

# INEOS

## Crack Susceptibility Analysis

Pedro Barbosa & Jamie Martin | INEOS Crack Susceptibility Analysis | © ROSEN Group | 26<sup>th</sup> February 2025

Obere Spichermatt 14 · 6370 Stans · Switzerland · Phone: +41-41-618-0300 · info@rosen-group.com  
© 2024 ROSEN Swiss AG All Rights Reserved.

This document is the property of ROSEN Swiss AG who will safeguard its rights according to the applicable civil and criminal law provisions. No part of this document may be reproduced or disclosed to any third party without the prior written consent of ROSEN Swiss AG. The information provided in this document is for general informational purposes only and does not constitute any professional advice or any legally binding offer. While every effort has been made to ensure the accuracy of the information provided, no warranties, guarantees or representations, either expressed or implied, are made as to the completeness, accuracy, reliability, or timeliness of the information. Any data, specifications, and any other information included are subject to change without prior notice. Any liability for damages or losses including but not limited to, compensatory, direct, indirect or consequential damage, loss of income or profit, loss of or damage to property and claims by a third party resulting from the use of the information in this document is excluded to the extent permitted by law.

# Content

- 01 | ROSEN UK
- 02 | The Importance of Crack Susceptibility Analysis
- 03 | INEOS Case Study

# 1. ROSEN UK



**Pedro Barbosa**  
Head of Sales  
(Distribution Office)  
ROSEN UK



**Jamie Martin**  
Senior Engineer  
(Crack Management)  
ROSEN UK

# ROSEN IN THE UK

## ROSEN UK vs ROSEN EUROPE (BV)

**Integrity Solutions:**  
Integrity Assessment & Engineering Consultancy Services  
*ROSEN (UK) Ltd*

**Test Facility & Lab:**  
Materials, Corrosion & Welding Testing  
NDT & CP  
*ROSEN (UK) Ltd*

**Diagnostic Solutions:**  
In-line Inspection, NDT & Pigging Services  
*ROSEN Europe BV*

**Integrity Solutions:**  
Offshore Consultancy Services  
*ROSEN(UK) Ltd*

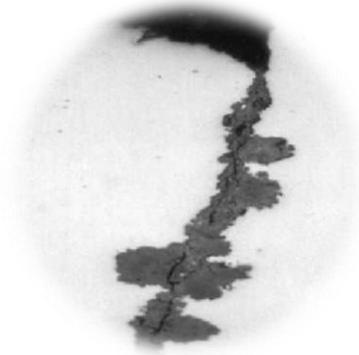


## 2. The Importance of Crack Susceptibility Analysis

# TYPES OF CRACKING AND SUSCEPTIBILITY INDICATORS

## Typical Cracking Mechanisms

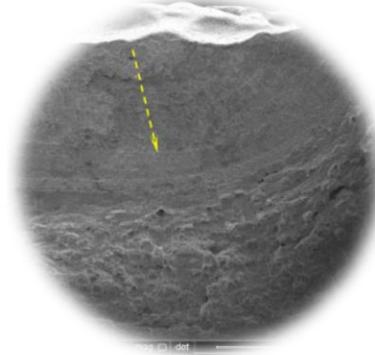
**Near-neutral pH SCC**



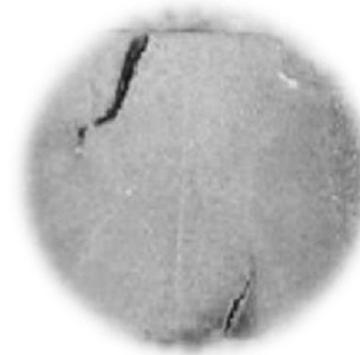
**Weld metal cracks**



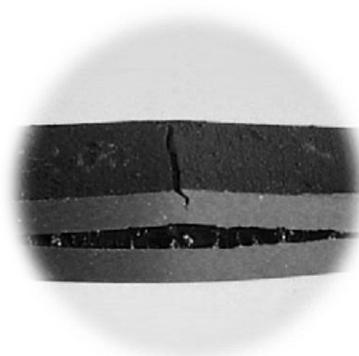
**HAZ fatigue cracks**



**ERW hook cracks**



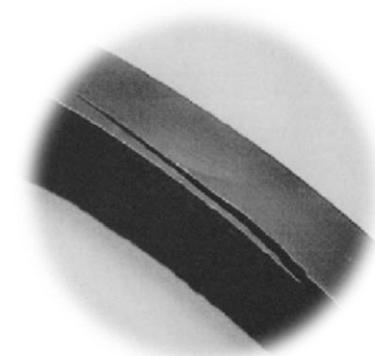
**Hydrogen Induced Cracking**



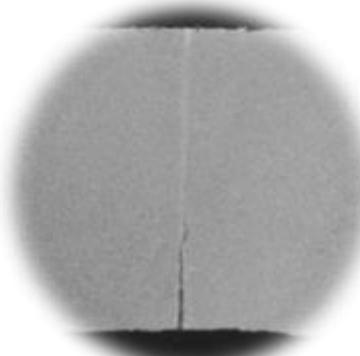
**High pH SCC**



**Laminations**



**ERW lack of fusion**

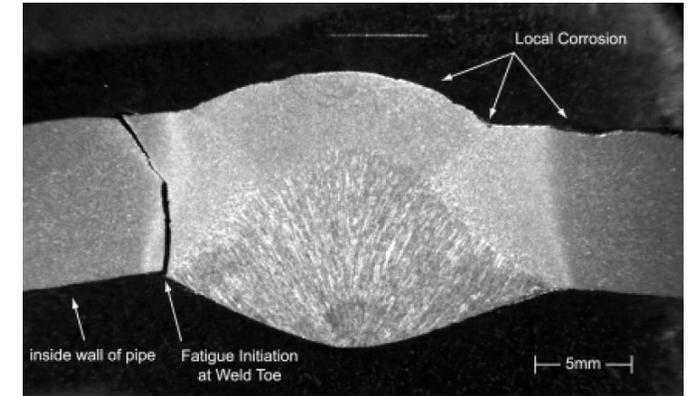


# TYPES OF CRACKING AND SUSCEPTIBILITY INDICATORS

## What is a Crack? ...and what is a Crack-Like?

ASME B31.8S defines a **crack** as a....

