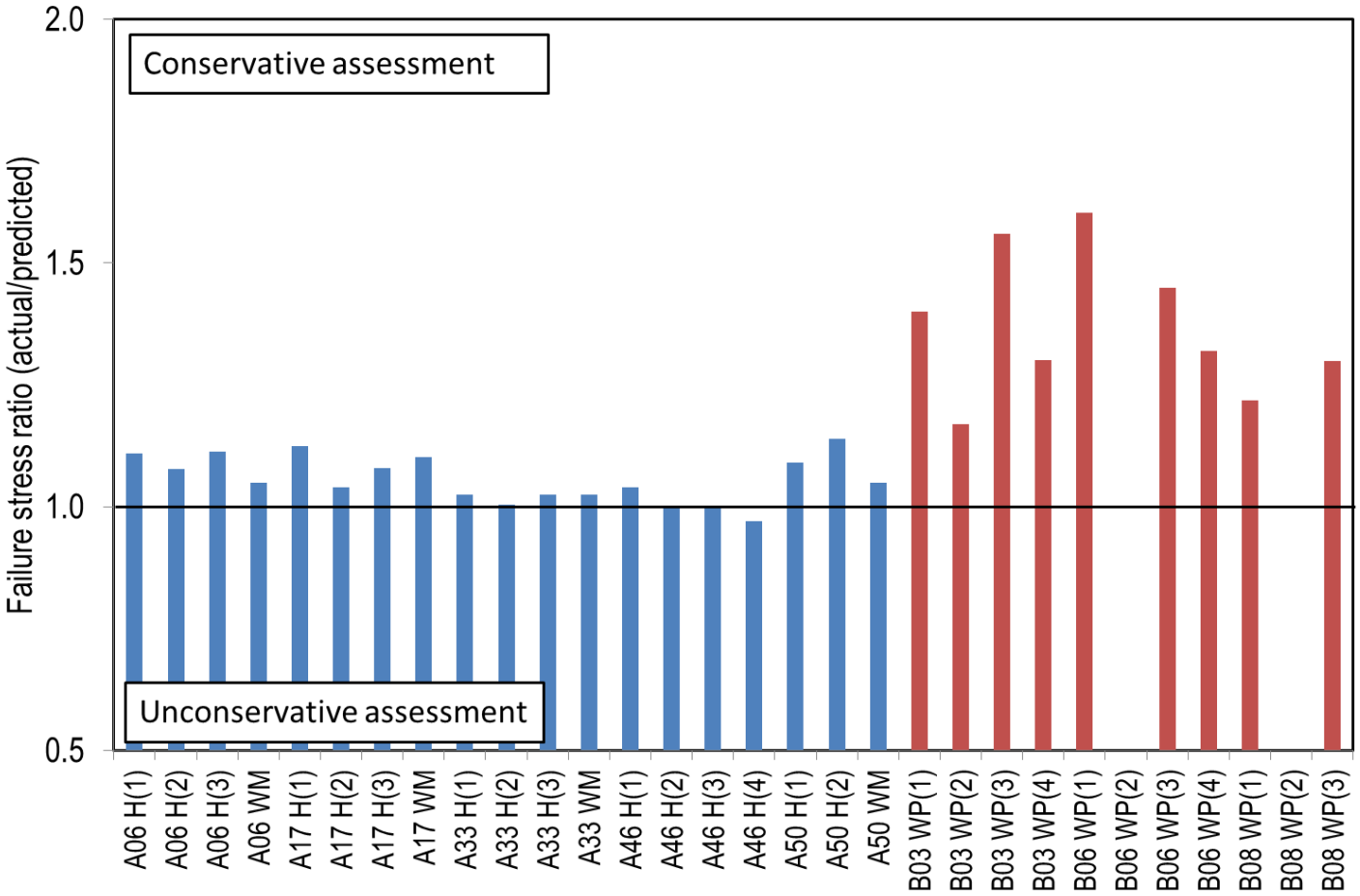


API 1104 (Option 2)…..

- Only Welds A06 and A17 exhibited weld metal yield strength undermatching
- Only 1 fracture specimen failed the minimum CTOD requirement
- The following analyses were undertaken;

1. Construct a loci of critical defect height as a function of defect length specific to each weld. Compare this with the defects tested. Locus constructed from minimum tensile properties and fracture toughness of the weld, with an applied longitudinal stress equal to SMYS
2. Construct a material specific FAD for the weldment. Determine the failure assessment point (K_r, L_r) and compare this with the FAC
3. Based on (2), determine the critical stress for failure of the test specimen. This was achieved by varying the applied longitudinal stress until the assessment point was coincident with the FAC. The critical stress was then compared with the actual failure stress to determine a margin of safety

API 1104 (Option 2)…..(All CWP data)



CSA Z662…..

