BETA LAB NO.M10198- LS2-CS3 TEE INDICATIONS	TESORO REFINING AND MARKETING COMPANY ANACORTES REFINERY 10200 W. MARCH POINT ROAD T91WA4428 ANACORTES, WA 98221	CUSTOMER P.O. NO.: 4501667904
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LABORATORY REPORT- LS2-CS3 TEE INDICATIONS FINDINGS

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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.

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In this report the LS# and CS# refer to longitudinal and circumferential weld seams, respectively, while the part number refers to the chain of custody. This report is the fourth of a series on failed parts of 6600E heat exchanger. The following is a list of previous reports:

M10198- Receipt Inspection July 29, 2010 M10198-LS3 Bottom Findings July 30, 2010.
M10198- CS4 Findings August 5, 2010

TEST PERFORMED: The tests on the exchanger parts included visual examination, chemical analysis via Vacuum Spectrometry 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 16-1 and 16-2 (LS2-01/CS3-01) containing the field UT indication T2 shown in Figure 1 and 2, was received at BETA Lab for testing. These were given two part numbers because Halvorsen was requested to cut the piece in half for ease of handling and cutting.
The ID surface of part 16-1 and 2 were magnetic particle inspected (by others, see attachment 3) and no reportable indications were found.

Three locations were selected, by others, for metallurgical mounting. The locations for the samples removal and the photos of the etched mounts are shown in Figure 3. 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 4-23.

Samples of the can 2 and 3, previously removed for a previous report, and the ID and OD crowns of CS3 and LS2 were obtained and chemically analyzed. The results of those chemical analyses are detailed in Table 2.

Rockwell hardness testing, previously performed for a previous report, was performed at approximately the mid wall on transverse section for can 2 and 3 and the results are reported in Table 3.

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 24 and the data is presented in Table 4 with a summary of the range of micro-hardness for each zone in Table 5

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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/ & 8/11/2010	TABLE 2
Carbon Analysis	Leco Carbon/Sulfur Determination CS-444	M. Belviso	BETA, 7/26/2010 & later	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, 7/24/2010	TABLES 4 & 5
OPTICAL METALLOGRAPHY	LECO PMG-3 OPTICAL MICROSCOPE	J. BLOUGH	BETA, VARIOUS	FIGURES 4-23
MAGNETIC PARTICLE TESTING	FLUORESCENT	TEAM INDUSTRIAL SERVICE ,MICHAEL BUCKLEY	BETA, 6-15-2010	ATTACHMENT 3

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TABLE 2
CHEMICAL ANALYSIS FOR BASE METAL AND WELD DEPOSITS

SAMPLE IDENTIFICATION	CHEMICAL COMPOSITION, WT. %											
	C	SI	P	S	MN	NI	CR	MO	V	CU	CO	AL
14-3 CAN 2	0.259	0.23	0.008	0.019	0.59	0.12	0.12	0.02	<0.001	0.18	0.01	0.01
14-3 CAN 3	0.260	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	0.13-0.45	0.035 MAX	0.035 MAX	1.30 MAX	NS	NS	NS	NS	NS	NS	NS
14-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
14-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
16-1 LS2 ID SURFACE	0.13▲	0.54	0.011	0.018	1.15	0.05	0.07	0.01	0.002	0.14	0.01	0.010
16-1 LS2 OD CROWN	0.09▲	0.49	0.011	0.021	1.12	0.07	0.08	0.02	0.001	0.04	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	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

▲ PRELIMINARY CARBON BY OPTICAL EMISSION SPECTROMETRY WITH LECO CARBON PRESENTLY BEING PERFORMED

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

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

SAMPLE IDENTIFICATION	HARDNESS			
	MINIMUM	MAXIMUM	AVERAGE	NUMBER OF INDENTATIONS
14 CAN 2	82.3	83.5	83.1	7
14 CAN 3	82.5	83.7	83.1	7

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TABLE 4
MICRO-HARDNESS MEASUREMENTS MOUNT T2L LS2
VICKERS 500Gm (HV_{500})