*“.. narrow, elongated defect caused by **mechanical splitting into two parts...**”*



**“Crack-like” defects....**

*“..feature **has the shape of a crack** but where material on opposite face of feature **was never fused or bonded**”...” (USA NTSB)...*

*An anomaly, similar to a crack that may or may not have a sharp root radius and with an opening of the fracture surfaces in the order of 0.1 mm or more. (POF)*

# TYPES OF CRACKING AND SUSCEPTIBILITY INDICATORS

What is a Crack? ...and what is a Crack-Like?

API 579 definition: ***“A flaw that may or may not be the result of linear rupture, but which has the physical characteristics of a crack when detected by an NDE technique...”***

*Examples of crack-like flaws include planar cracks, lack of fusion and lack of penetration in welds, sharp groove-like localized corrosion, and branch type cracks associated with environmental cracking.”*

@Pedro definition: “A crack-like anomaly presents itself as a planar (2D) feature that may or may not have a sharp root radius, and because it has the physical characteristics of a crack when detected by an NDE technique it can’t be disregarded as a potential “real crack” until further investigation.”

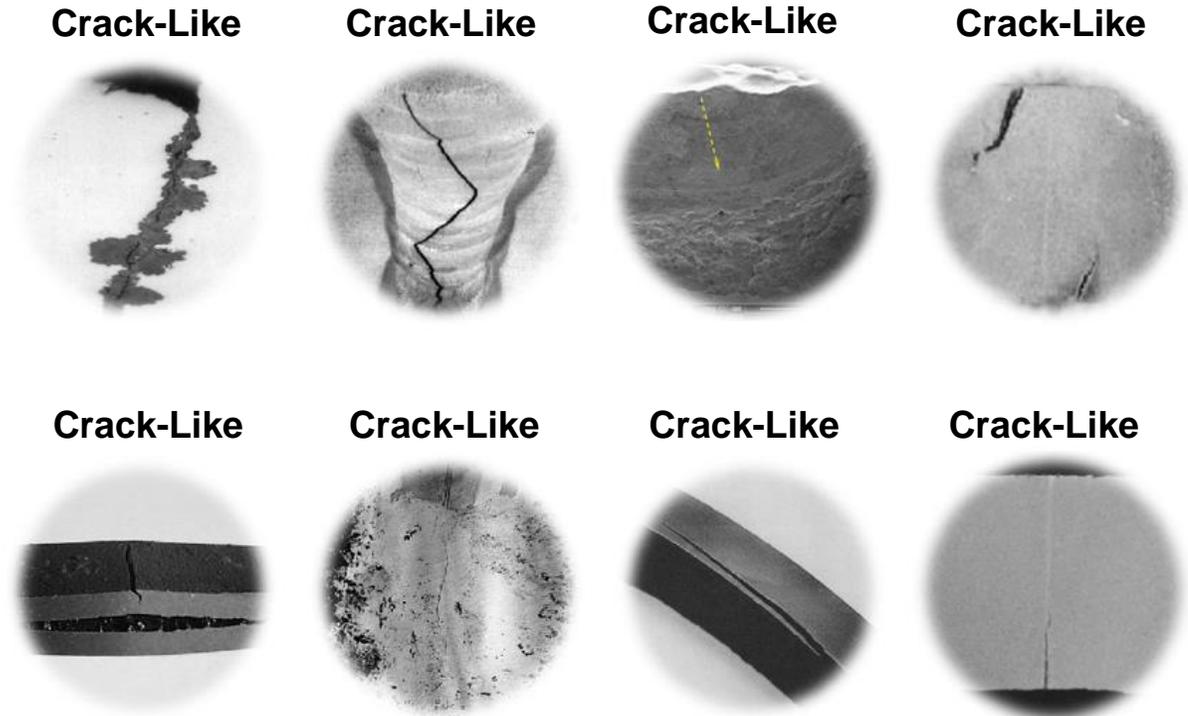
# TYPES OF CRACKING AND SUSCEPTIBILITY INDICATORS

What is a Crack? ...and what is a Crack-Like?

NDE / ILI tools can't generally discriminate between 2D anomalies that pose an integrity threat from those that don't

This uncertainty also contributes to the challenge that is the management of cracking in pipelines

1. Detection
2. Identification
3. Sizing



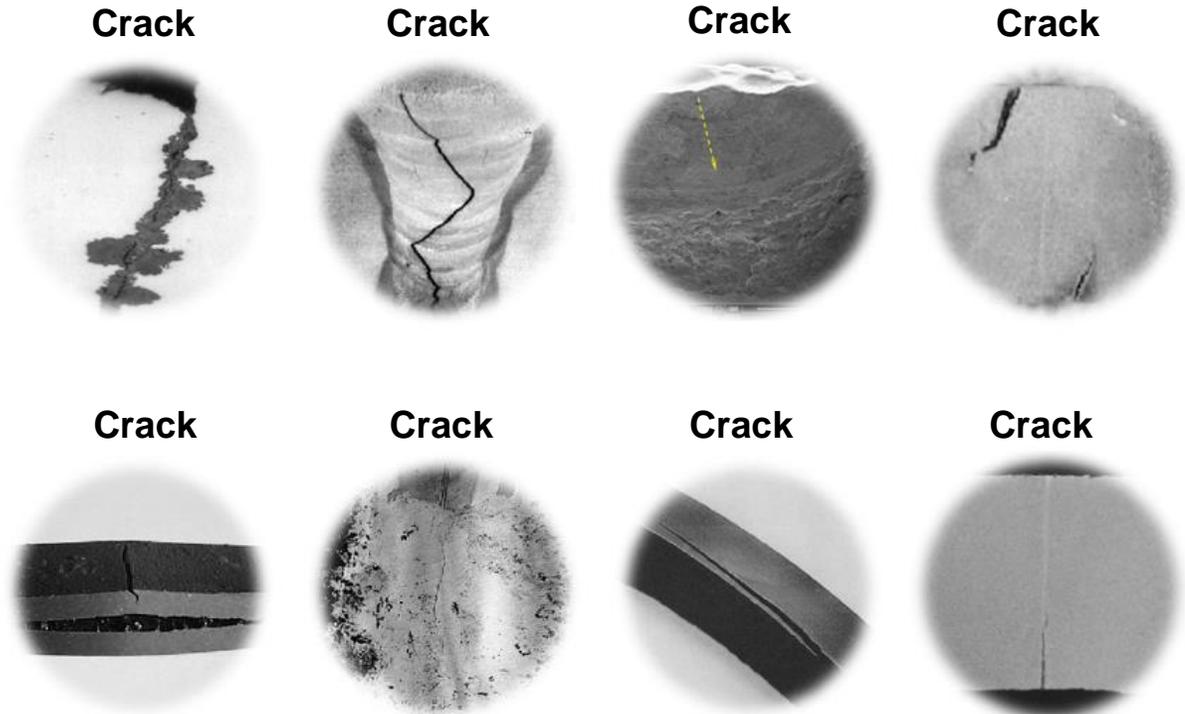
# TYPES OF CRACKING AND SUSCEPTIBILITY INDICATORS

What is a Crack? ...and what is a Crack-Like?