- Application of the procedure is dependent on;
  - The yield strength of the weldment is not less than SMYS of the line pipe
  - The Charpy impact energy of the weldment is not less than 40J
  - Fracture toughness of the weldment
  - Stress analysis to be undertaken to determine the axial stress and additional longitudinal stresses to which the weld will be subjected during construction and operation

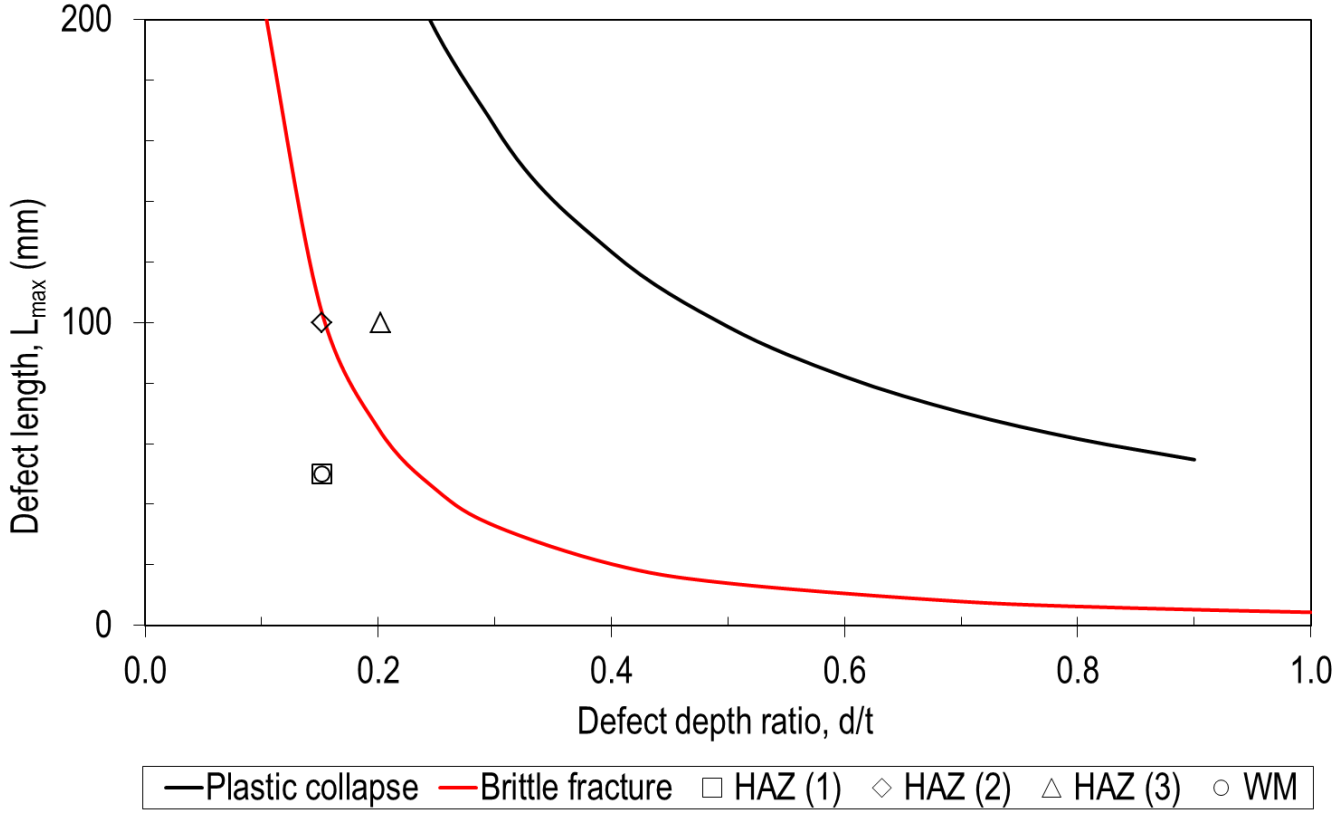
CSA Z662…..

- The minimum measured yield strength for each of the nine welds exceeded SMYS of the line pipe
- The minimum Charpy impact energy was not less than 40J
- The following analyses were undertaken;

1. Construct loci of critical defect height as a function of defect length for the prevention of brittle fracture and plastic collapse. Compare these loci with the defects tested. Each locus was constructed based on the minimum measured mechanical properties for the weldment and the applied longitudinal bending stress was limited to SMYS

CSA Z662…..(Example: Weld A06)

- Comparison of maximum allowable defect sizes with the CWP test specimen defects

