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TESORO ANACORTES REFINERY

EXCHANGER E6600B

June 24, 2010 Inspection Report

Note to Reader: This report labels the indications identified in the E-6600B exchanger shell as "Lack of Fusion" due to their proximity to welds. This report also concludes that cracking caused by HTHA was not present. However, subsequent metallurgical testing confirmed the identified areas of "Lack of Fusion" are cracks and that HTHA was the primary cause of the cracking in the E-6600B exchanger. The HTHA cracks that formed in the E-6600B heat exchanger are atypical; normally, HTHA forms small fissures rather than large cracks. Because the inspector was looking for small fissures and did not identify any, he concluded that the cracking was not a result of HTHA.

INTRODUCTION

Spectrum Inspection Engineering was requested to perform Phased Array weld inspection, Hydrogen Attack AUBT, Material Identification and Hardness test on Exchanger E6600B.

SCOPE OF WORK

Phased Array inspection on 100% Longitudinal and Circumferential welds.

Hydrogen Attack AUBT inspection and circumferential welds CW3, CW4 and Longitudinal weld LW3

Material Identification (PMI) on all longitudinal welds, circumferential welds and based metal.

Hardness test on all longitudinal welds, circumferential welds and HAZ.

INSPECTION TECHNIQUES

Phased Array: Weld defect and cracking inspection

Hydrogen Attack AUBT

PMI Material Identification

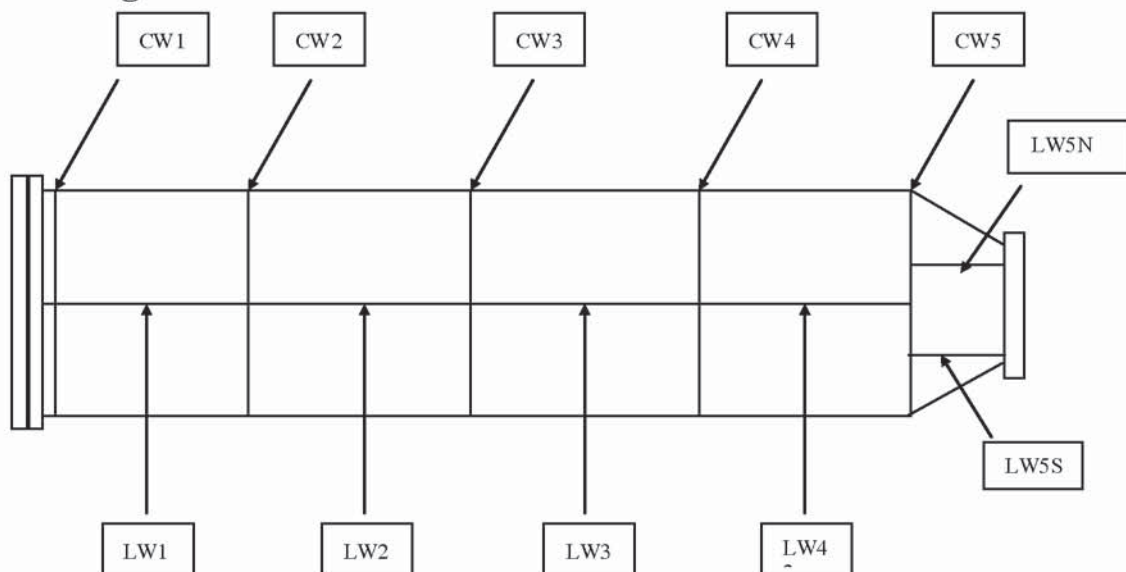
EQU TIP Brinell Hardness test

PROCEDURE

Spectrum Inspection Engineering Phased Array Inspection

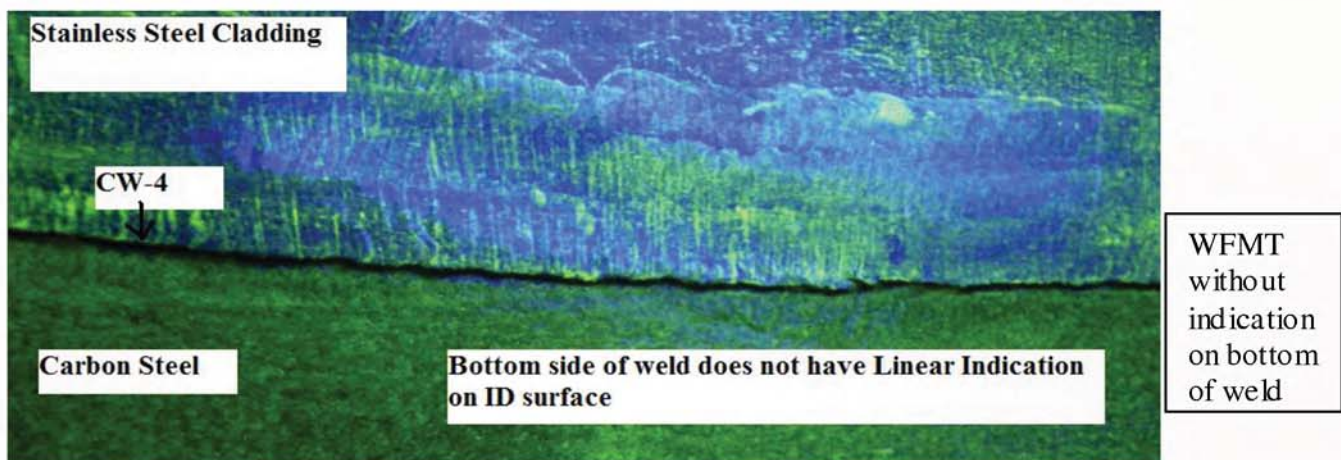
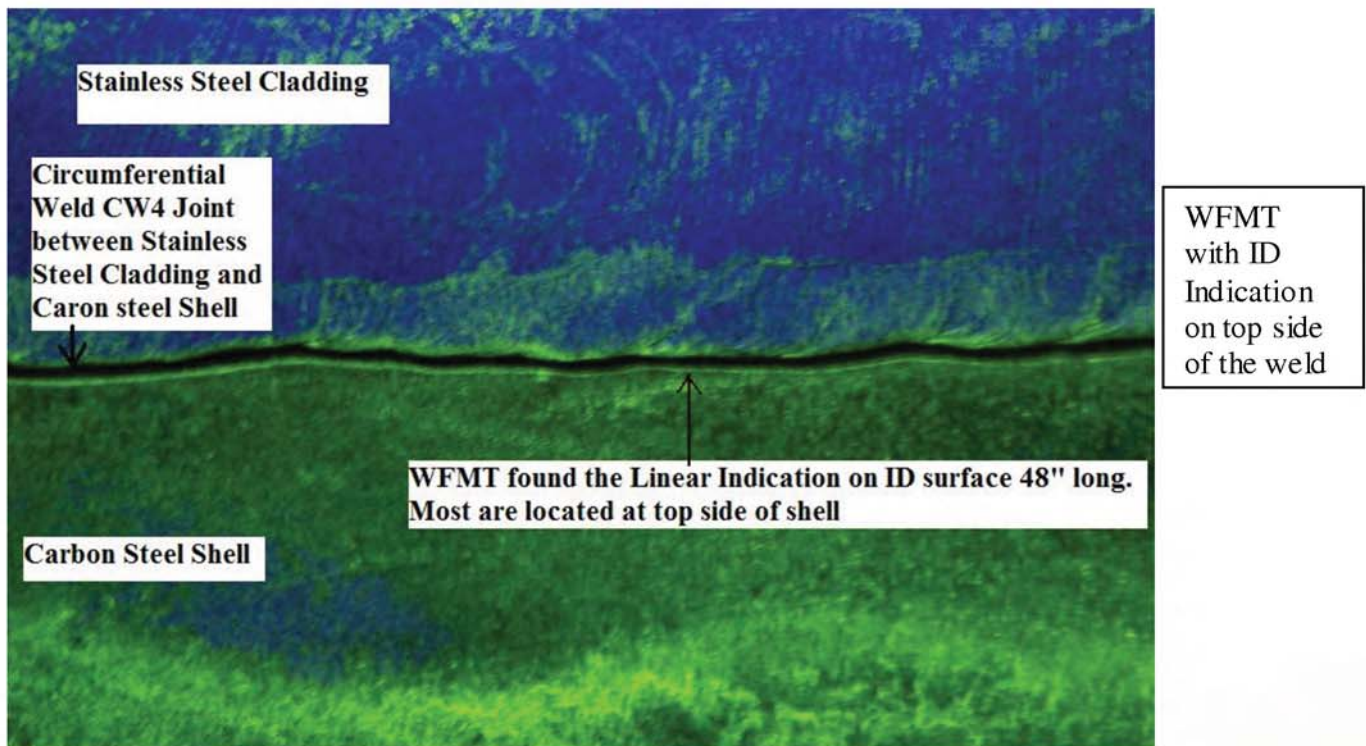
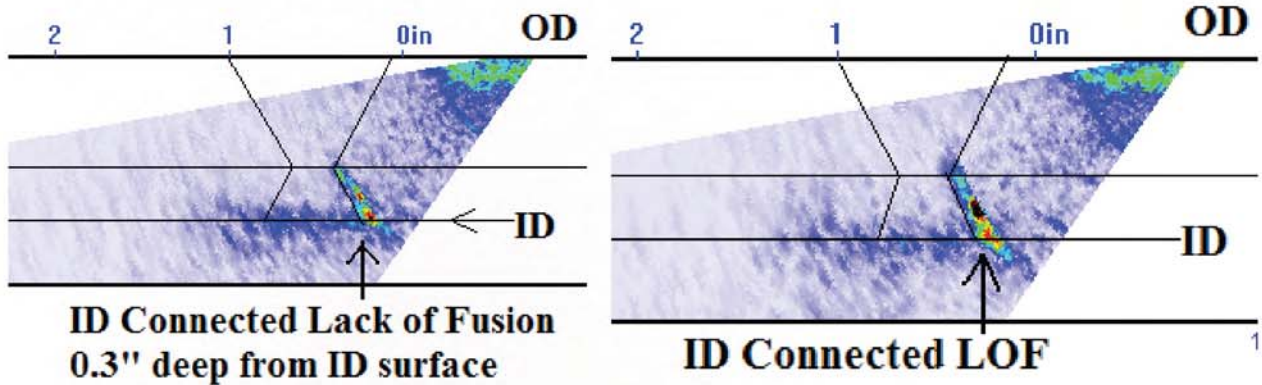
Spectrum Inspection Engineering Hydrogen Attack AUBT Inspection