NDE / ILI tools can't generally discriminate between 2D anomalies that pose an integrity threat from those that don't

This uncertainty also contributes to the challenge that is the management of cracking in pipelines

1. Detection
2. Identification
3. Sizing



# TYPES OF CRACKING AND SUSCEPTIBILITY INDICATORS

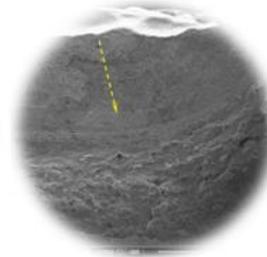
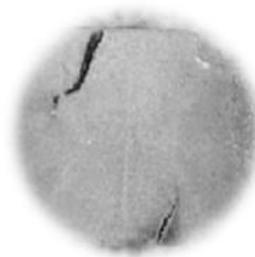
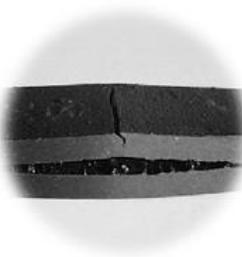
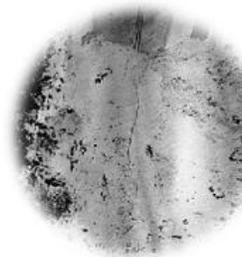
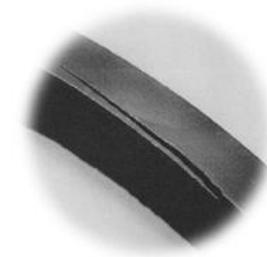
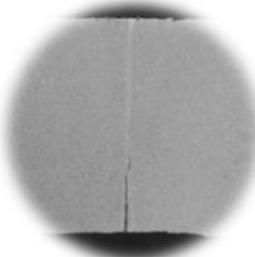
What is a Crack? ...and what is a Crack-Like?

Therefore, the importance of characterising the cracking threat ahead of an inspection, which will support the prioritisation of anomalies and the subsequent integrity management plan

## 0. Susceptibility

1. Detection
2. Identification
3. Sizing

Example:

<b>Possible</b> Near-neutral pH SCC	Weld Metal cracks <b>Not Likely</b>	HAZ Fatigue Cracks <b>Not Likely</b>	ERW Hook cracks <b>Not Likely</b>
			
Hydrogen Induced Cracking <b>Not Likely</b>	<b>Possible</b> High pH SCC	Laminations <b>Not Likely</b>	ERW lack of fusion <b>Not Likely</b>
			

# TYPES OF CRACKING AND SUSCEPTIBILITY INDICATORS

What is a Crack? ...and what is a Crack-Like?

Therefore, the importance of characterising the cracking threat ahead of an inspection, which will support the prioritisation of anomalies and the subsequent integrity management plan

- 0. Susceptibility
- 1. Detection
- 2. Identification
- 3. Sizing
- 4. **Validation**



Example:

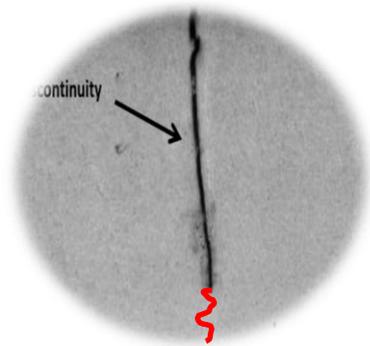
Verified	Weld Metal cracks	HAZ Fatigue cracks	ERW Hook cracks
Near-neutral pH SCC	<b>Not Present</b>	<b>Not Present</b>	<b>Not Present</b>
Hydrogen Induced Cracking	High pH SCC	Laminations	ERW lack of fusion
<b>Not Present</b>	<b>Not Present</b>	<b>Not Present</b>	<b>Not Present</b>

# TYPES OF CRACKING AND SUSCEPTIBILITY INDICATORS

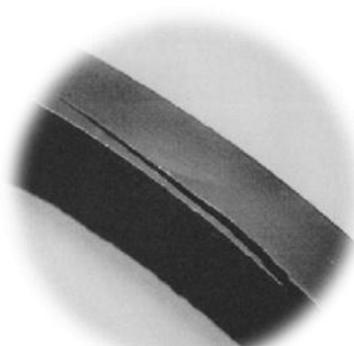
## 'Crack-like' Anomalies

Crack-like anomalies can be formed during manufacturing, construction or in operation, either in the base pipe or in welds

They may have passed hydrotest, but they can still act as a nucleation point for crack growth mechanisms (time-dependent).



**Lack of Fusion**



**Laminations**



**ERW Hook Cracking**



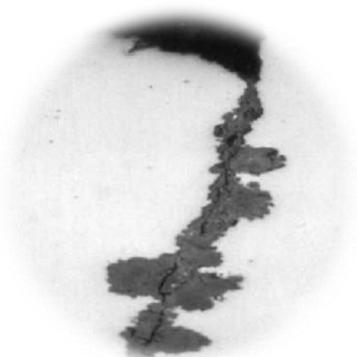
**Weld Metal Cracking**

# TYPES OF CRACKING AND SUSCEPTIBILITY INDICATORS

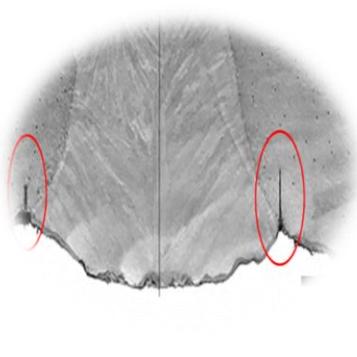
## 'Crack' Anomalies

Cracks are usually associated with either **Mechanical** or **Environmental** growth mechanisms, therefore posing an integrity threat to the pipeline that needs to be managed

