

BETA LAB No.M10198- LS3 TOP	TESORO REFINING AND MARKETING COMPANY ANACORTES REFINERY 10200 W. MARCH POINT ROAD T91WA4428 ANACORTES, WA 98221	CUSTOMER P.O. No.: 4501667904
PART: 6600-E HEAT EXCHANGER LS 3 TOP PART 15		DATE: SEPTEMBER 20, 2010
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**REPORT ISSUED TO:**

Jim McVay	Robert J. Hall	Robert Parker
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**SAMPLE DESCRIPTION:** A heat exchanger failed and a test protocol was developed for the failure analysis of the component. This test protocol and its addendum, as of this date and contained in Attachment 1, were developed and signed by Tesoro Companies, Division of Occupational Safety and Health and U.S. Chemical Safety Board. FirstEnergy BETA Laboratory was selected as the referee test laboratory to perform the testing requirements of the test protocol. The test protocol was not specific as to the test samples to be removed from the heat exchanger or the test locations/test parameters for each specific test within the test sample. Therefore it was agreed

“The laboratory, acting as a referee laboratory, will be supplied the locations to take the test samples and the type of test and test parameters to be performed at each location on the test sample, i.e. magnification, hardness load/test method. The signatory parties or their technical representatives that are present in the laboratory at the time shall make those decisions and give that information directly to the laboratory. Comments from other technical experts will be considered and factored into the signatory parties or their technical representative’s decisions but all decisions on protocol or samples shall remain as decisions of the signatory parties or their representatives.”

Additionally it was determined that BETA laboratory as a referee test laboratory is to report the data obtained but not give any interpretation or conclusion on any data, or on details in the photo.

On June 5, 2010 the heat exchanger arrived at Halvorsen Company’s warehouse, in a June 11, 2010 meeting locations were selected for sample removal and on June 12, 2010 samples were cut by Halvorsen for submittal to BETA laboratory.

This report is the seventh of a series on the failed parts of the 6600E heat exchanger. The LS# and CS# refer to longitudinal and circumferential weld seams while the part number refers to the chain of custody number.

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Below is the list of the reports issued previously:

- |   |   |
|---|---|
| M10198- Receipt Inspection July 29, 2010  | M10198-LS3 Bottom Findings July 30, 2010.                               |
| M10198- CS4 Findings August 5, 2010       | M10198 LS2-CS3 Tee Indications Findings<br>Aug. 13, 2010                |
| M10198- CS4-01/LS3 Bottom August 25, 2010 | M10198- Tesoro LS1-CS2 LS2-CS3 CS4<br>Mechanical Tests, August 27, 2010 |

**TEST PERFORMED:** The tests on the LS3 Top part of the exchanger included visual examination, thickness measurements, fracture surfaces recording, magnetic particle inspection and photo-microscopy. The details of the apparatus utilized and the test procedures are given in Table 1 and Attachment 2.

**TEST RESULTS:** The heat exchanger weld seams had been previous labeled as shown in Figure 1 and the same labeling was used for this report.

The fracture surfaces were photographed and are shown on Figures 4 through 8. The thickness measurement results by micrometer are in Table 5. The magnetic particle test results (performed by others) are on Figures 9 through 13, the NDE Report is in Attachment 3.

This report concerns the evaluation of three mounts from Part 15 which are matching parts of the mounts from part 14 evaluated in the previous report M10198-LS3 Bottom Findings July 30, 2010. The locations for the three samples were selected by others for mounting. The mounted pieces are shown in Figure 14 with the matching parts.

The mounts were examined in the un-etched and etched conditions and photomicrographs were taken as selected by others. The photomicrographs are shown in Figures 15 through 33.

Samples of the can 3 and the ID and OD crowns of CS3, and LS3 were obtained and chemically analyzed (see Table 2). The can is the designation for the rolled plate that has been longitudinally welded to make a cylinder. The various cylinders or cans are then welded together with circumferential welds to make the heat exchanger shell.