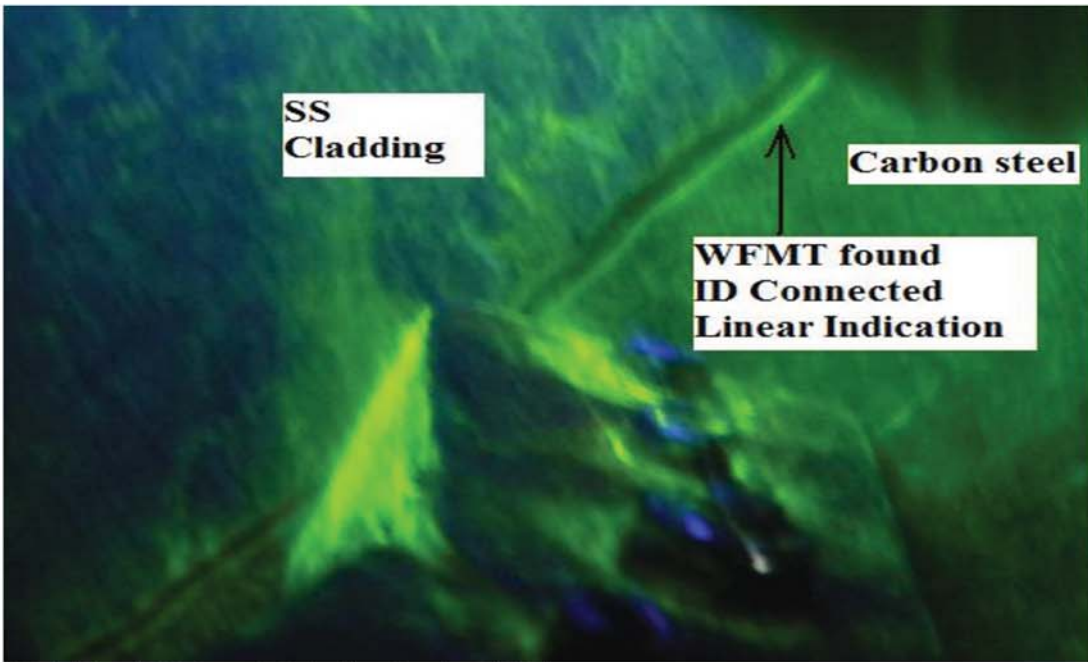
Drawing:



SUMMARY OF RESULT

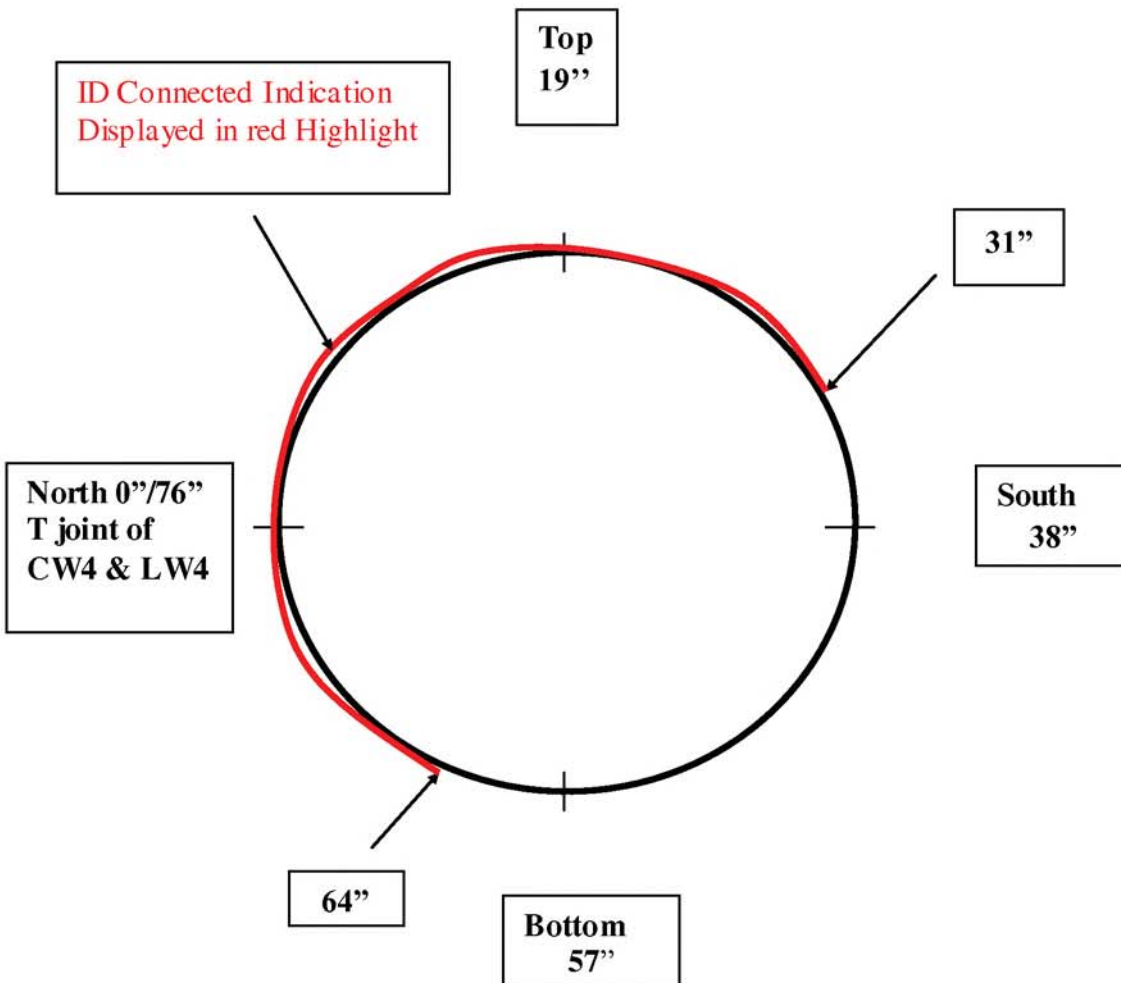
1. Phased Array inspection found ID connected Lack of fusion (0.3" deep from ID) or crack (since it is ID connected) at the edge of stainless cladding on circumferential weld CW4. Internal visual and internal WFMT confirmed the Phased Array finding and found it cover at least 50% of the weld. (48" long linear indication on ID surface).



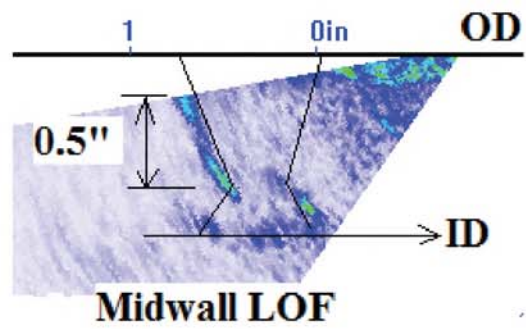
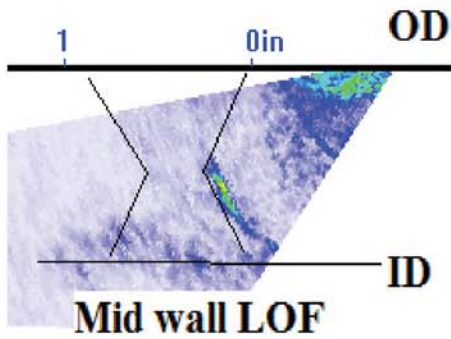


WFMT with Linear ID indication in CW-4.

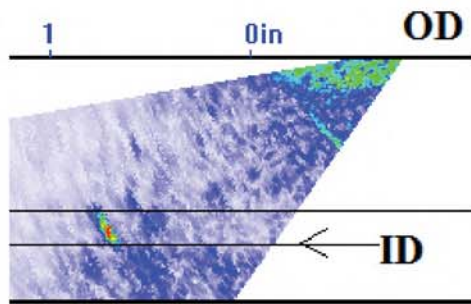
Total circumference of CW4 was 76". ID connected indication ran from 0"- 31". It was also present from 64"-76".



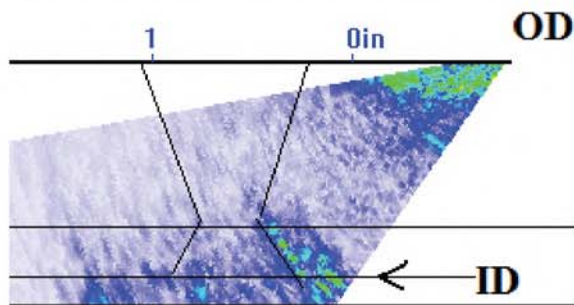
2. Phased Array inspection found 30" long intermittent mid wall lack of fusion (LOF) in longitudinal weld LW3 (include 10" continuous LOF). Internal visual and WFMT does not find indication on ID surface.



3. Localized ID connected Lack of fusion found in circumferential weld CW5. It was measured at 4' long and 0.17" deep from ID surface. WFMT confirmed the indication on ID surface.