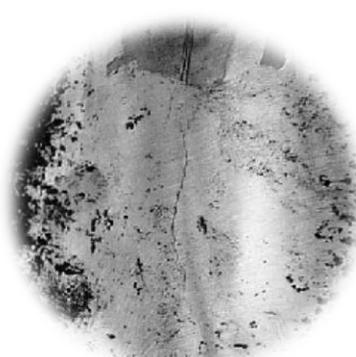
Some examples of **Time-Dependent** cracks are:



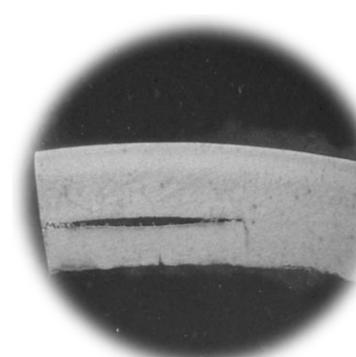
Near-neutral pH SCC



HAZ fatigue cracking



High pH SCC



Hydrogen Induced Cracking

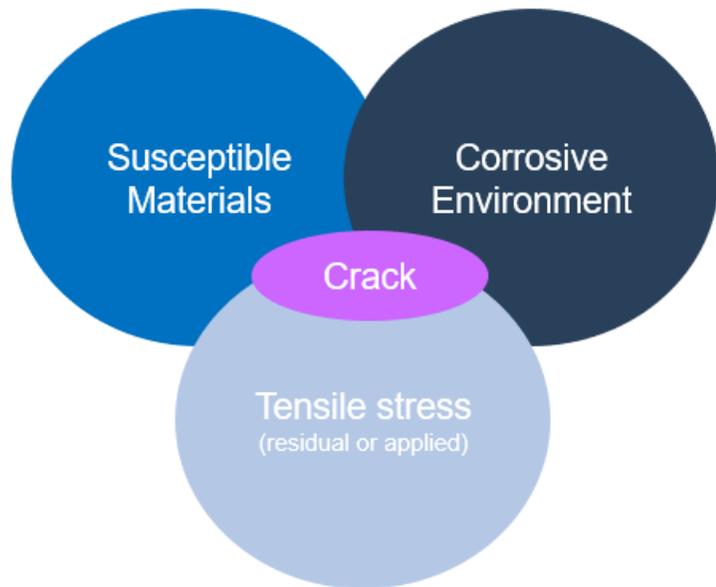
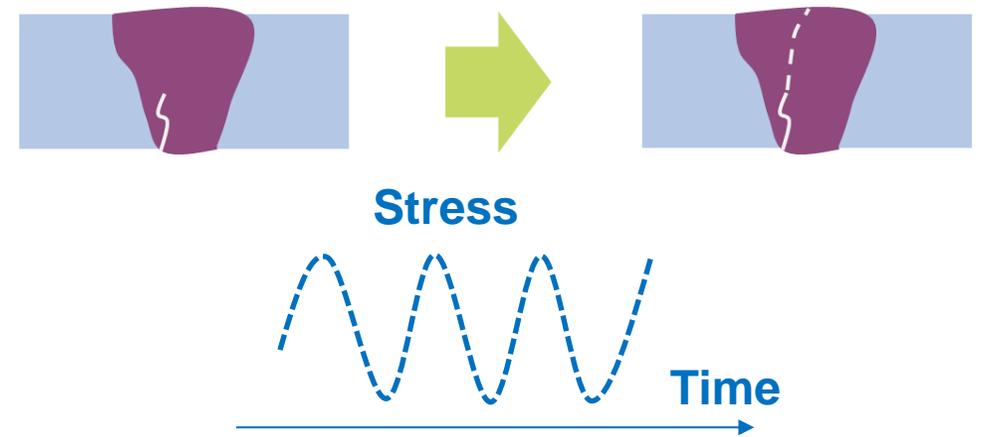


Sulphide Stress Cracking

# TYPES OF CRACKING AND SUSCEPTIBILITY INDICATORS

## Time-Dependency

- **Fatigue** is caused by repeated cycling of the applied load, causing progressive localised damage and failure at a stress below that seen in a tensile test. **Growth rates are generally better understood**



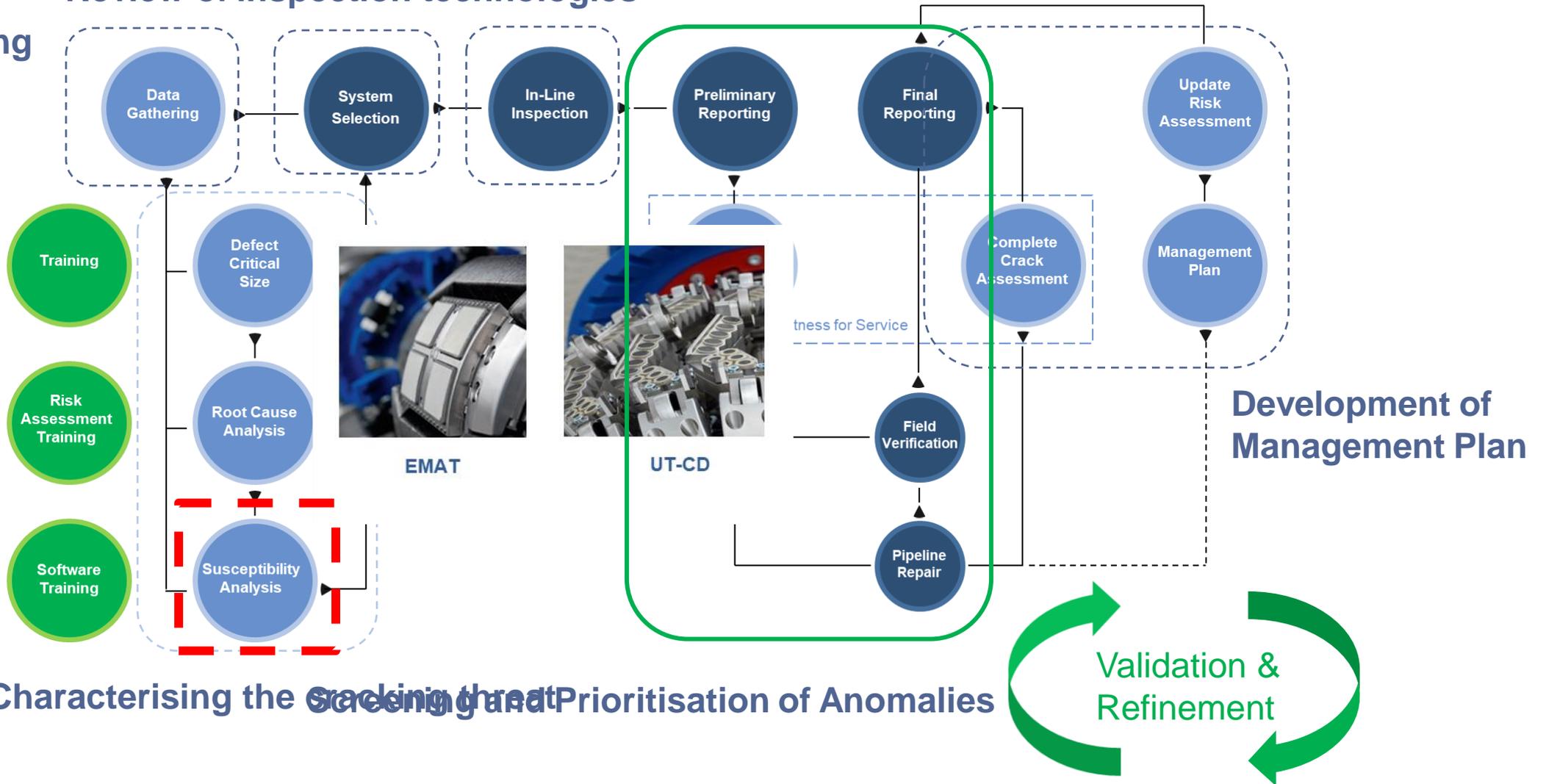
- **Environmentally Assisted Cracking** (EAC) is caused by a combination of multiple factors. **Growth rates are difficult to predict, and can be synergetic with mechanical mechanisms**

