BETA LAB NO.M10198- CS4-02	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 CS4 PART 19 & 20		DATE: AUGUST 5, 2010
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REPORT ISSUED TO:

Jim McVay	**Robert J. Hall**	**Robert Parker**

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 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. The results of the receipt inspection for the heat exchanger at Halvorsen Companies warehouse are contained in FirstEnergy's Report titled M10198- Receipt Inspection dated July 29, 2010. Additionally the report on LS3 Bottom Findings was issued July 30, 2010.

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

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TEST PERFORMED: The tests on the exchanger parts included visual examination, chemical analysis via Vacuum Spectrosmetry and LECO carbon, macro and micro-hardness measurements, wall thickness measurements, liquid penetrant inspection (by others), and photomicroscopy. 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 pieces labeled part 19 (CS4-02 East) and part 20 (CS4-02 West) containing about a 6 inch wide of the band of the fracture along CS4, as shown in Figure 2, was received at BETA Lab for testing. These were given two part numbers because Halvorsen was requested to cut the 360 degree band into two 180 degree arcs. The approximately 109 inches of the CS4 fracture edge are shown in Figures 3-8.

The ID surface of part 19 and 20 were liquid penetrant inspected (by others, see attachment 3) and no reportable indications were found.

Four locations were selected, by others, for metallurgical mounting. The locations on pieces and the photos of the etched mounts are shown in Figures 9 and 10. 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 11-32.

Samples of the can 4 (clad and backing plate) and the ID and OD crowns of CS4 and LS4 were obtained and chemically analyzed. The results of those chemical analyses are detailed in Table 2.

One location was selected for SEM fractography but fracture surface was very heavily coated with scale/corrosion product. The fracture surface of sample 19East-SEM1 was cleaned with the following procedure and the as cleaned surface is shown in Figures 33.

1. Alconox, ultrasonic, up to 5 minutes, rinse with warm water
2. Inhibited HCl, ultrasonic, 30 – 60 seconds, rinse with warm water
3. Alconox, ultrasonic, approximately 30 seconds, rinse with warm water
4. Inhibited HCl, ultrasonic, approximately 15 – 30 seconds, rinse with warm water
5. Alconox, ultrasonic, approximately 30 seconds, rinse with warm water
6. Methanol, ultrasonic, approximately 10 seconds

The Alconox solution was made up from approximately 35g/l and the inhibited HCl was made up of 6N HCl inhibited with 5g/l of 1,3 Di-n-butyl-2 thiourea

The surface was still heavily scaled so the following cathodic cleaning step was performed:

19East- Total accumulated time was 1 hour on 6/29/2010

1. 200g/l Na_2CO_3@~3-4 V., 800mamps
2. Alconox (~ 4 % W/V) Ultrasonically for ~ 5 minutes

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3. 5% H_2SO_4 to desmut for ~ 10 – 15 seconds
4. repeat Alconox
5. Flush and rinse with acetone

The results of the chemical cleaning, cathodic cleaning for this sample and the previous cleaning of the SEM samples in the LS3 report were discussed with the signature parties and all SEM work of the oxidized fracture surfaces was placed on HOLD.

Rockwell hardness testing was performed at approximately the mid wall on transverse section for can 4 and the results are reported in Table 3.

Wall thickness measurements were performed about 2 inch away from the fracture surface and the details are contained in Table 4.

Additionally micro-hardness measurements in the 500gm Vickers (HV_{500}) scale were performed, as directed, on some of the mounts. The locations where the traverses were performed are shown in Figure 31 and the data is presented in Tables 5 and 6 with a summary of the range of micro-hardness for each zone in Table 7