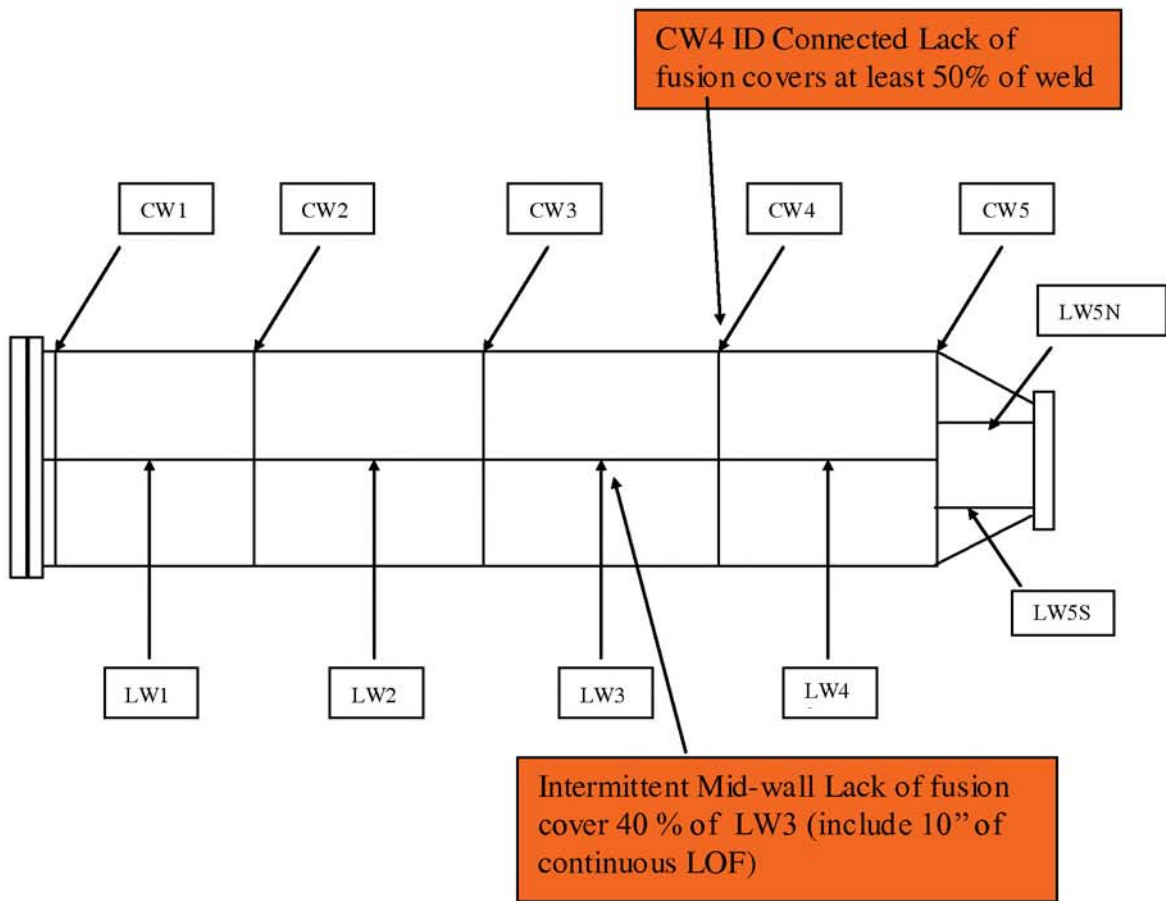
4. Localized ID connected Lack of fusion found in longitudinal weld LW-5



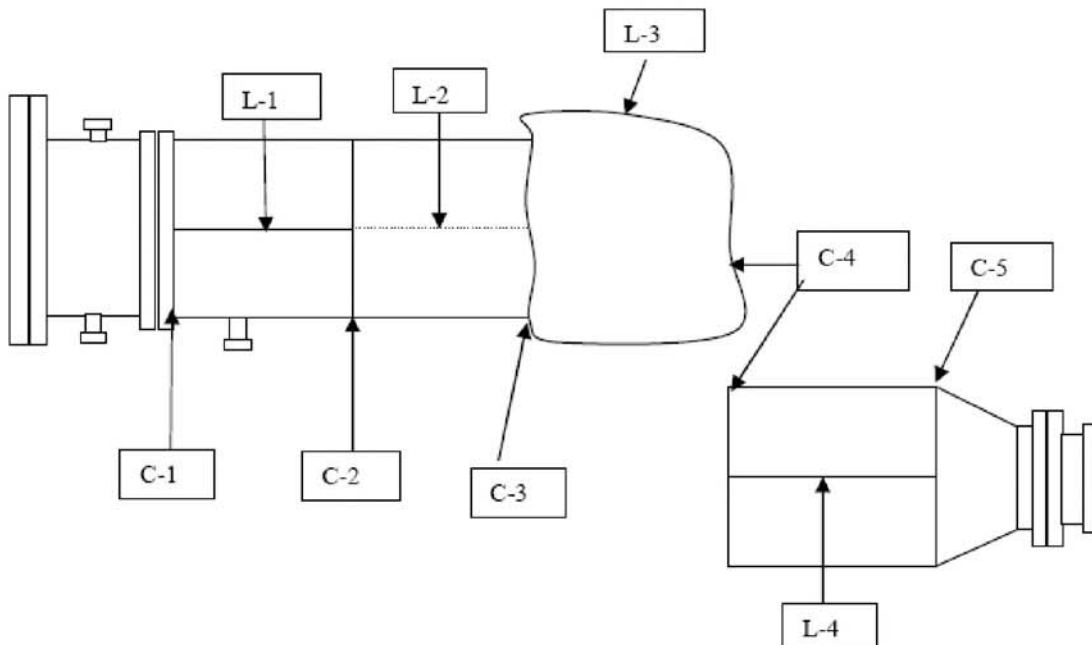
5. Above indications found in Circumferential weld CW4 (ID connected Lack of fusion or crack) and Longitudinal weld LW3 (Mid wall lack of fusion) are same location as exchanger E6600-E fracture area.
6. Rest of welds (CW1, CW2, CW3, LW1, LW2 and LW4) in good condition.
7. No Hydrogen attack fissure indication found in exchanger shell based metal.
8. No Hydrogen attack fissure indication found in weld and HAZ.
9. Material identification confirmed exchanger E6600B is made of carbon steel. Please see detail composition in page 12.
10. Hardness test found average hardness number in welds are 130 BHN to 159 BHN. HAZ are 120 BHN to 157 BHN. Based metal are 114 BHN to 146 BHN. Please see detail hardness number in page 11.

E6600B defect location same as E6600E fracture area

Exchanger E6600B Indication locations



Exchanger E6600E Fracture Location



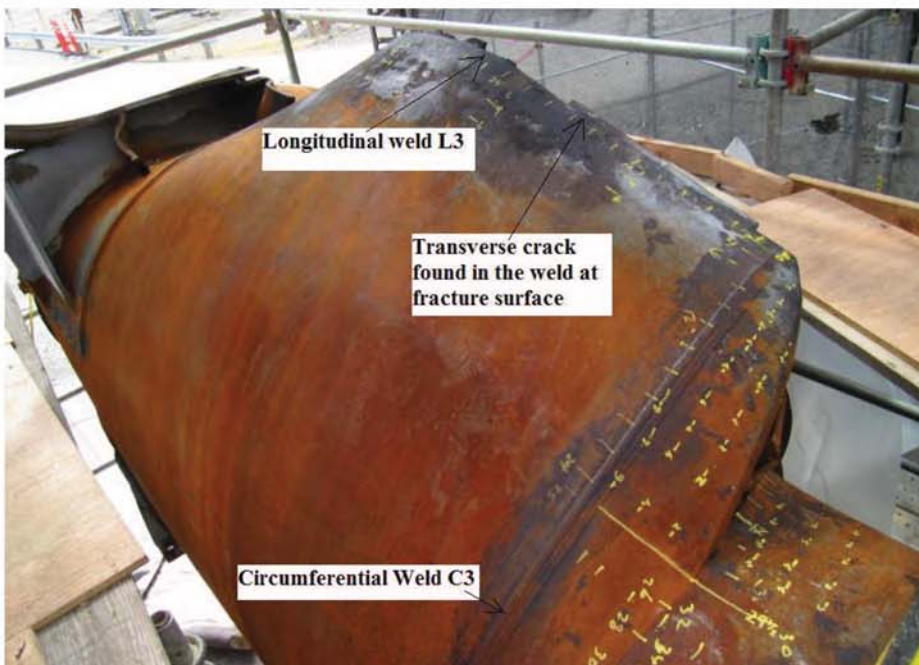
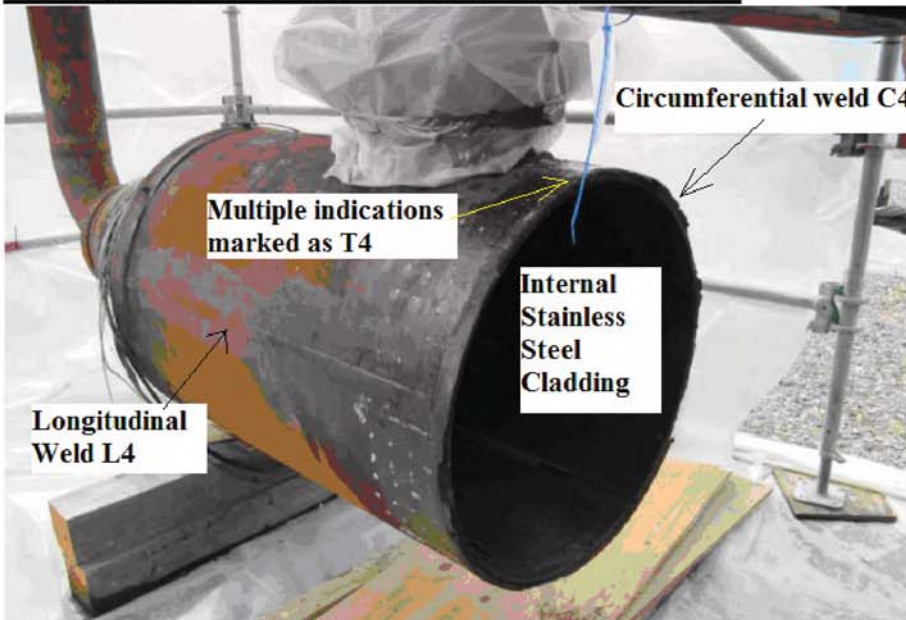
Exchanger E6600B Indication locations CW4 and LW3



