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"Gas: Sustaining Future Global Growth"

Managing Integrity of High Pressure Gas Pipeline: Root Cause Analysis and Hydrogen Induced Crack (HIC) Direct Assessment of Weldment Crack on 30" Gas Pipeline

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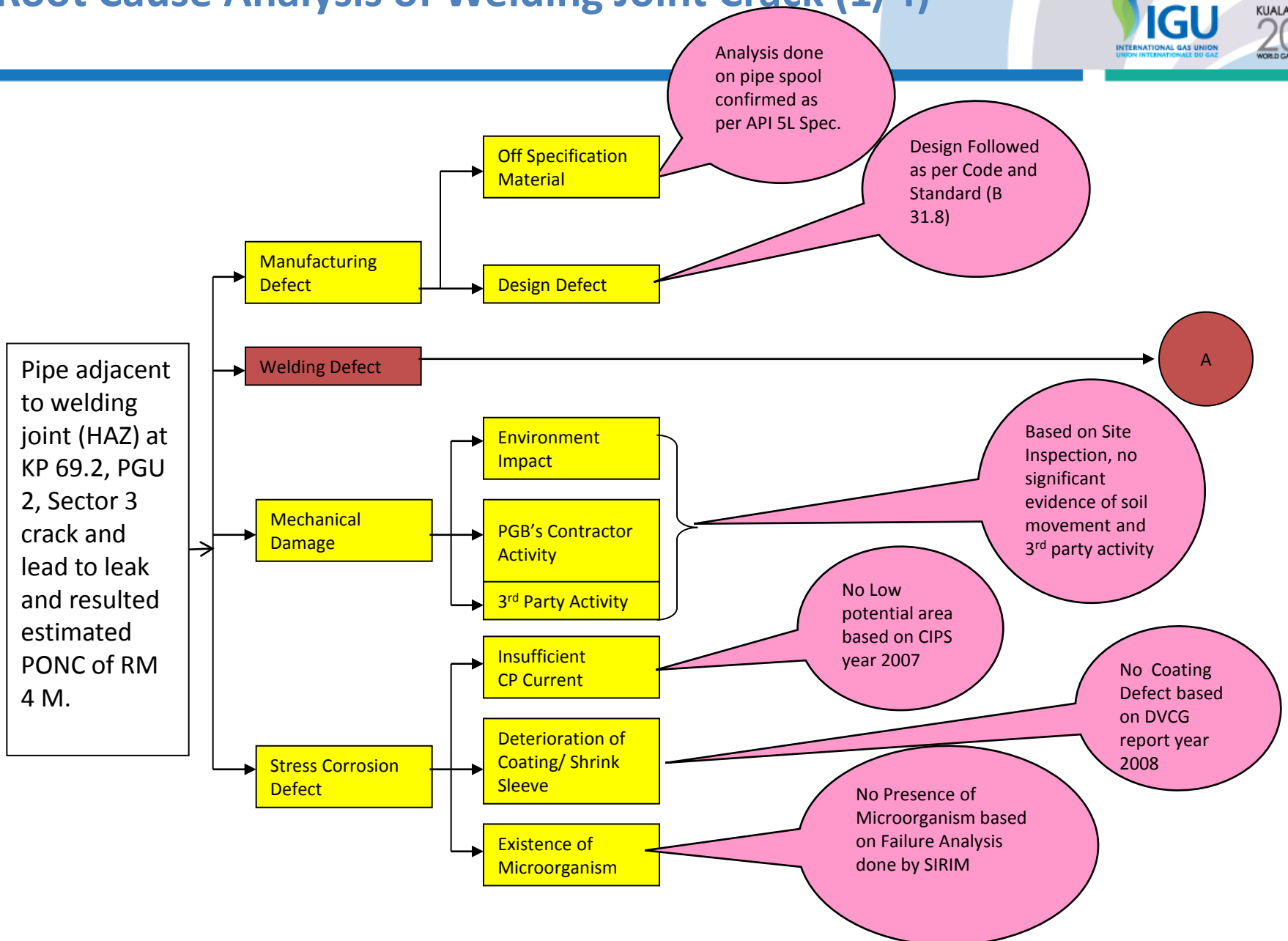
Presentation Content