Rockwell hardness testing was performed at approximately the mid wall on transverse section for can 3 plate material and the results are reported in Table 3. Additionally micro-hardness measurements in the 500gm Vickers scale were performed, as directed, on some of the mounts. The locations and the summary results are in Table 4.

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**TABLE 1**  
**TESTS PERFORMED**

(See Attachment 2 for Test/Equipment Specifications)

TEST	METHOD OR INSTRUMENT	PERFORMED BY	LOCATION, DATE	RESULTS LOCATION
VISUAL EXAMINATION	LECO SZH STEREO MACROSCOPE OR PORTRAIT CAMERA	M. BRIDAVSKY & J. BLOUGH	BETA, VARIOUS	TEST RESULTS
OPTICAL METALLOGRAPHY	LECO PMG-3 OPTICAL MICROSCOPE	M. BRIDAVSKY & J. BLOUGH	BETA, VARIOUS	FIGURES 14 - 32
WET MAGNETIC PARTICLE TESTING	WET FLUORESCENT AC YOKE	TEAM INDUSTRIAL SERVICE ,MICHAEL BUCKLEY	BETA, 6-15-2010	ATTACHMENT 3 FIGURES 9-13
WALL THICKNESS	MICROMETER	M. TASCAR	BETA, 6/15 & 7/26/10	TABLE 5
FRACTURE SURFACES RECORDING	PHOTO CAMERA	M. BRIDAVSKY & J. BLOUGH	BETA, VARIOUS	FIGURES 4-8



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**TABLE 2**  
**CHEMICAL ANALYSIS FOR BASE METAL AND WELD DEPOSITS**  
**(THE DATA ARE FROM PREVIOUS REPORT M10198-LS3 BOTTOM FINDINGS JULY 30, 2010)**

SAMPLE IDENTIFICATION	CHEMICAL COMPOSITION, WT. %											
	C	SI	P	S	MN	NI	CR	MO	V	CU	CO	AL
CAN 3	0.26	0.23	0.008	0.021	0.60	0.12	0.13	0.02	<0.001	0.18	0.01	0.01
SA- 515 GRADE 70	0.31 MAX	0.13- 0.45	0.035 MAX	0.035 MAX	1.30 MAX	NS	NS	NS	NS	NS	NS	NS
CS3 OD CROWN	0.08	0.57	0.011	0.018	1.14	0.05	0.08	0.01	0.002	0.15	0.01	0.005
CS3 ID WELD SURFACE	0.09	0.64	0.017	0.022	1.31	0.05	0.09	0.01	0.002	0.24	0.01	0.005
LS3 OD CROWN	0.10	0.50	0.011	0.019	1.12	0.06	0.08	0.01	0.001	0.14	0.01	0.005
LS3 ID WELD SURFACE	0.16	0.37	0.010	0.021	1.04	0.08	0.09	0.02	0.001	0.14	0.01	0.005
SFA 5.1 (E7016, E7018)*	NS	0.75 MAX	NS	NS	1.60 MAX	0.30 MAX	0.20 MAX	0.30 MAX	0.08 MAX	NS	NS	NS
SFA 5.17 (EM11K)	0.07- 0.15	0.65- 0.85	0.030 MAX	0.025 MAX	1.00- 1.50	NS	NS	NS	NS	0.35	NS	NS
SFA 5.17 (EL12)	0.04- 0.14	0.10 MAX	0.030 MAX	0.030 MAX	0.25- 0.60	NS	NS	NS	NS	0.35	NS	NS
SFA 5.17 (EM12K)	0.05- 0.15	0.10- 0.35	0.030 MAX	0.030 MAX	0.80- 1.25	NS	NS	NS	NS	0.35	NS	NS