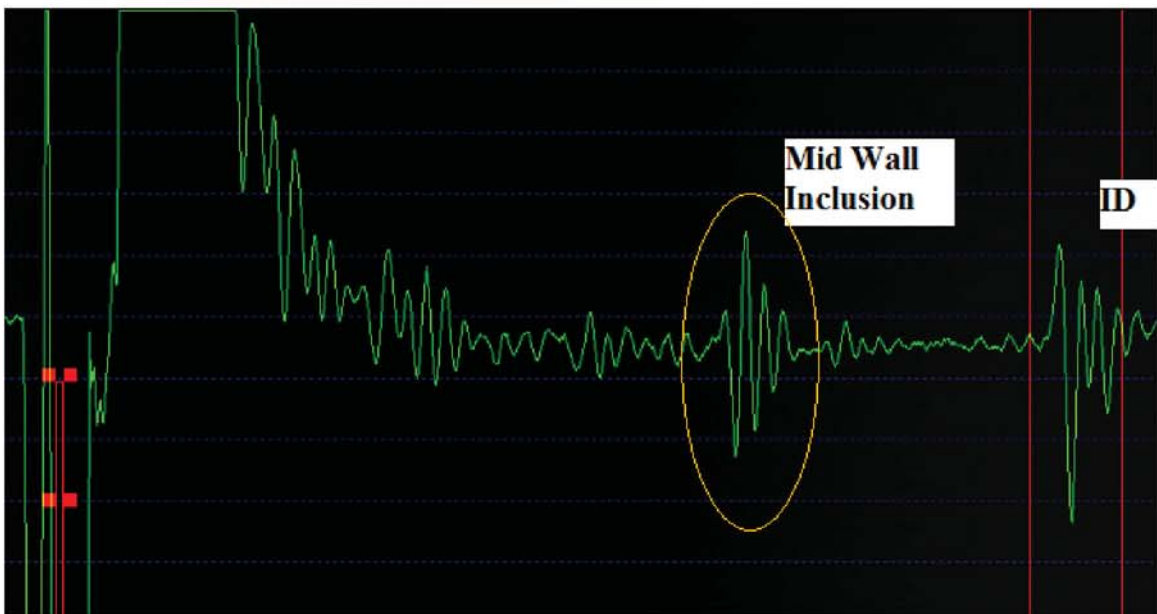
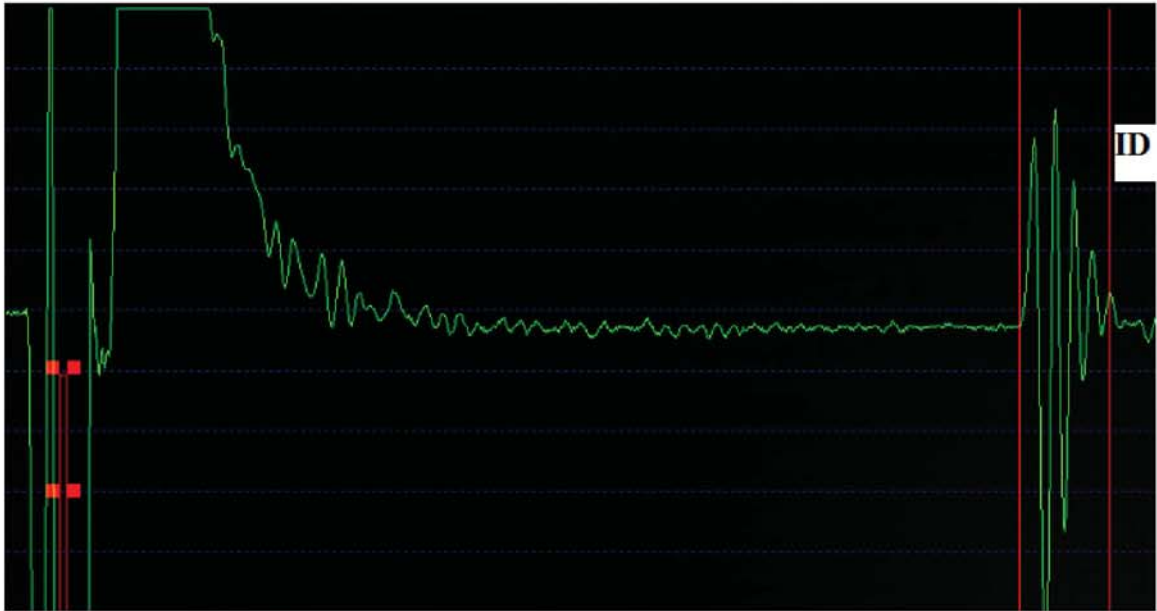
Exchanger E6600-B

**ID Connected
Lack of fusion**

Exchanger E6600E Fracture Location CW4 and LW3

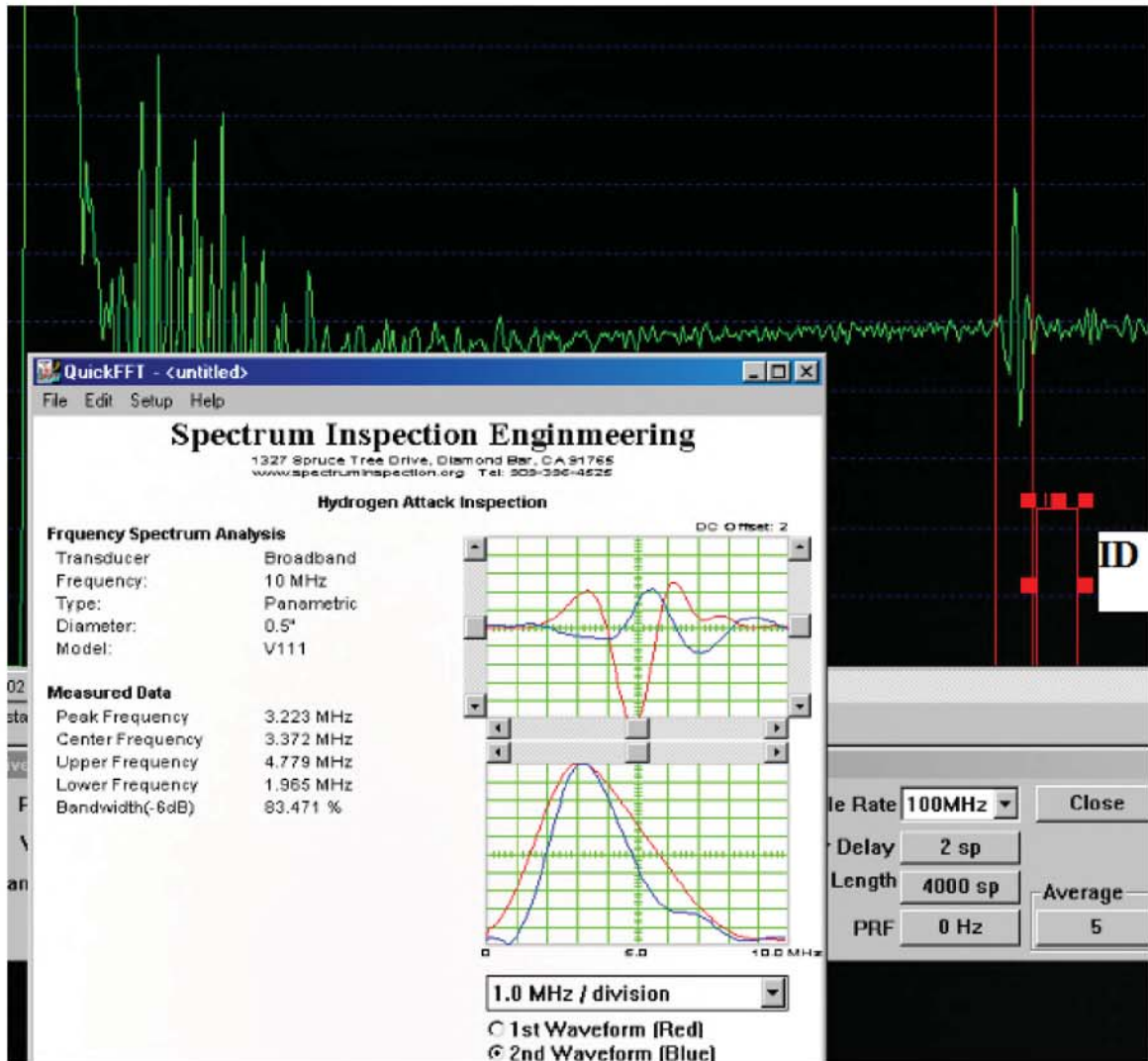


AUBT in Based Metal did not find Hydrogen Attack fissures.



AUBT did not find hydrogen attack fissures in weld and HAZ.

All indications are confirmed that small Hydrogen attack fissures were not found by frequency Spectrum Analysis. (Red curve is reference back wall frequency spectrum and blue curve is frequency spectrum of indication found in the weld). These large indications are welding defects or large macro-cracking but not small fissures along grain boundary.



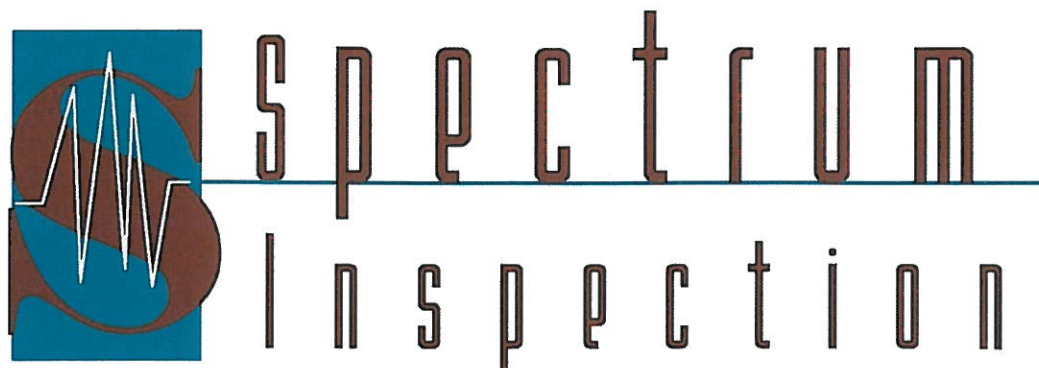
B6600-B Hardness Test Data

CW1	132	130	130
CW1 HAZ	121	120	127
CW2	130	138	130
CW2 HAZ	132	120	120
CW3	138	142	147
CW3 HAZ	150	148	157
CW4	136	140	133
CW4 HAZ	143	150	141
CW5	153	149	159
CW5 HAZ	146	146	148
Base Metal 1	131	135	131
Base Metal 2	115	114	116
Base Metal 3	121	116	125
Base Metal 4	140	143	146
Base Metal 5	130	134	135

LW1	131	136	130
LW1 HAZ	122	122	123
LW2	138	137	136
LW2 HAZ	120	117	119
LW3	135	138	138
LW3 HAZ	138	136	138
LW4	139	141	154
LW4 HAZ	153	156	146
LW5	133	139	143
LW5 HAZ	133	136	133

B6600-B PMI Test Data

	Base 1	CW 1	LW 1	Base 2	CW 2	LW 2
Zn						
Mn		2.060%	0.240%	1.060%	2.050%	1.810%
Fe	95.400%	95.770%	95.400%	96.980%	95.420%	95.600%
Ni	0.661%					
Mo	0.333%	0.183%	0.825%	0.259%		0.302%
Nb			0.240%			
Cr	0.241%				0.261%	
CU		0.67%			0.58%	0.59
	Base 3	CW 3	LW 3	Base 4	CW 4	LW 4
Zn						
Mn	1.370%	1.850%	1.810%	1.380%	2.160%	1.760%
Fe	96.120%	96.450%	96.210%	96.160%	95.310%	96.190%
Ni						
Mo	0.320%	0.260%	0.346%	0.235%	0.250%	0.326%
Nb						
Co						
CU				0.85%		
	Base 5	CW 5	LW 5			
Zn			0.253%			
Mn	1.250%	1.910%	1.800%			
Fe	96.430%	95.770%	95.320%			
Ni						
Mo	0.264%	0.289%	0.253%			
Nb			0.30%			
Co						
CU		0.627%				



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**TESORO ANACORTES REFINERY
HEAT EXCHANGER E-6600E
Unit: NHT**

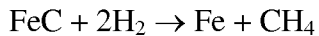
**PHASED ARRAY AND HIGH TEMPERATURE
HYDROGEN ATTACK AUBT INSPECTION**

Note to Reader: This report concludes that the large cracks identified in the E-6600E exchanger shell were not caused by HTHA. However, subsequent metallurgical testing confirmed that HTHA was the primary cause of the cracking in the E-6600E exchanger. The HTHA cracks that formed in the E-6600E heat exchanger are atypical; normally, HTHA forms small fissures rather than large cracks. Because the inspector was looking for small fissures and did not identify any, he concluded that the cracking was not a result of HTHA.