T2L OD Line HV	Location		T2L Cusp Line HV	Locations		T2L ID Line HV	Locations
178	BM		167	BM		173	BM
177	BM		167	BM		184	BM
178	BM		184	BM		167	BM
165	BM		165	BM		175	BM
193	HAZ FG		183	HAZ FG		180	HAZ FG
197	HAZ FG		182	HAZ FG		180	HAZ FG
189	HAZ FG		183	HAZ FG		187	HAZ FG
207	HAZ FG					181	HAZ FG
219	HAZ CG					192	HAZ Finer FG
229	HAZ CG					185	HAZ Finer FG
218	HAZ CG					186	HAZ Finer FG
217	HAZ CG					192	HAZ Finer FG
183	Weld		175	Weld		172	Weld
172	Weld		169	Weld		171	Weld
196	Weld		162	Weld		166	Weld
183	Weld		168	Weld		161	Weld
172	Weld		176	Weld			
181	Weld		170	Weld			
225	HAZ CG		182	HAZ FG		190	HAZ Finer FG
226	HAZ CG		180	HAZ FG		197	HAZ Finer FG
218	HAZ CG		175	HAZ FG		191	HAZ Finer FG
242	HAZ CG		178	HAZ FG		195	HAZ Finer FG
201	HAZ FG					182	HAZ FG
200	HAZ FG					185	HAZ FG
198	HAZ FG					186	HAZ FG
205	HAZ FG					189	HAZ FG
177	BM		172	BM		181	BM
178	BM		178	BM		186	BM
173	BM		179	BM		173	BM
163	BM		191	BM			

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

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TABLE 5

SUMMARY OF MICRO-HARDNESS MEASUREMENTS FROM TABLE 4 VICKERS 500Gm (HV_{500})

	T2L
Base Metal Can 2	163-191
HAZ Can 2 one side	180-229
HAZ Can 2 other side	175-226
Weld Metal	161-196
Notes: HAZ = heat Affected Zone NA = not applicable	

