EPRG-PRCI-APGA
23rd Joint Technical Meeting
Edinburgh, Scotland • 6–10 June 2022

Materials test program results to support Australia's first hydrogen pipeline conversion project (APGA)

8 June 2022

Agenda

1. Project Overview
2. Phase 1
   - Overview
   - Laboratory Testing
   - Engineering Calculations
   - Operating Parameters Summary
   - Safety Management Study
   - Conclusions & Outlook
3. Phase 2
   - Overview
   - Laboratory Testing
   - Round Robin Testing
   - Conclusions & Outlook
4. Conclusions & Future Work

Project Overview

Project in Brief

In an Australian-first 43 kilometres of Parmelia Gas Pipeline (PGP) will be transformed to 100 percent hydrogen-ready transmission pipeline.

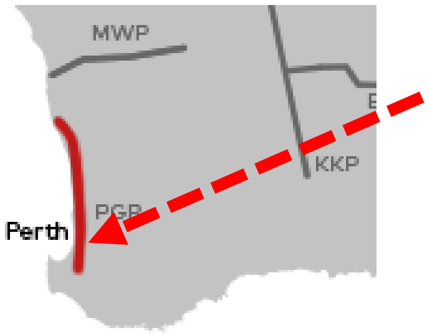
The project is supported by The Future Fuels Cooperative Research Centre, Wollongong University and GPA Engineering.

The project will provide information into the pipeline industry hydrogen body of knowledge – supporting the H2 Pipeline CoP

The project will be delivered in three phases – testing, transformation and commissioning

APA is committed to working with the regulator and State Government to demonstrate the safety case for hydrogen

Research team preparing pipe sections for testing



Kwinana is a key potential hydrogen production location, linked to a large industrial base, domestic network and transport hubs, with the potential to one day service export markets.

Project Need, Challenges & Approach

Phase 1: Investigate if the pipeline can transport hydrogen

- Complete gap analysis of current standards
- Prepare safety management approach
- Collate existing pipeline data incl. properties and current condition
- Conduct laboratory testing of pipe sections in air at atmospheric pressure

12 months

Phase 2: Confirm how to convert the pipeline to hydrogen-ready

- Finalise safety management study
- Engage with technical regulator and WA State Government
- Complete supply and demand analysis and commence negotiations
- Conduct laboratory testing of pipe sections in a gaseous hydrogen environment

12-18 months

PGP is here

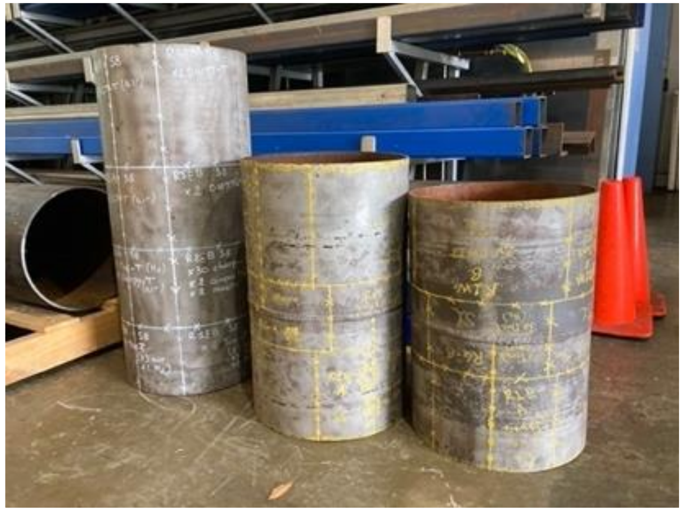
Phase 3: Prepare the pipeline for transformation

- Full-scale testing if required
- Assessment and conversion of above-ground and ancillary equipment changes required for hydrogen-ready
- Firm understanding of supply and offtake arrangements incl. points of connection

12-18 months

Laboratory Test Program

General information on the PGP Kwinana section	
Material specification	API 5L
Grade	X52
Diameter	355.6
Wall thickness	5.56, 7.92 mm
SMYS	360 MPa
SMTS	460 MPa
Allowances	0 mm
Length	42.3 km
Location classses (AS 2885.6)	T1, T2 and R2
Design temperature range	-7 to 65 °C
Year of construction	Circa 1970
Original design code	ANSI B31.8 (probably 1968 Ed.)