- Background
- Root Cause Analysis of Welding Joint Crack
- Hydrogen Induced Cracking Direct Assessment (HICDA)
- Advance Crack Assessment via API 579-1/ASME FFS-1
- Conclusions
- Recommendations

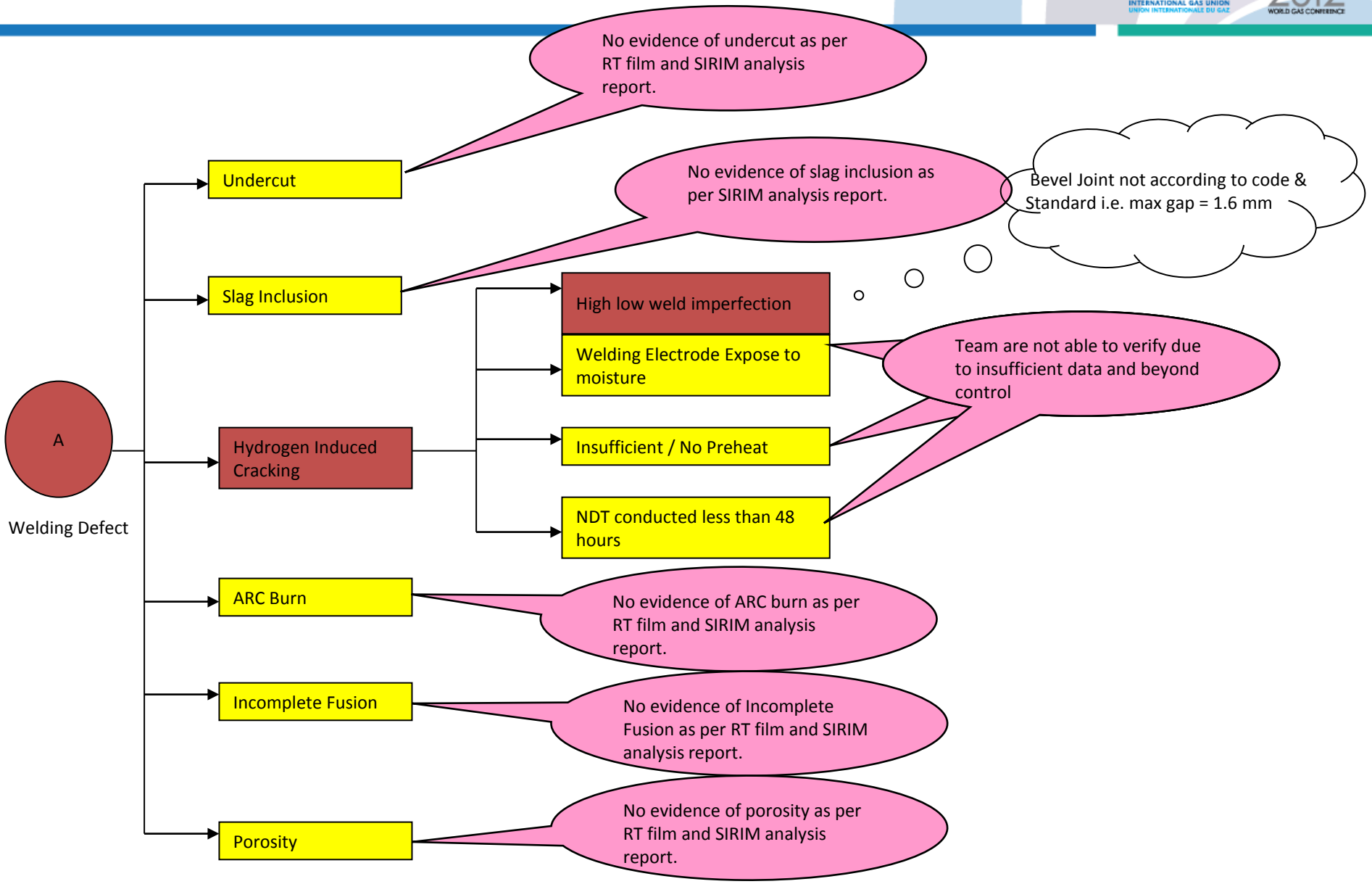
Background

- Constructed in 1989 and commissioned in 1991. It has been in operation for 20 years.
- 209 km length from SOC to Pasir Gudang MS.
- On 15 Feb 2009, pipe cracked at KP 69.2, Bekok along the circumferential weld from about 5-to-7 o'clock positions.