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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	J. BLOUGH	HALVORSEN & BETA, VARIOUS	TEST RESULTS
CHEMICAL ANALYSIS	THERMO ARL-3460 OE SPECTROMETER	M. TASCAR	BETA, 6/25/2010	TABLE 2
Carbon Analysis	Leco Carbon/Sulfur Determination CS-444	M. Belviso	BETA, 7/26/2010	Table 2
ROCKWELL HARDNESS	Wilson Rockwell 524THardness Tester	M, Tascar	BETA, 7/26/10	Table 3
KNOOP/VICKERS, SEMI-MACRO VICKERS	INSTRON TUKON 2100B HARDNESS TESTER, MODEL T2100BR1942	M. TASCAR	BETA, 7/31/2010	TABLES 5 & 6
OPTICAL METALLOGRAPHY	LECO PMG-3 OPTICAL MICROSCOPE	J. BLOUGH	BETA, VARIOUS	FIGURES 11-31
FRACTOGRAPHY	CAMSCAN SCANNING ELECTRON MICROSCOPE WITH IXRF EDS2000 ENERGY DISPERSIVE X-RAY SPECTROMETER	C. HOLP	BETA, 6/30/2010	TEST RESULTS, FIGURE 32
LIQUID PENETRANT TESTING	FLUORESCENT DYE	TEAM INDUSTRIAL SERVICE ,MICHAEL BUCKLEY	BETA, 6-15-2010	ATTACHMENT 3
WALL THICKNESS	MICROMETER, STARRETT S/N 120A	M. TASCAR	BETA, 7/28/2010	TABLE 4

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TABLE 2
CHEMICAL ANALYSIS FOR BAST METAL AND WELD DEPOSITS

SAMPLE IDENTIFICATION	CHEMICAL COMPOSITION, WT. %											
	C	SI	P	S	MN	NI	CR	MO	V	CU	CO	AL
19E CAN 4	0.285	0.25	0.008	0.031	0.65	0.11	0.10	0.03	<0.001	0.13	0.01	0.005
19E CAN 4 CLAD	0.067	0.61	0.016	0.012	1.67	13.02	17.37	2.3	0.06	0.14	0.32	0.002
SA- 515 GRADE 70	0.31	0.13-0.45	0.035 MAX	0.035 MAX	1.30 MAX	NS	NS	NS	NS	NS	NS	NS
SA 240 TYPE 316 S31600▲	0.08 MAX	0.75 MAX	0.045 MAX	0.030 MAX	2.00 MAX	10.00-14.00	16.00-18.00	2.00-3.00	NS	NS	NS	NS
▲N 0.10 MAX MEASURED 0.04												
19W CS4 OD CROWN	0.08	0.53	0.011	0.020	1.07	0.06	0.07	0.02	0.001	0.13	0.001	0.005
19W CS4 ID SURFACE	0.05	0.69	0.14	0.16	1.18	12.37	19.42	2.80	0.03	0.05	0.05	ND
19W LS4 OD	0.07	0.53	0.011	0.021	1.13	0.06	0.07	0.01	0.001	0.13	0.01	0.006
19W LS4 ID	0.03	0.78	0.014	0.019	0.89	13.27	19.05	2.92	0.05	0.07	0.08	ND
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	0.025	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

NOTES: NS = NOT SPECIFIED, ND = NOT DETECTED

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

SA-240 SPECIFICATION FOR HEAT-RESISTING CHROMIUM AND CHROMIUM-NICKEL STAINLESS STEEL PLATE, SHEET, AND STRIP FOR PRESSURE VESSELS

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

TABLE 3
ROCKWELL (HRB) HARDNESS MEASUREMENTS ON PLATE CROSS SECTION

SAMPLE IDENTIFICATION	HARDNESS			
	MINIMUM	MAXIMUM	AVERAGE	NUMBER OF INDENTATIONS
19E CAN 4	79.3	80.2	79.8	7

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TABLE 4
WALL THICKNESS MICOMETER (BETA 2005) MEASUREMENTS CS4 FRACTURE

Location Number from UT reading	2 inch from fracture (inch)	Location Number from UT reading	2 inch from fracture (inch)	Location Number from UT reading	2 inch from fracture (inch)	Location Number from UT reading	2 inch from fracture (inch)	Location Number from UT reading	2 inch from fracture (inch)
0	0.911	24	0.900	48	0.875	72	0.901	96	0.896
2	0.899	26	0.886	50	0.879	74	0.887	98	0.896
4	0.898	28	0.884	52	0.882	76	0.886	100	0.884
6	0.903	30	0.883	54	0.884	78	0.880	102	0.885
8	0.904	32	0.881	56	0.891	80	0.878	104	0.890
10	0.912	34	0.871	58	0.893	82	0.878	106	0.887
12	0.908	36	0.875	60	0.898	84	0.884	108	0.915
14	0.907	38	0.844*	62	0.898**	86	0.896		
16	0.910	40	0.877	64	0.901**	88	0.898		
18	0.899	42	0.882	66	0.905	90	0.898		
20	0.900	44	0.878	68	0.903	92	0.899		
22	0.895	46	0.869**	70	0.906	94	0.900		