INTRODUCTION

Spectrum Inspection Engineering was requested to perform High Temperature Hydrogen Attack AUBT and Phased Array cracking inspection on Exchanger E-6600E before sending to lab destructive test.

Hydrogen Attack is produced in steels from the seepage of hydrogen that reacts with carbides to form methane gas (CH₄). This gas decarburizes the steel and produces micro-fissures. It can decrease the strength and fracture toughness of steel without necessarily loss of thickness.



SCOPE OF WORK

Phased Array and Hydrogen Attack AUBT inspection on exchanger E-6600E fracture surface weld, HAZ and Base Metal.

Inspection Area covers: Circumferential weld **C-3**, **C-4** and Longitudinal weld **L-3** on both Phased Array and Hydrogen Attack AUBT inspection.

INSPECTION TECHNIQUES

Phased Array: Weld defect and cracking inspection

Advanced Ultrasonic Backscatter Technique (AUBT): Backscattering, Frequency Spectrum Analysis and Velocity Ratio

Backscattering technique is for initial scanning (detection). Frequency Spectrum Analysis and Velocity Ratio are defect confirmation.

LIMITATION OF AUBT:

AUBT can detect and differentiate the different between small hydrogen attack fissures and large macro-cracking or welding defect, however AUBT cannot identify if final stage large macro-cracking is initiated from hydrogen attack fissures.

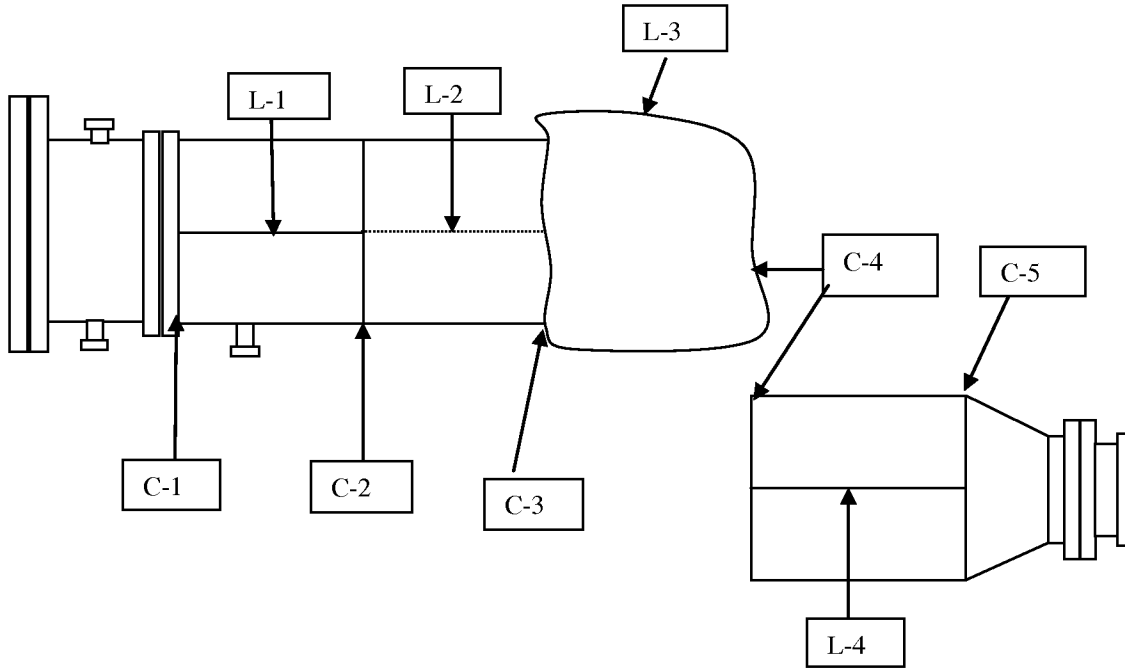
PROCEDURE

Spectrum Inspection Engineering Hydrogen Attack AUBT Inspection Procedure.
Spectrum Inspection Engineering Phased Array Inspection

TRANSDUCERS

- 10 MHz / .5" L-wave straight beam
- 5 MHz / .5" L-wave straight beam
- 5 MHz / .5" 0 degree S-wave straight beam
- 10 MHz 45 degree angle beam transducers
- 5 MHz Phased Array 32 element transducer

Exchanger Drawing:



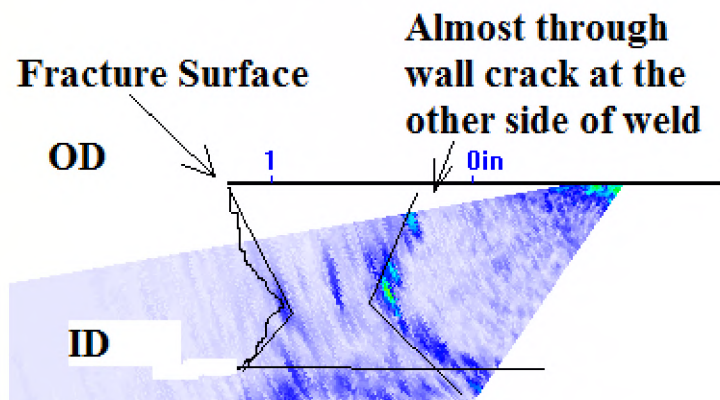
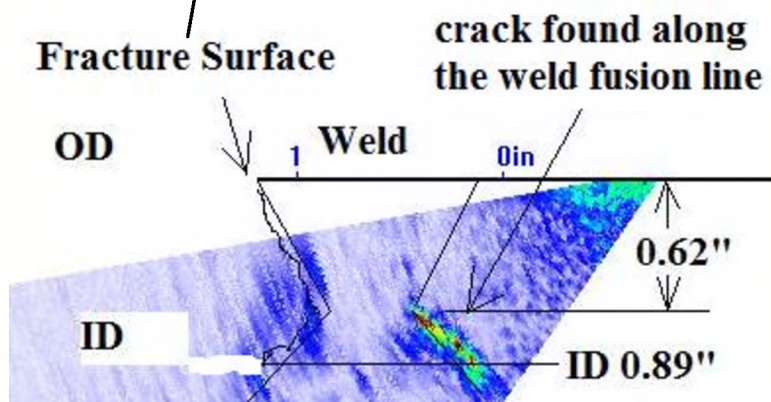
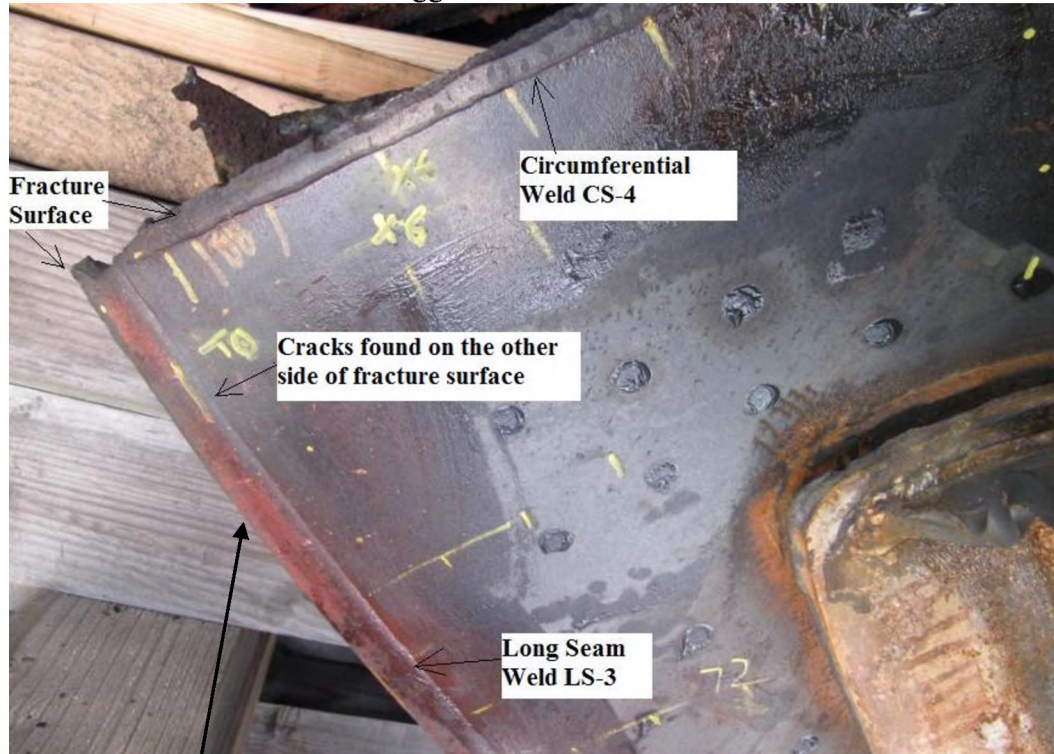
Inspection Area covers: Circumferential weld C-3, C-4 and Longitudinal weld L-3

