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?

NDT GLOBAL

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 CO_2 or H_2S 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***

CRA : CORROSION RESISTANT ALLOY
Properties & Types of CRA Pipe

1. COMPARED TO CARBON STEEL, CRA …

- *… has much better corrosion resistance properties*
- *… has (usually) lower strength/toughness*
- *… is more expensive*

2. TYPES OF CRA PIPE

- ***SOLID CRA PIPE***
- ***COMBINED SOLUTION***
  - *carbon steel (CS) as carrier pipe (→ mechanical strength)*
  - *CRA inliner (→ corrosion protection)*

SOLID CRA PIPE (FE based)

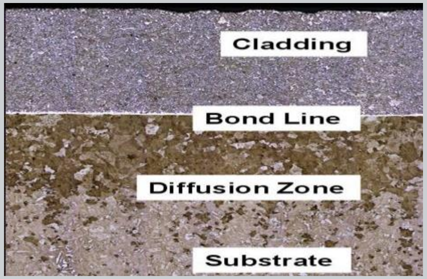
STEEL TYPE	EXAMPLES	COMPOSITION	COMMENT
Ferritic	AISI 444 *(1.4521)*	18 Cr - 2 Mo	
Martensitic	SMSS	13 Cr	Super-Martensitic Stainless Steel; High Strength (~ X80)
Austenitic	AISI 304L *(1.4306)* AISI 316L *(1.4404)*	18 Cr - 8 Ni 18 Cr - 10 Ni	L – low carbon
Duplex	2205 *(1.4462)*	22 Cr - 5 Ni	50 % Ferrite / 50% Austenite

RELATIVE COSTS OF SOLID CRA PIPE

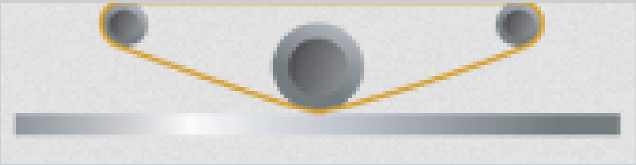
TYPE OF STEEL	RELATIVE COSTS*
Carbon Steel (reference)	1
13% Cr	3
Super 13% Cr	5
Duplex SS	8-10
Austenitic SS	12-15
Nickel based Alloys	20

* Source: GeKEngineering 2009

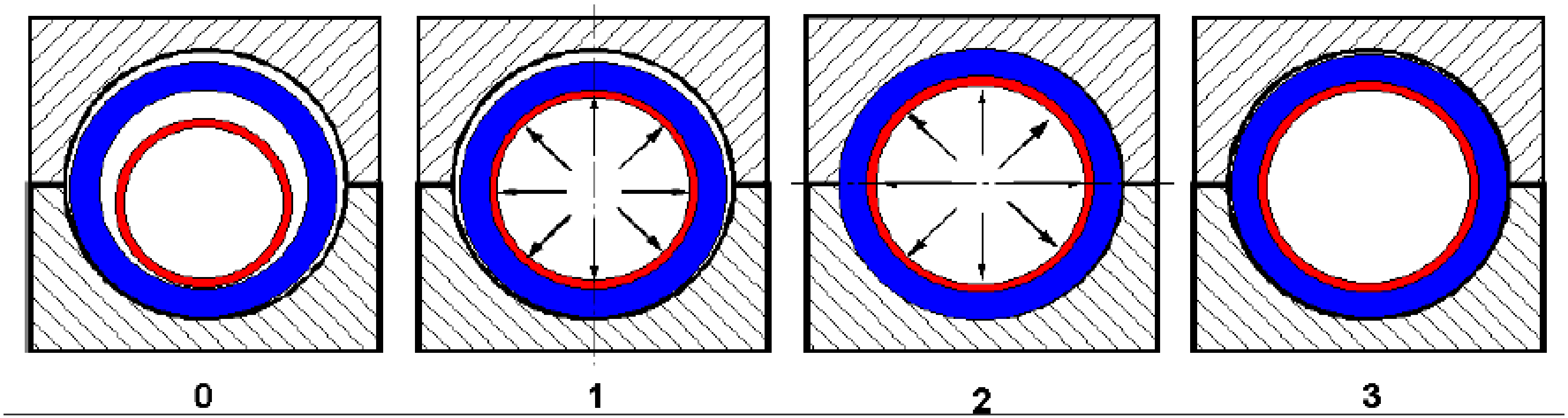
ALTERNATIVES TO SOLID CRA PIPE
Clad & Lined Pipe

TYPE OF PIPE	CHARACTERISTICS	EXAMPLE
Clad pipe	metallurgical bond	

MANUFACTURING OF CLAD PIPE

TYPE OF BONDING	EXAMPLE
Roll Bonding	
Weld Overlaying	

MANUFACTURING OF LINED PIPE BY HYDRAULIC EXPANSION

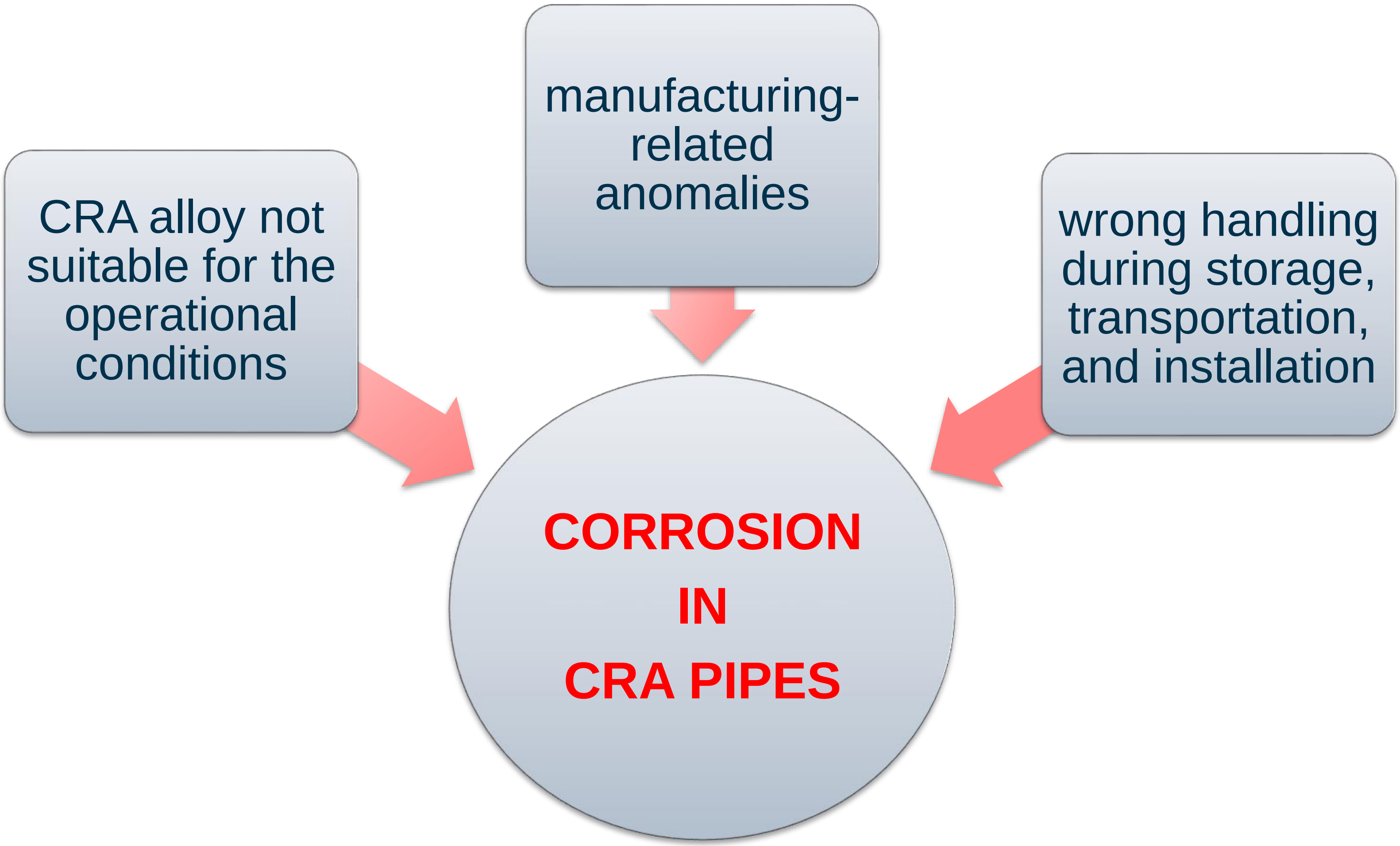


Blue: Carrier pipe
Red: Liner

STEELS USED FOR COMBINED CRA PIPE

CARRIER	CLADDING
X52, X60, X65, X70	AISI 316L, 317L, 904L, ...
(ferritic)	(austenitic)

WHY DO CRA PIPES CORRODE?