Notes:
* in a groove
** next to weld
UT = Ultrasonic testing in the field by others

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TABLE 5
MICRO-HARDNESS MEASUREMENTS MOUNT M2 CS4
VICKERS 500Gm (HV_{500}) UNLESS SPECIFIIED

M2 OD Line HV	Location	M2 Cusp Line HV	Locations	M1 ID Line HV	Locations	M1 Can 3 HAZ HV	Locations
		174	BM Can3	141	BM Can3	145	Lower Diag BM (Can3)
		226	BM Can3	156	BM Can3	159	Lower Diag BM (Can3)
		223	BM Can3	146	BM Can3	170	Lower Diag BM (Can3)
		224	BM Can3	153	BM Can3	181	Lower Diag BM (Can3)
		175	HAZ CG	188	HAZ CG Can3		
		202	HAZ CG	181	HAZ CG Can3		
		217	HAZ CG	186	HAZ CG Can3		
		216	HAZ CG	179	HAZ CG Can3	178	Upper Diag HAZ (Can3)
		202	HAZ FG	199	HAZ FG Can3	218	Upper Diag HAZ (Can3)
		202	HAZ FG	195	HAZ FG Can3	192	Upper Diag HAZ (Can3)
		204	HAZ FG	193	HAZ FG Can3	196	Upper Diag HAZ (Can3)
		199	HAZ FG	198	HAZ FG Can3	205	Upper Diag HAZ (Can3)
178	Weld Metal	173	Weld Metal	242	Weld Metal		
180	Weld Metal	168	Weld Metal	236	Weld Metal		
168	Weld Metal	162	Weld Metal	234	Weld Metal		
161	Weld Metal	156	Weld Metal	235	Weld Metal		
171	Weld Metal			239	Weld Metal		
173	Weld Metal			234	Weld Metal		
221	HAZ CG	178	HAZ CG				
203	HAZ CG	182	HAZ CG				
198	HAZ CG	182	HAZ CG				
214	HAZ CG	170	HAZ CG				
186	HAZ FG	169	HAZ FG	165	HAZ FG		
177	HAZ FG	166	HAZ FG	165	HAZ FG		
187	HAZ FG	172	HAZ FG	149	HAZ FG		
174	HAZ FG	172	HAZ FG	138	HAZ CG		
		159	HAZ CG	144	HAZ CG		
		167	HAZ CG				
		159	HAZ CG				
		162	HAZ CG				
151	BM Can4	165	BM Can4	165	BM Can4		
151	BM Can4	159	BM Can4	172	BM Can4		
165	BM Can4	146	BM Can4				
157	BM CAN4	167	BM Can4				

Notes: BM = Base Metal, HAZ = Heat Affected Zone, CG = coarse grain, FG = fine grain

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TABLE 6
MICRO-HARDNESS MEASUREMENTS MOUNT M3 LS4
VICKERS 500Gm (HV_{500})

M3 OD Line HV	Location		M3 Cusp Line HV	Locations		M3 ID Line HV	Locations
167	BM		179	BM		163	BM
160	BM		169	BM		164	BM
170	BM						
164	BM						
			175	CG HAZ		167	CG HAZ
			164	CG HAZ		146	CG HAZ
			180	CG HAZ		165	CG HAZ
			175	CG HAZ		169	CG HAZ
193	FG HAZ		189	FG HAZ		181	FG HAZ
188	FG HAZ		185	FG HAZ		170	FG HAZ
198	FG HAZ		183	FG HAZ		159	FG HAZ
207	FG HAZ		196	FG HAZ		164	FG HAZ
215	CG HAZ		192	CG HAZ			
223	CG HAZ		201	CG HAZ			
205	CG HAZ		196	CG HAZ			
214	CG HAZ		192	CG HAZ			
167	Weld Metal		172	Weld Metal		213	Weld Metal
153	Weld Metal		167	Weld Metal		206	Weld Metal
168	Weld Metal		173	Weld Metal		224	Weld Metal
163	Weld Metal		172	Weld Metal		228	Weld Metal
167	Weld Metal					369	Weld Metal)
						237	Weld Metal
197	CG HAZ		199	CG HAZ		178	FG HAZ
205	CG HAZ		184	CG HAZ		177	FG HAZ
213	CG HAZ		194	CG HAZ		183	FG HAZ
204	CG HAZ		201	CG HAZ		179	FG HAZ
198	FG HAZ		185	FG HAZ		186	CG HAZ
190	FG HAZ		186	FG HAZ		191	CG HAZ
188	FG HAZ		180	FG HAZ		174	CG HAZ
191	FG HAZ		173	FG HAZ		200	CG HAZ
			167	CG HAZ			
			165	CG HAZ			