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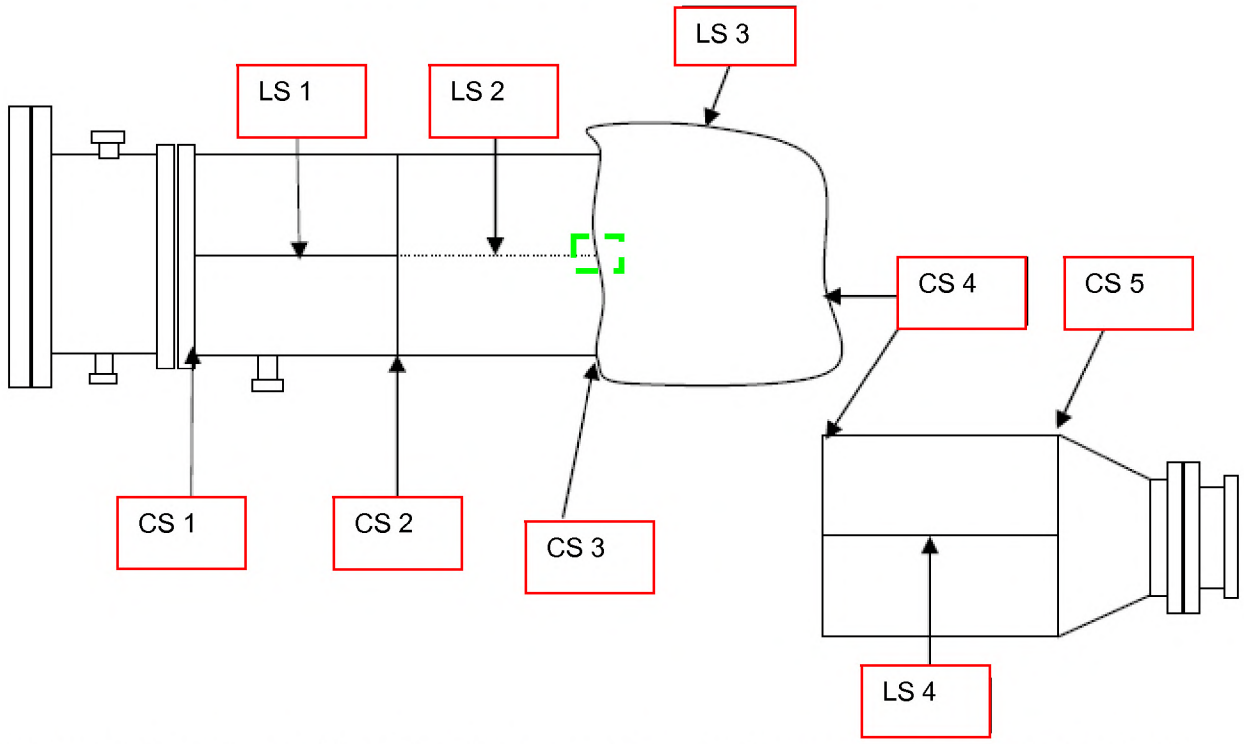
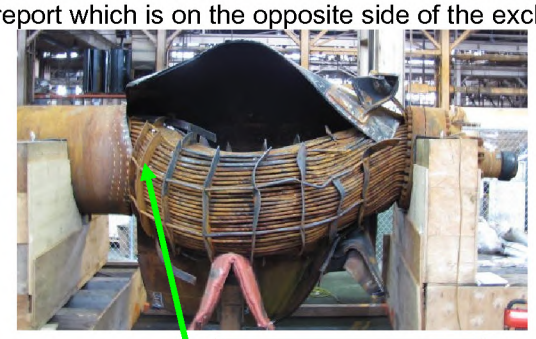
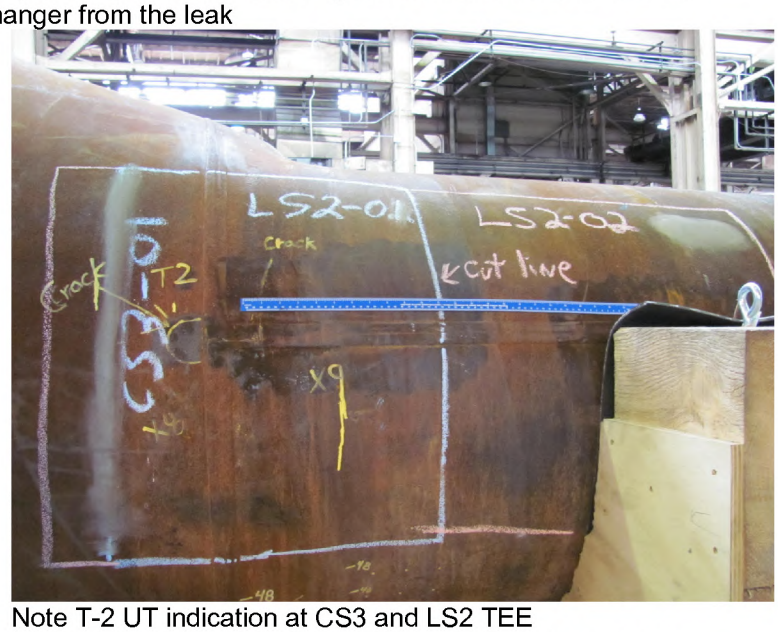


Sketch of main heat exchanger Cans 1-3 and separated back head Can 4- green dotted line is item for this report which is on the opposite side of the exchanger from the leak



Leak side of the heat exchanger with areas of interest for this report on the backside



Note T-2 UT indication at CS3 and LS2 TEE

FIGURE 1 Un-packaged 6600E heat exchanger with area marking for removal in two pieces

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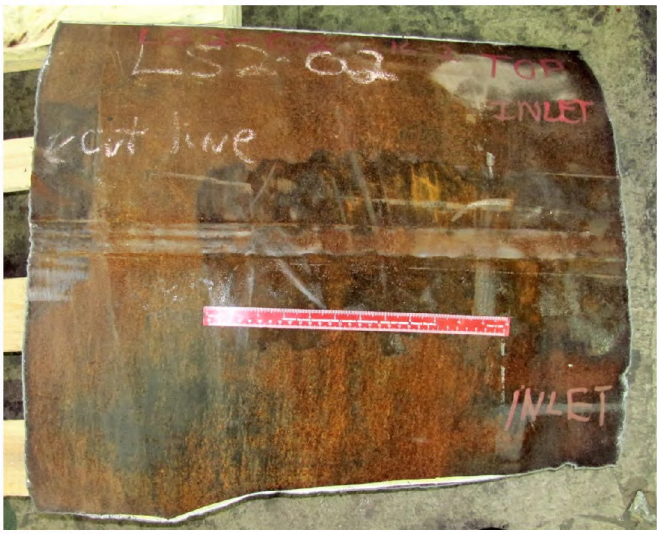
Part 16-1 cut out ready for shipment