NS = NOT SPECIFIED  
 ALL ANALYSIS IS OPTICAL EMISSION SPECTROSCOPY EXCEPT THE CARBON WHICH IS LECO  
 NO ALLOYS OR WELD WIRE GRADES WERE SPECIFIED SO TYPICAL ARE PRESENTED  
 \* TOTAL OF MN+NI+CR+MO+V 1.75 MAX  
 SA-515 SPECIFICATION FOR PRESSURE VESSEL PLATES, CARBON STEEL, FOR INTERMEDIATE-AND HIGHER-TEMPERATURE SERVICE – JULY 2003 ADDENDUM  
 SFA 5.1 SPECIFICATION FOR CARBON STEEL ELECTRODES FOR SHIELD METAL ARC WELDING-JULY 2003 ADDENDUM  
 SFA 5.17 SPECIFICATION FOR CARBON STEEL ELECTRODES AND FLUXES FOR SUBMERGED ARC WELDING- JULY 2003 ADDENDUM

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**TABLE 3**  
**ROCKWELL (HRB) HARDNESS MEASUREMENTS**  
**ON PLATE CROSS SECTIONS**  
 (THE DATA ARE FROM PREVIOUS REPORT M10198-LS3 BOTTOM FINDINGS JULY 30, 2010)

SAMPLE IDENTIFICATION	HARDNESS			
	MINIMUM	MAXIMUM	AVERAGE	NUMBER OF INDENTATIONS
CAN 3	82.5	83.7	83.1	7

**TABLE 4**  
**SUMMARY OF MICRO-HARDNESS MEASUREMENTS**  
**VICKERS 500Gm**  
 (THE DATA ARE FROM PREVIOUS REPORT M10198-LS3 BOTTOM FINDINGS JULY 30, 2010)

TEST OBJECT	14 M3 LS3	14 M4 LS3	14 TO LS3
Base Metal 3	182-215	181-193	129-149
HAZ 3	203-245	181-204	
Weld Metal	178-255		134-147

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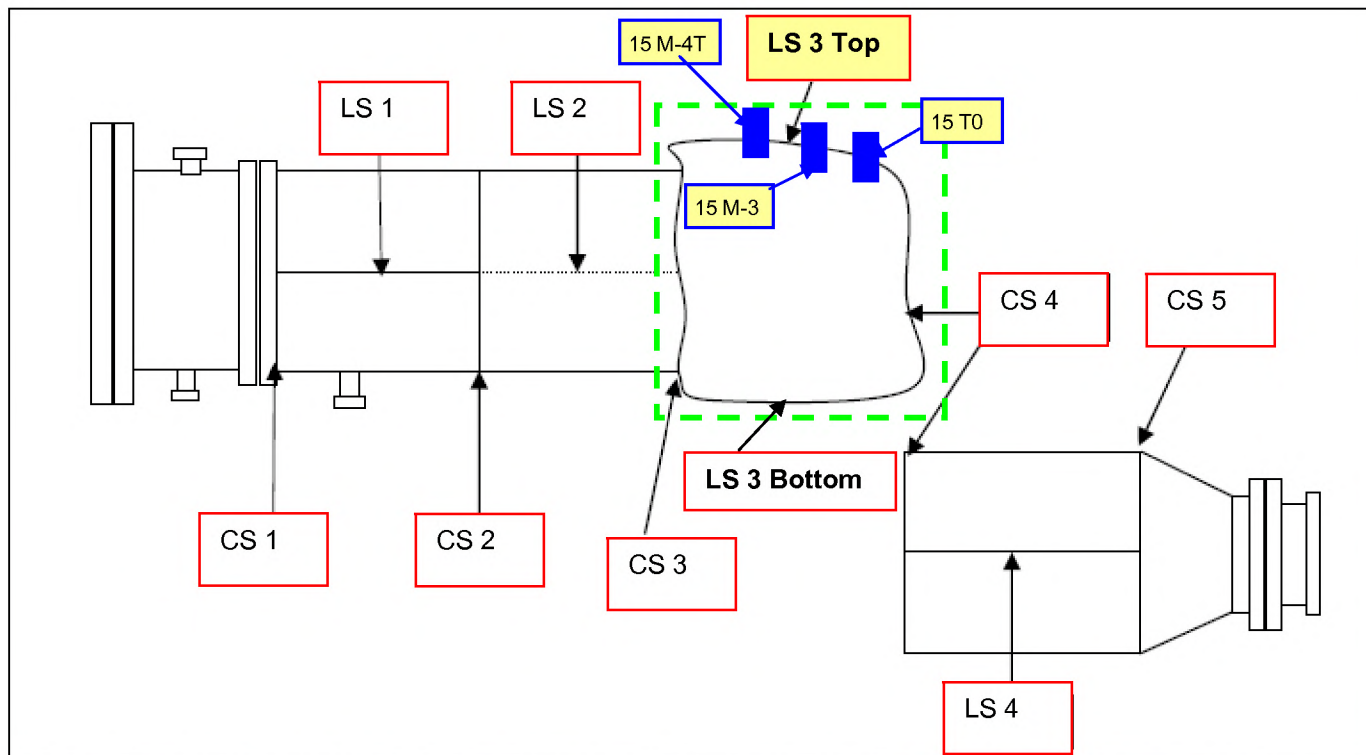
**TABLE 5. WALL THICKNESS MEASUREMENTS**