Phase 1

Overview

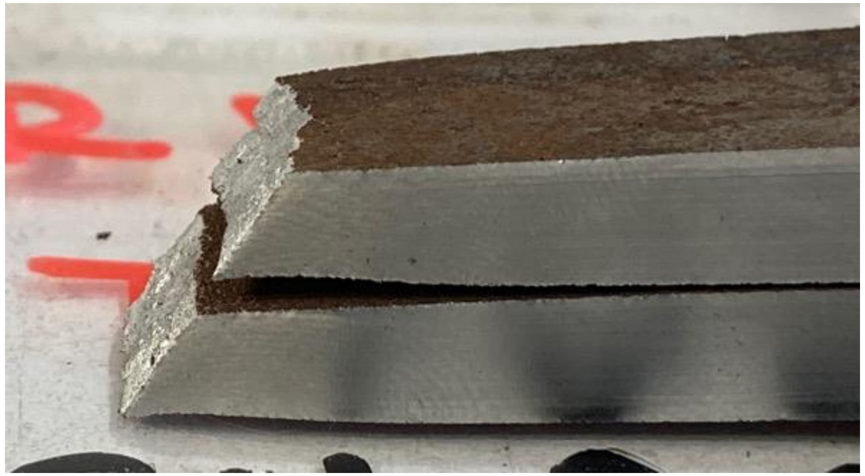
Test Program

All test are conducted in *air* at ambient temperature

- Vintage pipe so testing required to fill in gaps

Material Characterisation

- Chemical Composition (OES)
- Optical Macro- & Micrographs
- Seam & Girth Weld Hardness Maps



Strength

- Base Metal Circumferential & Longitudinal Tensile Tests
- Cross Seam & Girth Weld Tensile Tests

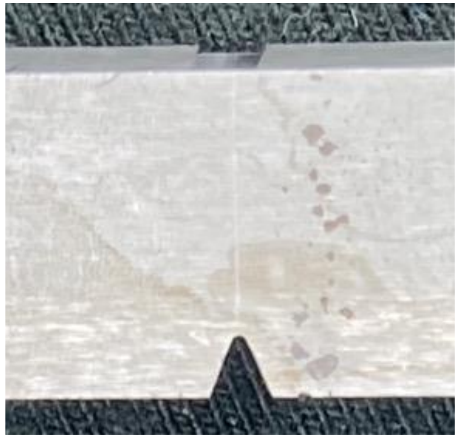
Test Program

Fracture Toughness

- Static Fracture
    - Base Metal Circumferential & Longitudinal C(T) Tests
    - Cross Girth Weld C(T) Tests in the HAZ & WCL
- Dynamic Fracture
    - Base Metal Circumferential Charpy V-notch Impact Tests
    - Seam Weld Charpy V-notch Impact Tests
    - Base Metal Circumferential DWTTs

Fatigue

- Base Metal Circumferential & Longitudinal C(T) Tests
- Cross Girth Weld C(T) Tests in the HAZ & WCL



Phase 1

Laboratory Testing

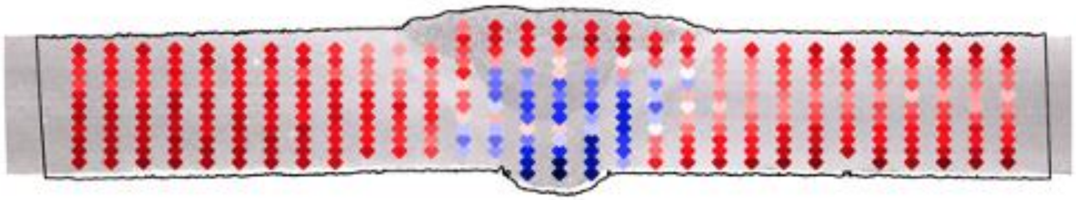
Results

Chemical Composition

- Mostly fits modern specifications API 5L PSL2 X52N welded pipes
  - Section S8-E had %wt phosphorus and C_{eq} fell outside specifications
- ASME B31.12 option B requires phosphorous ≤0.015%wt
  - Some pipes above the limit

Material Hardness

- AS2885.2 Cl. 6.4.6
  - 350 HV in non-sour service
  - 250 HV in sour service
- ASME B31.12 Cl. GR-3.10
  - 235 HV, 1.5 mm below surface
- BM, HAZ and WM met requirements



Results

Strength

- API 5L PSL2 (X52)
- AS/NZS 2885.2
  - TS of GW > SMTS of BM
- All specimens met requirements

Drop Weight Tear Test

- API 5L & ISO 3183 do not require DWTTs for < DN500
- AS 2885.1 requires FATT(85%) < TBFC (-10 °C)
- ASME B31.12 requires %SA > 40% at TBFC
- All specimens met requirements