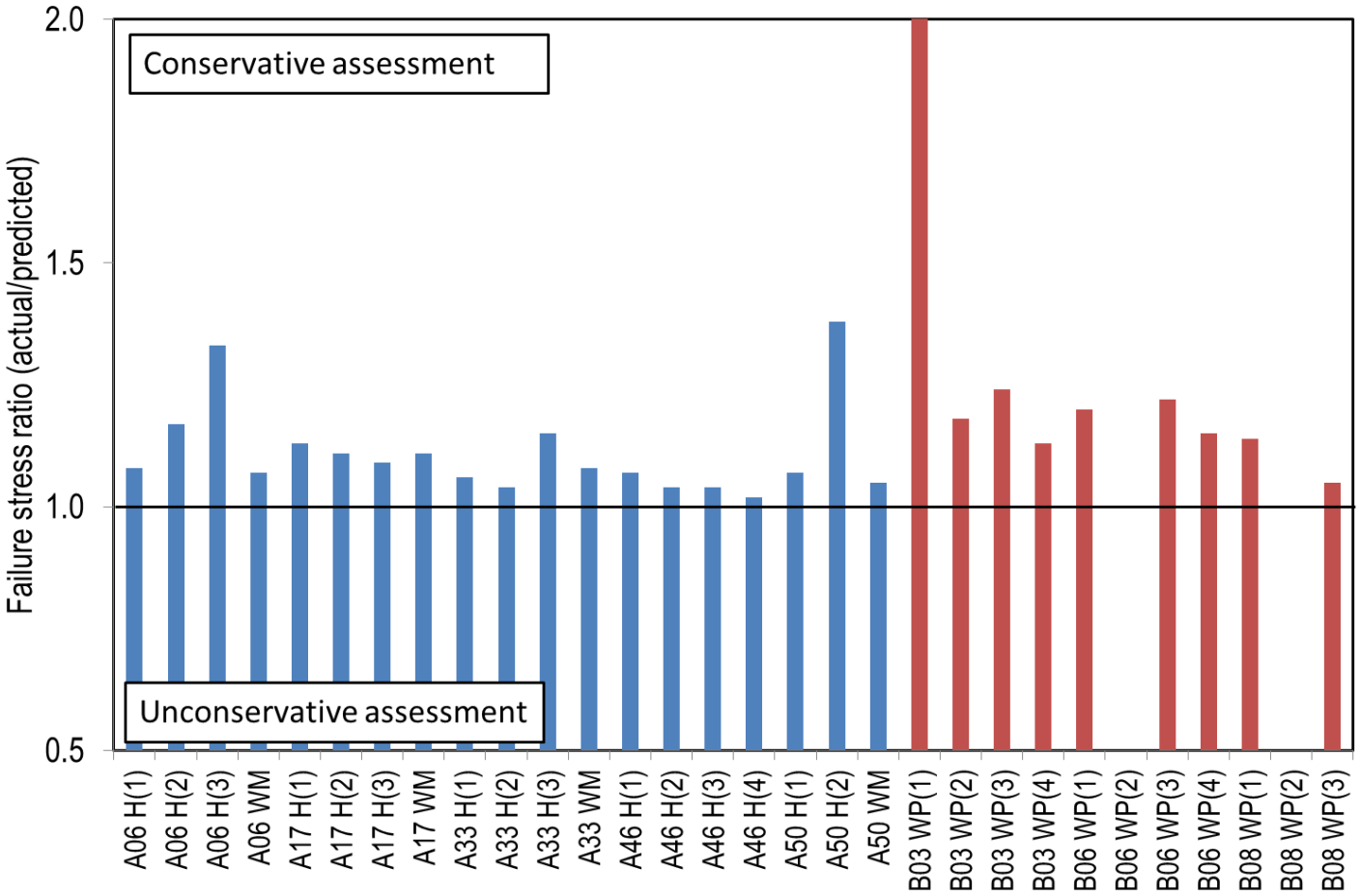


CSA Z662…..

- The minimum measured yield strength for each of the nine welds exceeded SMYS of the line pipe
- The minimum Charpy impact energy was not less than 40J
- The following analyses were undertaken;

1. Construct loci of critical defect height as a function of defect length for the prevention of brittle fracture and plastic collapse. Compare these loci with the defects tested. Each locus was constructed based on the minimum measured mechanical properties for the weldment and the applied longitudinal bending stress was limited to SMYS
2. For each CWP specimen tested, determine the theoretical maximum longitudinal bending stress for failure. This maximum stress was then compared with the actual failure stress to determine a margin of safety

CSA Z662…..(All CWP data)



EPRG-TIER 2…..