SELECTION OF APPROPRIATE CRA

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

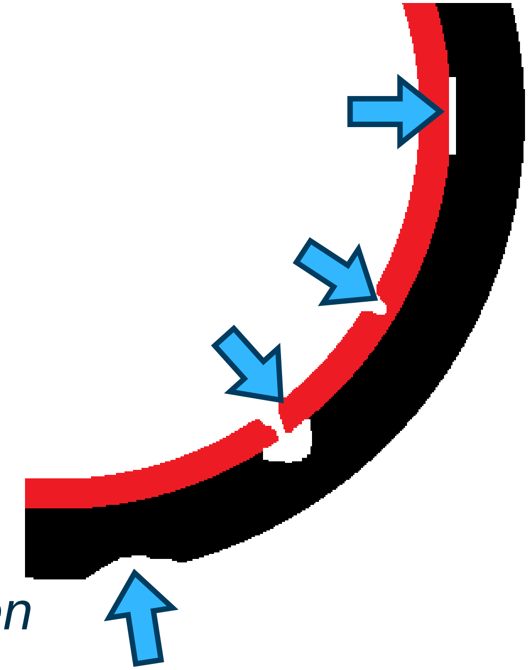
CORROSION TYPES

- ***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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- *Types of CRA Pipe*

IN-LINE INSPECTION OF CRA PIPELINES

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- *Clad Pipe*
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EXAMPLES

- *Metal loss inspection*
- *Crack inspection*
- *Disbonding*

SUMMARY

ULTRASONIC SPEED IN DIFFERENT CRA

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

** for crack inspection using water as medium*

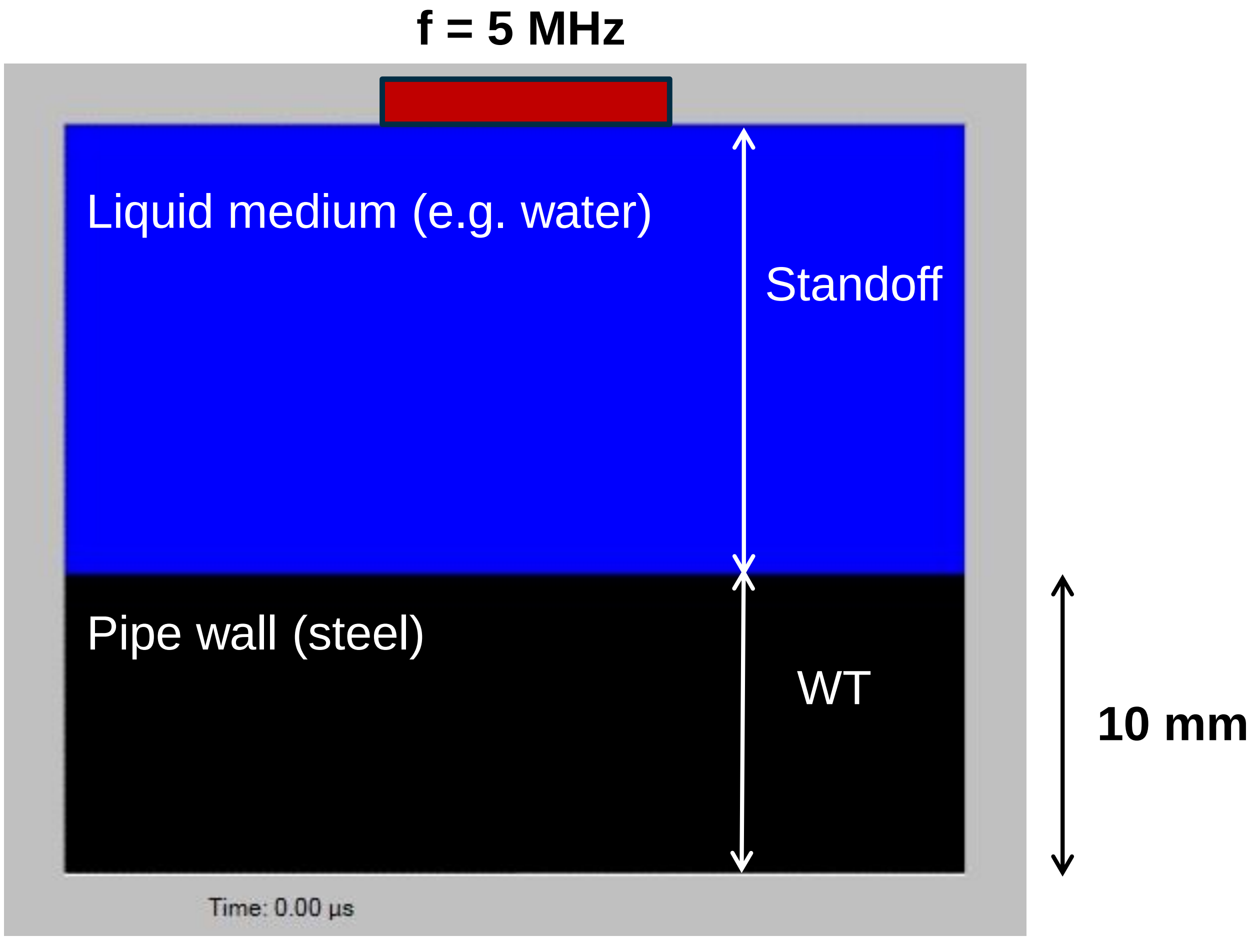
ILI INSPECTION OF CRA PIPES

Solid CRA Pipe

The ultrasonic propagation and attenuation in solid CRA (e.g. duplex SS or 13% Cr steel) is similar to those in carbon steel.

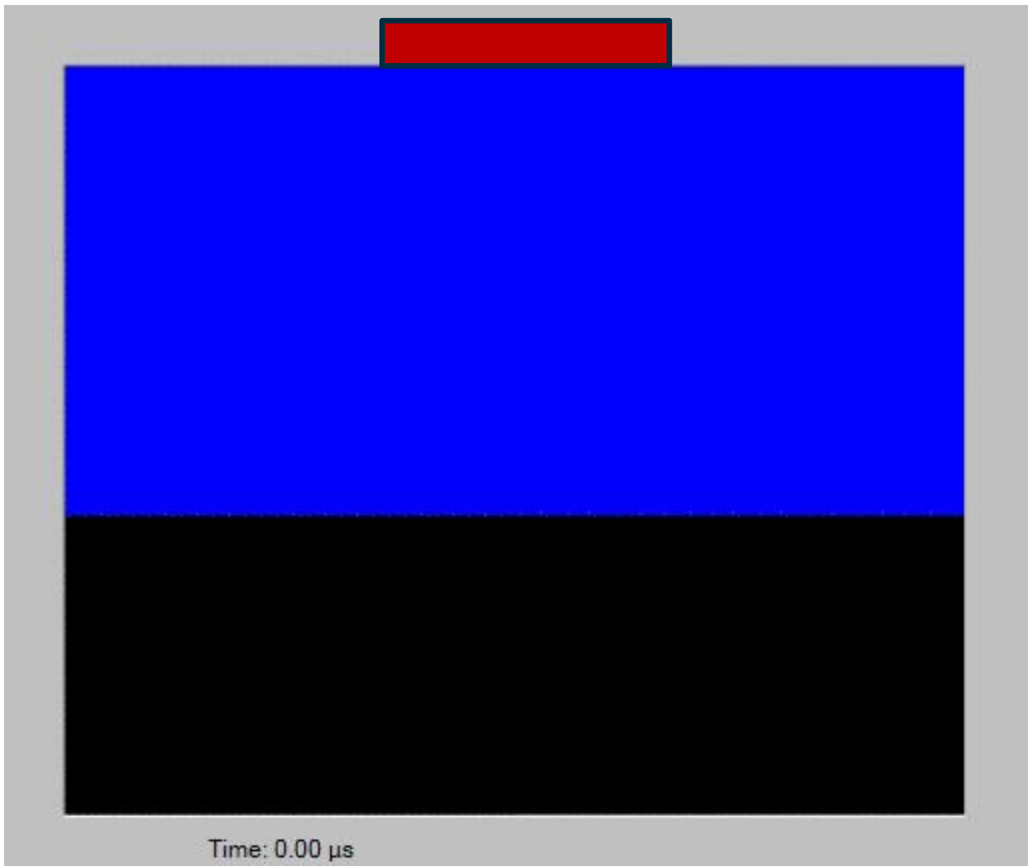
Therefore, the UT tool performance (detection and sizing capabilities) valid for carbon steels is also valid for most solid CRA.