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TABLE 6 CONTINUED

M3 OD Line HV	Location		M3 Cusp Line HV	Locations		M3 ID Line HV	Locations
			164	CG HAZ			
			163	CG HAZ			
168	BM		163	BM		155	BM
162	BM		165	BM		157	BM
167	BM						
155	BM						
Notes: BM = Base Metal, HAZ = Heat Affected Zone, CG = coarse grain, FG = fine grain							

TABLE 7

SUMMARY OF MICRO-HARDNESS MEASUREMENTS FROM TABLE 5 and 6 VICKERS 500Gm (HV_{500})

	M 2 CS4	M3 LS4
Base Metal 3	141-226	NA
Base Metal 4	146-172	160-170
HAZ 3	145-218	NA
HAZ 4	138-221	164-223
Weld Metal	161-242	153-173
Notes: HAZ = heat Affected Zone NA = not applicable		

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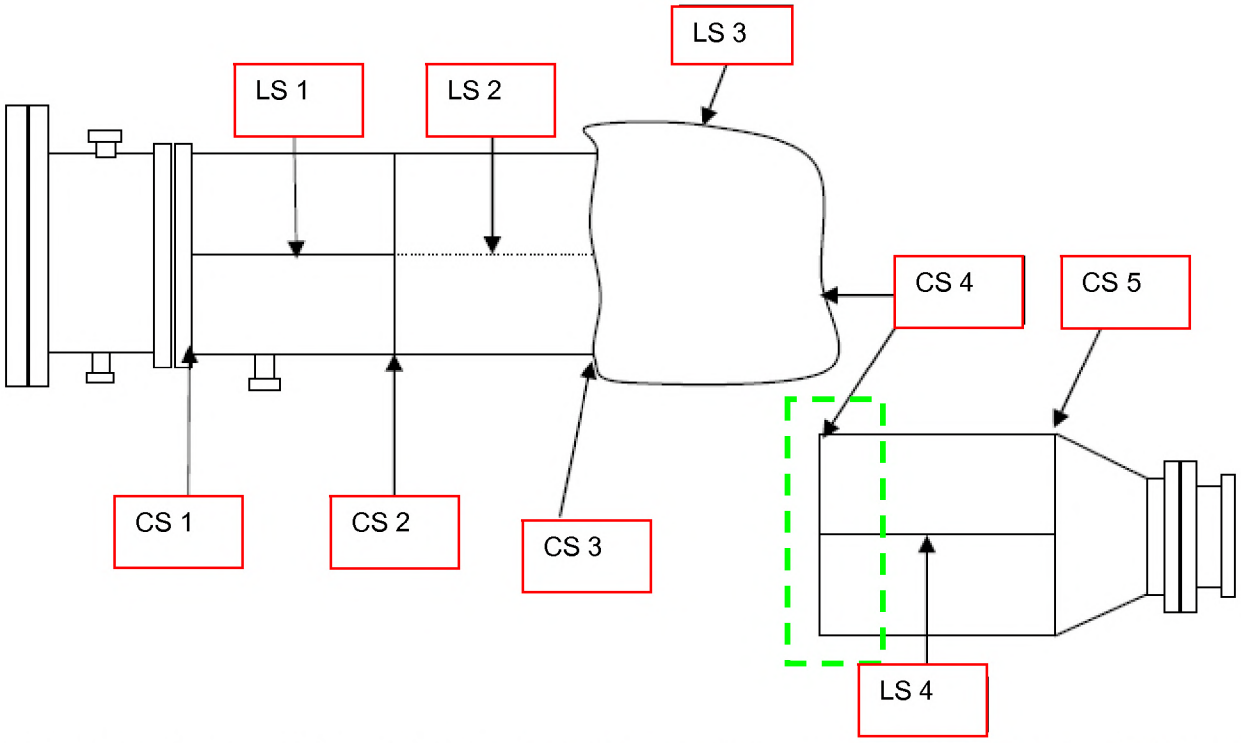