WALL THICKNESSES ALONG THE LS-3		WALL THICKNESSES ALONG THE CS-3		WALL THICKNESSES ALONG THE CS-4	
LOCATION OF THE READING, INCHES ALONG LS-3	MICROMETER READINGS, IN 2" FROM FRACTURE	LOCATION OF THE READING, IN ALONG THE FRACTURE	MICROMETER READINGS, IN 2" FROM FRACTURE	LOCATION OF THE READING, IN ALONG THE FRACTURE	MICROMETER READINGS, IN 2" FROM FRACTURE
0 (at CS-3)	0.938*	0 (at the C-3)	Not measured	0 (at CS-4)	Not measured
2	0.854	2	0.830	2	0.851
4	0.864	4	0.831	4	0.852
6	0.861	6	0.830	6	0.846
8	0.861				
10	0.875				
12	0.857				
14	0.858				
16	0.854				
18	0.859				
20	0.856				
22	0.857				
24	0.862				
26	0.865				
28	0.865				
30	0.873				
32	0.870				
34	0.872				
36	0.866				
38	0.864				
40	0.866				
42	0.866				
44	0.871				
46	0.869				
48	0.884				
50	0.879				
52	0.870				
54	0.875				
56	0.879				
58	0.870				
60	0.862				
62	0.859				
64	0.856				
66	0.856				
68	0.852				
70	0.849				
72	0.854				
74	0.851				
76	0.852				
78	0.854				
80	0.857				
82	0.854				
84 (at CS-4)	0.852				