Root Cause Analysis of Welding Joint Crack (1/4)



Root Cause Analysis of Welding Joint Crack (2/4)



Root Cause Analysis of Welding Joint Crack (3/4)

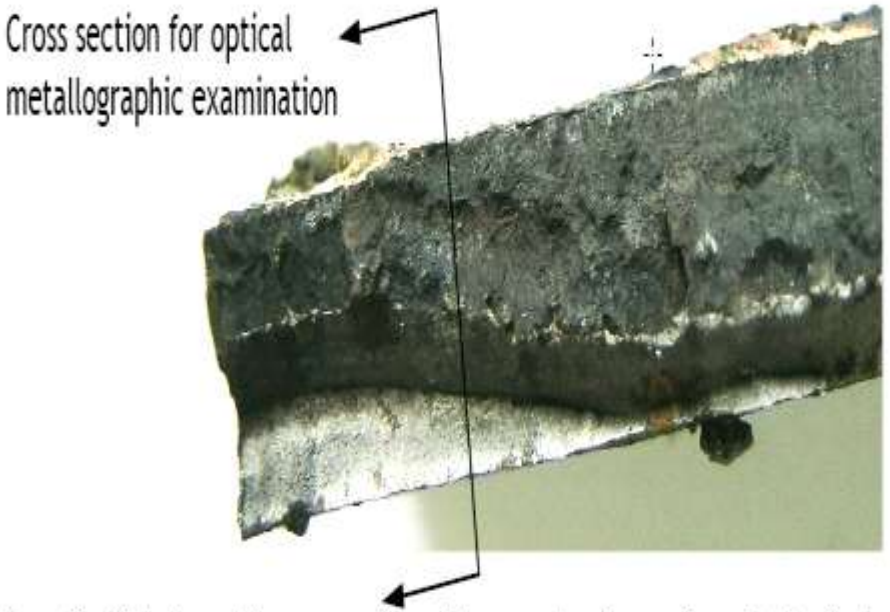


Figure 8: Metallographic cross section at the same location on the matching fracture surface (with that of Figure 7)

- Cracks initiated at weld toes due to hydrogen induced cracking mechanism leading to the formation of dark fracture surface filled with oxides.

<u>Factors contributed to HIC :</u>

- ✓ High-low weld imperfection
- ✓ Insufficient (or no) preheat
- ✓ Welding electrodes exposed to moisture in hot and humid conditions.
- ✓ NDT inspection conducted in less than 48 hours after the welding might miss any sign of HIC which might occur after a period of several hours.

Root Cause Analysis of Welding Joint Crack (4/4)