Results

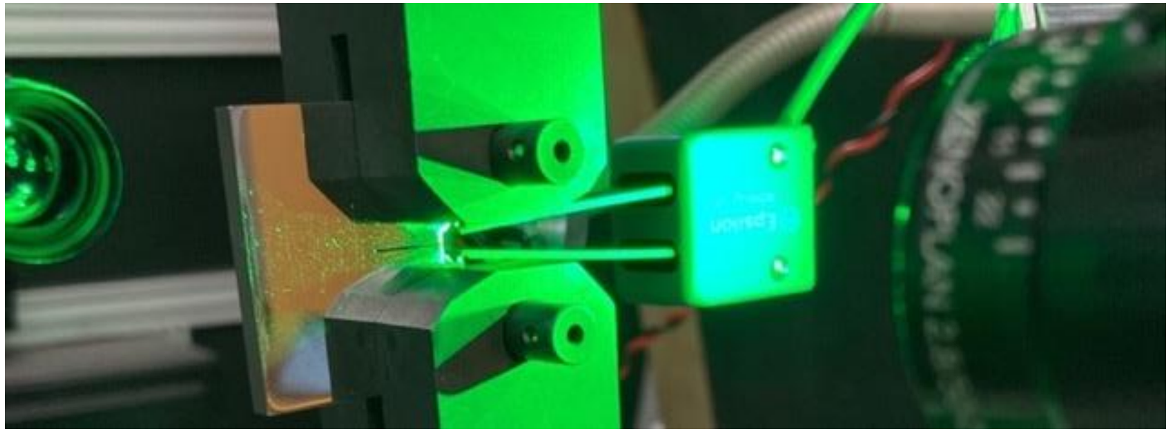
Charpy V-notch Impact Test

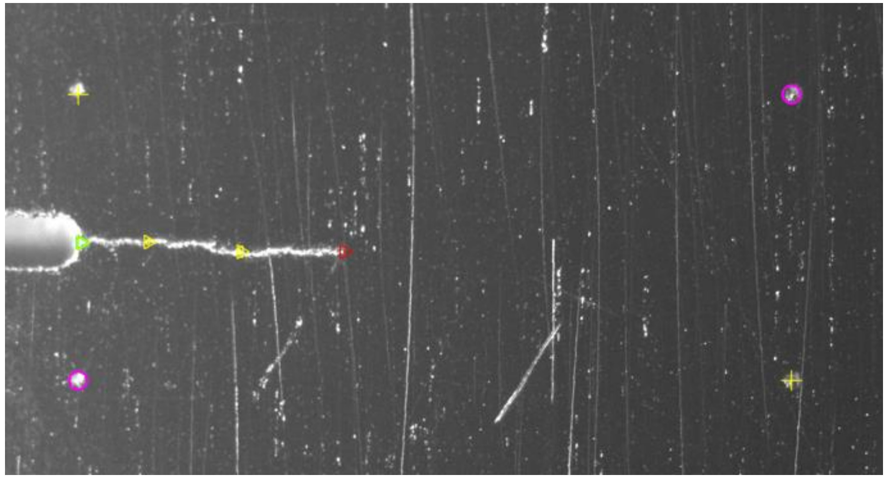
- AS 2885.1
  - Min 27 J for pipe metal
  - Higher as part of the FCP for initiation and propagation
  - HFW seam meet requirements for fracture initiation in HCA in WCL only
- ASME B31.12
  - Min 27 J for WM and HAZ
- BM & HAZ specimens met requirements
- SW centreline did not (vintage steel)

Results

Fatigue Test (ASTM E647)

- Not typically seen as issue with NG pipeline
- Critical to have the FCGR in H_2 to assess remaining life based on operating scenarios
- Results consistent with literature
- Literature was used as basis for preliminary assessment in H_2





Phase 1

Engineering Calculations

Fatigue

Calculations

- Remaining life based on historical cycling
- Maximum cycling for a 100-year life

Defect Cases

- Infinitely long internal defect surviving hydrotest
- Semi-elliptical defect surviving hydrotest
- ASME B31.12 semi-elliptical defect
  - Assumed toughness:
    - 100 Mpa.m$^{0.5}$ in air
    - 50 Mpa.m$^{0.5}$ in H_2

Outputs

- For largest defect to survive hydrotest:
  - Cycling at 1.5 MPa daily is permissible for design life of 100 years at current MAOP
  - Based on historical cycling fatigue life is >1000 years in all cases

Case	Initial defect Depth [mm]	Initial defect Length [mm]	Life with current cycling	Maximum cycling for a 100 year life
1	1.31 (max hydrotest defect)	Inf. Length	Historical cycling H_2: 3,400 years Air: 119,000 years	**2.11 MPa daily cycle** H_2: 100 years Air: 792 years
2	2.36 (max hydrotest defect)	50	Historical cycling H_2: 1,392 years Air: 62,056 years	**1.58 MPa daily cycle** H_2: 100 years Air: 1,029 years
3	1.44 (ASME B31.12 defect)	8.4	Historical cycling H_2: 45,840 years Air:1,023,000 years	**5.28 MPa daily cycle** H_2: 100 years Air: 2,180 years

Fracture Initiation & Propagation

Initiation

Calculations

- Max. axial through-wall CDL for different pressures
- Calcs based on AS 2885.1 Cl 5.5.4 and API 579
    - assuming 50% loss of toughness in hydrogen

Outputs

- 20% CDL reduction in the BM for all wall thicknesses

Case	CDL (mm) at internal pressure of …		
	4.5 MPa(g)	5.6 MPa(g)	10.6 MPa(g)
Wall thickness 5.56 mm			
High toughness	164	125	44
30 J (pipe metal)	150	119	44
15 J (pipe metal with H_2)	128	104	N/A
10 J (weld)	114	93	39
5 J (weld - with H_2)	91	74	N/A