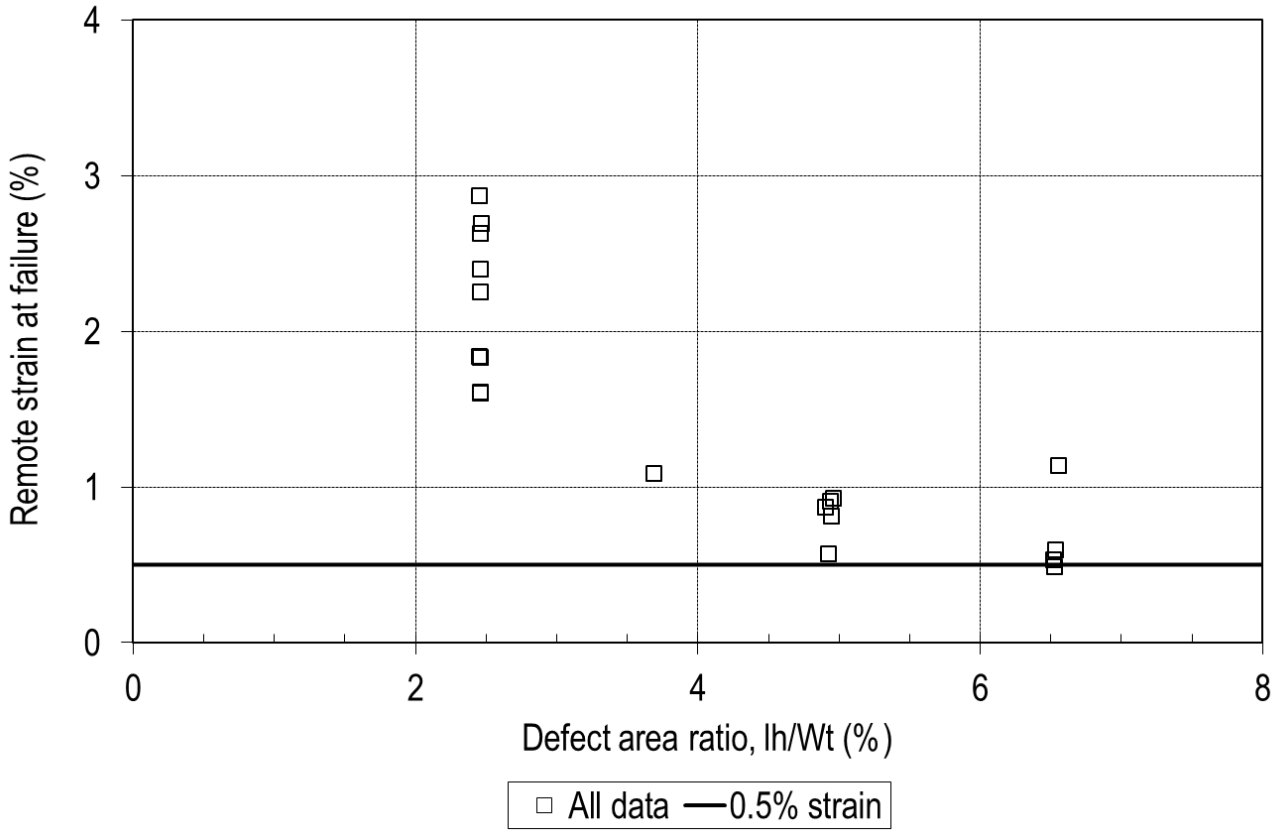
- Application of the procedure is dependent on;
  - The weld metal yield strength is not less than the pipe
  - The pipe's Y/T ratio in the axial direction is not greater than 0.90
  - The Charpy impact energy of the region containing the defect is not less than 30(40)J min(avg)
  - The total axial strain across the weldment is not greater than 0.5%
  - The defect area in a 300mm arc length is not greater than 7%

EPRG-TIER 2…..

- Each weldment exceeded the Charpy impact energy requirements of 30(40)J min(avg)
- There was significant variation in the pipe and weld metal tensile properties; resulting in weld metal yield strength mismatch ranging from -11% (undermatching) up to +26% (overmatching), and Y/T ratio's ranging from 0.86 to 0.99