MODELLING RESULT
Wall Thickness Inspection

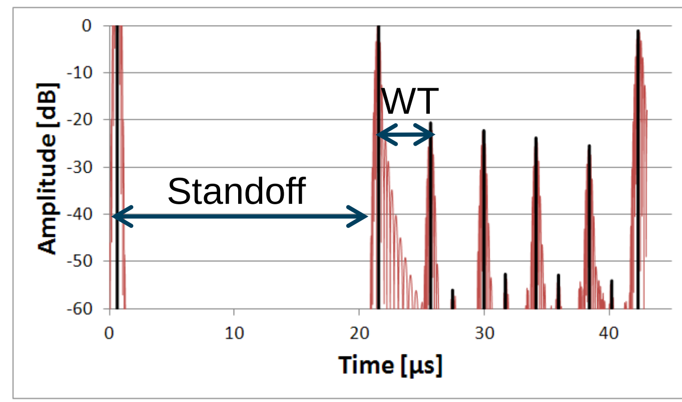


MODELLING RESULT
Wall Thickness Inspection

f = 5 MHz

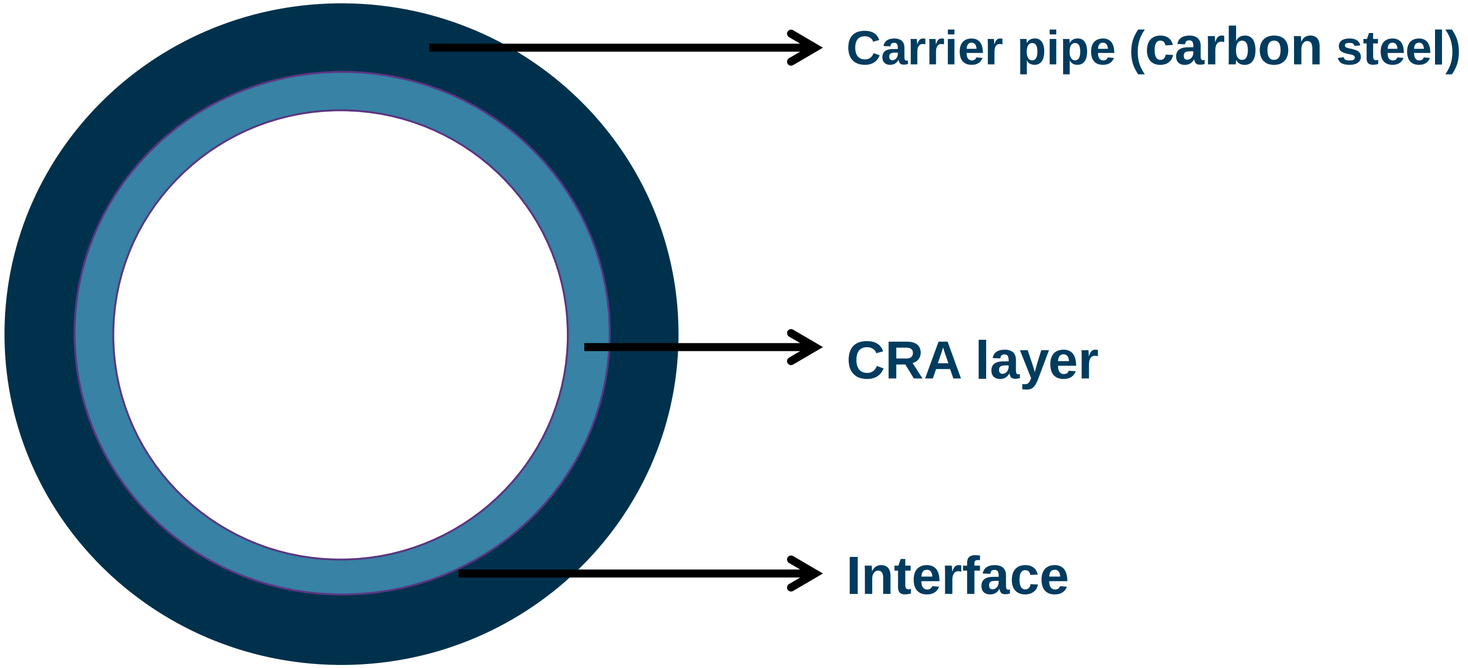


A-Scan



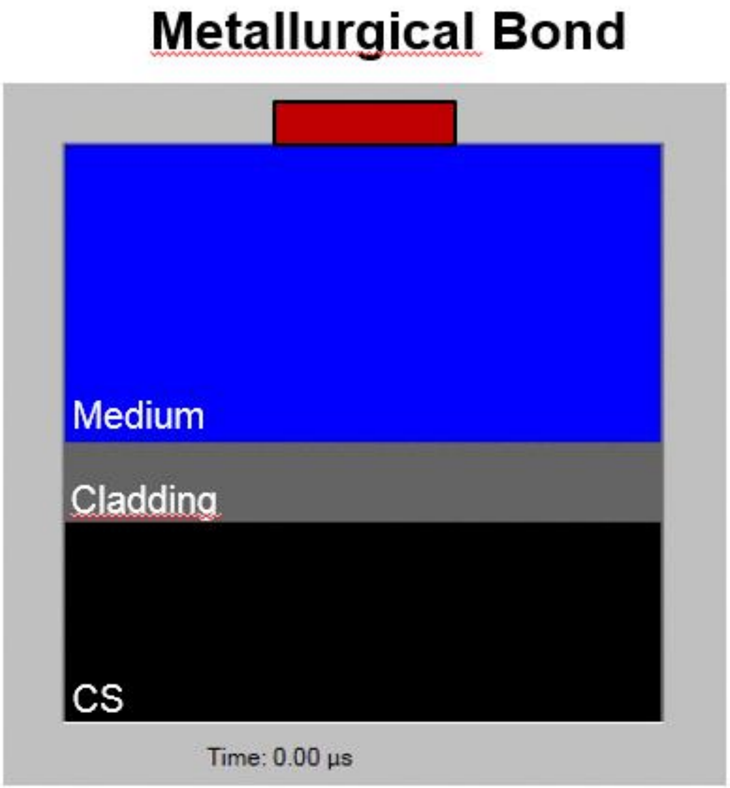
10 mm

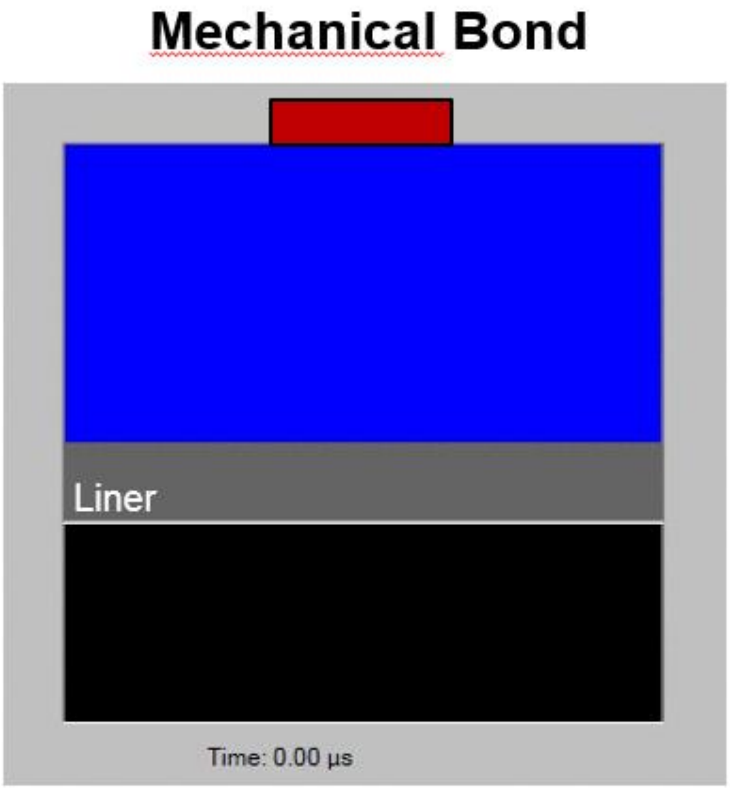
IN-LINE INSPECTION OF CRA PIPE
Geometry of Clad / Lined Pipe



ULTRASONIC METAL LOSS INSPECTION

Metallurgical Bond vs. Mechanical Bond (Modelling Result)