# The SOLUTION

## The Pipeline Integrity Framework for Cracks

### Review of inspection technologies

Understanding the pipeline history



# INTRODUCTION TO SUSCEPTIBILITY ANALYSIS

## Concept

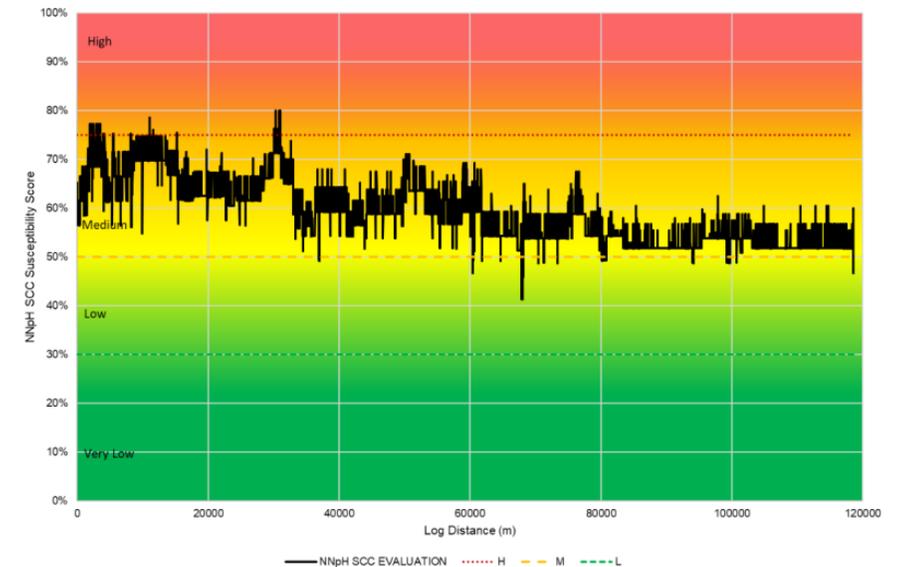
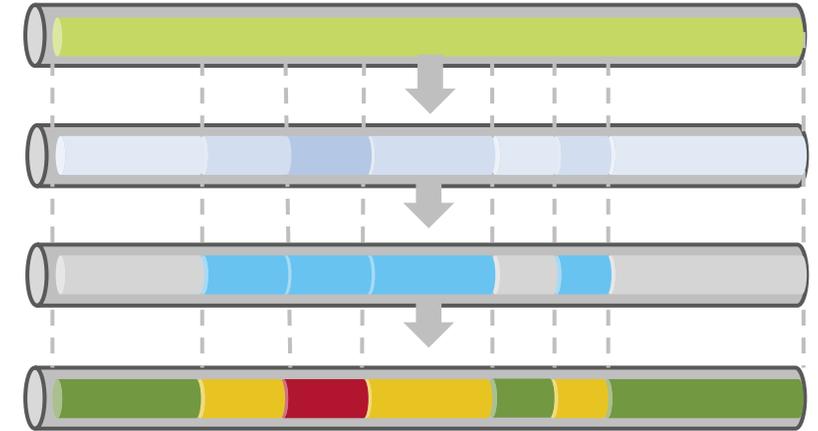
Susceptibility analysis uses knowledge of the threat 'drivers' to segment and prioritise locations along the pipeline most likely to experience the threat.

### 1. High-Level Crack Susceptibility Analysis

- Suitable for a network susceptibility study

### 2. Detailed Crack Susceptibility Analysis

- Joint-by-joint data analysis
- Identifies specific locations of interest in a pipeline



# 3. INEOS Case Study

## Crack Susceptibility (Blackness to Grangemouth)

# Cracking Susceptibility Pipeline Background

- **12 inch Natural Gas** pipeline from Blackness to Grangemouth (12BLAGRA)
- Constructed in **1999** from **X60** grade **ERW** line pipe
- **12 km** in length with nominal wall thicknesses of **6.40 mm** and **12.38 mm**
- Maximum Allowable Operating Pressure (MAOP) of **85 bar** (typical operation between **50-75 bar**)



# Cracking Susceptibility

## Scope of Work

- The scope of work was to conduct a desktop crack susceptibility study on **12BLAGRA**.
- The analysis considered the following **time-dependant** cracking threats, on a joint-by-joint basis:

### Stress Corrosion Cracking (SCC)

External: High pH and Near-Neutral pH SCC



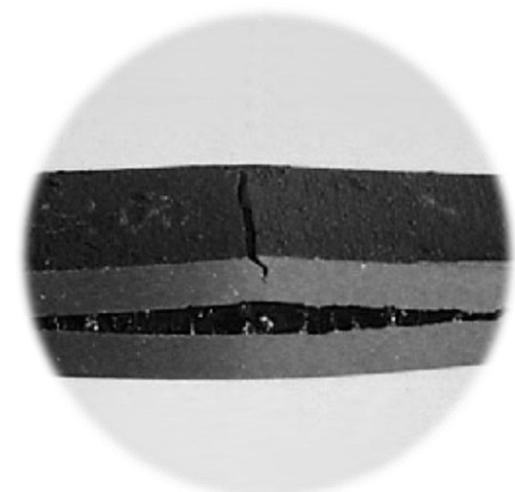
### Fatigue Cracking

Both External and Internal



### Hydrogen Embrittlement

Due to Cathodic Protection (CP) overprotection

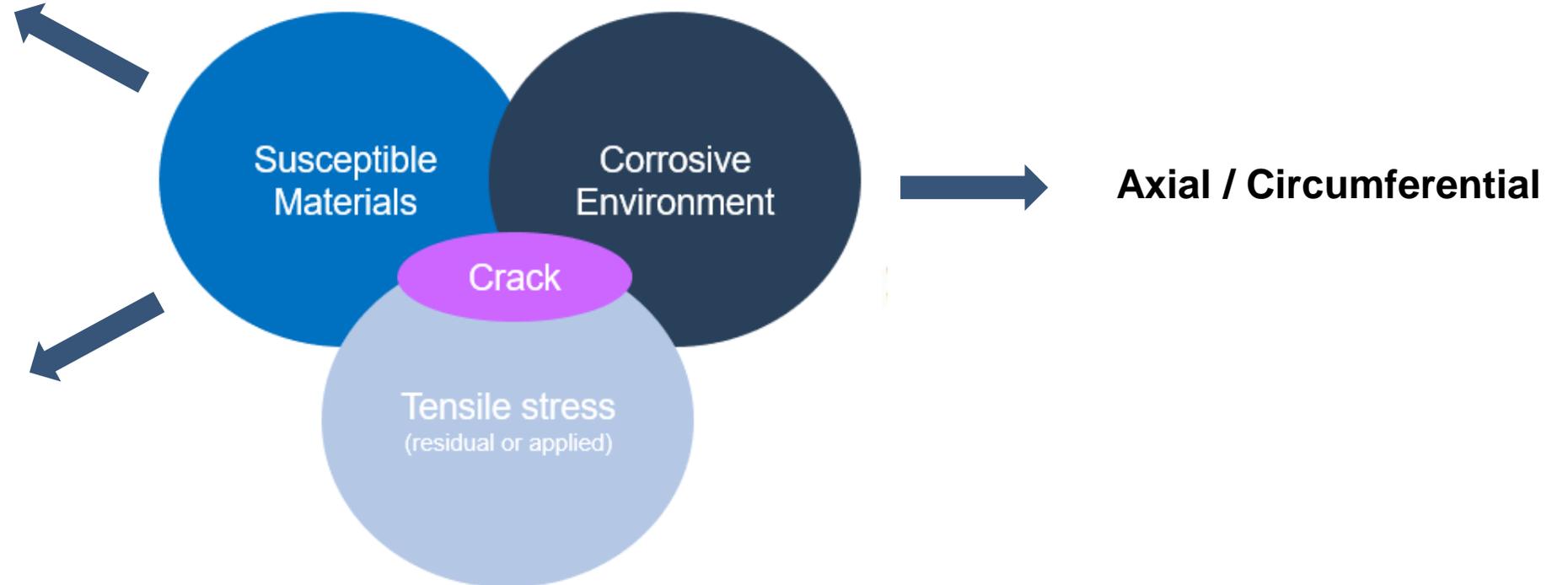


# Cracking Susceptibility

## Methodology – Stress Corrosion Cracking

**Near Neutral pH SCC**

**High pH SCC**



# Cracking Susceptibility

## Methodology – Stress Corrosion Cracking

### Near Neutral pH SCC

pH 5.5 – 7.5

Cyclic pressure, CP shielding and disbonded coatings

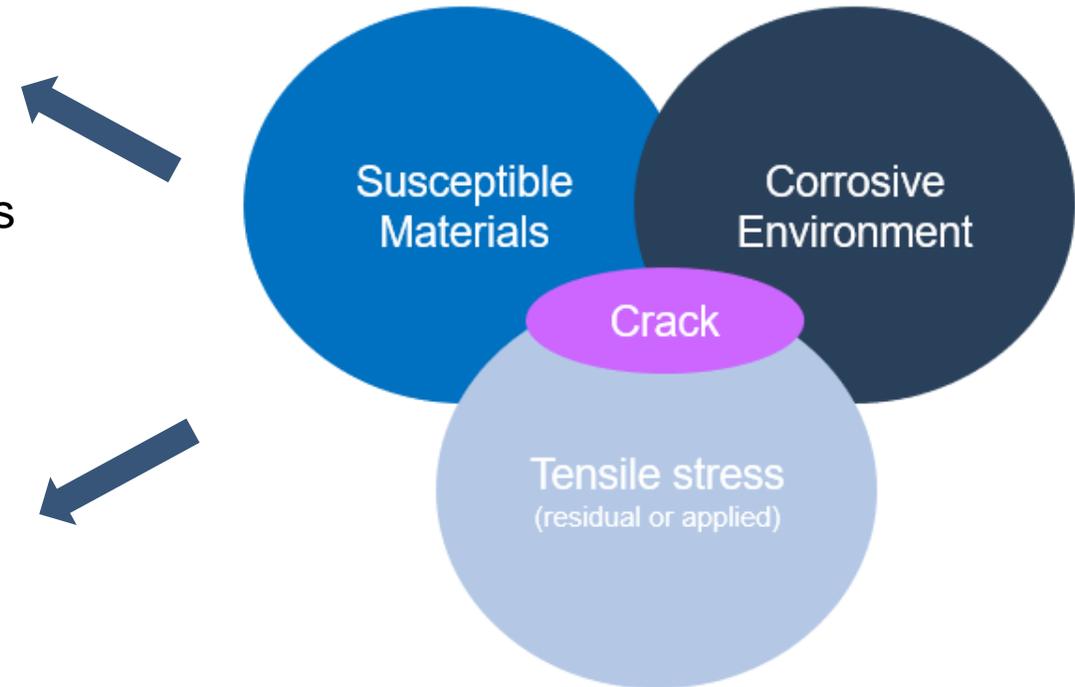
More common in Liquid pipelines with aggressive pressure cycling