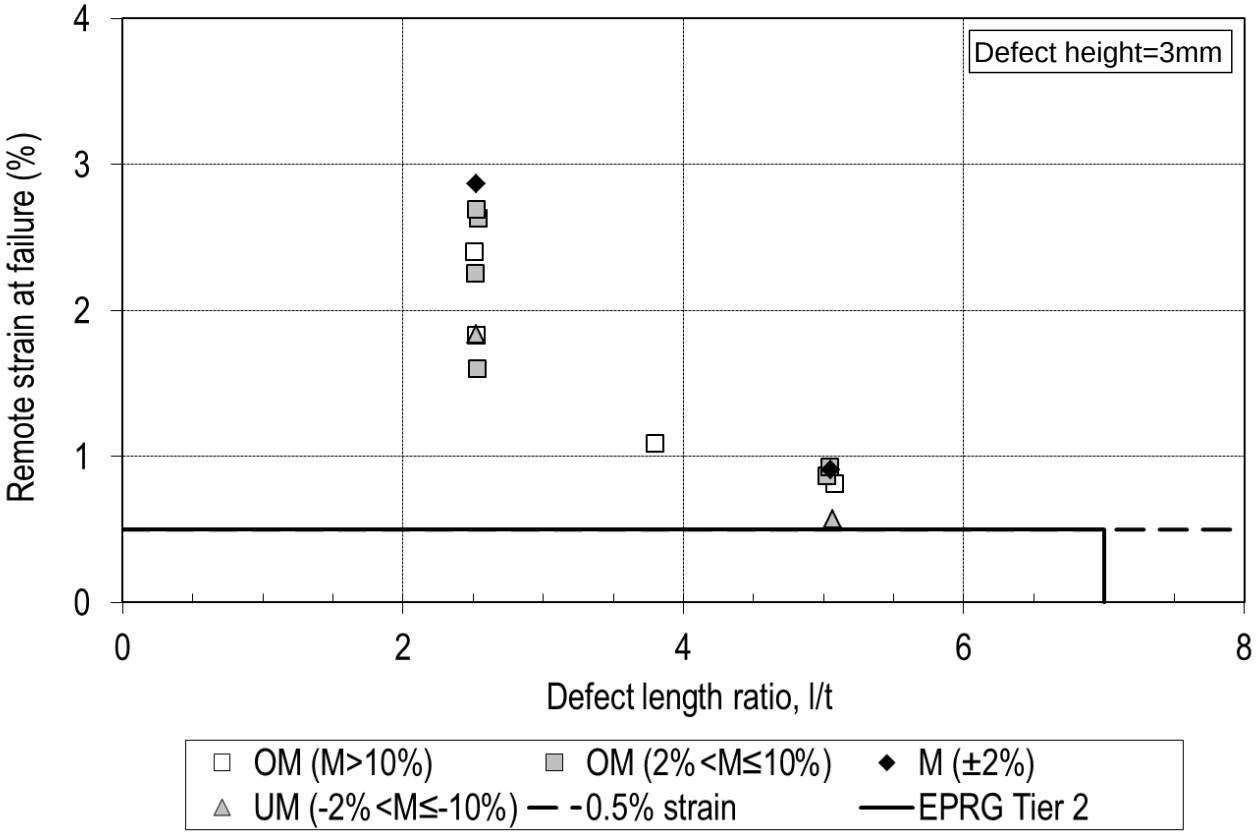
EPRG-TIER 2…..(All data from A-welds)

- Remote failure strain as a function of defect area



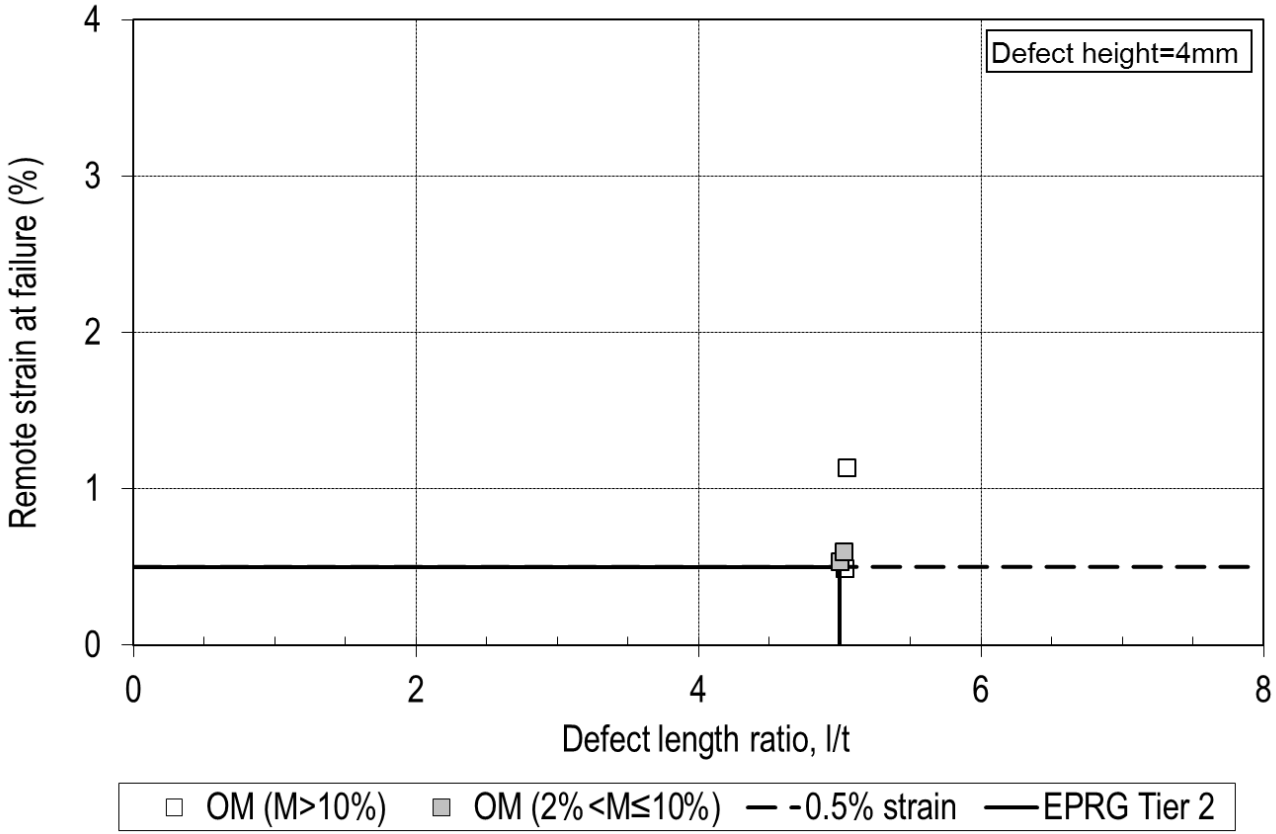
EPRG-TIER 2…..(Data from A-welds)