Propagation

Calculations

- Minimum required CVN for RDF control

Cases

- NG, 10% H_2, 100% H_2 ,at 3 pressures

Outputs

- Req fracture arrest energy decrease in H_2

Pressure [MPa(g)]	Minimum required CVN FSE energy [J]		
	Pure methane	10% H_2	Pure H_2
4.5	10.4	9.7	3.8
5.6	14.5	13.4	5.4

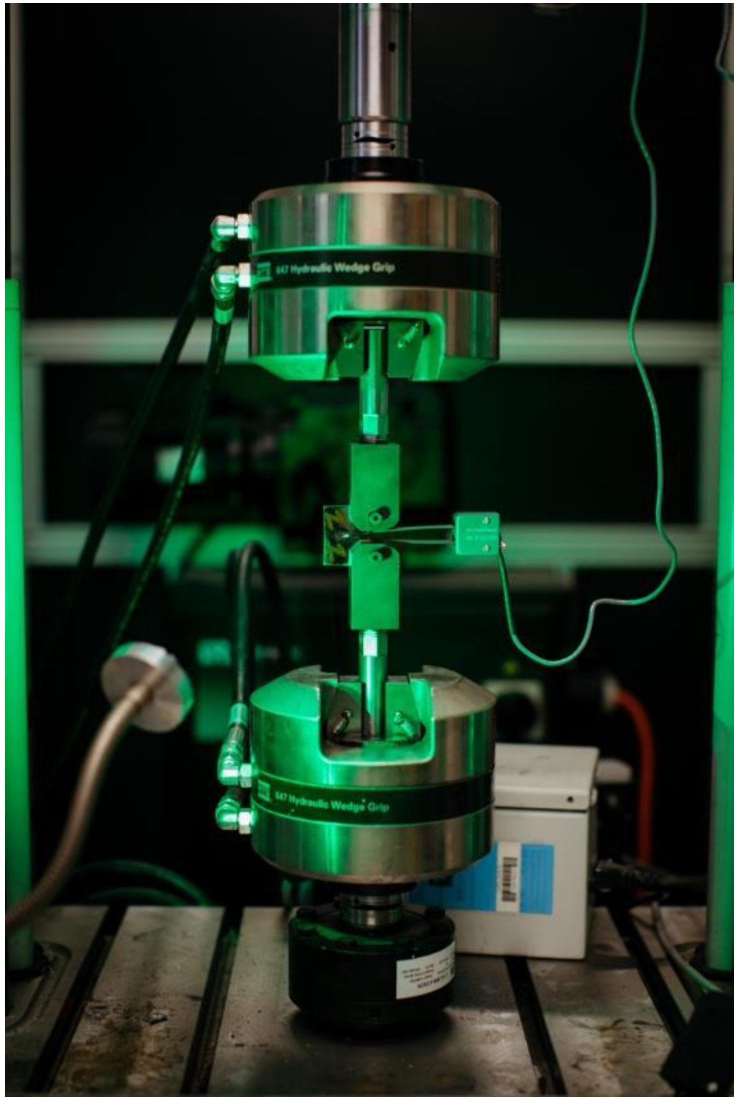
Phase 1

Conclusions & Outlook

Conclusions & Outlook

Phase 1 works indicate the PGP will be suitable for 100% H_2 service

- No service pressure de-rating will be required
- Conversion capacity of 20-50TJ/day achievable
- Safely cycled to about 1.5 MPa/day
- The existing pipeline safety management is altered due to inclusion of hydrogen (e.g. failure mode change)
- Phase 1 results provided confidence for the project to progress to Phase 2 detailed testing and conversion planning



Phase 2

Overview

Test Program

Introduction of hydrogen testing

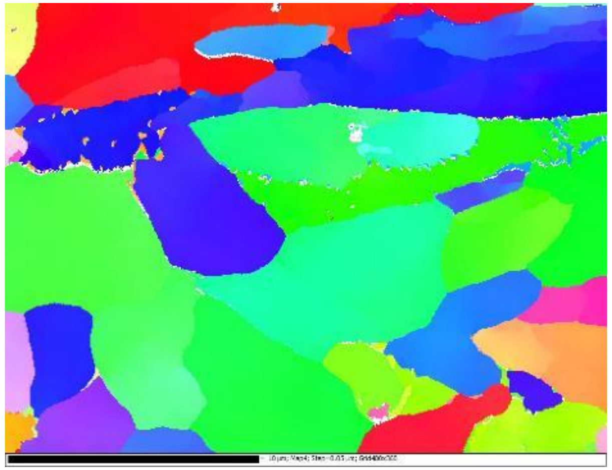
- 5.6 MPa(g)
- Other scenarios for some tests