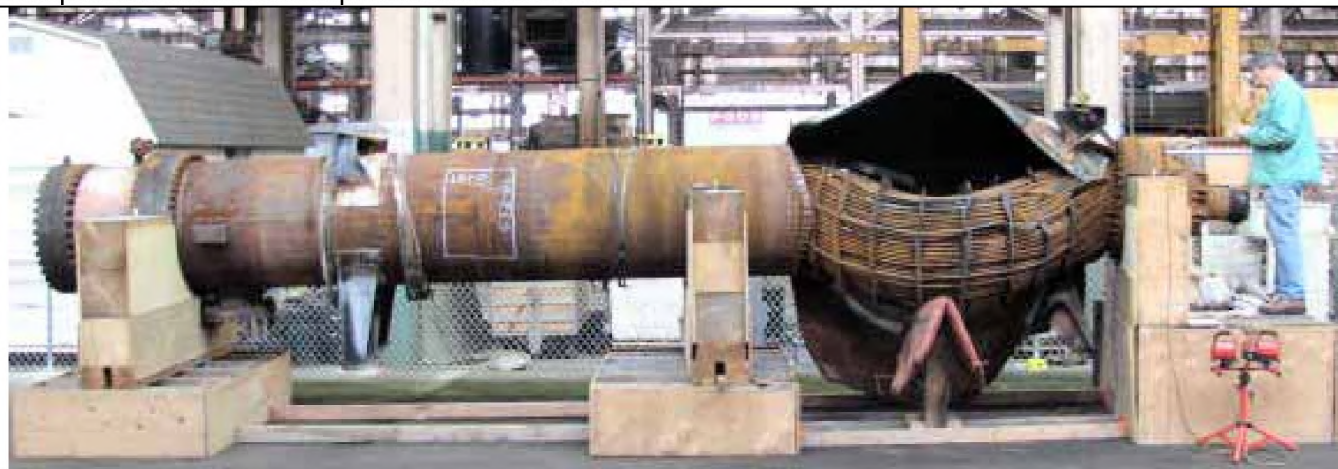
\*Reading on weld

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Sketch of main heat exchanger Cans 1-3 and separated back head can 4. The approximate locations of the samples evaluated in this report are shown in blue.



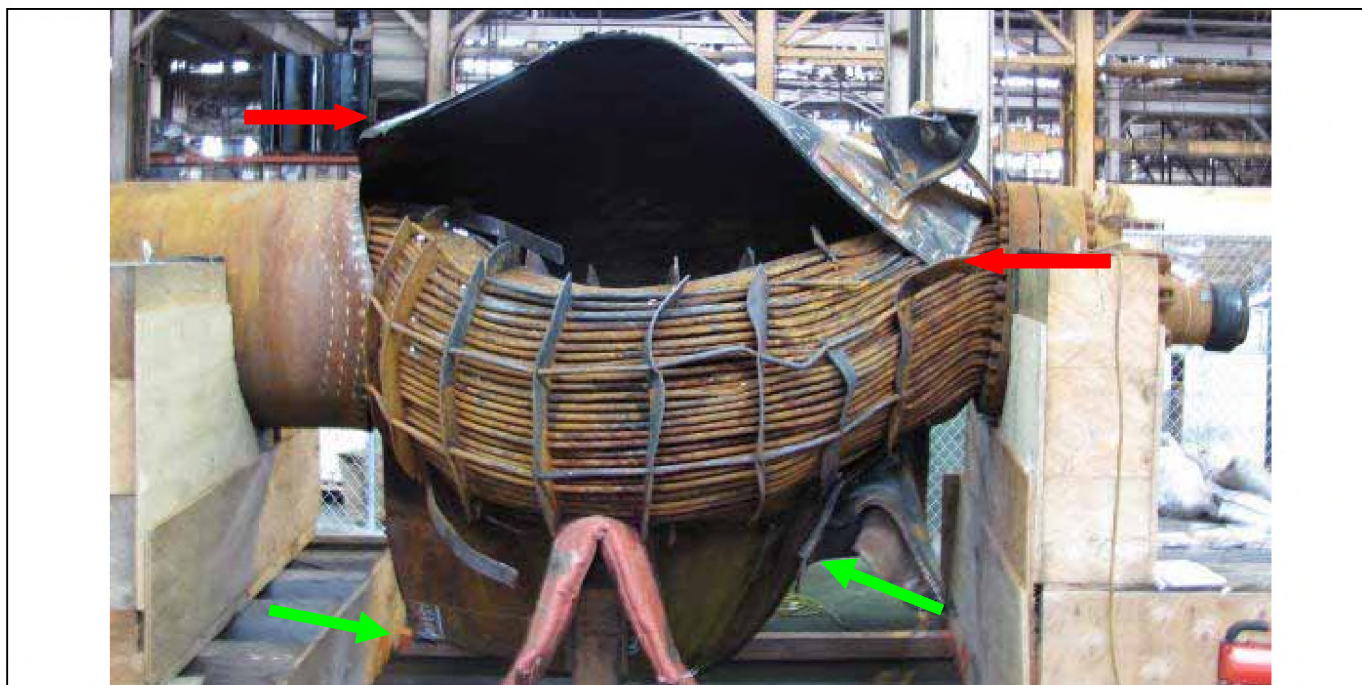
Overall main heat exchanger with "fish mouth " rupture primarily along LS3 and CS4 as shown by green box above

