P231: Preparations of the full scale $H_2$ fatigue crack growth test

6th June 2022
Preparation of the test on the modern pipe:

- Scope
- Material selection
- Test setup
- Girth welding
- Sizing of the notches
- Notching trial
- Environment control (Oxygen, Humidity)
- Residual stress measurement
- Crack initiation (nucleation)
- NDE monitoring of crack growth
- Test execution planning
Scope for full scale tests:

- Effect of hardness over the ASME limit (Hv10>248) on material performance (fracture/fatigue/ductility) in gaseous H2
- Material performance $\Delta$ between modern steels + AUT welding vs vintages steels + cellulosic welding,
- Fatigue behavior from small scale tests via fracture mechanics vs full scale behavior for all the defects,
- Estimate of the fracture behavior of seam weld (after fatiguing to failure), compared to the prediction via fracture mechanics.
European pipeline modern materials

- To meet the lower $Y/T$ ratios as given in the Annex A of ISO 3183 for European on-shore pipelines
  - Low carbon (0.07 ~ 0.09%)
  - Polygonal/equiaxed ferrite structure with pearlitic banding (C > 0.07%)
- Pearlite areas can act as gathering sites for hydrogen atoms $\rightarrow$ HIC

### Material selection

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specimen #1 (Vintage)</th>
<th>Specimen #2 (Modern)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pipe Material</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diameter</td>
<td>26&quot;/DN650</td>
<td>28&quot;/DN 700</td>
</tr>
<tr>
<td>Wall thickness</td>
<td>11.13 mm</td>
<td>17.5 mm</td>
</tr>
<tr>
<td>Grade</td>
<td>X60/L415</td>
<td>X70/L485M</td>
</tr>
<tr>
<td>Seam weld</td>
<td>SAW</td>
<td>DSAW</td>
</tr>
<tr>
<td>Production Date</td>
<td>1970’s</td>
<td>2021</td>
</tr>
<tr>
<td><strong>Girth weld</strong></td>
<td>Welding Process</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1. Existing vintage</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2. Manual cellulosic</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mechanized; normal and high hardness</td>
<td></td>
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</tbody>
</table>
Test setup: modern pipe

- Safety chamber
- Test vessel
- Girth welds
- Construction weld

Color codes:
- End caps GW (manual)
- Seam weld
- GW with 257HV (root) – 262HV (weld)
- GW with 293HV (root) – 320HV (weld)
- Defects (EDM)
- Defects (LOP flaw)
Girth welding

• Normal and high hardness girth welds made by Subsea 7
  • Modern welding: narrow gap (2°)
  • WPS developed & validated (PQR completed)
  • (very) Lean pipe chemistry → HAZ hardness only around 220 Hv despite forced cooling
  • Controlled the weld consumable and heat input to achieve a normal hardness (~250 Hv) weld metal and a high hardness (~300 Hv) weld metal with the accelerated interpass cooling (middle pic)
  • Aim to also create a lack of penetration (LOP) flaw in weld root for final welds
Sizing of the notches

- Based on the ECA calculations
  - Calculations done using the actual FCGR and FT data from a representative pipe material
  - Range of notches considered: 1.7mm ~ 2.5 mm deep
  - Some findings below:

  **Boundary conditions for the notch sizing:**
  - ECA calc’d notch to fail within 3 months of net cycling
  - Crack growth must be discernible by TOFD in 2 week inspection intervals
  - Starter notch should be no smaller than the N10 notch (1.7 mm)
Sizing of the notches

- Current proposal for the **longitudinal** notches:

  - 2.5 mm x 15 mm: WCL
  - 2.5 mm x 15 mm: HAZ
  - 1.7 mm x 50 mm: Parent metal
  - 1.7 mm x 50 mm: HAZ

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**End caps GW (manual)**

**Seam weld**

**Defects (EDM)**

**GW with 257HV (root) – 262HV (weld)**

**GW with 293HV (root) – 320HV (weld)**

**Defects (LOP flaw)**
Sizing of the notches

- Current proposal for the **circumferential** notches:

![Diagram showing EDM and LOP flaw positioning with different markers for notches and welds.]