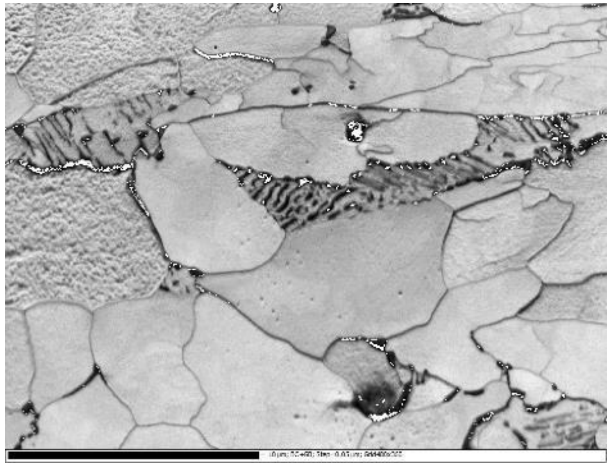
Material Characterisation

- More Detailed Analysis
- Inclusion & Grain Analysis

Strength

- Base Metal Circumferential & Longitudinal Tensile Tests [H_2]
- Cross Seam & Girth Weld Tensile Tests [H_2]





Test Program

3-Point Bend Tests (Static Fracture)

- Base Metal Circumferential & Longitudinal 3-Point Bend Test [air & H_2]

Combined Fracture Toughness & Fatigue

- Base Metal Circumferential & Longitudinal C(T) Tests [H_2]
- Cross Seam Weld C(T) Tests [air & H_2]
- Cross Girth Weld C(T) Tests in the HAZ & WCL [H_2]

Test Program

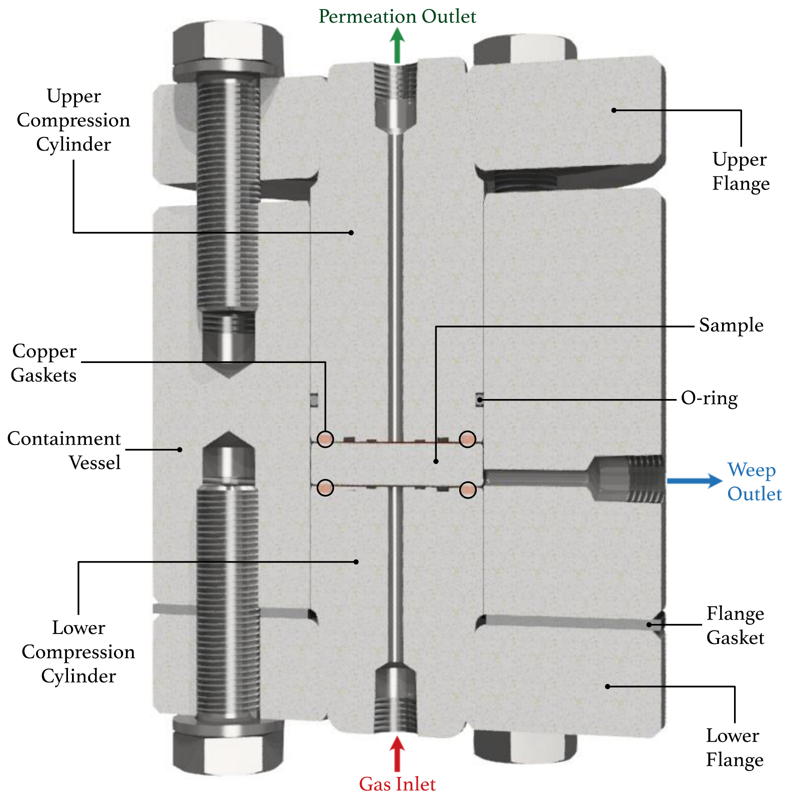
Round Robin

- Sandia National Testing Labs
- Base Metal Circumferential & Longitudinal C(T) Tests [H_2]
- Cross Girth Weld C(T) Tests in the HAZ & WCL [H_2]

Sandia National Laboratories

Permeation

- Multiple pressures and holding times
- Determine time to H_2 saturation
- Compare with fully submerged specimens