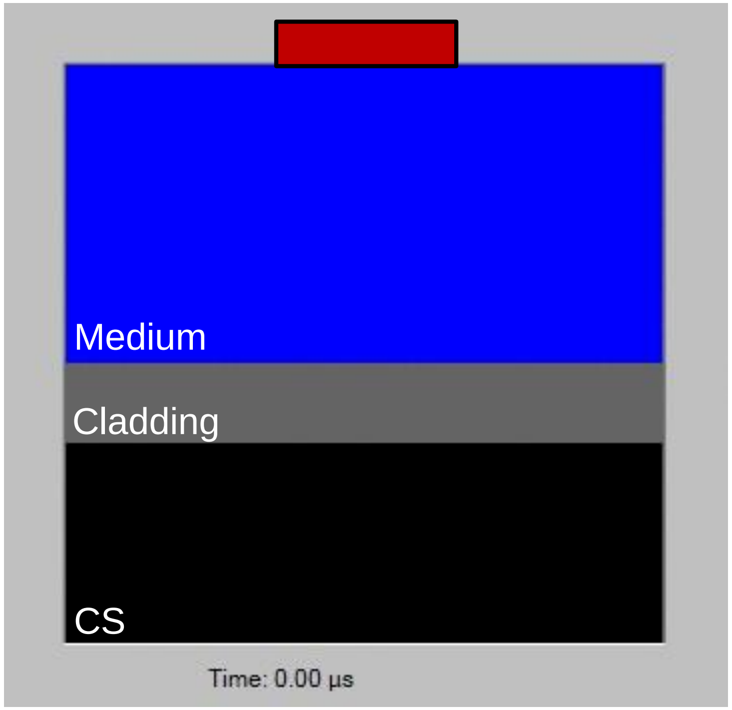




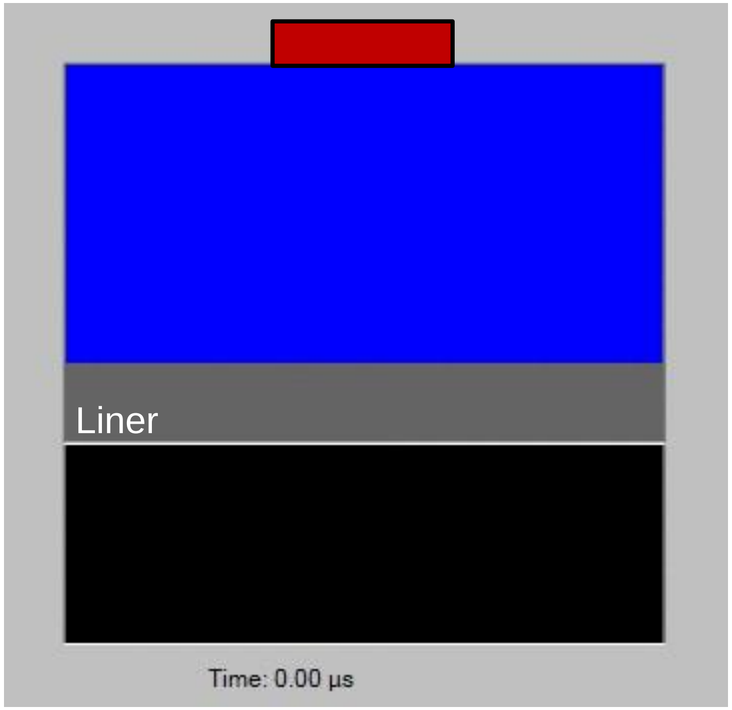
ULTRASONIC METAL LOSS INSPECTION

Metallurgical Bond vs. Mechanical Bond (Modelling Result)

