INTRODUCTION TO ULTRASONIC IN-LINE INSPECTION OF CRA PIPELINES

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OUTLINE

BACKGROUND

- Application of CRA Pipe
- Types of CRA Pipe

IN-LINE INSPECTION OF CRA PIPELINES

- Solid CRA Pipe
- Clad Pipe
- Lined Pipe

EXAMPLES

- Metal loss inspection
- Crack inspection
- Disbonding

SUMMARY
CRA - CORROSION RESISTANT ALLOY

Why are they used for pipelines?

NUMBER OF PIPELINES IN HIGHLY CORROSIVE ENVIRONMENTS INCREASES

- mature oil fields
  - increasing water fraction
- development of (ultra-)deepwater offshore fields
  - high pressure & high temperature (HPHT) regime
- increased production of corrosive sour gas and sour crude oil
  - high CO₂ or H₂S concentration

COUNTERACTION: Use of corrosion resistant alloys (CRA)

- better corrosion protection compared to carbon steel (CS) based on chemical composition, e.g. increased chromium and/or nickel content
1. COMPARED TO CARBON STEEL, CRA …
   o … has *much better* corrosion resistance properties
   o … has (usually) *lower strength/toughness*
   o … is *more expensive*

2. TYPES OF CRA PIPE
   o **SOLID CRA PIPE**
   o **COMBINED SOLUTION**
     - carbon steel (CS) as carrier pipe (➔ *mechanical strength*)
     - CRA inliner (➔ *corrosion protection*)
# SOLID CRA PIPE (FE based)

<table>
<thead>
<tr>
<th>STEEL TYPE</th>
<th>EXAMPLES</th>
<th>COMPOSITION</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferritic</td>
<td>AISI 444 (1.4521)</td>
<td>18 Cr - 2 Mo</td>
<td></td>
</tr>
<tr>
<td>Martensitic</td>
<td>SMSS</td>
<td>13 Cr</td>
<td>Super-Martensitic Stainless Steel; High Strength (~ X80)</td>
</tr>
<tr>
<td>Austenitic</td>
<td>AISI 304L (1.4306)</td>
<td>18 Cr - 8 Ni</td>
<td>L – low carbon</td>
</tr>
<tr>
<td></td>
<td>AISI 316L (1.4404)</td>
<td>18 Cr - 10 Ni</td>
<td></td>
</tr>
<tr>
<td>Duplex</td>
<td>2205 (1.4462)</td>
<td>22 Cr - 5 Ni</td>
<td>50 % Ferrite / 50% Austenite</td>
</tr>
</tbody>
</table>
## RELATIVE COSTS OF SOLID CRA PIPE

<table>
<thead>
<tr>
<th>TYPE OF STEEL</th>
<th>RELATIVE COSTS*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Steel (reference)</td>
<td>1</td>
</tr>
<tr>
<td>13% Cr</td>
<td>3</td>
</tr>
<tr>
<td>Super 13% Cr</td>
<td>5</td>
</tr>
<tr>
<td>Duplex SS</td>
<td>8-10</td>
</tr>
<tr>
<td>Austenitic SS</td>
<td>12-15</td>
</tr>
<tr>
<td>Nickel based Alloys</td>
<td>20</td>
</tr>
</tbody>
</table>

* Source: GeKEngineering 2009
## ALTERNATIVES TO SOLID CRA PIPE

### Clad & Lined Pipe

<table>
<thead>
<tr>
<th>TYPE OF PIPE</th>
<th>CHARACTERISTICS</th>
<th>EXAMPLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clad pipe</td>
<td>metallurgical bond</td>
<td><img src="image_url" alt="Image" /></td>
</tr>
</tbody>
</table>

**Note:** The example image shows a cross-sectional view of clad pipe, highlighting the cladding, bond line, diffusion zone, and substrate.
## MANUFACTURING OF CLAD PIPE

<table>
<thead>
<tr>
<th>TYPE OF BONDING</th>
<th>EXAMPLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roll Bonding</td>
<td><img src="image1.png" alt="Roll Bonding Example" /></td>
</tr>
<tr>
<td>Weld Overlaying</td>
<td><img src="image2.png" alt="Weld Overlaying Example" /></td>
</tr>
</tbody>
</table>
MANUFACTURING OF LINED PIPE BY HYDRAULIC EXPANSION

Blue: Carrier pipe
Red: Liner

0 1 2 3
### STEELS USED FOR COMBINED CRA PIPE

<table>
<thead>
<tr>
<th>CARRIER</th>
<th>CLADDING</th>
</tr>
</thead>
<tbody>
<tr>
<td>X52, X60, X65, X70 ......</td>
<td>AISI 316L, 317L, 904L, .....</td>
</tr>
<tr>
<td>(ferritic)</td>
<td>(austenitic)</td>
</tr>
</tbody>
</table>
WHY DO CRA PIPES CORRODE?