Sketch of main heat exchanger Cans 1-3 and separated back head Can 4- green dotted line is item for this report

Back Head with fracture on left at CS4

FIGURE 1 Un-packed back head of the 6600E heat exchanger

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Fracture along CS4 seam between the green arrows mates up with fracture on back head shown below

Bottom half of about 6 inch wide ring is cut- red line is zero degrees

Fracture edge of CS4 from one angle

Fracture edge of CS4 from another angle

CS04cut samples with fracture edge protected

Fracture edge of CS4 from nozzle angle note T4 UT

FIGURE 2 Back Head fracture along CS4 in prior to cutting condition and after cutting about 6 inch wide ring containing the full fracture – note 0 degrees is for nozzle location which is at 12:00 for the shell. All numbers around the circumference in the photos are applied by others during the field inspections

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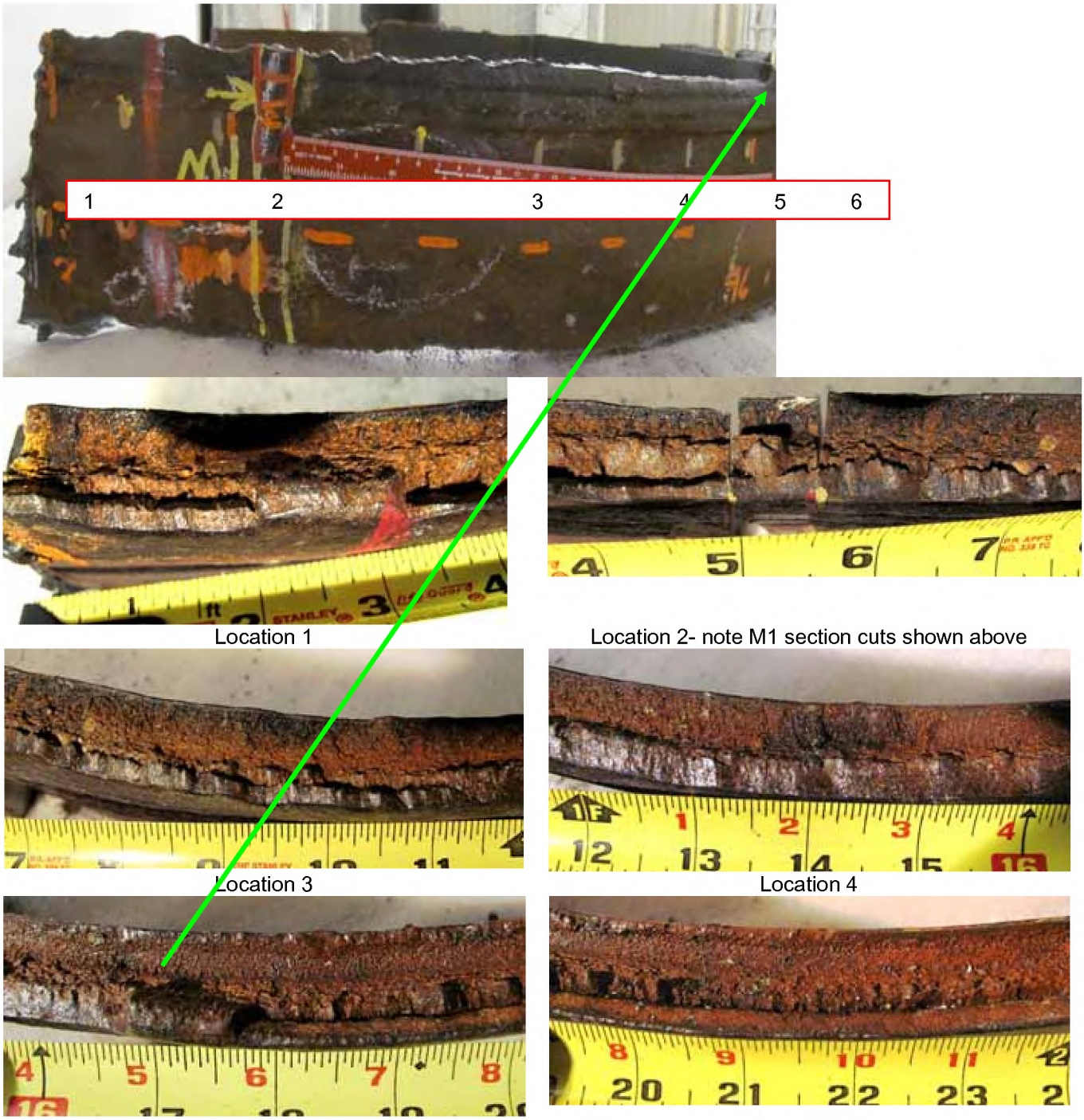