Metallurgical Bond

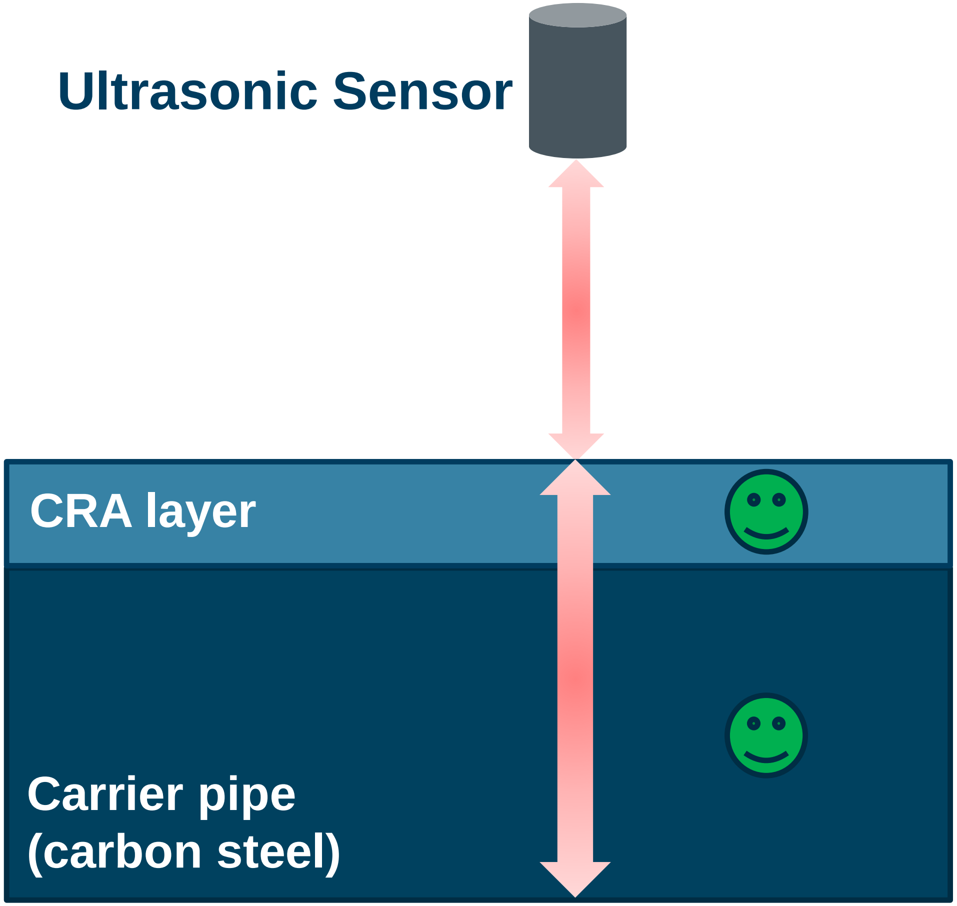


Mechanical Bond



ULTRASONIC INSPECTION OF CRA PIPE

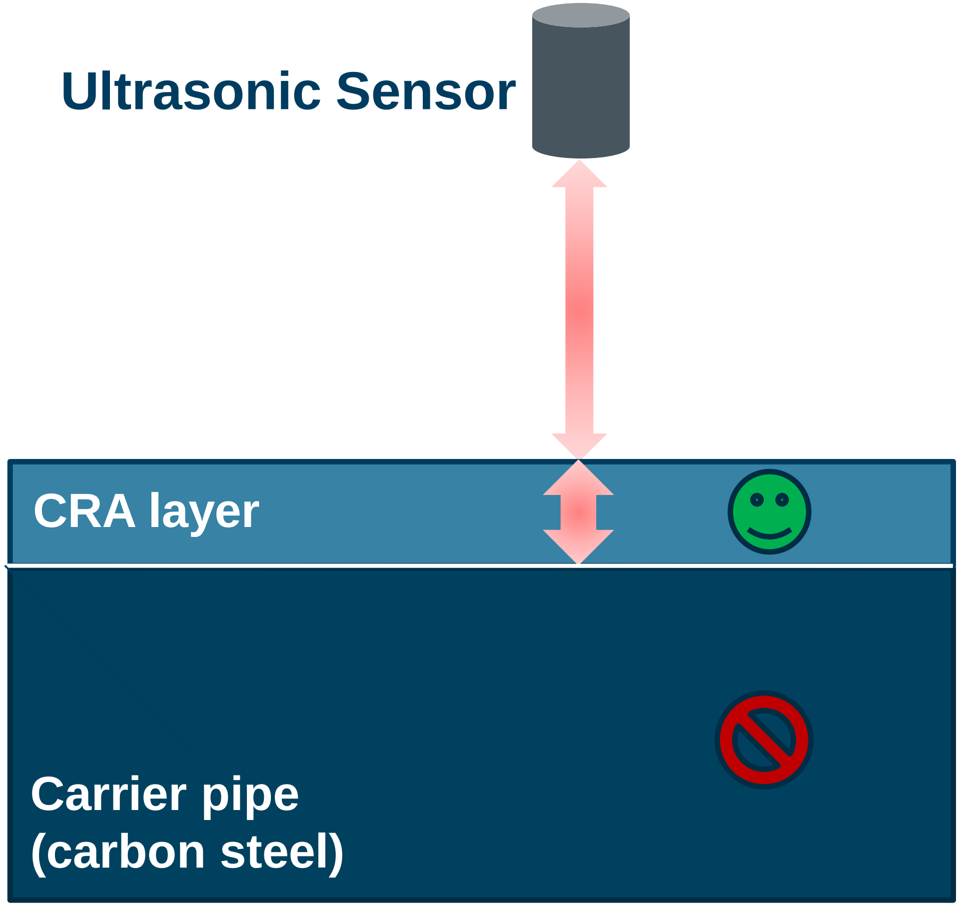
Metallurgical Bond



Reflection coefficient < 0.03

ULTRASONIC INSPECTION OF CRA PIPE

Mechanical Bond



Reflection coefficient ≈ 100%

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EXAMPLES

- ***Metal loss inspection***
- ***Crack inspection***
- ***Disbonding***

SUMMARY

IN-LINE INSPECTIONS OF CRA PIPES

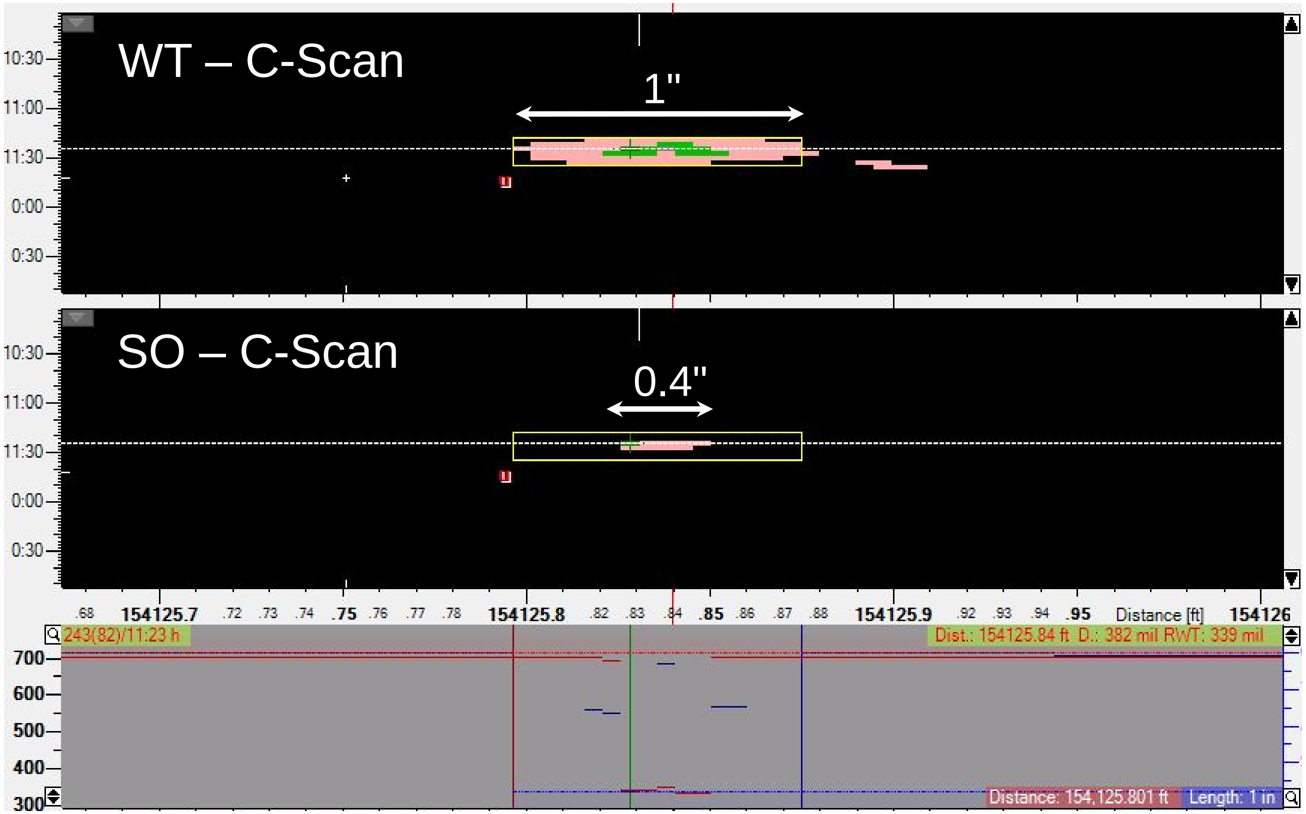
Seam Welded Clad Pipe

- *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*

IN-LINE INSPECTION OF CRA PIPE

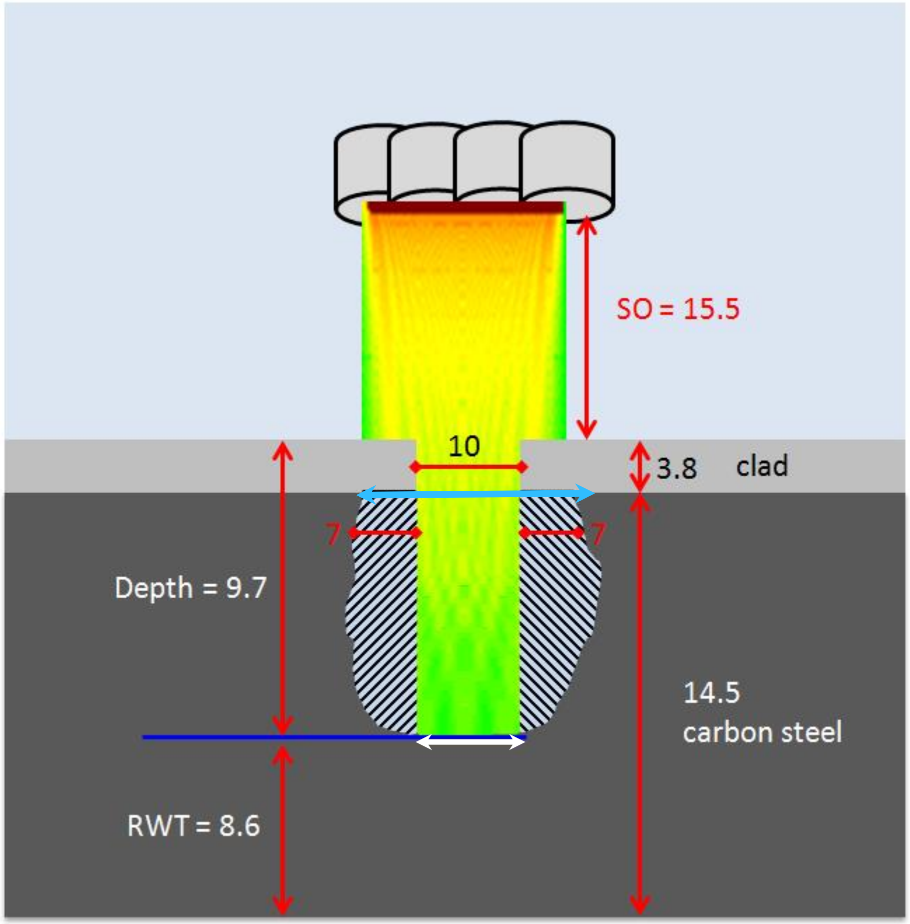
Deep Internal Pit in Clad Plate (Incoloy 825)

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

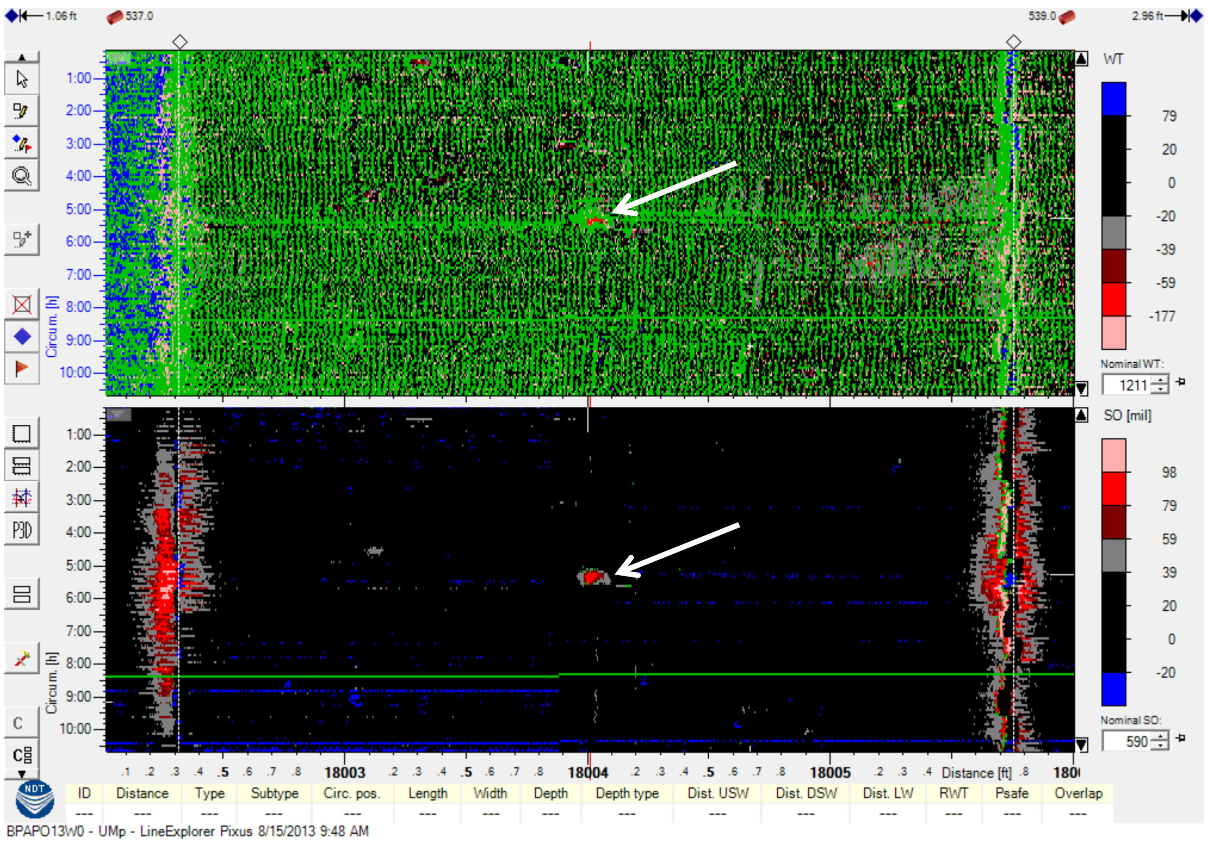
circumfer. weld overlay

axial weld overlay

IN-LINE INSPECTION OF CRA PIPES

Internal Metal Loss in Orbital 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.