Longitudinal Weld: L-1, L-2, L-3 and L-4

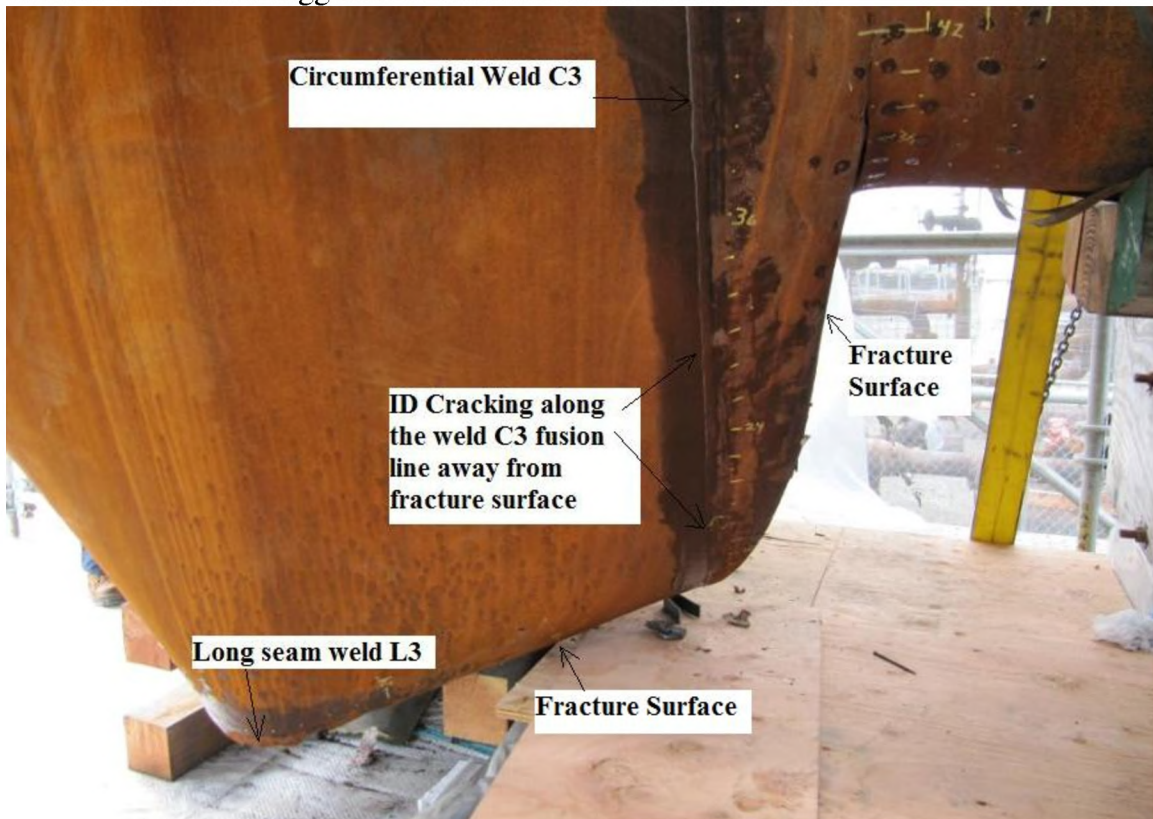
Circumferential Weld: C-1, C-2, C-3, C-4 and C-5

SUMMARY OF RESULT

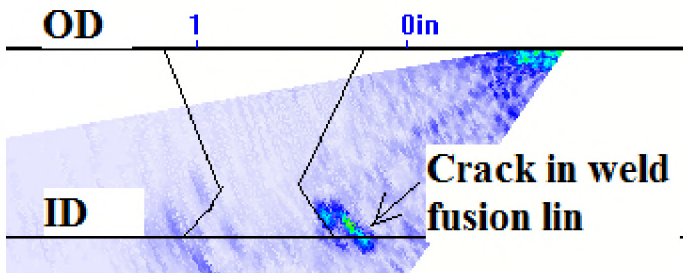
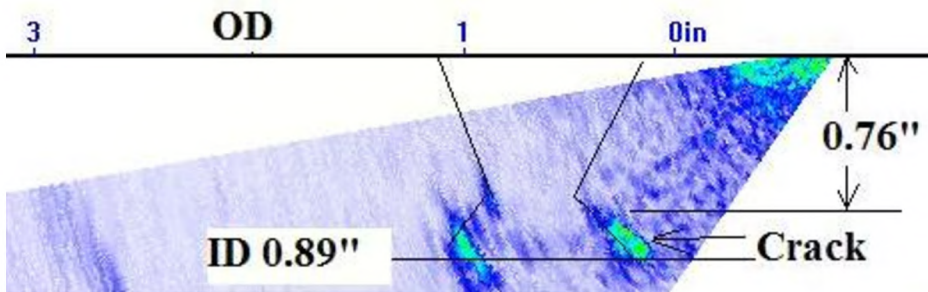
1. Phased Array found cracks in both side of weld in Long Seam L-3 (cracks at fracture surface and the other side of weld fusion line). Letter Stamp T0 marked on vessel external surface. This area is suggested to have lab microstructure exam.



2. Phased Array found ID cracking in Circumferential weld C-3 away from fracture surface (crack is 0.13" deep from ID surface). Letter Stamp T1 Marked on vessel external surface. This area is suggested to have lab microstructure exam.



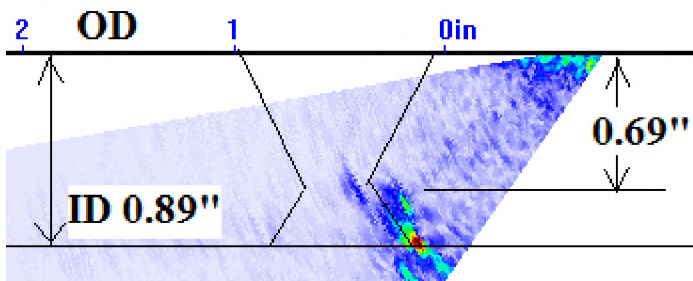
**Crack in C3 weld fusion line
2" from fracture surface**



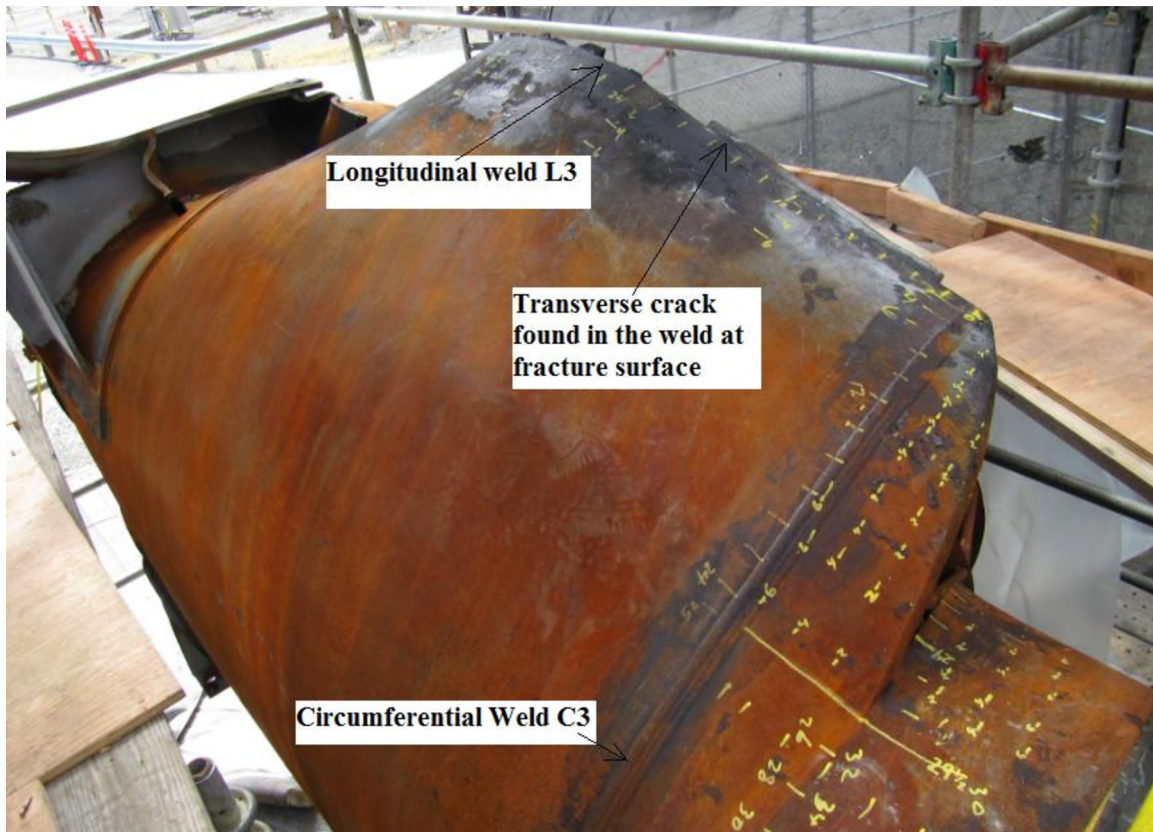
3. Phased Array found crack in T joint of C3 and L2. Letter stamp T2 marked on vessel external surface. It is suggested to have lab microstructure exam at this location.



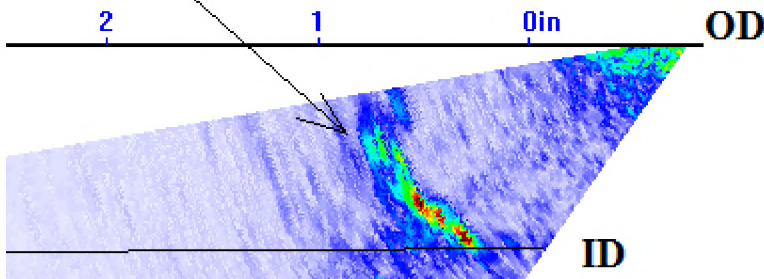
T joint of Circumferential weld C3 and Longitudinal L2



3. Transverse crack found on top of long seam weld LS-3. Letter stamp T3 marked on vessel external surface. This area is suggested to have lab microstructure exam.