### High pH SCC

pH  $\geq 9$  (typically 9-11)

High operating stress / temperatures

More common in Gas pipelines with long-term sustained stress



# Cracking Susceptibility

## Methodology – Stress Corrosion Cracking

### External Coating

- Coating types such as **Tape Wrap / Coal Tar** that are prone to **disbondment** and **CP shielding**, have an increased susceptibility to SCC

### SCC History

- Historical evidence of SCC indicates a **localised** increased susceptibility to SCC

### Operating Stress

- SCC **severity** and **likelihood** is generally observed with operating stress **>60% SMYS**
- Close proximity to **compressor / pump** stations increases susceptibility to HpH SCC

### Operating Temperature

- Operating temperatures **>40 °C** increases susceptibility to HpH SCC

### Cathodic Protection

- For HpH SCC, CP off-potentials between **-750 mV** and **-650 mV** have been associated with increased susceptibility
- For NNpH SCC, potentials more negative than **-1200 mV** or more positive than **-650 mV**

### ILI History

- **External corrosion**, **dents** or **ovalities** provide indication of additional **stress concentrations** and **coating damage**
- Areas of **bending strain** indicate potential increased **circumferential SCC** susceptibility

# Results – Stress Corrosion Cracking

## Cracking Susceptibility

### External Coating

- The pipeline is coated with a **fusion bonded epoxy (FBE)** external coating

### SCC History

- **No history** of SCC reported

### Operating Stress

- Operating stress is max **52% SMYS** and **no compressor stations** on pipeline.

### Operating Temperature

- Operating temperature is low (max **15°C**)

### Cathodic Protection

- **2023 CIPS** data recorded instant-OFF pipe to soil potentials more negative than **-1200 mV**

### ILI History

- **No external corrosion** anomalies
- **5** bottom of line **dents** reported suggest possible **coating damage** and **future external corrosion**
- **No bending strain** areas were reported

# Results – Stress Corrosion Cracking Cracking Susceptibility

## Axial High pH SCC

The threat of HpH SCC was found to be **‘Low’** for the full length of the pipeline.

- Low temperatures
- High-performance external coating
- No upstream compressor stations / low operating stress

## Axial Near-Neutral pH SCC

The threat of NNpH SCC was found to be **‘Low’** for the full length of the pipeline.

- High-performance external coating
- Low operating stress
- No external corrosion reported



# Results – Stress Corrosion Cracking Cracking Susceptibility

## Circumferential SCC

The threat of C-SCC was found to be '**Low**' for the full length of the pipeline.

- No reported instances of additional axial loading
- Recent Bending Strain ILI reported no areas of bending strain or pipeline movement



# Methodology – Fatigue Cracking

## Cracking Susceptibility

- The threat of crack growth from fatigue is considered as a result of pressure cycling
- To understand the threat of fatigue:
  - **Rainflow and Miners** was used to simplify pressure readings
  - Pressure cycling **aggressiveness** was assessed using the **TTO5 OPS** report criteria, based on Rainflow and Miners results
  - TTO5 qualitatively categorises pressure cycling aggressiveness from **‘light’** to **‘very aggressive’**
  - The threat of fatigue is inferred from the pressure cycling aggressiveness

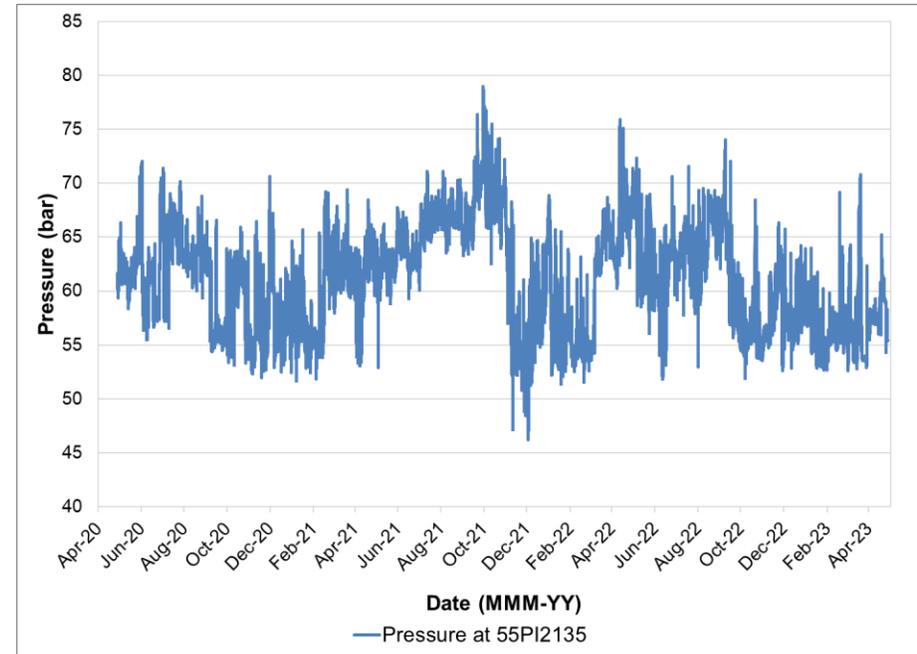
## Fatigue Cracking

Both externally and internally



# Results – Fatigue Cracking Cracking Susceptibility

- **3** years pressure cycling data provided from **April 2020** to **April 2023**
- The simplified pressure results calculated:
  - **2.44** equivalent cycles per year,
  - at a pressure range of **32.8 bar**
- The TTO5 results categorised the pipeline pressure cycling aggressiveness to be “**Light**”
- The threat from fatigue cracking was considered to be ‘**Low**’