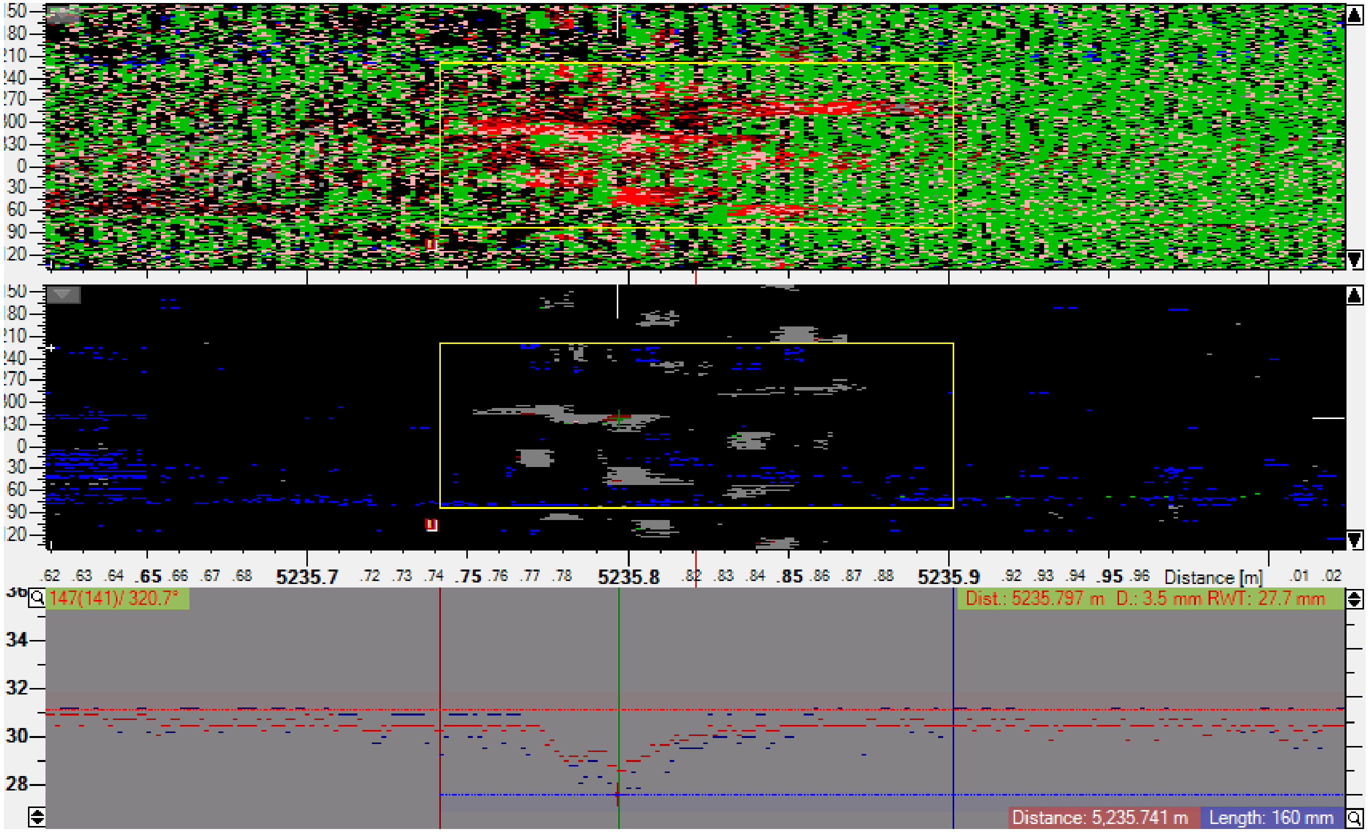
C-Scan Wall thickness

C-Scan Standoff

IN-LINE INSPECTION OF CRA PIPES

Internal General Metal Loss in Orbital Weld-Overlay

Scattered area of internal metal loss (3.5 mm deep) detected in an orbital weld-overlay clad pipe (Inconel 625).



C-Scan Wall thickness

C-Scan Standoff

B-Scan Profiles

INSPECTION REQUIREMENTS FOR CRA PIPES
Tool Resolution & Typical CRA Anomalies

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

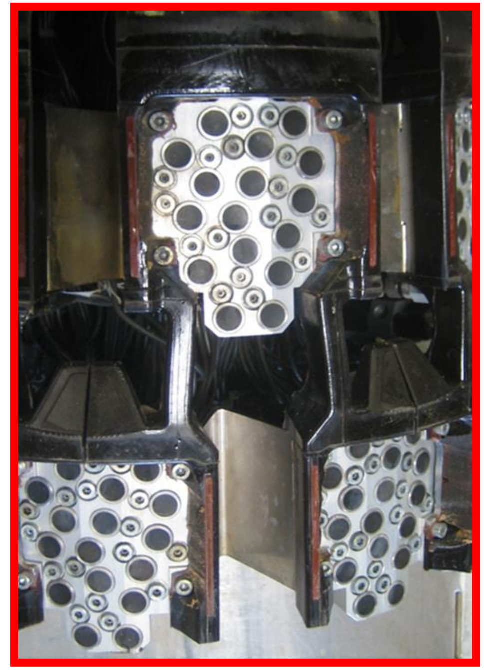
Improvement of Circumferential Resolution

UM (Standard Resolution)

Circumf. Resolution: 8 mm

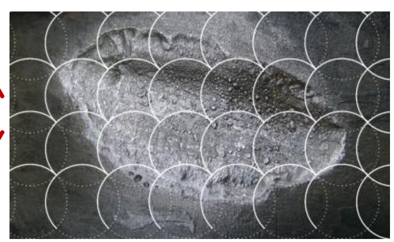
8 mm

UMp (Pitting Resolution)