EDM EPRG Tier 2

LOP flaw

End caps GW (manual)

Seam weld

Defects (EDM)

GW with 257HV (root) – 262HV (weld)

GW with 293HV (root) – 320HV (weld)

Defects (LOP flaw)
Notching trial

- EDM technique used
- 3 circumferential notches
- 3 longitudinal notches
- Aim is to confirm repeatability and to measure the notch geometry with sectioning

Sample for Notch trial

- Modern pipe OD 711 mm WT 17.5 mm with longitudinal seam weld
- Sample length about 1 m

<table>
<thead>
<tr>
<th>Defect type</th>
<th>Defect size</th>
<th>Number of notches to be performed during trial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circumferential Base metal</td>
<td>4 mm</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>2c1 (mm)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Width (proposal)</td>
<td></td>
</tr>
<tr>
<td>Longitudinal Seam weld toe</td>
<td>3 mm</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>1.5 WT = 26.3 mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.3 mm</td>
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</tbody>
</table>

Notch depth (a): constant along notch axis, except at the edges. All rounding radius will be agreed with the workshop.
Environment control

- Target to keep O\textsubscript{2} as low as practical (<< 10 ppm)
  - O\textsubscript{2} is one of key elements affecting fatigue crack growth
  - EPRG test aiming at O\textsubscript{2} ‘free’ FCG test

- Target to keep H\textsubscript{2}O < 5 ppm
  - Excessive H\textsubscript{2}O may interact with H\textsubscript{2} in a similar way as O\textsubscript{2} (+ hydrate concerns) hence controls put in place

- Plan:
  1. Extensive purging with N\textsubscript{2}
  2. Fuel cell ISO 14687 compliant H\textsubscript{2} source
  3. Periodic measurement of O\textsubscript{2} levels at low pressure using a vent line → possible sensor was found
Residual stress measurements

- Some data received from Europipe (historic) and Liberty steel
- Some literature data found
- ECA calculations so far assumed WRS at ½ Yield value

- Plan to do shallow hole drilling measurements on the actual pipe at
  - Pipe body (notch location)
  - Parent metal near seam weld toe
  - Seam weld centerline
- Also plan to do the same measurement on the CT sample coupons
- Also plan some deep hole drilling in the seam weld centerline location on the full pipe

- Important as this feeds into post test interpretations of the fracture event and into the fatigue crack growth interpretations
Upcoming activities

• **Crack initiation at a machined notch**
  • Using round notched tensile samples
  • Aim is to understand the duration of crack nucleation at a notch as a function of delta stress & notch geometry

• **NDE monitoring of crack growth**
  • TOFD measurements are planned for every 2 weeks.
  • Aiming for accuracy on flaw depth measurement of ± 0.3 mm (requirements on consistency)
  • Preparing the inspection work procedure with the local NDE contractor
  • Exploring opportunity with Applus RTD to attach some probes permanently to some notches for real time measurements.
Test site

- CSM-RINA confirmed Perdasdefogu (Sardinia)

<table>
<thead>
<tr>
<th>Location</th>
<th>Pro</th>
<th>Con</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perdasdefogu</td>
<td>Easier permitting</td>
<td>Distance from some Suppliers</td>
</tr>
<tr>
<td>(Sardinia)</td>
<td>Easier heavy works</td>
<td>Travel for RINA people</td>
</tr>
<tr>
<td></td>
<td>Easier safety</td>
<td>Possible stop due to military activities*</td>
</tr>
<tr>
<td></td>
<td>Safety chamber already there</td>
<td></td>
</tr>
<tr>
<td>Roma</td>
<td>Easier access from Suppliers</td>
<td>More difficult permitting</td>
</tr>
<tr>
<td></td>
<td>No travel for RINA people</td>
<td>More difficult heavy works</td>
</tr>
<tr>
<td></td>
<td>No stop due to military activities</td>
<td>Safety more complex</td>
</tr>
<tr>
<td></td>
<td>Safety chamber to be moved from Sardinia</td>
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</tbody>
</table>

* This would NOT imply long stop during summer and Christmas periods; these stops are for explosive related activities (bursting) which are not foreseen in EPRG Pj 231
Planning for the test execution

- **Main steps**
  - System purging with N\(_2\) and pressurisation up with H\(_2\)
  - Fatigue cycling with stoppages every 2 weeks, decompression (venting) and TOFD inspection (total 3 days)
  - Start fatigue cycling at \(\Delta P\) of HOLD % (for nucleation)
  - Then reduce to \(\Delta P\) of 30% for the initial phase of flaw growth
  - Then reduce to \(\Delta P\) of 25% and 20% for final stages of crack growth
  - Fatigue cycle until leakage (failure) in one of the defects \(\rightarrow\) STOP.

Informed by live ECA re-calculations
Schedule

- Test vessel preparations: June ~ August
- Test plant preparations: June ~ September
- Fatigue test start: Expect to be October
- Fatigue test duration: Targeting 4 months, but may run longer
Thank you for your attention.