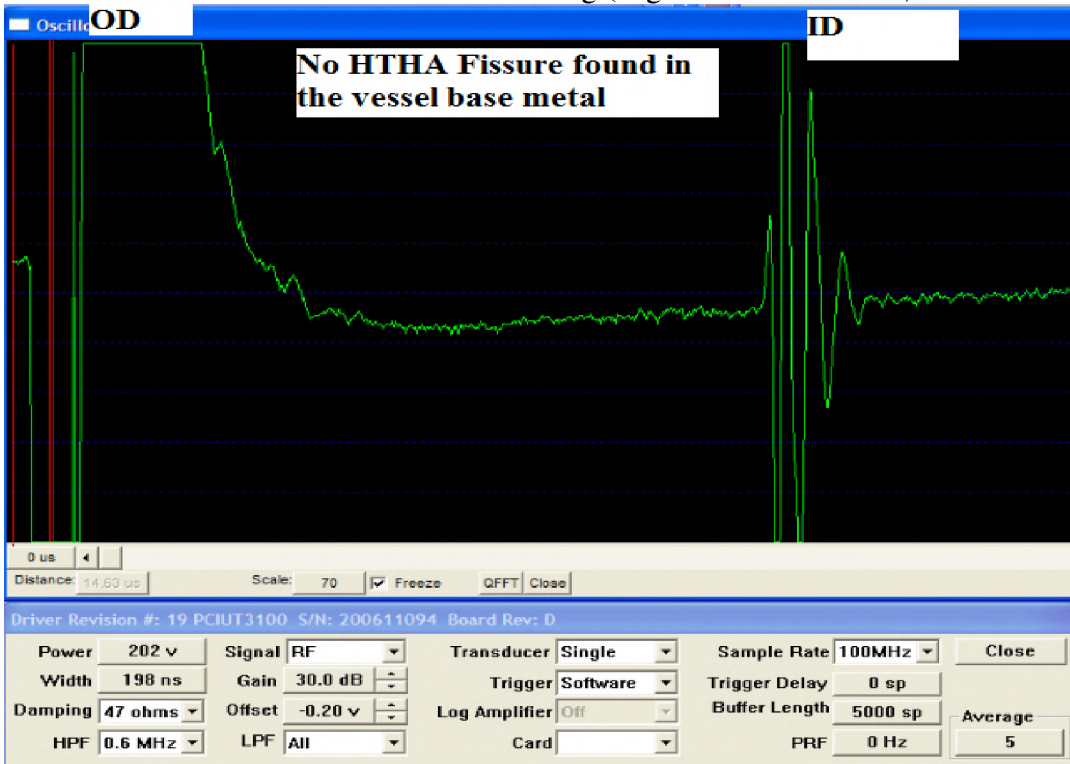


**Fracture surface follow
with weld fusion line**

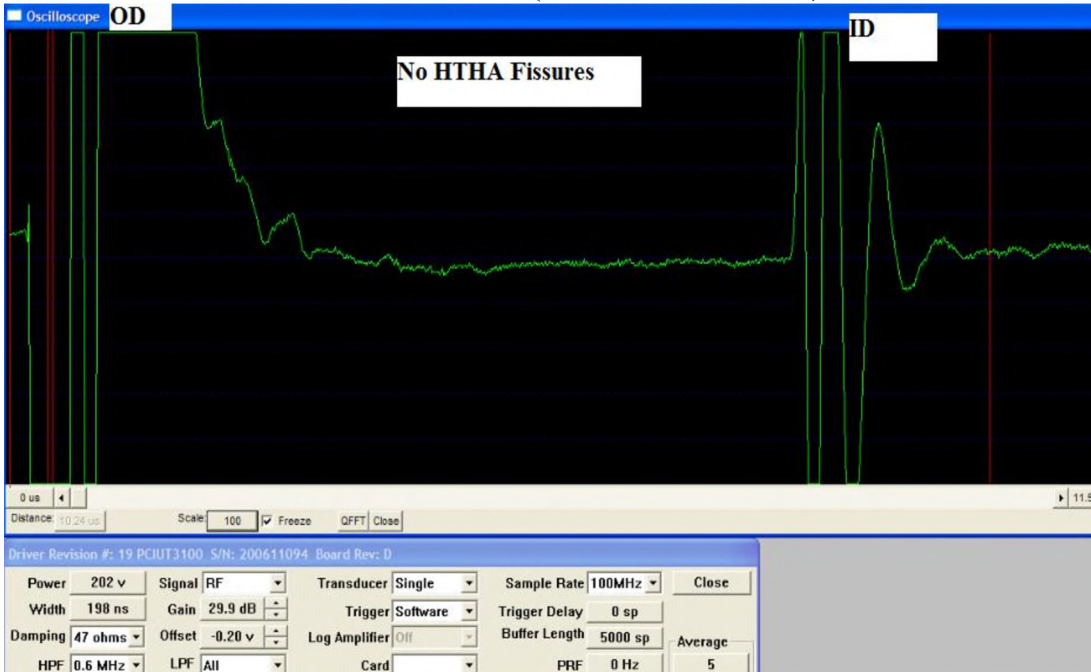


4. No HTHA fissures found in Shell base metal.

Shell base metal with Stainless Steel Cladding (Right side of Weld C4)

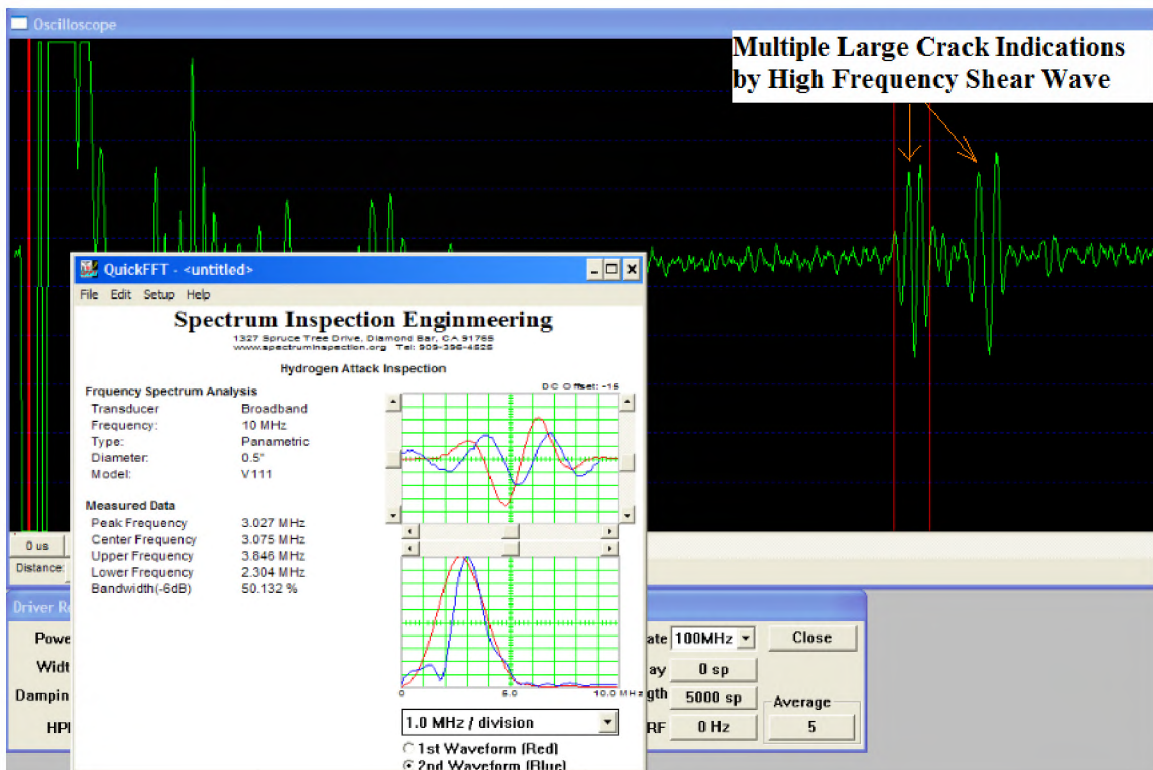
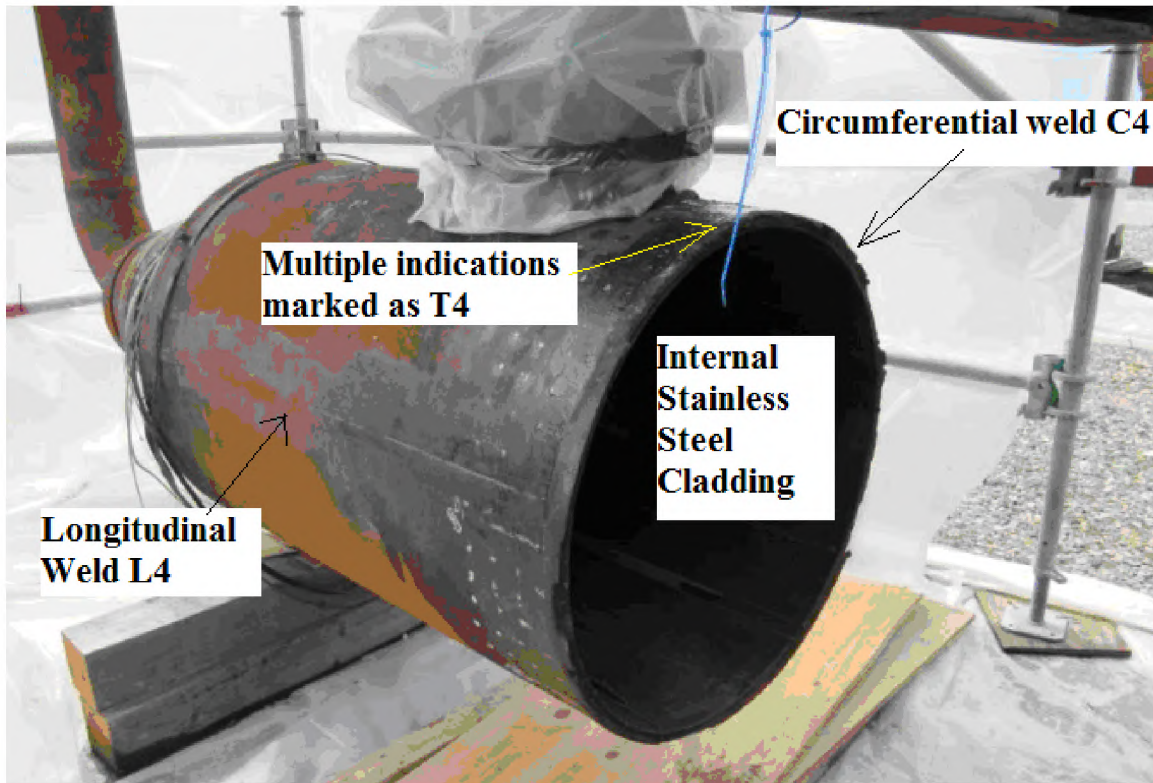