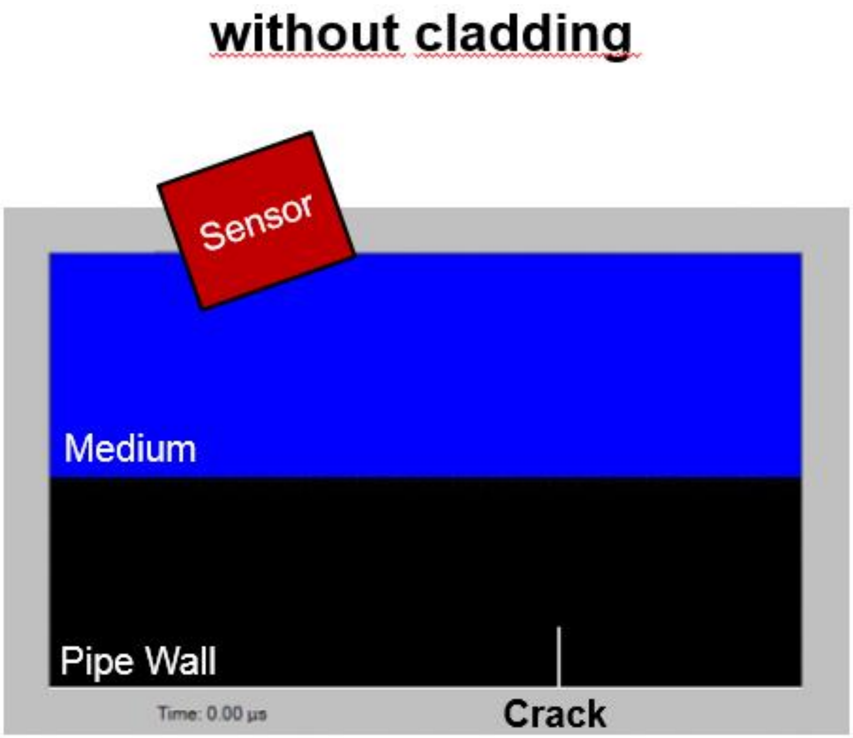


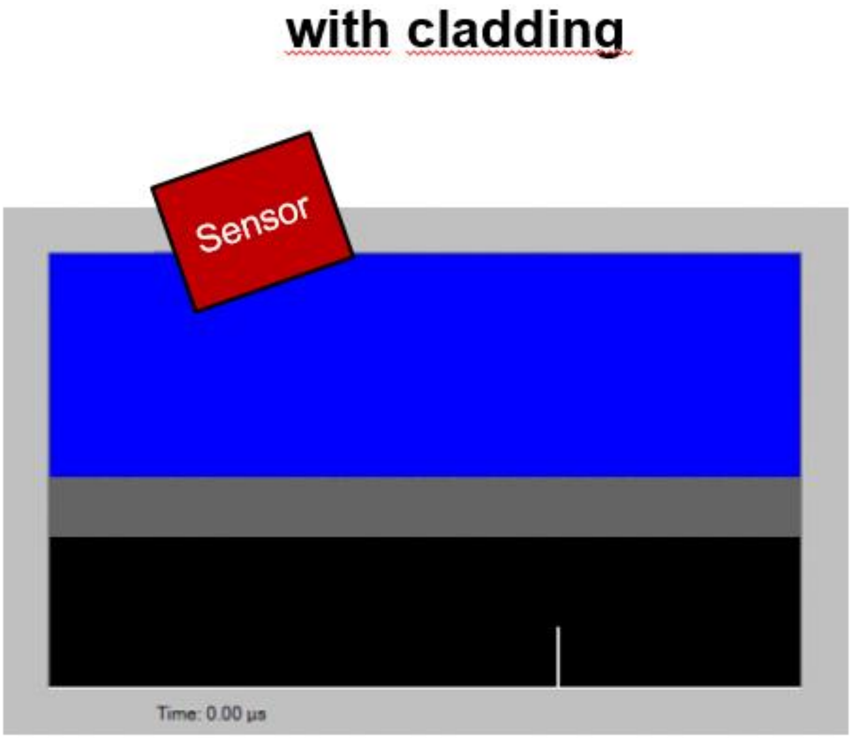
Circumf. Resolution: 4 mm

4 mm



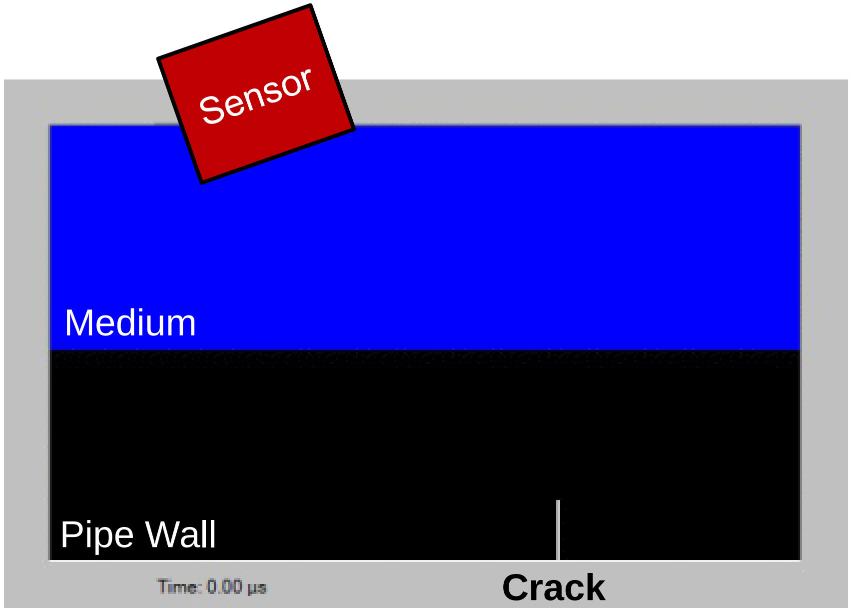
ULTRASONIC CRACK INSPECTION
Comparison with & without cladding (modelling)



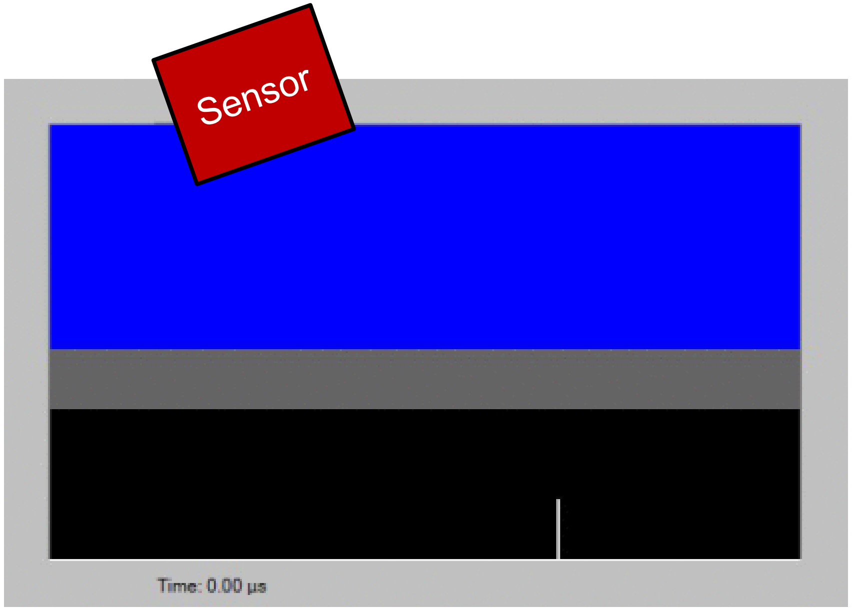


ULTRASONIC CRACK INSPECTION
Comparison with & without cladding (modelling)

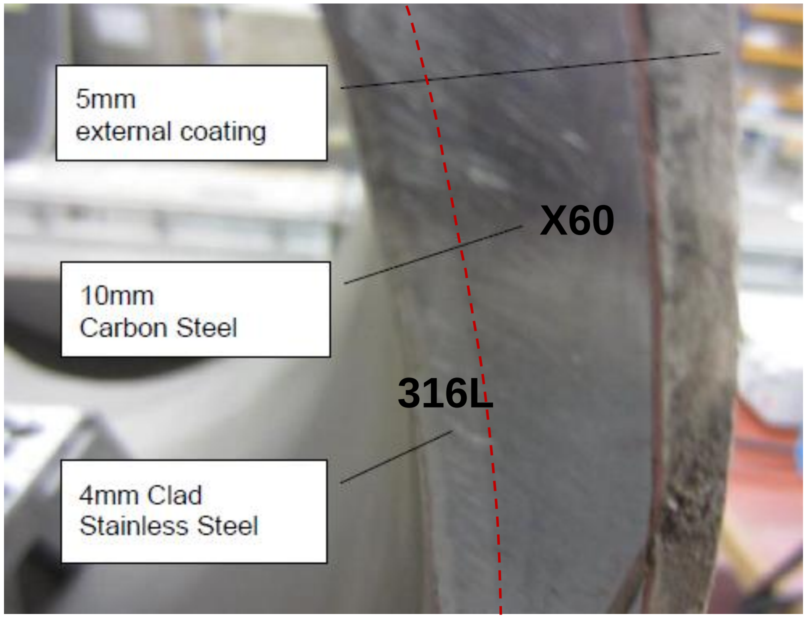
without cladding

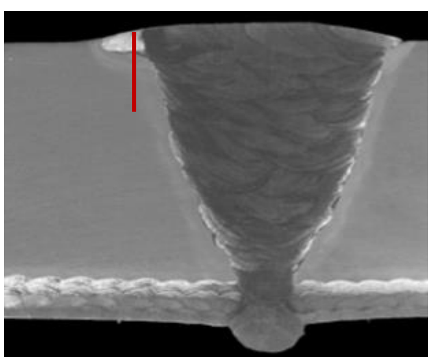


with cladding



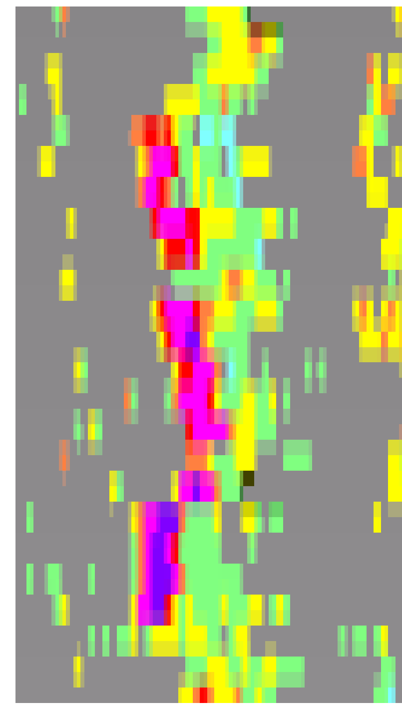
CRACK INSPECTION IN CLAD PIPE
Crack-like Defects at the Girth Weld