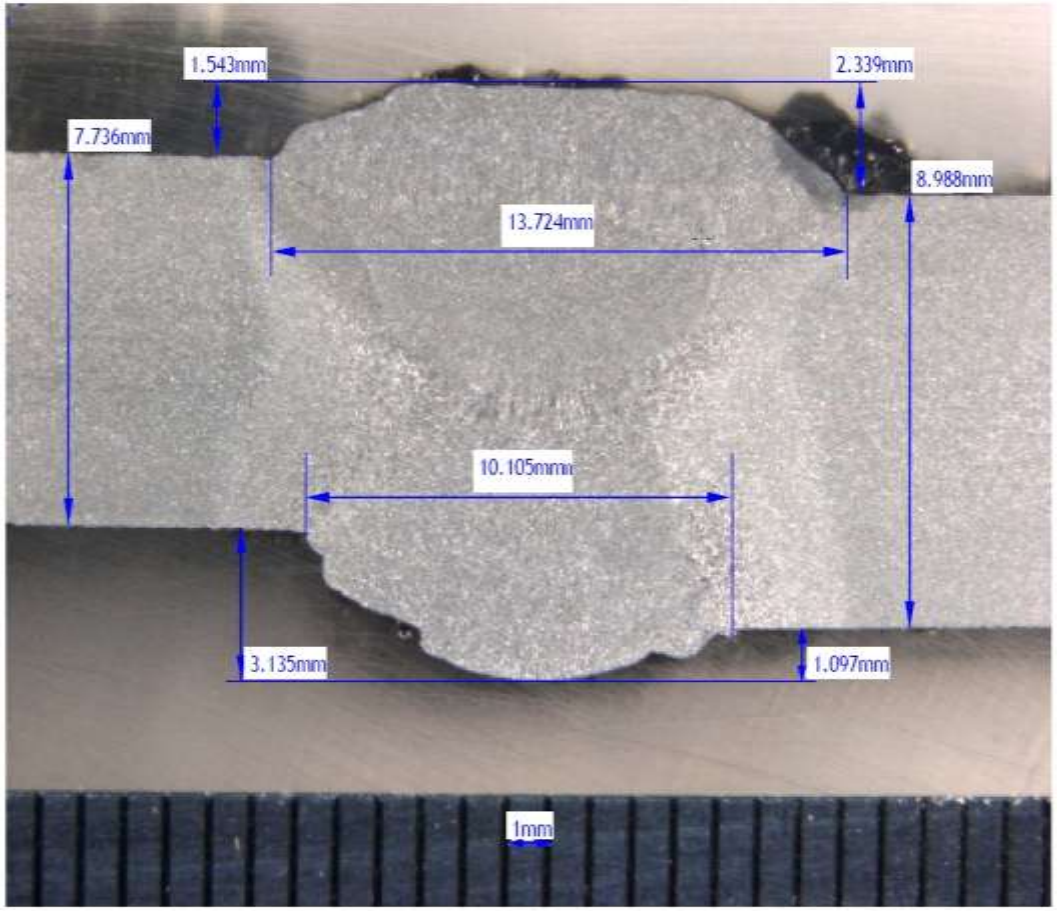
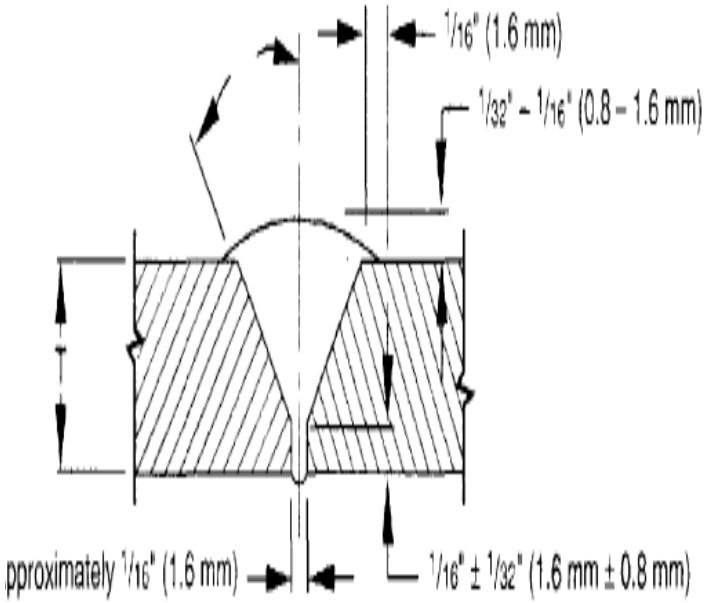


Figure 18: Macro examination of weld imperfection randomly selected from the sample

API 1104:



Standard V-Bevel Butt Joint

Hydrogen Induced Cracking Direct Assessment (HICDA) (1/9) - The 3-steps approach (1/3)

- **Step 1- Pre-assessment**
  - ✓Established a set of prescriptive criteria to enable team to focus on the issue at hand rather than being too general.
  - ✓The criteria are:-
    - Weldment welded by same welder/s during construction.
    - Weldment that is tie-in and/or golden weld during construction.
    - Weldment that has gone through repair i.e. cut-out during construction.
    - Pipeline portion that is located at downhill and/or uphill area.
  - ✓Cross referencing with the following records/reports:-
    - Route & Profile as-built drawings.
    - Tie-in and cut-out reports.
    - Pipeline welding book.
    - NDT records during construction i.e. radiographic testing.
  - ✓Utilising GIS to identify the locations.
  - ✓Prioritising the weldments for the next step of direct assessment based on pipeline location i.e. in High Consequence Areas (HCAs).