- CRA alloy not suitable for the operational conditions
- Manufacturing-related anomalies
- Wrong handling during storage, transportation, and installation

CORROSION IN CRA PIPES
QUOTE:

...... A CRA selection method that is not recommended but is often used is to select a CRA that is readily available or most economical, without regard to its corrosion resistance in the intended environment. Misapplication of CRAs is becoming more common for this reason and has resulted in corrosion and cracking problems of the inappropriately selected alloys.*

*Source: SELECTION GUIDELINES FOR CORROSION RESISTANT ALLOYS IN THE OIL AND GAS INDUSTRY (Bruce D. Craig)
CORROSION IN CRA PIPE

CORROSION TYPES

- **Crevice Corrosion**: Intensive localized electro-chemical corrosion occurs within crevices when in contact with a corrosive medium.

- **Pitting Corrosion**: Highly localized attack that results in holes in the metal.

- **Galvanic Corrosion**: Potential difference between dissimilar metals in contact creates a current flow.

- **Stress Corrosion**: Occurs in metal that is subject to both stress and a corrosive environment often starting at “stress risers”.
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EXAMPLES
- Metal loss inspection
- Crack inspection
- Disbonding

SUMMARY
# Ultrasonic Speed in Different CRA

<table>
<thead>
<tr>
<th>Material</th>
<th>$v_{\text{Long}}$ (mm/µs)</th>
<th>$v_{\text{Trans}}$ (mm/µs)</th>
<th>Density (gr/ccm)</th>
<th>Transmission Angle for 45° Shear Wave (°)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Steel</td>
<td>5.96</td>
<td>3.23</td>
<td>7.85</td>
<td>18.5</td>
</tr>
<tr>
<td>13% Cr (SMSS)</td>
<td>5.90</td>
<td>3.20</td>
<td>7.72</td>
<td>18.7</td>
</tr>
<tr>
<td>AISI 316L</td>
<td>5.75</td>
<td>3.27</td>
<td>8.00</td>
<td>18.3</td>
</tr>
<tr>
<td>Duplex</td>
<td>5.80</td>
<td>3.30</td>
<td>7.80</td>
<td>18.1</td>
</tr>
<tr>
<td>Super-Duplex</td>
<td>5.85</td>
<td>3.20</td>
<td>7.80</td>
<td>18.7</td>
</tr>
<tr>
<td><strong>Deviations (%)</strong></td>
<td><strong>± 1.4</strong></td>
<td><strong>± 1.4</strong></td>
<td><strong>± 1.3</strong></td>
<td><strong>± 1.4</strong></td>
</tr>
</tbody>
</table>

* for crack inspection using water as medium
The ultrasonic propagation and attenuation in solid CRA (e.g. duplex SS or 13% Cr steel) is similar to those in carbon steel.

Therefore, the UT tool performance (detection and sizing capabilities) valid for carbon steels is also valid for most solid CRA.
MODELLING RESULT
Wall Thickness Inspection

Liquid medium (e.g. water)

Pipe wall (steel)

WT

Standoff

10 mm

Time: 0.00 μs

f = 5 MHz
MODELLING RESULT

Wall Thickness Inspection

f = 5 MHz

A-Scan

WT

Standoff

10 mm

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Geometry of Clad / Lined Pipe

- Carrier pipe (carbon steel)
- CRA layer
- Interface
ULTRASONIC METAL LOSS INSPECTION
Metallurgical Bond vs. Mechanical Bond (Modelling Result)
ULTRASONIC METAL LOSS INSPECTION

Metallurgical Bond vs. Mechanical Bond (Modelling Result)

Metallurgical Bond

Mechanical Bond

Medium

Cladding

CS

Time: 0.00 μs

Liner

Time: 0.00 μs
ULTRASONIC INSPECTION OF CRA PIPE

Metallurgical Bond

Ultrasonic Sensor

CRA layer

Carrier pipe (carbon steel)

Reflection coefficient < 0.03
ULTRASONIC INSPECTION OF CRA PIPE

Mechanical Bond

Ultrasonic Sensor

CRA layer

Carrier pipe (carbon steel)

Reflection coefficient $\approx 100\%$
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SUMMARY
IN-LINE INSPECTIONS OF CRA PIPES
Seam Welded Clad Pipe

- Very smooth internal pipe surface providing high-quality ultrasonic inspection data.

