BETA LAB NO.M10329, TESORO EXCHANGER E6600B EXAMINATION DATA	TESORO REFINING AND MARKETING COMPANY ANACORTES REFINERY 10200 W. MARCH POINT ROAD T91WA4428 ANACORTES, WA 98221	CUSTOMER P.O. NO.: 4501667904, CHANGE ORDER #1
PARTS: 6600B HEAT EXCHANGER, PARTS 1B, 2B, AND 3B		DATE: DECEMBER 27, 2010
		PAGE 1 OF 91

LABORATORY REPORT

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

SAMPLE DESCRIPTION: A heat exchanger 6600B (Beta Exchanger) was removed from operation at the Tesoro after undisclosed duration in service. The Exchanger B Shall Examination Protocol (Protocol) and Addendum 1 were developed and signed by Tesoro Companies, Division of Occupational Safety and Health, and U.S. Chemical Safety Board. The mentioned above Protocol and Addendum 1 are located in the Appendix 1 at the end of this Report. FirstEnergy BETA Laboratory was selected as the data collecting laboratory to perform the testing required by the Protocol.

The BETA Laboratory, as a data collecting (referee) laboratory, acts under the same rules as in the previous job on the exchanger E6600E, which are as follows:

> "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."

Thus, the sample locations, the tests to be performed, as well as details of the tests were chosen by the signatory parties or their technical representatives.

It was requested that the BETA Laboratory as a data collecting laboratory issue a Level 2 report without any interpretation or conclusion on any data obtained in the process of the laboratory tests, or any details on the photographs. All tests to be performed in the laboratory under the direct supervision of the signatory parties or their technical representative.

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The Exchanger B arrived at the Halvorsen Company's warehouse on August 23, 2010. The BETA LAB was informed the day before of the time of arrival at Halvorsen, but when BETA representative came to the warehouse, which was well before the time of reported arrival, the exchanger was already removed from the truck and unpacked. Thus the as arrived condition of the exchanger on the truck, as well as the integrity of the packaging could not be verified and recorded. The exchanger in as-unpacked condition at the Halvorsen is recorded on the photographs 1 through 10 of this report.

TEST PERFORMED: The tests of the heat exchanger parts included:
Visual examination, chemical analysis of the base and weld metal via vacuum spectrometry and carbon by LECO, macro and semi-micro hardness measurements of the base metal of the three cans and traverse hardness across the wed joints, wall thickness measurements, liquid Penetrant (PT) non-destructive testing (done by others), photo microscopy (metallography), depth of the damage , damage location and width of the Coarse Grain HAZ (CG HAZ) and Fine Grain HAZ (FG HAZ) measured, fractography by Scanning Electron Microscopy (SEM), tensile testing of the welded joints (done by others). The details of the apparatus utilized and the test procedures are given in Table 1 and Attachment 2.

TEST RESULTS: The exchanger welds were labeled by others – CW signified circumferential weld, LW – longitudinal. The selection, location and labeling of the test samples as it shown in Table 2 was done by others as well. The areas of the shell for the testing were chosen by others and consisted of three parts labeled Part 1B, 2B, and 3B. Part 1B contained Cans 3 and 4 base metals and circumferential weld CW4; Part 2B had Can 3 base metal and a longitudinal weld LW3; Part 3B included Cans 3 and 2 base metals and a T-joint of longitudinal weld LW3 and circumferential weld CW3. The Part 1B and 2B were located to include indications found in the welds by NDE (done by others). The heat exchanger with the parts marked, samples cut out, samples laid out, the samples lay out sketches, as well as the tables indicating the samples labels and tests to be performed are on Figures 11 through 19.

The test sample locations on each part of the shell were selected by others and are summarized in Tables 2 and 3 and shown on Figures 11 – 19.

Part 1B and 2B were PT tested (by others) and the results are on the Figure 15 and Appendix 3. The wall thickness of all three test plates was measured and the results are in Table 4.