Hydrogen Induced Cracking Direct Assessment (HICDA) (2/9) - The 3-steps approach (2/3)

- **Step 2- Direct examination**
  - ✓Based on the prioritised list, excavations were carried out based on company's procedures, work instructions and HSE requirements.
  - ✓The original field joint coating i.e. heat shrink sleeve was removed and the weldment was cleaned and prepared for NDT.
  - ✓Three NDT methods were employed i.e. radiographic test (RT), ultrasonic test flaw detection (UTFD) and magnetic particle inspection (MPI). Results from NDT were assessed and evaluated based on acceptance criteria from ASME B31.8-2010 Gas Transmission and Distribution Piping System and API 1104-2005 Welding of Pipelines and Related Facilities.
  - ✓If found crack, temporary repair was performed i.e. installation of leak clamp and/or installation of overlapped composite sleeve.

Hydrogen Induced Cracking Direct Assessment (HICDA) (3/9) - The 3-steps approach (3/3)

- **Step 3- Post assessment**
  - ✓Results from the NDT were assessed and evaluated based on acceptance criteria from ASME B31.8-2010 Gas Transmission and Distribution Piping System and API 1104-2005 Welding of Pipelines and Related Facilities.
  - ✓For crack that was unacceptable to the above codes, advance assessment was conducted utilising API 579-1/ASME FFS-1 2007 Fitness-For-Service Part 9- Assessment of Crack-Like Flaws - Level 3 and remaining life assessments. Following the assessments, re-inspection period was determined.
  - ✓If requires permanent repair, it will be conducted per PTS 31.40.60.12 Pipeline Repairs.
  - ✓A comprehensive report will be prepared for future reference.

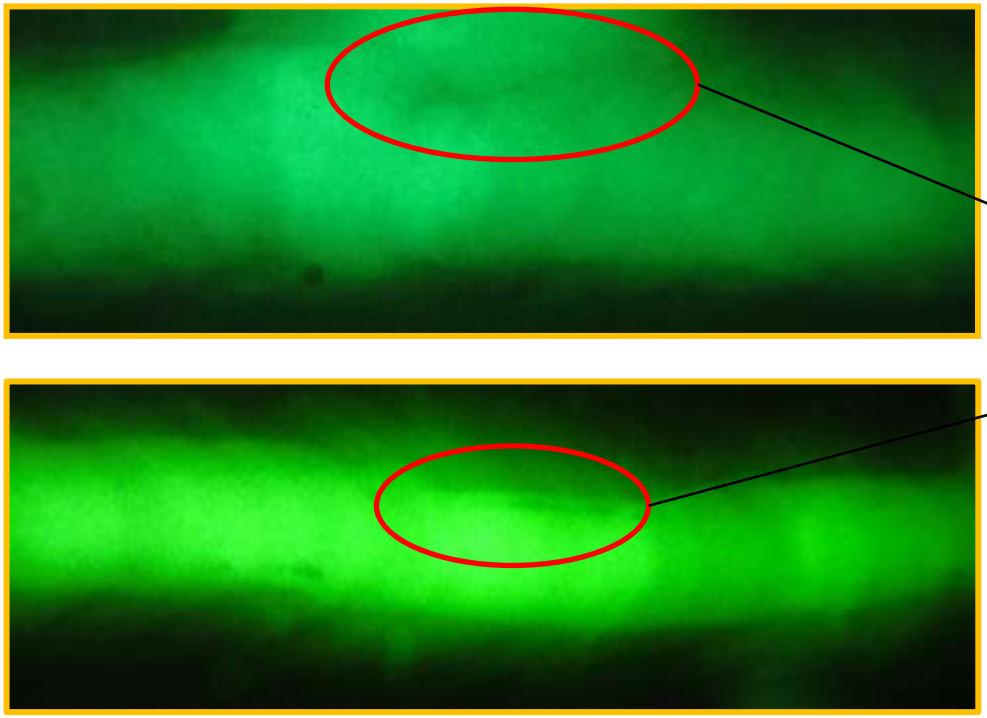
Hydrogen Induced Cracking Direct Assessment (HICDA) (4/9) - Findings from Pre-assessment