Part 16-2 cut out ready for shipment

Area in shell wall where the samples above were removed

FIGURE 2 Samples cut out at Halvorsen

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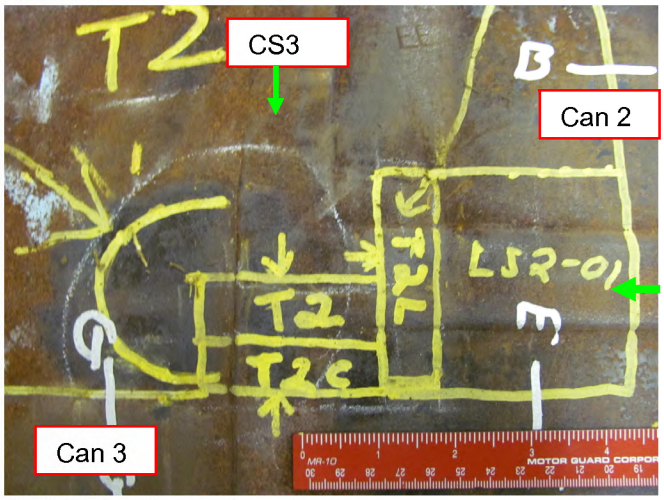
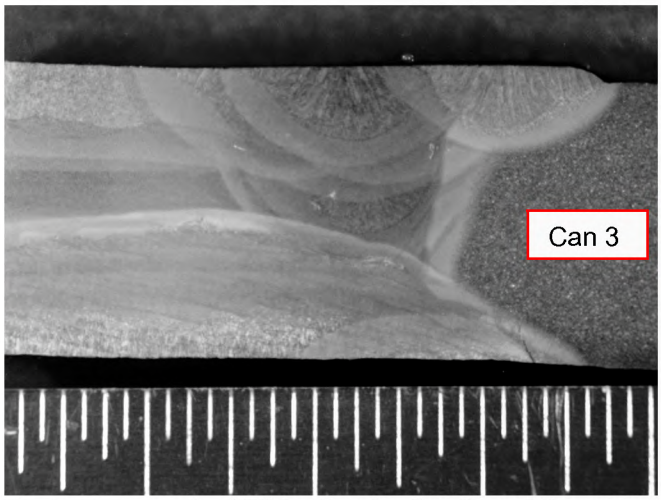
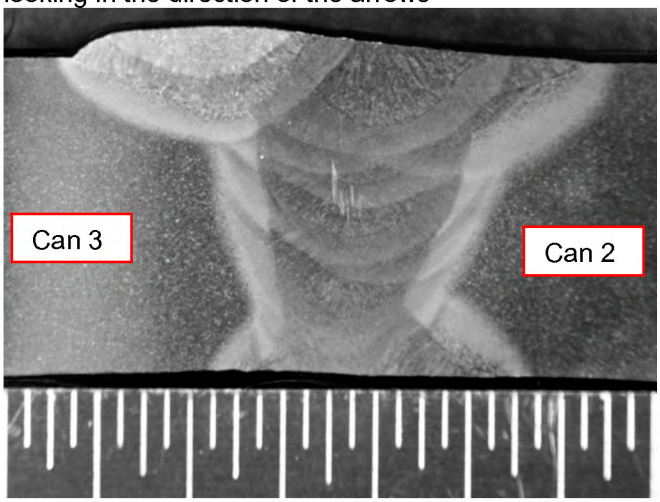