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Three samples each were selected by others for: a). chemical analysis of the base metal (cans 2, 3, and 4), b). base metal Rockwell hardness measurements performed at the wall thickness middle line, c). weld metal chemistry (welds CW3, LW3, and CW4, performed at the cap and the root of the welds), and d). semi-micro hardness measurements of the three weld joints across the welds. The results are in Tables 5 (Rockwell hardness of the base metal), 6 through 9 (traverse hardness), and 11 (chemical composition of the base and weld metals).

Four samples were selected by others to be mounted for the evaluation of the microstructure. The mounted and polished samples were examined as directed by others in un-etched and etched conditions by optical metallographic microscope at the magnifications 15x, 50x, 200x, and 500x. The photographs which were taken as selected by others are on Figures 20 through 40.

It was requested to measure the following parameters in the microstructure of the welded joints: the depth of the damaged material, the location of the damage in the HAZ, and the widths of the coarse grain HAZ (CG HAZ) and fine grain of the HAZ (FG HAZ) at the deepest damage location. The results are in Table 12.

Two locations were selected for Fractography in SEM. The two samples (sample CS4 with weld CW4 from Part 1B, and sample LS3 with weld LW3 from Part 2B) were V-shape cut from the O.D. to decrease the cross section but leaving untouched the damaged area, submerged in the liquid nitrogen for over half an hour and then impact failed to expose fracture surface (see Figure 41). The fracture surfaces than were examined in Scanning Electron Microscope and the results introduced on Figures 42 through 45.

Semi-micro Vickers hardness under 500 g load were performed as directed by others across the welds. The Vickers hardness numbers were converted to Rockwell Scale B hardness numbers. The results are plotted on Figures 46 through 48 and in Tables 6 through 9.

As it was directed by others a coupon from Part 1B was cut out for tensile test of two samples. It was decided by others to remove damaged material from I.D. and make the samples 0.3 in. thick (see Figure 49). The tensile testing facility by mistake tested the samples of full thickness. The Laboratory was directed to cut out another coupon which was done (see Figures 17b and 50). The test results of both, full thickness and reduced thickness samples are in Table 10 and Appendix 4.

LABORATORY REPORT

TABLE 1
TESTS PERFORMED IN THIS REPORT
(See Attachment 2 for Test/Equipment Specifications)

TEST	METHOD OR INSTRUMENT	PERFORMED BY	LOCATION, DATE	RESULTS LOCATION
VISUAL EXAMINATION	LECO SZH STEREO MICROSCOPE OR PORTRAIT CAMERA	J. BLOUGH AND M. BRIDAVSKY	BETA, VARIOUS	TEST RESULTS
ROCKWELL HARDNESS	NEWAGE NI300-C HARDNESS TESTER	M. TASCAR	BETA, 10/21/2010	TABLE 5
SEMI-MACRO VICKERS	INSTRON TUKON 2100B HARDNESS TESTER, MODEL T2100BR1942	M. TASCAR	BETA, VARIOUS	TABLES 6-9, FIGURES 46-48
OPTICAL METALLOGRAPHY	LECO PMG-3 OPTICAL MICROSCOPE	M. BRIDAVSKY	BETA, VARIOUS	FIGURES 20-40
FRACTOGRAPHY	CAMSCAN SCANNING ELECTRON MICROSCOPE	C. HOLP	BETA, VARIOUS	FIGURES 41-45
LINEAR MEASUREMENTS	LECO PMG-3 OPTICAL MICROSCOPE WITH BUEHLER OMNIMET SYSTEM	M. BRIDAVSKY	BETA, 11/15/2010	TEST RESULTS, TABLE 12
LINEAR MEASUREMENTS	STARRETT MICROMETER NUMBER 222	M. TASCAR	BETA, 10/12/2010	TABLE 4
PT	LIQUID PENETRANT TEST	TEAM INDUSTRIAL SERVICE	BETA, 10/12/2010	FIGURE 15, APPENDIX 3
WALL THICKNESS	MICROMETER	M. TASCAR	BETA, 10/12/2010	TABLE 4
TENSILE PROPERTIES	TENSILE TEST	TENSILE TESTING METALLURGICAL LABORATORY	TTML, 11/1/2010 AND 11/29/2010	TABLE 10, FIGURES 49-53 APPENDIX 4
CHEMICAL ANALYSIS	THERMO ARL-3460 OE SPECTROMETER	M. TASCAR	BETA, 10/20/2010	TABLE 11
Carbon Analysis	Leco Carbon/Sulfur Determination CS-444	M. Belviso	BETA, 10/20/2010	Table 11