- 160 nos of tie-in joints were identified by same welder.
- 20 nos of tie-in joints were located at hilly terrain area.
- Revisit inspection on RT films during construction:-
  - ✓ 9 weldments are suspected to have delayed HIC cracks

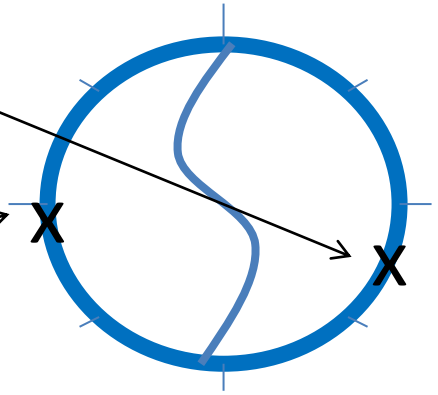
No	Weld No	Location	Finding
1	22zt45B	Bukit Siput	**Confirmed cracks at 2 locations**
2	39zt16		**Acceptable**
3	39zt19	Tenang	**Confirmed cracks at 2 locations**
4	43zt41A		**Acceptable**
5	48zt64		**Acceptable**
6	62zt17A		**Acceptable**
7	65z38c/o		**Acceptable**
8	99zt22Ac/o		**Acceptable**
9	151zt68	Sedenak	**Confirmed cracks at 2 locations**

Hydrogen Induced Cracking Direct Assessment (HICDA) (5/9) - Findings from Direct Examination (1/2)

Location	Findings	Remarks
Bukit Siput	Cracks at 2 locations	1) 840 mm from 12 o'clock (L: 25 mm, D: 4-6 mm) 2) 1600 mm from 12 o'clock (L: 15 mm, D: 4-6 mm)



Cracks RT Film



Position of cracks

Hydrogen Induced Cracking Direct Assessment (HICDA) (6/9) - Findings from Direct Examination (2/2)

RT report

DENSITY : 2-9

WELD IDENTIFICATION	POSITION	PIPE DIAMETER	MATERIAL THICKNESS/ REINFORCEMENT	EXCESS PENETRATION	BURN THROUGH	SLAG INCLUSION	POROSITY	CONCAVITY	UNDERCUT	INCOMPLETE PENETRATION	LACK OF FUSION	CRACK	TUNGSTEN	SURFACE	NO SIGNIFICANT DISCONTINUITY	ACCEPT	REJECT	REMARKS
22 ZT 45 B - KP : 22-658 DRT-SIPUT-	0 - 1	30"	T-56mm				/	/	/							/		
	1 - 2						/		/			/					/	LONG. SEAM
	2 - 3					/	/	/	/							/		
	3 - 4						/	/				/					/	D. SEAM
	4 - 6			/		/	/		/							/		
			/															