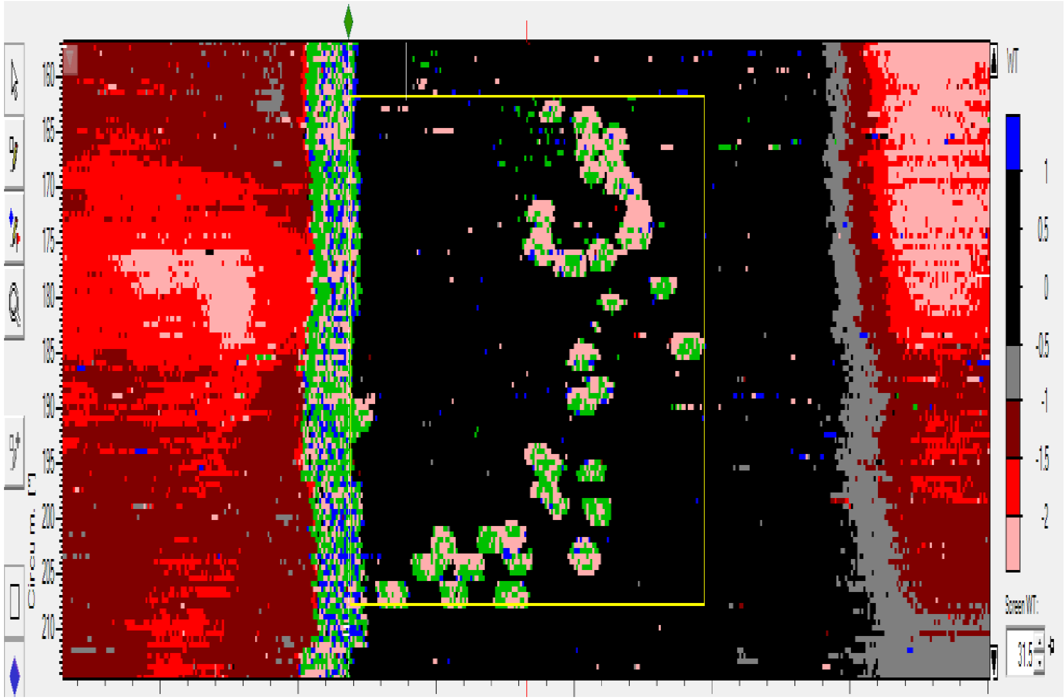
View of external defects

Ultrasonic C-Scan



IN-LINE INSPECTION OF CRA PIPELINES
Disbonding in Clad Pipe

Cluster of disbondment anomalies between cladding and CS carrier

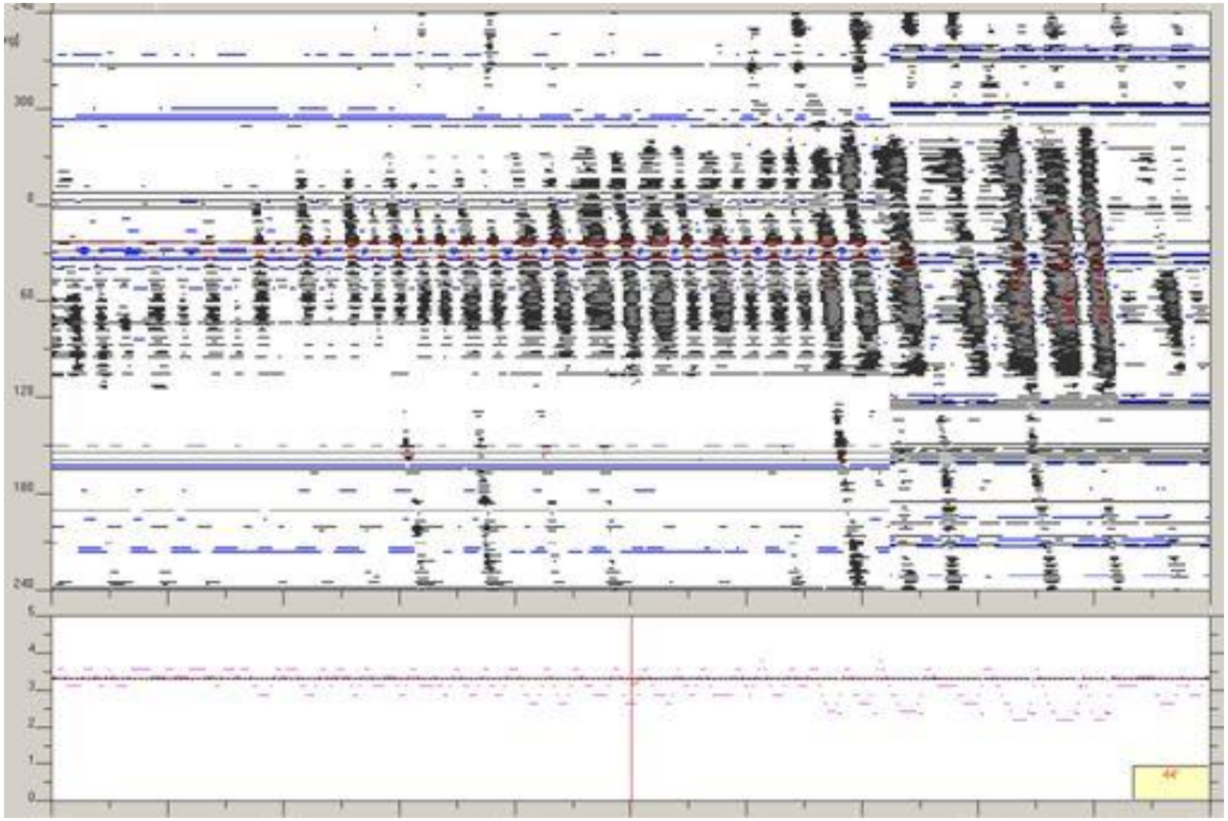


Results from ILI (NDT Global)

WRINKLING / BUCKLING IN CRA LINER

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

IN-LINE INSPECTION OF CRA PIPES

Importance of Baseline Surveys

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

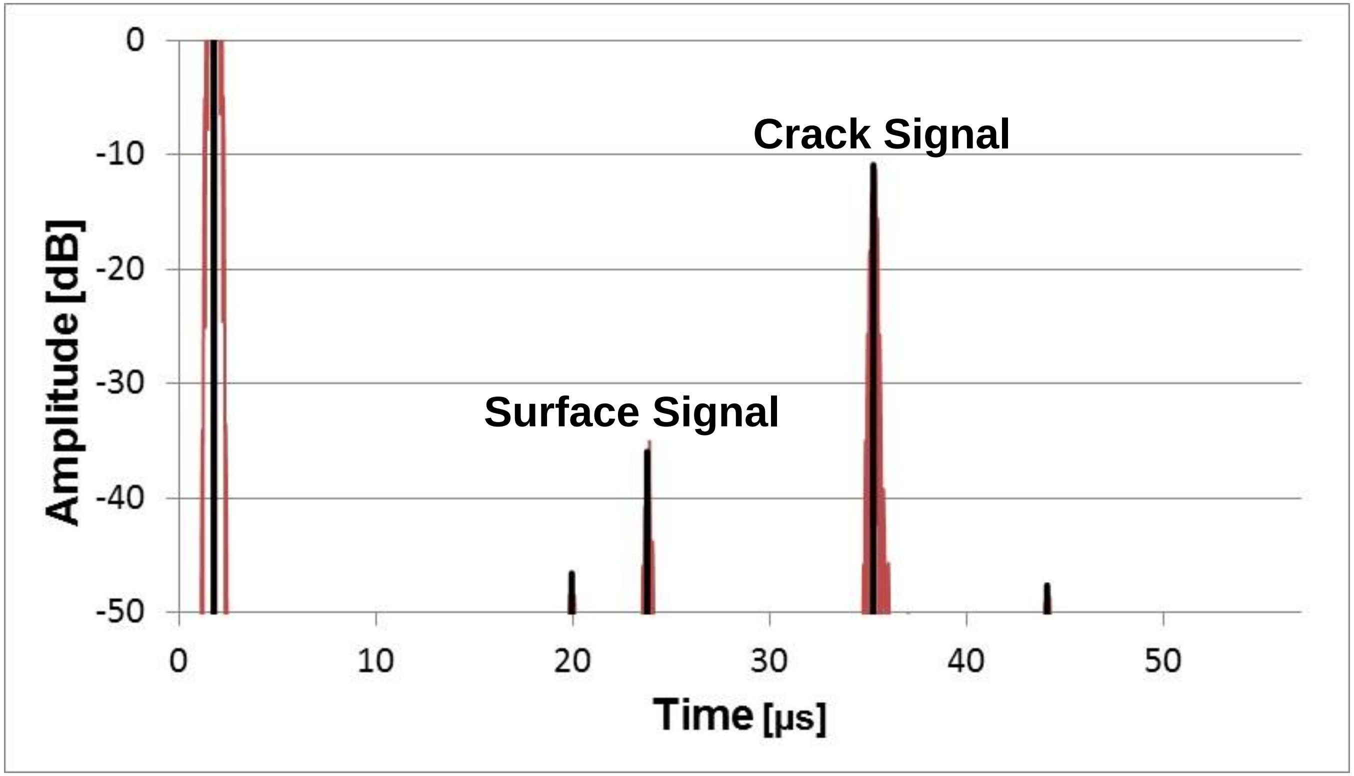
- **ALL THE DIFFERENT CRA PIPES (SOLID, CLAD AND LINED) CAN BE INSPECTED USING ULTRASONIC ILI TOOLS:**
  - ***Solid CRA pipe & seam welded clad pipe:*** *no restrictions*
  - ***Weld-overlay clad pipe:*** *ok for internal corrosion (reduced quality for external corrosion due to wavy surface pattern)*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

TYPE OF CRA PIPE	DESCRIPTION	Metal Loss		Radial Cracking		Disbonding		Comment
		UT	MFL	UT	MFL	UT	MFL	
Lined Pipe	***Carrier***					n.a.		mechanical bonding
	Liner							
Clad Pipe	***Carrier***							metallurgical bonding
	Cladding							Weld overlaying causes wavy surface/interface
Solid Pipe	***ferritic***					n.a.		
	Duplex							MFL: modified calibration
	austenitic							UT: to be checked for Ni-based alloys


Crack Signal
Surface Signal
Amplitude [dB]
Time [µs]
0
-10
-20
-30
-40
-50
0
10
20
30
40
50