High-Strain Rate Testing

- Split Hopkinson Pressure Bar
- Pre-charged H_2 specimens

Phase 2

Laboratory Testing

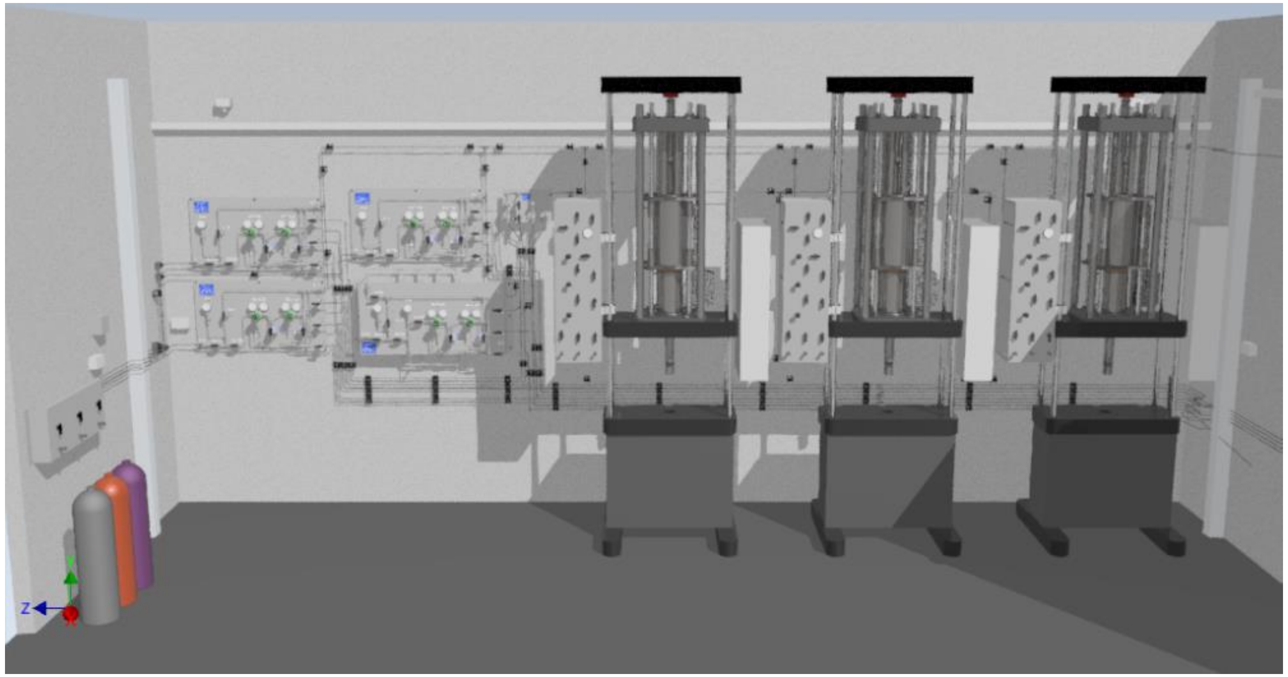
Hydrogen Testing Lab @ UOW

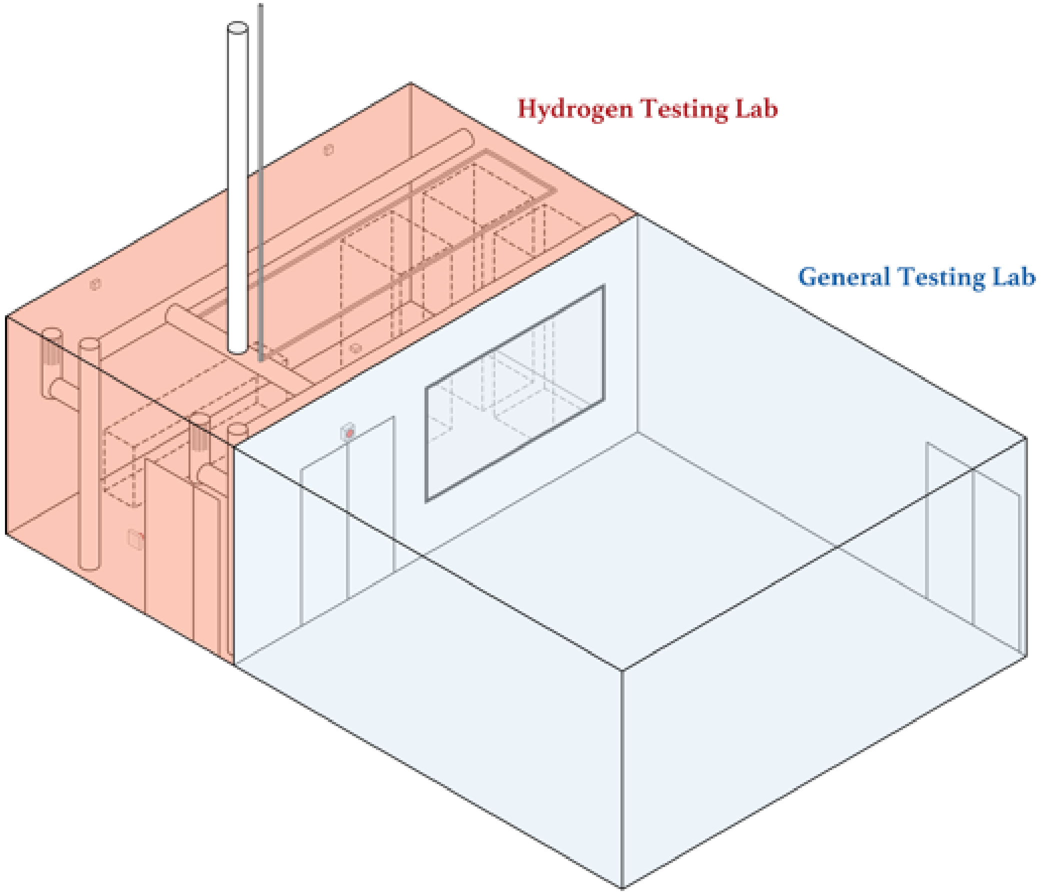
UNIVERSITY OF WOLLONGONG AUSTRALIA

H_2SAFETI LAB

FUTURE FUELS CRC

Hydrogen Testing Lab @ UOW





Test pressure up to 200 bar @ RT

Minimise Volume

- Max volume of hydrogen at any time in the lab <50% of the LEL (i.e. 2% v/v)
- Generally H_2 volume <25% v/v