UT report

NO	PART INSPECTED	WELDER NO	RESULT	REMAKS
	JT NO : 22 ZT 45B		☐ ACC ☐ REJ	④ Crack L = 20 mm D = 4-6 mm ① Crack L = 40 mm D = 4-7 mm ③ Slag / Porosity L = 30 mm D = 3-6 mm ⑤ Slag / Porosity L = 20 mm D = 3-6 mm
			☐ ACC ☐ REJ	
			☐ ACC ☐ REJ	
			☐ ACC ☐ REJ	
			☐ ACC ☐ REJ	
			☐ ACC ☐ REJ	
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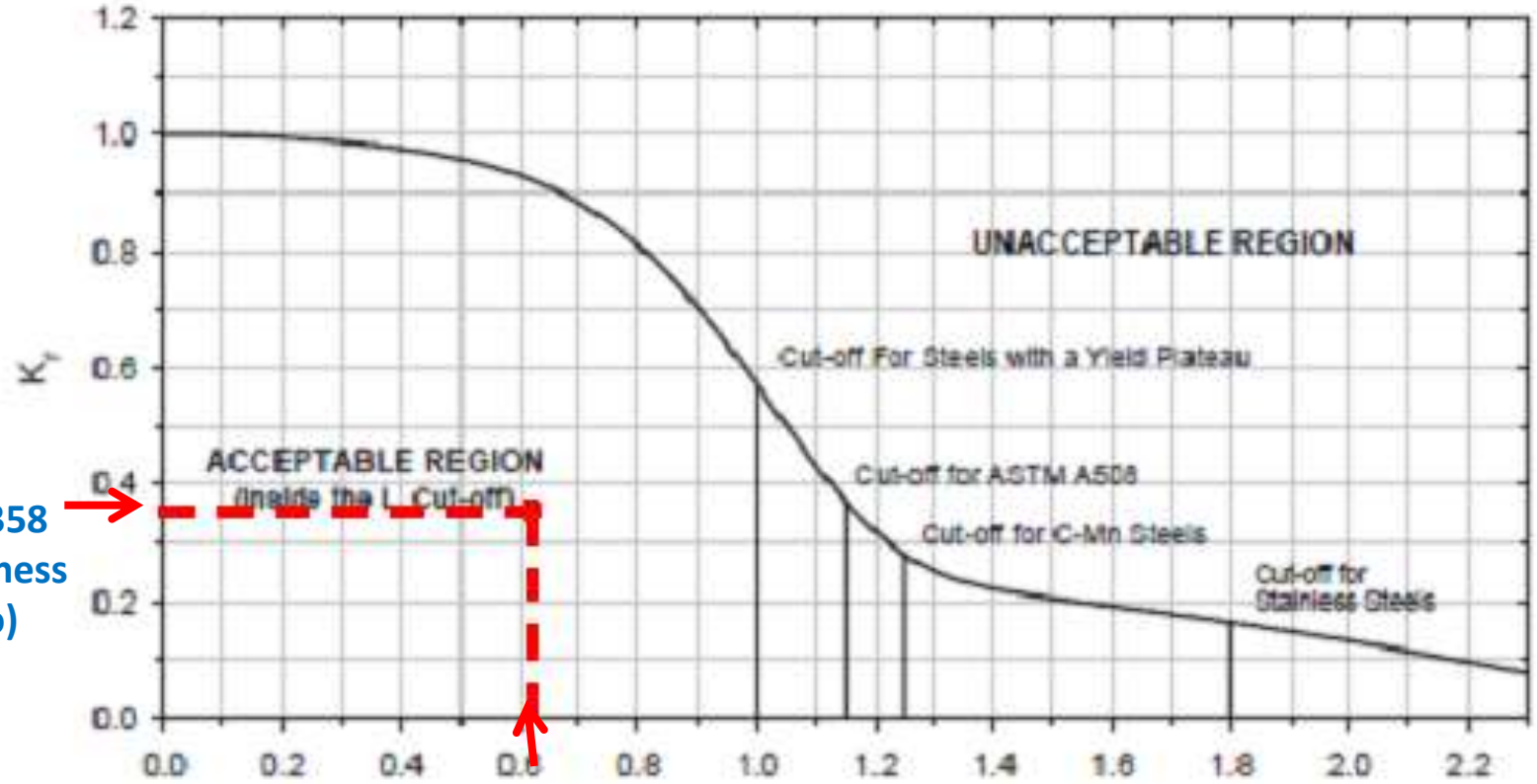
Hydrogen Induced Cracking Direct Assessment (HICDA) (7/9) - Results from Post-assessment – FFS API 579-1/ASME FFS-1 (1/2)



Kr=0.358 (Toughness ratio)

Lr=0.61 (Load ratio)

Conclusion: The crack on the weldment of the pipeline is acceptable per Level 2 assessment

Hydrogen Induced Cracking Direct Assessment (HICDA) (8/9) - Results from Post-assessment – FFS API 579-1/ASME FFS-1 (2/2)

Crack Growth Preliminary / Screening Assessment

The procedure for this calculation sheet is to compare the ΔK_{th} value based on maximum (take as pipeline MAOP) and minimum operating pressure with the threshold ΔK_{th} value as define in paragraph F.5.3.2.d