- Remote failure strain as a function of defect length ratio (3mm high defects)



EPRG-TIER 2…..(Data from A-welds)

- Remote failure strain as a function of defect length ratio (4mm high defects)



EPRG-TIER 2…..

- The results of the CWP tests suggest that the proposed limits for grade X80 pipelines are also applicable to grade X100

	Maximum allowable defect length as a function of defect height (h)		
	h ≤ 3mm	3 < h ≤ 4mm	4 < h ≤ 5mm
Y/T ≤ 0.9	≤ 7t	≤ 5t	≤ 3t

- The defect sizes tested were not sufficient to verify their use; the length ratio only extended to 5t rather than 7t
- However, the data do support use of the theoretical limits for grade X80 pipelines

Y/T ≤ 0.9	≤ 5.3t	≤ 3.9t	≤ 3.2t

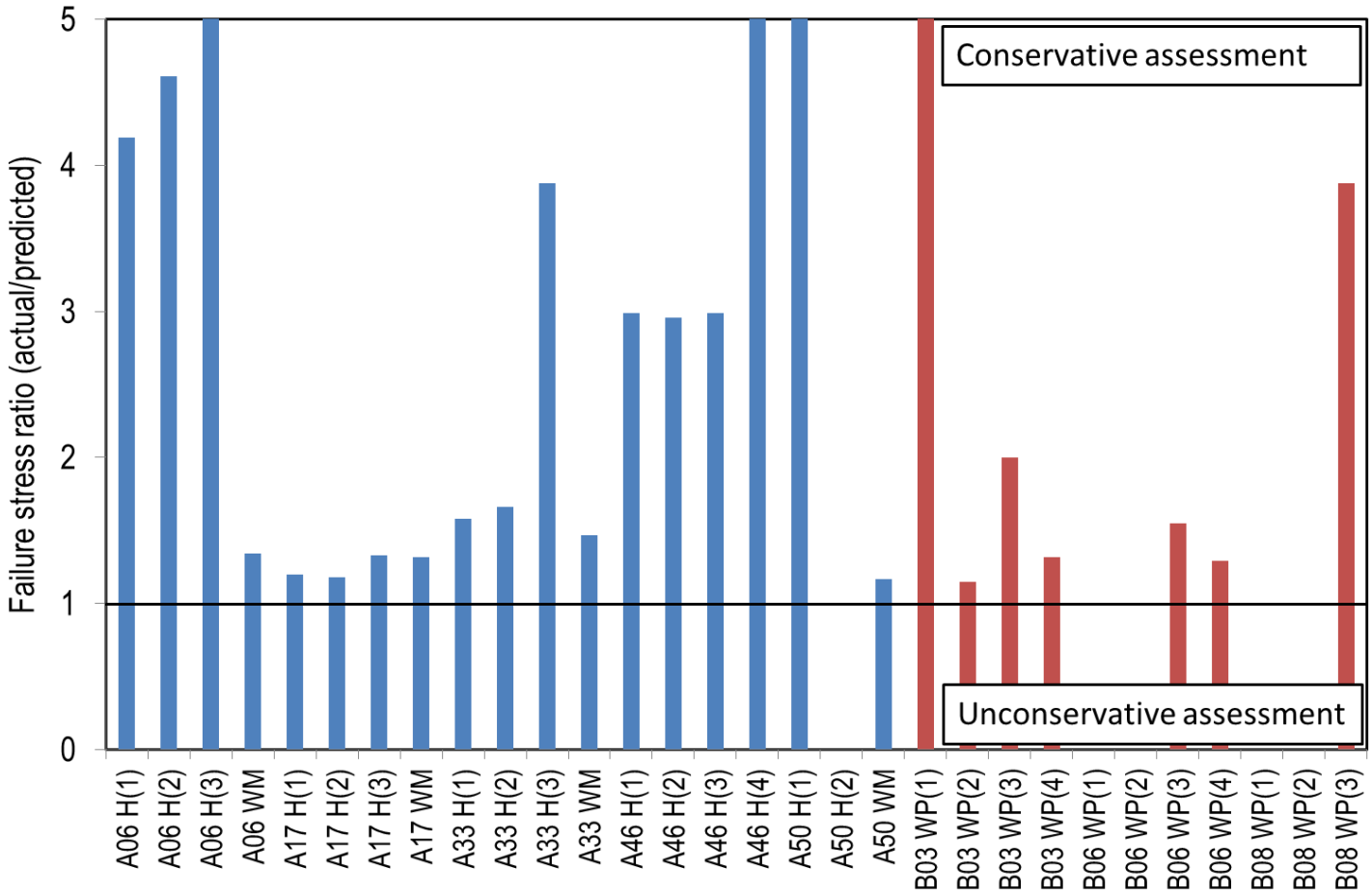
BS 7910 & API 579-1/ASME FFS-1…..