**Figure 1 Un-packed main heat exchanger**



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Fracture along LS3 seam between the green arrows for the bottom part of the fracture, and for the LS3 top – between the red arrows

**Figure 2 Photo showing the fracture along LS3 where an approximate 6 inch wide portion was removed**



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Figure 3. Part 15 with LS-3 and parts of CS-3 (left end) and CS-4 (right end).



Location V1



Location V2

Figure 4. Fracture surfaces along the CS4 weld. ID is on the right.



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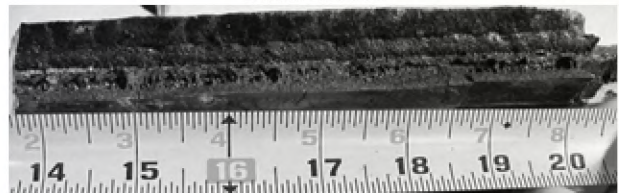
Location H1



Location H2



Location H3



Location H4



Location H5



Location H6-cut is where the mate 14 M3 LS3 mount was removed



Location H7



Location H8

**Figure 5. Fracture surfaces along the LS3 weld. ID is on the bottom, where the measure tape is located.**



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Location H9



Location H10



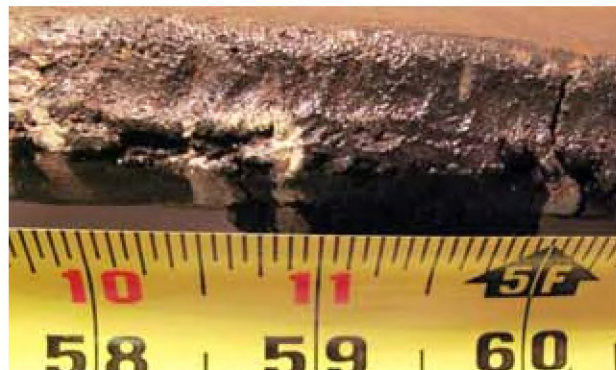
Location H11



Location H12



Location H13



Location H14



Location H15



Location H16

**Figure 6. Fracture surfaces along the LS3 weld. ID is on the bottom, where the measure tape is located.**



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Location H17



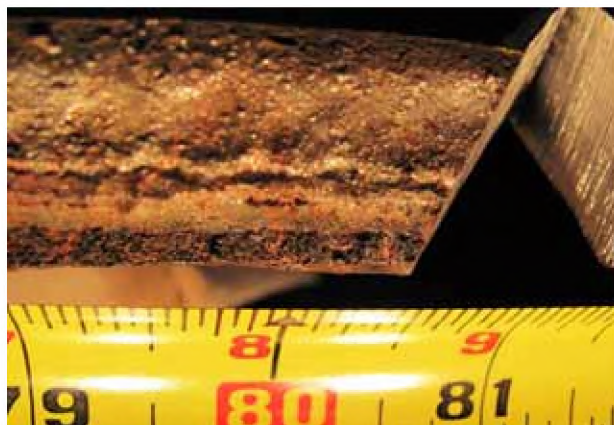
Location H18



Location H19



Location H20



Location H21-cut is where the mate 14 M3 TO mount was removed



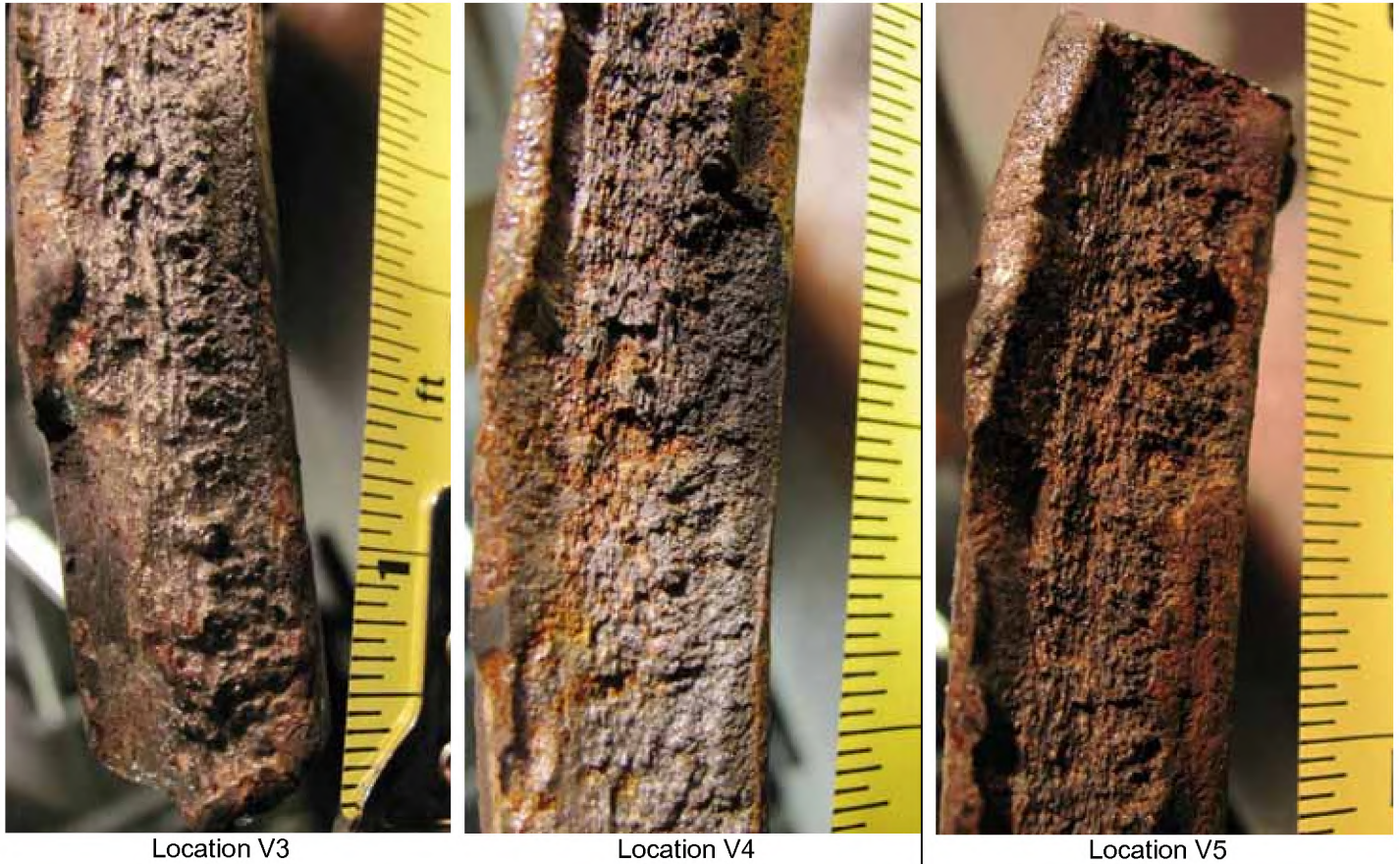
Location H22

**Figure 7. Fracture surfaces along the LS3 weld. ID is on the bottom, where the measure tape is located.**



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**Figure 8. Fracture surfaces along the CS4 weld. ID is on the right, where the measure tape is located.**