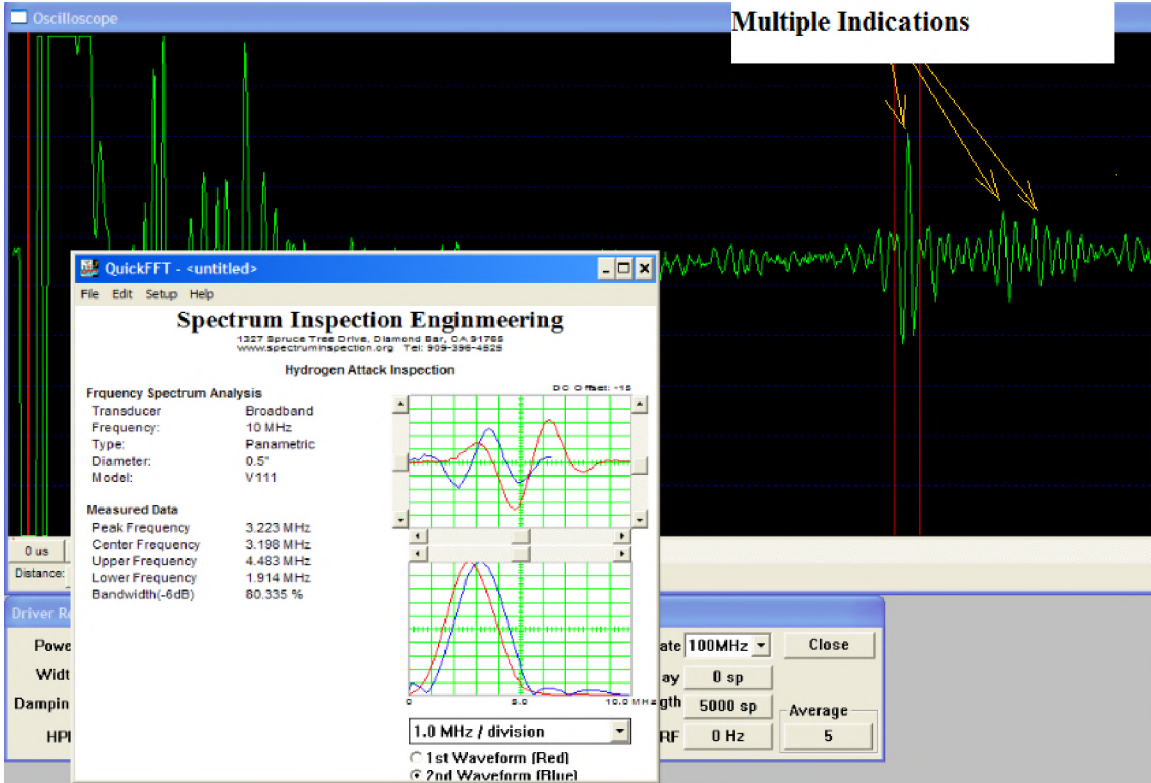
Shell Base Metal without Stainless Steel (Left side of Weld C4)



5. Velocity Ratio (Longitudinal wave Vs Shear wave) found 0.549 that indicates less chance of Hydrogen Attack in base metal.

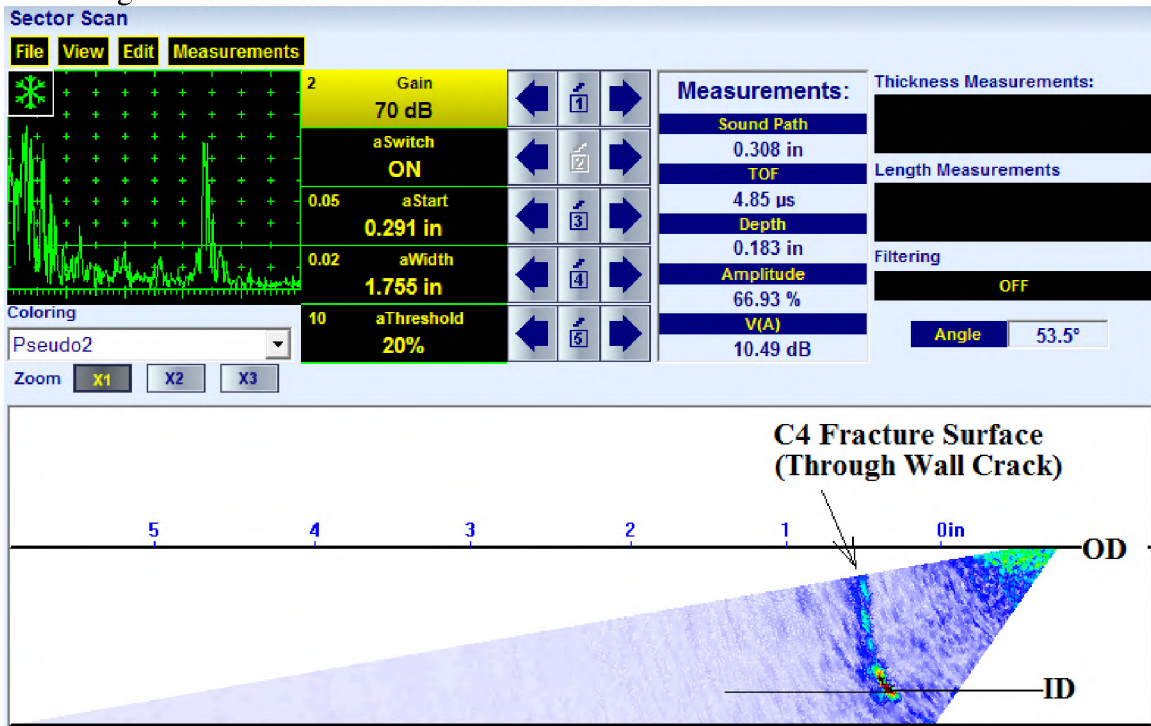
6. High frequency shear wave AUBT found multiple large crack indications in the fracture surface weld/HAZ. These large cracks are not hydrogen attack fissures. However, due to the size of the cracks they may mask small hydrogen attack fissures near the HAZ. Letter Stamp T4 is suggested to have lab microstructure examination.



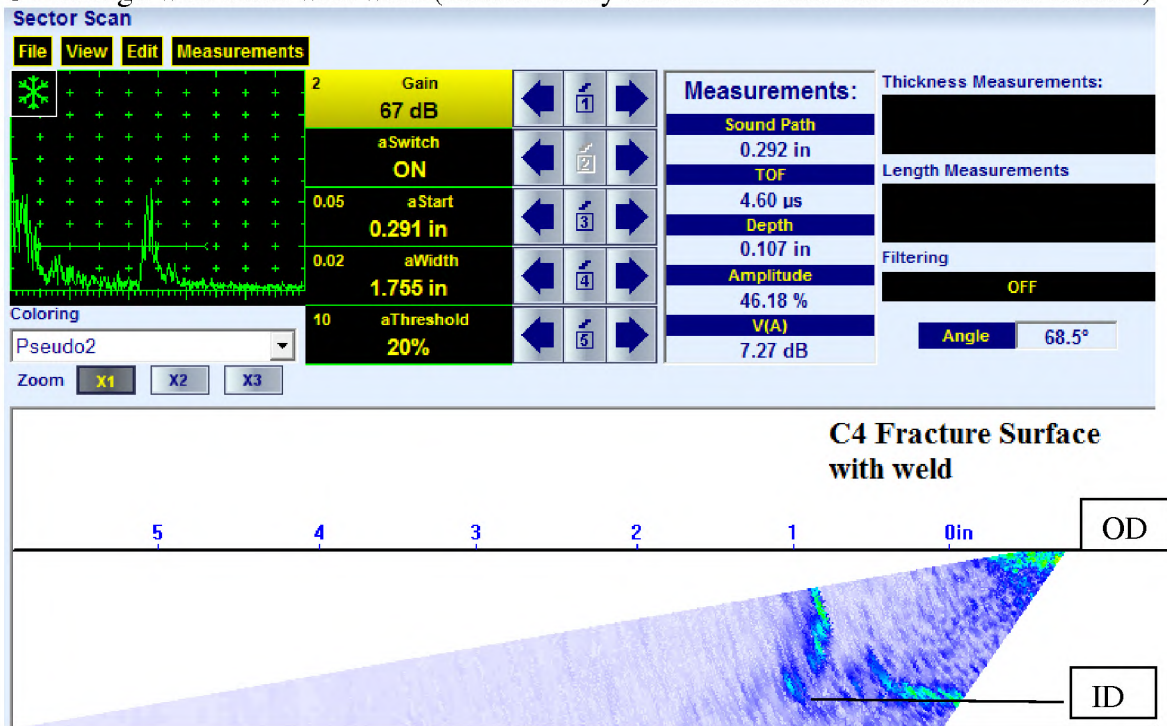


Phased Array Data:

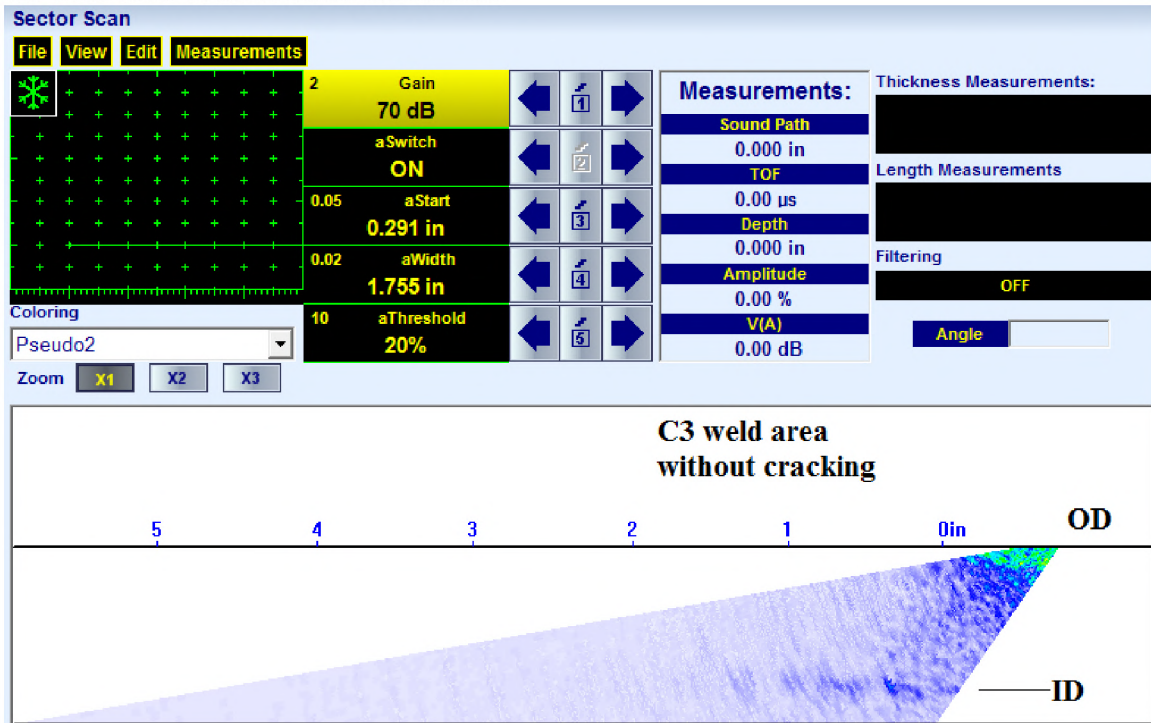
C4 through wall crack at Fracture Surface without weld



C4 through wall crack with weld (Phased Array scan at the other side of Fracture surface)



C3 weld area without crack indication.



AUBT High Frequency Shear Wave data:

Long Seam L3 bottom fracture surface cracking are not Hydrogen attack fissures.