- The following assessments were undertaken for each weldment;
  - Prediction of the critical defect size locus for the weldment
- The following analyses were then undertaken for each CWP test;
  - Assessment based on the global stress at failure during the test to confirm whether the assessment point lies inside or outside the FAC
  - Criticality study – calculation of the critical failure stress for the assessment point to lay on the FAC. Determine a margin of safety by comparing the actual failure stress with the predicted failure stress
  - Combined criticality and sensitivity study – investigation of the effect of material toughness on failure stress when compared with the test failure stress

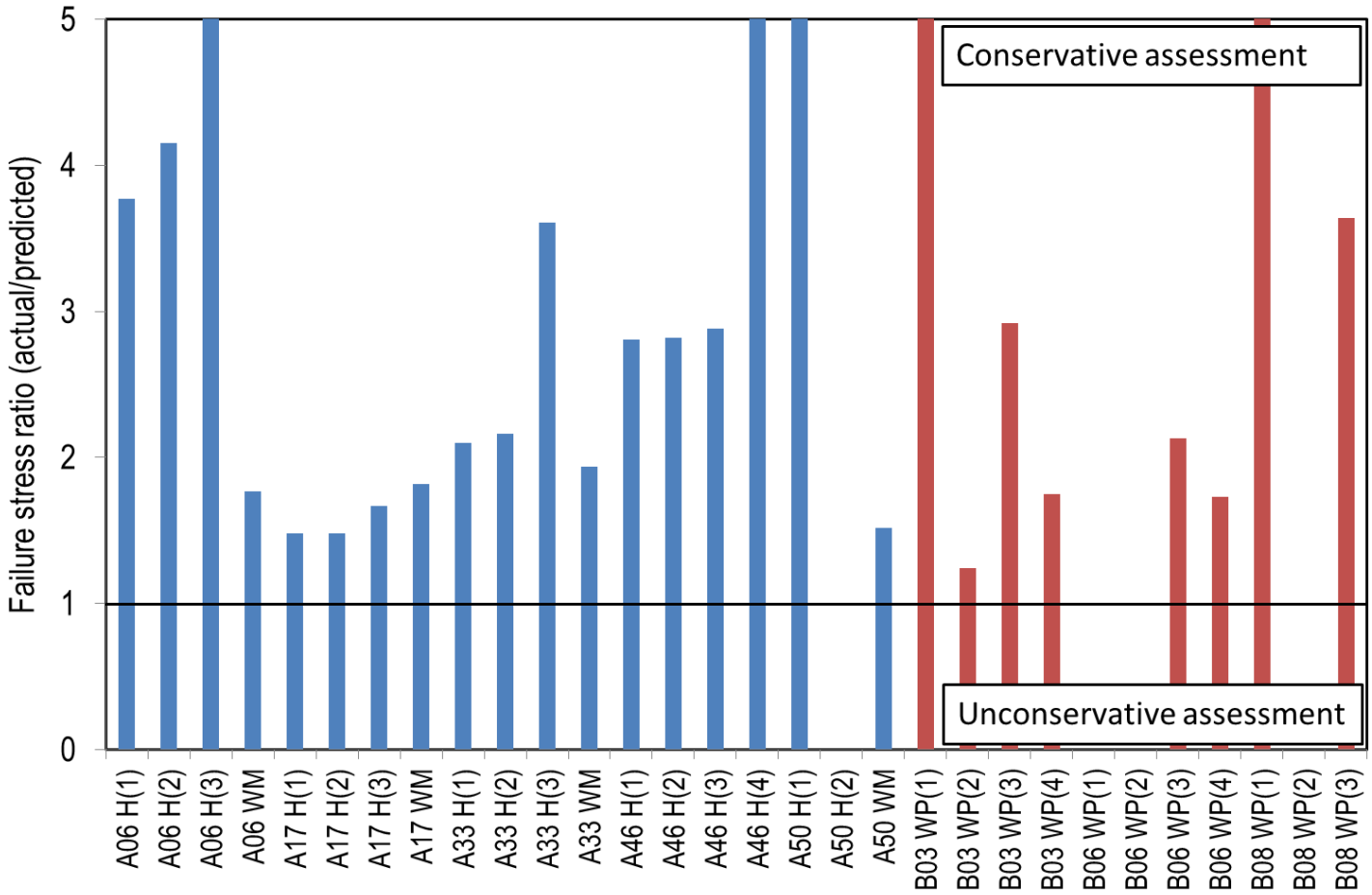
BS 7910 & API 579-1/ASME FFS-1…..