The following threshold stress intensity value can be used to identify the possibilities of fatigue crack growth:

$$\Delta K_{th} := 2.0 \cdot MPa \cdot m^{0.5}$$

At maximum pressure, $P_{op(max)}$ = 68.95 barg

K_{max} = 38.8 MPa.$m^{0.5}$

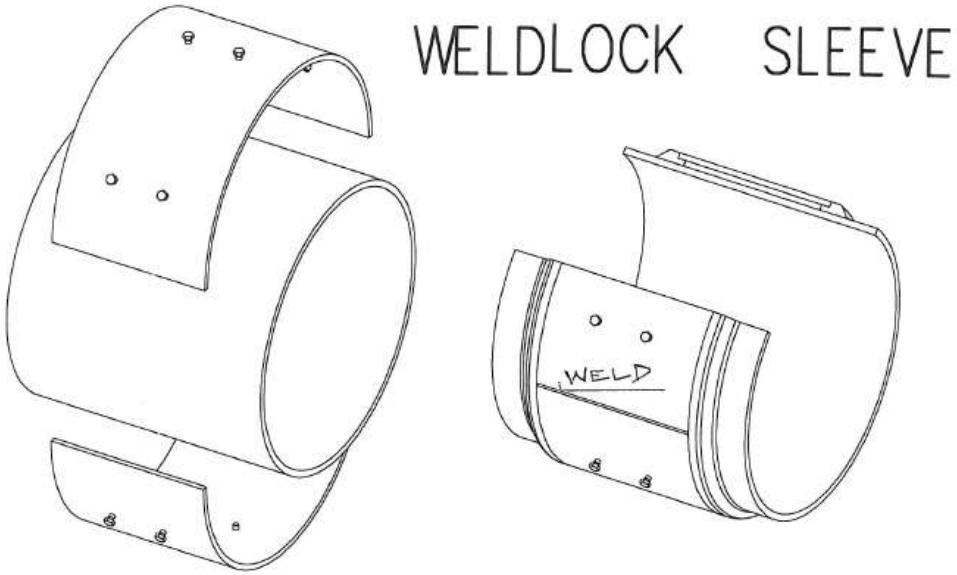
At minimum pressure, $P_{op(min)}$ = 28.9 barg

K_{min} = 18.2 MPa.$m^{0.5}$

$\Delta K = K_{max} - K_{min}$ = 20.6 MPa.$m^{0.5}$

ΔK (20.6 MPa.$m^{0.5}$) > ΔK_{th} (2 MPa.$m^{0.5}$), the crack is propagating in through thickness direction

Hydrogen Induced Cracking Direct Assessment (HICDA) (9/9) - Results from Post-assessment – Repair using Welded Sleeve



Installation Effects of Sleeve

- Local reinforcing of pipe wall in defect area.
- Prevention from defect bulging and crack opening—reduced static and cyclic load in the defect from internal pressure of medium transported.

Application of Sleeves

- Suitable for all types of defects with a depth up to 80 % WT.
- Installation without shutdown.
- High integrity of the reinforced pipeline.

Conclusions

- The Root Cause Analysis (RCA) conducted for the failed welding joint of the 30” gas pipeline yields the followings:-
  - ✓ It was hydrogen induced cracking (HIC) mechanism that failed the welding joint
  - ✓ The contributing factor highly possibly due to the welding process i.e. joint design incompliance with API 1104 standard
  - ✓ The defect/crack was not detected in the radiographic testing during the project/construction of the pipeline
- Lessons learnt from the incident as well as from the RCA are follows:-
  - ✓ Requirement of performing NDT for field joint welding i.e. after 48 hours need to be clearly stated in construction procedure
  - ✓ Requirement of using low hydrogen electrode need to be clearly stated in construction procedure
  - ✓ Requirement of having at least two inspectors for field welding inspection and verification to be strongly considered especially for tie-in and golden weld
- The 3-steps HIC direct assessment (HICDA) process yields satisfactory and acceptable results to maintain the integrity of the pipeline AND can be regarded as one of alternative integrity assessment methods to assess pipeline with HIC threat
- Fitness-for-service (FFS) assessment using API 579-1/ASME FFS-1 codes for the weldment crack was conducted for both cases i.e. current integrity and screening analysis for crack growth
- Pro-active repair was employed for the pipeline using fully welded sleeve

Recommendations

- PETRONAS recommends for pipeline operators to adopt the HICDA approach as an alternative integrity assessment method for pipeline that experiences HIC threat
- PETRONAS will codify the HIC direct assessment (HICDA) process as PETRONAS Technical Standard (PTS) and will share with international pipeline fraternity