Active Ventilation

- Continuous exchange with fresh air pumped in (> 4 air exchanges per hour)
- Can be manually switched to higher exchange rate

Continuous Monitoring

- O_2 and H_2 continuously measured
- Fed to centralised system

Centralised Purge Line

- All vessel contents can be purged to a central line that exhaust gases to atmosphere above roof

3rd Party Hazardous Assessment

- Certified as a Non-Hazardous Area

Hydrogen Testing Lab @ UOW

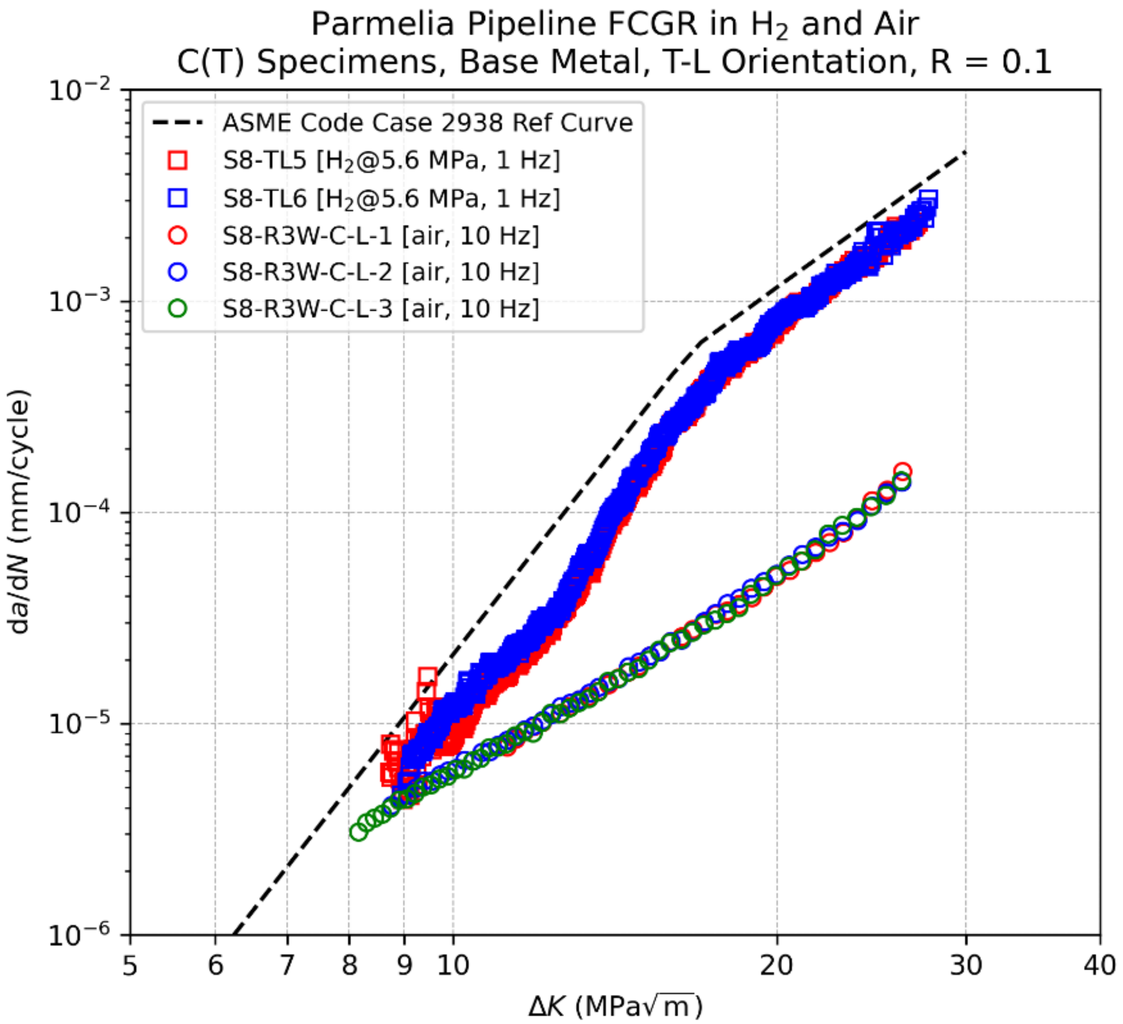
Hydrogen Testing Lab @ UOW

Hydrogen Testing Lab @ UOW

Phase 2

Round Robin Testing

Fatigue

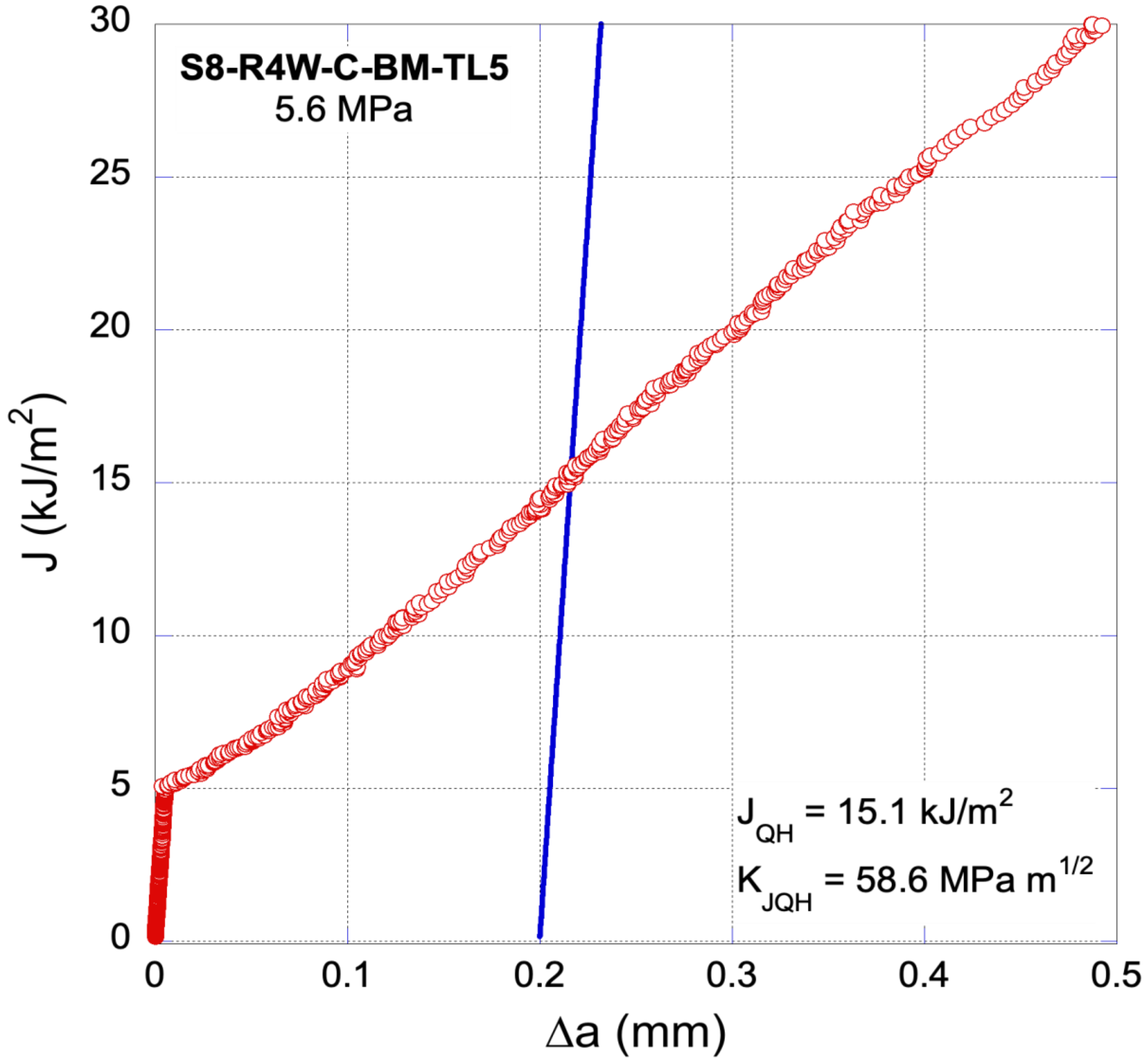


- So far two tests in H_2 @ 5.6 MPa
- Combined fatigue and fracture resistance
- Good repeatability
- Challenges observed during air (UOW) testing also showed up for H_2 testing (Sandia)

Fatigue