- The assessments were undertaken using commercially available software;
  - Crackwise, version 4 – BS 7910 procedures
  - SIGNAL fitness-for-service, version 3 – API 579-1/ASME FFS-1 procedures

BS 7910…..(All CWP data)



API 579-1/ASME FFS-1…..(All CWP data)



MAIN CONCLUSIONS…..

1. Verification of the applicability of API 1104, EPRG, CSA Z662, BS 7910 and API 579-1/ASME FFS 1 assessment methods to grade X100 pipelines was based on the performance of CWP tests undertaken on one pipe size; 1220 x 19.8mm
2. API 1104 (Option 2)
   - Despite some limitations in the assessment method the procedure gave conservative predictions of failure stress for all, except one CWP specimen (the predicted failure stress was 3% lower than the actual failure stress). In many cases the ratio of predicted failure stress to actual failure stress was close to 1.0
   - The least accurate (most conservative) predictions were for the natural/deliberate welding defects, embedded within the pipe wall

MAIN CONCLUSIONS…..

3. CSA Z662

- The procedure can be used for calculating defect size limits for either surface breaking defects or embedded defects
- The analysis procedure for brittle fracture is complex and not simple to use. For example, the user is required to interpret a log-log plot to construct a table of defect height as a function of length
- The procedure gave conservative predictions of failure stress, 2% or more when compared with the actual test data

MAIN CONCLUSIONS…..

4. EPRG Tier 2

- The limits calculated using the net-section collapse model are conservative when compared with the CWP test data.
- The defect size limits recommended for inclusion in the EPRG guidance document for X80 grade pipelines appear suitable for grade X100 pipelines. However, the length of the defects tested did not extend to the 7t (t is the pipe wall thickness) limit proposed.
- The CWP data for the natural/deliberate welding defects show that the proposed defect size limits are also applicable to equivalent sized embedded defects

MAIN CONCLUSIONS…..

5. BS 7910 and API 579-1 / ASME FFS-1

- The result of each CWP test was correctly predicted as a ‘failure’ using both methods
- Sensitivity studies were undertaken to determine the critical failure stress;
  - For the BS 7910 assessments, the ratio of actual to predicted failure stress ranged from 1.15 to 6.5 for all CWP specimen except for three. The failure stress of those specimens was predicted to be very low, resulting in ratios of 11.5, 19.8 and 23.0
  - For the API 579-1/ASME FFS-1 assessments, the ratio of actual to predicted failure stress ranged from 1.48 to 5.6 for all CWP specimen except for four, which had ratios of 11.3, 11.4, 13.9 and 19.9

MAIN CONCLUSIONS…..

5. BS 7910 and API 579-1 / ASME FFS-1 (continued)

- Sensitivity studies were undertaken assuming that the behavior of the girth welds was independent of fracture toughness;
  - For the BS 7910 assessment, the ratio of actual to predicted failure stress ranged from 1.07 to 1.45
  - For the API 579-1/ASME FFS-1 assessment, the ratio of actual to predicted failure stress ranged from 1.06 to 1.97
- The differences between the BS7910 and API 579-1/ASME FFS-1 results are due to the brittle fracture assessment and treatment of welding residual stress. The plastic collapse solutions, although different, give similar results

RECOMMENDATIONS…..

- Additional testing to investigate the effect of pipe diameter and wall thickness
- Provision of more detailed guidance in API 1104 and CSA Z662 on the type, orientation and number of tests, and the sampling position around the pipe circumference to fully characterise the behaviour of the weldment
- Provision of a testing plan in the EPRG guidelines to ensure sufficient testing is undertaken to fully characterise the behaviour of the weldment
- Consideration should be given to verifying some of the equations in the API 1104 Option 2 method for grade X100, or investigating the applicability of more appropriate models

THANK YOU FOR YOUR TIME

Final project report:

http://primis.phmsa.dot.gov/rd/
Project: 220

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