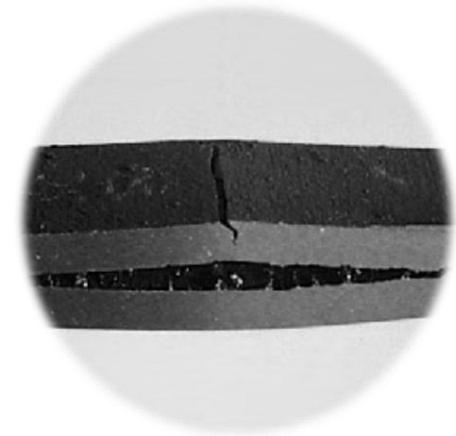


# Methodology – Hydrogen Embrittlement Cracking Susceptibility

- CP **overprotection** can cause **hydrogen damage** mechanisms that occur under the influence of **internal** or **external loads**
- Overprotection relates to the application of an OFF-CP potential typically **more negative** than the **-1200 mV Cu/CuSO<sub>4</sub>** (as per NACE SP0169)
- Susceptibilities to hydrogen embrittlement is typically associated with:
  - **Hard spots**
  - Steel materials with **high yield strength (>API 5L X70)**

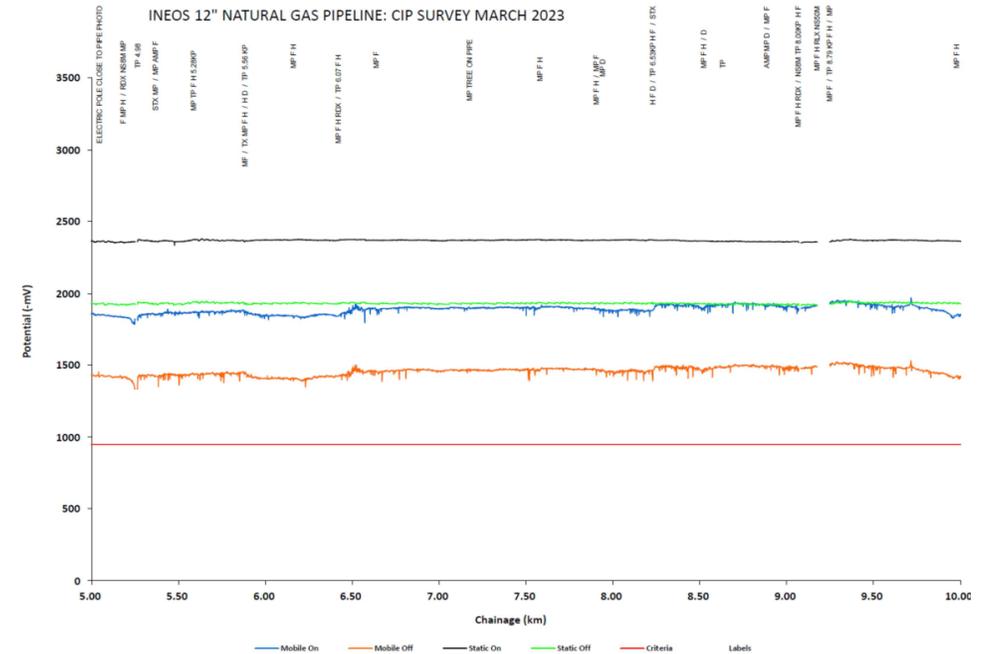
## Hydrogen Embrittlement

Due to Cathodic Protection (CP) overprotection



# Results – Hydrogen Embrittlement Cracking Susceptibility

- A **Close Interval Potential Survey** was provided for **2023**
- The survey identified **OFF** potentials more electronegative than **-1200 mV** vs Cu/CuSO<sub>4</sub> for most of the line
- The 2023 CP survey reported that due to a high population of **foreign-service pipelines**, recording **accurate** instant-OFF within the affected area was **extremely difficult**
- However, the threat of cracking due to hydrogen embrittlement was found to be **‘Potentially High’** based upon the results of the recent CP survey



# Conclusions

## Cracking Susceptibility

### Stress Corrosion Cracking (SCC)

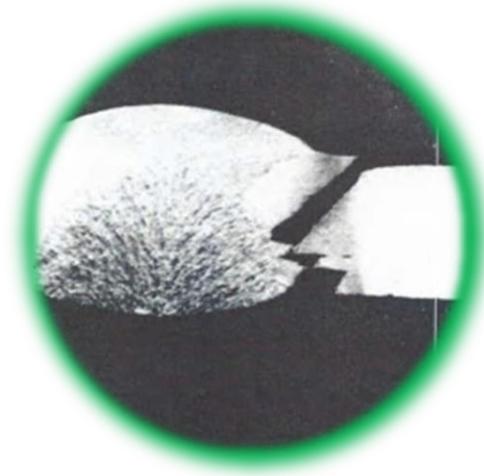
External: High pH and Near Neutral pH SCC



Susceptibility to **HpH & NNpH** SCC was assessed as '**low**' for the entire line

### Fatigue Cracking

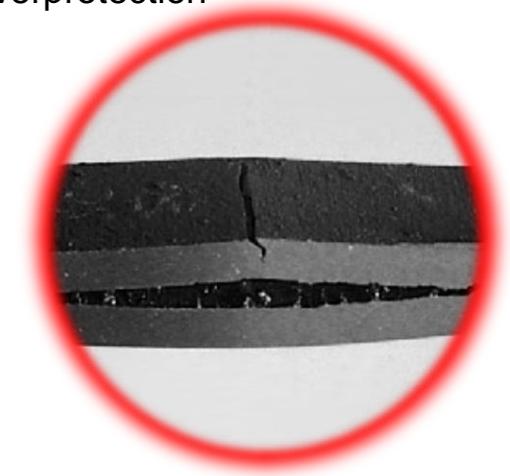
Both externally and internally



Susceptibility to **Fatigue Cracking** was assessed as '**low**'

### Hydrogen Embrittlement

Due to Cathodic Protection (CP) overprotection



Susceptibility to **Hydrogen Embrittlement** was assessed as '**Potentially high**'

# Recommendations

## Cracking Susceptibility

- The following recommendations were provided:

### Operating Conditions

If any of the following inputs change, the assessments should be re-evaluated:

- Operating pressure
- Operating temperature
- Increase in pressure cycling

### Axial loading

Circumferential SCC susceptibility assessment should be updated if axial loading is identified

### CP 'OFF' potentials

- Install AC sized potential measurement coupons at locations of over protection
- When possible, inspect coating condition at locations over protection
  - Damage to coating at locations of over protection may indicate threat of hydrogen embrittlement cracking

**ROSEN**

empowered by technology

Any Questions?