- Ref. curve from ASME Code Case 2938 provides a conservative prediction of the material performance at this R ratio and pressure
- Support the preliminary engineering calculations conducted in Phase 1 of the project based on expected material behaviour.

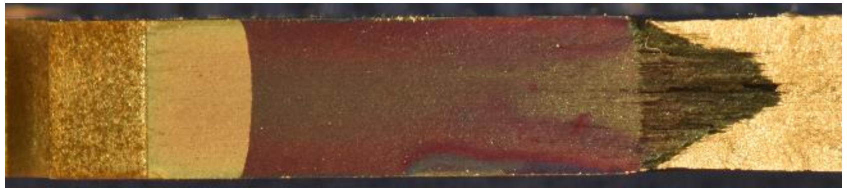
Fracture Resistance



Fracture Resistance

- 118 MPa.m$^{0.5}$ (air) to 58 MPa.m$^{0.5}$ (H_2)
- Loss of 50%
- Met ASME B31.12 requirement of 55 MPa.m$^{0.5}$

Air



H_2

Phase 2

Conclusions & Outlook

Conclusions & Outlook

- Hydrogen testing in the H2SAFE(TI) Lab @ UOW begins in June
- Project runs until December 2022
- Update Engineering Assessment
- Refine Safety Management Study
- Prepare Conversion Design Basis
- Inform Regulatory and Stakeholder Engagement
- Results will be disseminated in future proceedings

FUTURE FUELS CRC

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Thank you for your attention.