- Ultrasonic ILI performance similar to that for solid CRA pipe & CS pipe

- Manufacturing related anomalies: seam weld anomalies and clad disbondment

- Corrosion pits with very small diameter in the base material as well as in the girth welds
The internal pit has a depth of about 10 mm and perforates the CRA layer of 3 mm thickness. The pit diameter in the carbon steel (~ 1") is two times larger than in the CRA layer (~ 0.5").
IN-LINE INSPECTION OF CRA PIPE

Deep Internal Pit in Clad Pipe (Sketch)
EXAMPLES OF CLAD PIPE
Axial and Orbital Weld-Overlay

circumfer. weld overlay

axial weld overlay
Corrosion spot in weld-overlay cladding: The wall thickness data are scattered due to the weld pattern while the standoff signal is very clear.
Scattered area of internal metal loss (3.5 mm deep) detected in an orbital weld-overlay clad pipe (Inconel 625).
The performance and defect specifications of the ILI tools should take into account the dimensions of the anomalies which are typical for CRA pipes:

- Localized corrosion anomalies (pitting corrosion)
- Pitting diameters often below the specified minimum diameter for depth sizing of standard ultrasonic ILI tools
- High resolution UT tools for the detection of small pitting corrosion (D ≥ 5 mm) required
INSPECTION REQUIREMENTS FOR CRA PIPE

Improvement of Circumferential Resolution

UM (Standard Resolution)

Circumf. Resolution: 8 mm

UMp (Pitting Resolution)

Circumf. Resolution: 4 mm

8 mm

4 mm
ULTRASONIC CRACK INSPECTION
Comparison with & without cladding (modelling)
ULTRASONIC CRACK INSPECTION

Comparison with & without cladding (modelling)

without cladding

with cladding

Sensor

Medium

Pipe Wall

Crack

Time: 0.00 µs

Time: 0.00 µs
CRACK INSPECTION IN CLAD PIPE

Crack-like Defects at the Girth Weld

View of external defects

Ultrasonic C-Scan
Cluster of disbondment anomalies between cladding and CS carrier

Results from ILI
(NDT Global)
IN-LINE INSPECTION OF CRA PIPES

Wrinkling/Buckling in Lined Pipe

The CRA layer of the lined pipe is prone to wrinkling/buckling due to bending e.g. during off-shore pipeline laying.

Ultrasonic C-Scan (Standoff Data)

Ultrasonic B-Scan
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SUMMARY
Deep pits and severe weld anomalies were often found in CRA pipes before the pipeline was put into service.

- The origin of the anomalies in CRA pipes is often related to inappropriate handling during the manufacturing, storage, transportation and construction phases.

- Therefore, a baseline ILI survey before the pipeline goes into operation is recommended.
IN-LINE INSPECTIONS OF CRA PIPES

SUMMARY

- ALL THE DIFFERENT CRA PIPES (SOLID, CLAD AND LINED) CAN BE INSPECTED USING ULTRASONIC ILI TOOLS:
  - Solid CRA pipe & seam welded clad pipe: no restrictions
  - Weld-overlay clad pipe: ok for internal corrosion (reduced quality for external corrosion due to wavy surface pattern)
  - Lined pipe: Inspection is limited to the CRA inliner

- ANOMALY (PITTINGS) DIMENSIONS ARE OFTEN BELOW SPECIFIED MINIMUM DIMENSIONS FOR DETECTION/SIZING OF STANDARD ILI TOOLS:
  - High-resolution tools required (e.g. UMp tool)

- ILI EXPERIENCE AVAILABLE FOR ALL TYPES OF CRA PIPE
## INSPECTION OF CRA PIPE: UT vs. MFL

<table>
<thead>
<tr>
<th>TYPE OF CRA PIPE</th>
<th>DESCRIPTION</th>
<th>Metal Loss</th>
<th>Radial Cracking</th>
<th>Disbonding</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>UT MFL UT MFL</td>
<td>UT MFL</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Lined Pipe</strong></td>
<td>Carrier</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Liner</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Clad Pipe</strong></td>
<td>Carrier</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cladding</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Solid Pipe</strong></td>
<td>ferritic</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Duplex</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>austenitic</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Metal Loss**: Green indicates detection, red indicates non-detection.
- **Radial Cracking**: Green indicates detection, red indicates non-detection.
- **Disbonding**: Red indicates detection, green indicates non-detection.

**Comment**:
- **mechanical bonding**
- **metallurgical bonding**
- Weld overlaying causes wavy surface/interface
- MFL: modified calibration
- UT: to be checked for Ni-based alloys