Location 1

Location 2- note M1 section cuts shown above

Location 3

Location 4

Location 5

Location 6

FIGURE 3 Photos of the fracture along CS4 with the locations as shown in the upper left (ID on top)

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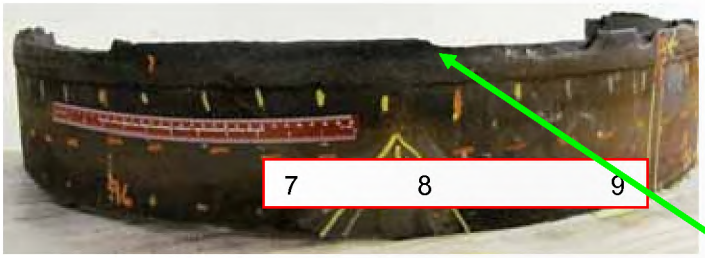
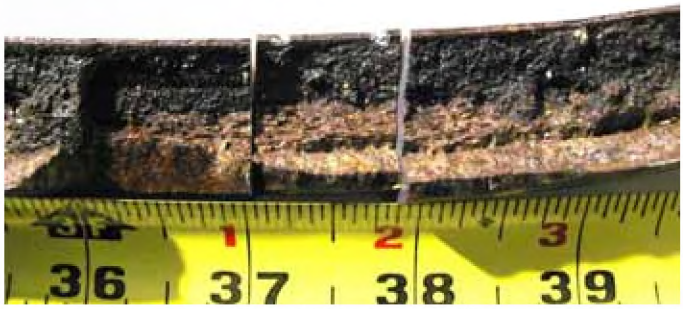


Location 7

Location 8

Location 9



Location 10- note the M3 section cuts

Location 11

Location 12

FIGURE 4 Photos of the fracture along CS4 with the locations as shown in the upper left (ID on top)

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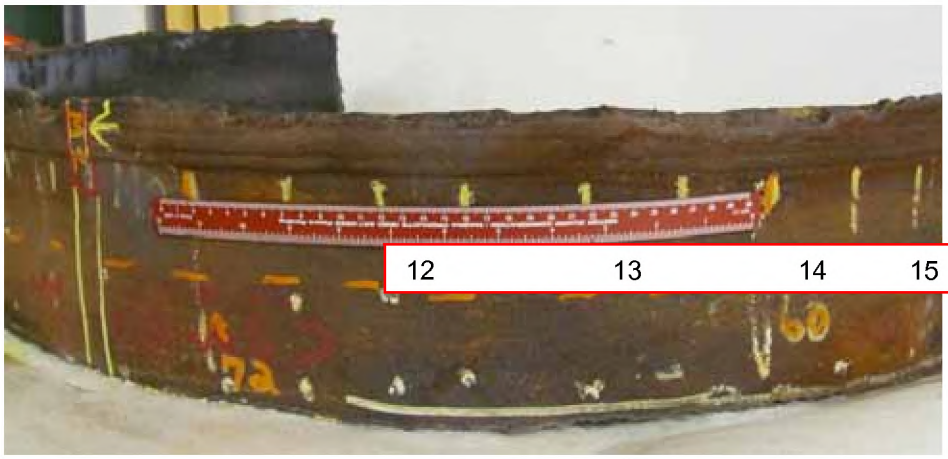

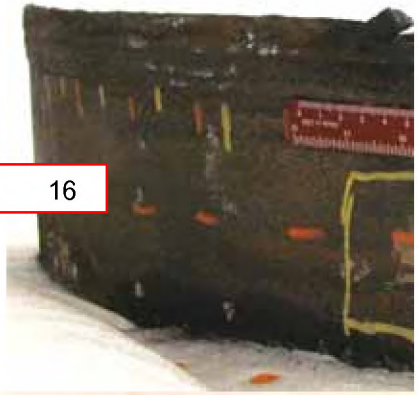

Location 13

Location 14

Location 15

Location 16

FIGURE 5 Photos of the fracture along CS4 with the locations as shown in the upper left (ID on top)