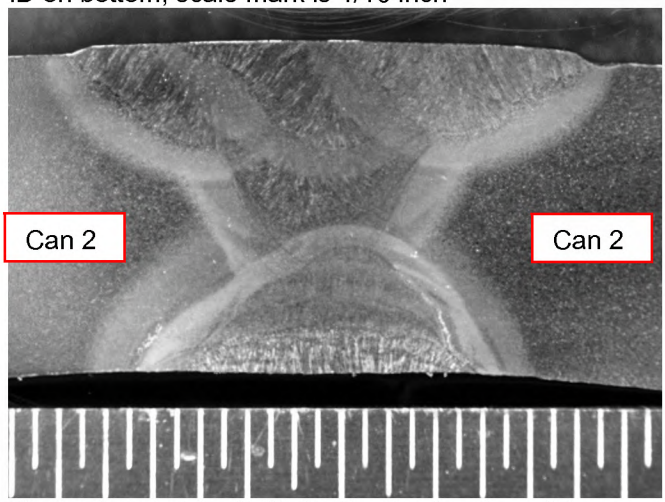
Part 16-1 with locations for three mounts at welds looking in the direction of the arrows



Photomicrograph of T2 looking in direction of the arrow ID on bottom, scale mark is 1/16 inch



Photomicrograph of T2C looking in direction of the arrow-ID on bottom, scale mark is 1/16 inch, artifact in center of weld



Photomicrograph of T2L looking in direction of the arrow-ID on bottom, scale mark is 1/16 inch

FIGURE 3 Photomicrographs of the mounts for T-2, T2C and T-2L looking at the UT indications for T2 and T2L – ID on the bottom of each mount

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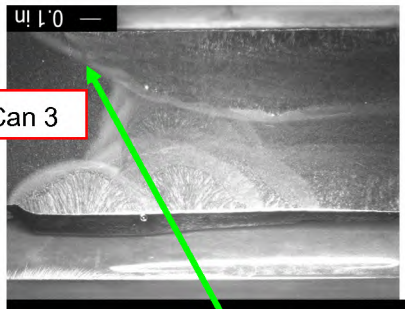
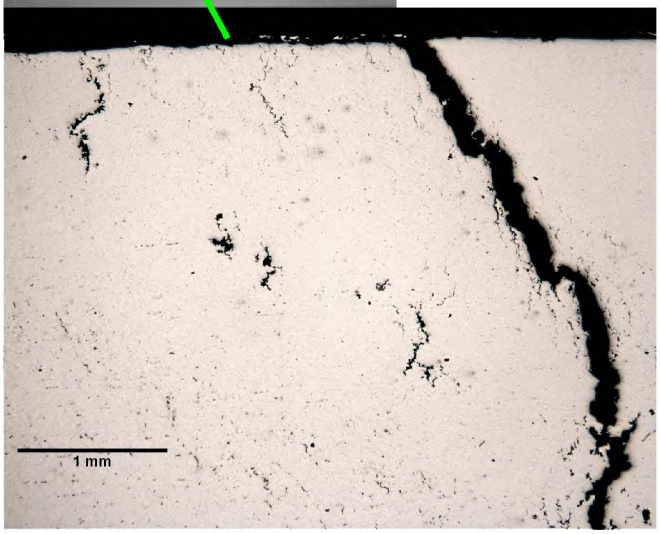
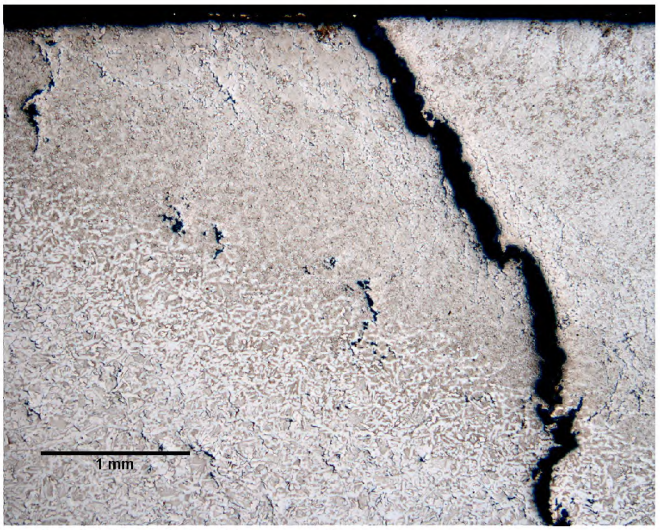


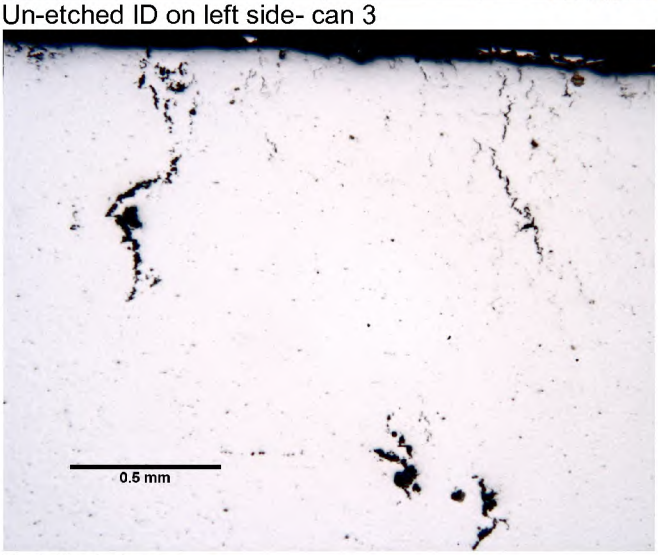
ID on top
OD on
bottom



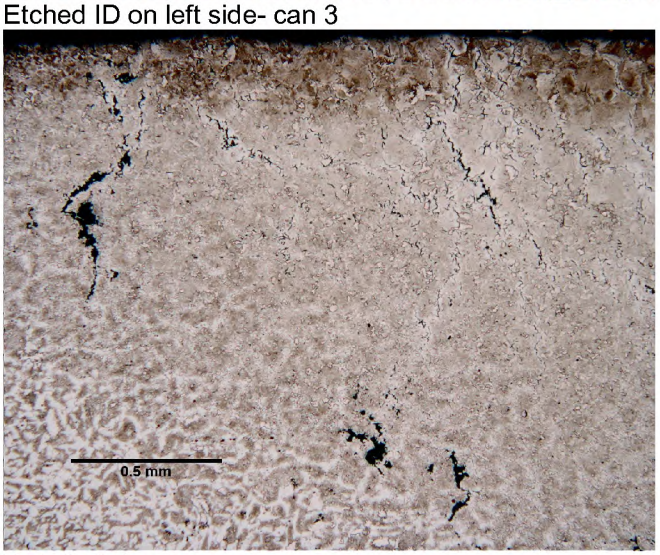
Un-etched ID on left side- can 3



Etched ID on left side- can 3



Detail of above



Detail of above

FIGURE 4 Photomicrographs of Mount T2 at ID on Can 3 side

BETA LAB NO.M10198- LS2-CS3 TEE INDICATIONS	TESORO REFINING AND MARKETING COMPANY ANACORTES REFINERY 10200 W. MARCH POINT ROAD T91WA4428 ANACORTES, WA 98221	CUSTOMER P.O. NO.: 4501667904
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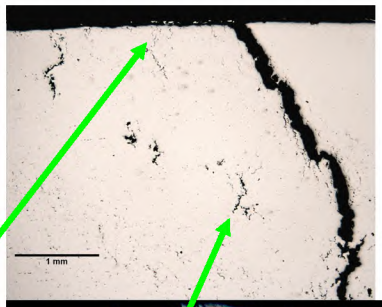
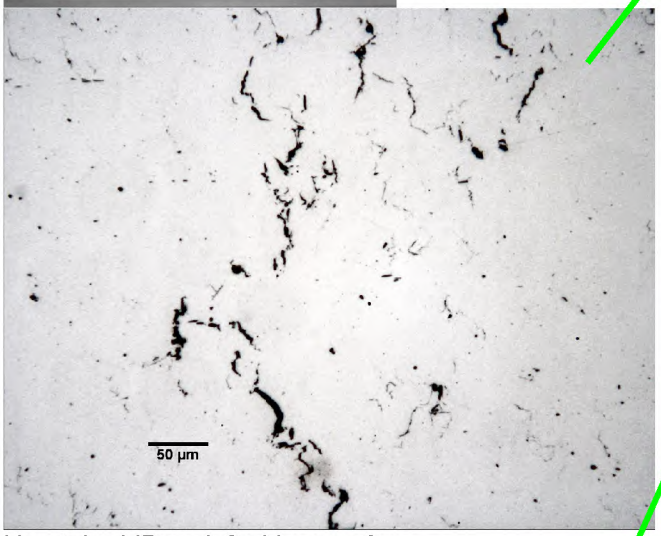
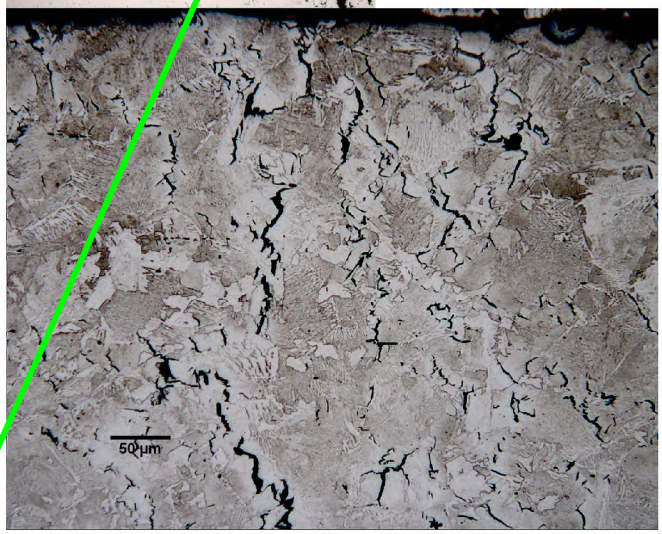
Can 3

ID on top
OD on
bottom

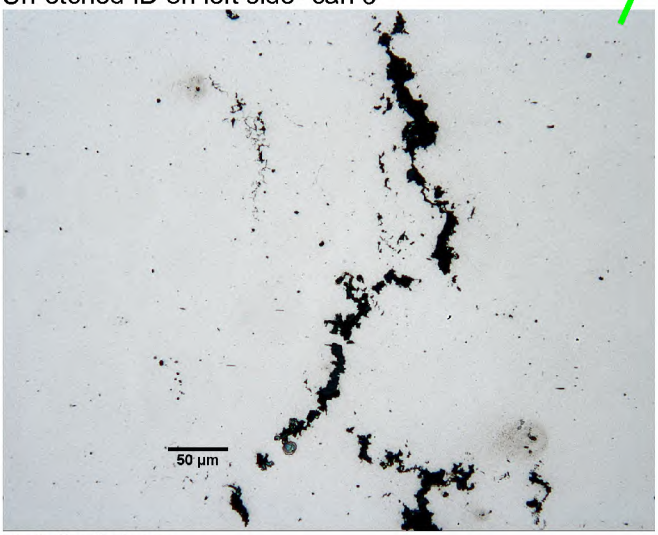




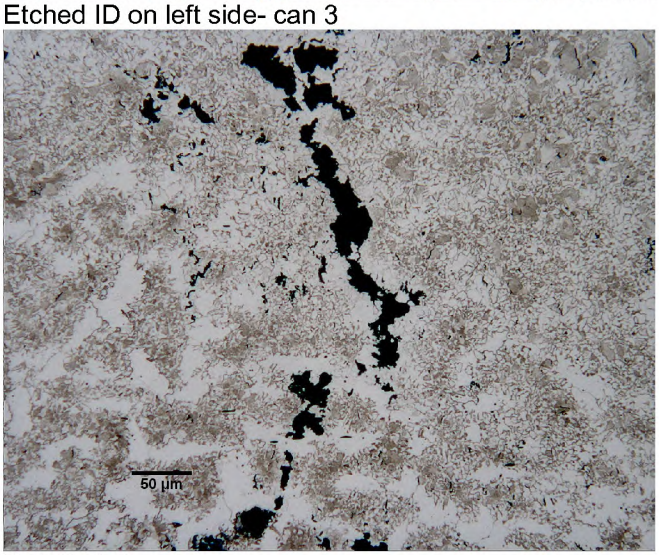
Un-etched ID on left side- can 3



Etched ID on left side- can 3



Detail of above



Detail of above

FIGURE 5 Photomicrographs of Mount T2 at or near ID on Can 3 side