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TABLE 2
SUMMARY OF TESTS/SAMPLES

PART NUMBER	LOCATION	SAMPLE ID	TESTS							
			CHEMISTRY		METALLOGRAPY AND HARDNESS TRAVERSE	BM ROCKWELL HARDNESS	FRACTURE SEM	TENSILE	ID NDE	SAMPLE SIZE, INCH
			WELD	BASE METAL						
1B	CW4	N4		1					1	14 ¾ X 13
		C4	1							
		CH4			1					
		R4				1				
		CS4					1			
		CT4						2+2		
2B	LW3	N3		1					1	7X6
		L3	1							
		LH3			1					
		R3				1				
		LS3					1			
3B	LW3/CW3 Tee	C3	1							9 X 9 ¼
		N2		1						
		R2				1				
		CH3			1					
		LM3			1 (MOUNT ONLY, NO TRAVERSE)					
Total samples			3	3	4	3	2	4		

TABLE 3
TOTALS OF SAMPLES PER TEST

TEST	NUMBER OF SAMPLES
CHEMISTRY	6
METALLOGRPHY	4
HARDNESS TRAVERSE	3
BM HARDNESS HR	3
FRACTURE SEM	2
TENSILE	4

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TABLE 4
WALL THICKNESS MEASUREMENTS RESULTS

1B		2B		3B	
LOCATION FROM LEFT UPPER CORNER AT THE TOP	2 IN FROM THE CUT AT 2 IN INCREMENTS	LOCATION FROM LEFT UPPER CORNER AT THE TOP	2 IN FROM THE CUT AT 2 IN INCREMENTS	LOCATION FROM LEFT UPPER CORNER AT THE TOP	2 IN FROM THE CUT AT 2 IN INCREMENTS
1	0.855	1	0.853	1	0.859
2	0.859	2	0.856	2	0.901*
3	0.846	3	0.855	3	0.862
4	0.880	4	0.858	4	0.855
5	0.887	5	0.858	5	0.857
6	0.888	6	0.859	6	0.862
7	0.888			7	0.861
8	0.899			8	0.927*
9	0.894*			9	0.856
10	0.888			10	0.860
11	0.886			11	0.862
12	0.889			12	0.865
13	0.889				
14	0.894				
15	0.847				
16	0.855				
17	0.858				
18	0.860				
19	0.860				
20	0.856				
21	0.856				

The shaded numbers are at the half with the s.s. clad on ID.
*** Measurements are at the weld**

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TABLE 5
ROCKWELL (HRB) HARDNESS MEASUREMENTS ON PLATE CROSS SECTIONS

SAMPLE IDENTIFICATION	HARDNESS, HRB			
	MINIMUM	MAXIMUM	AVERAGE	NUMBER OF INDENTATIONS
1B – R4 (CAN 4)	72	76	74	10
2B – R3 (CAN 3)	74	81	77	10
3B – R2 (CAN 2)	80	85	83	10

TABLE 6

SEMI-MICRO VICKERS 500g (HV^{500}) MEASUREMENTS OF TRAVERSES CONVERTED TO ROCKWELL SCALE B
1B-CH4

See Graphs on Figure 46

Line	Zone	Hardness, HV^{500}			Number of Indentations
		Minimum	Maximum	Average	
1 - (OD)	BM Can 3	71	79	75	12
	HAZ 3	76	80	78	6
	Weld	73	84	79	60
	HAZ 4	73	79	76	4
	BM Can4	73	82	79	11
2 (Middle)	BM Can 3	72	82	76	11
	HAZ 3	77	83	80	3
	Weld	74	82	77	17
	HAZ 4	74	79	76	5
	BM Can 4	71	82	75	10
3 - (ID)	BM Can 3	72	78	75	11
	HAZ 3	72	81	78	6
	Weld	77	88	82	20

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TABLE 7

SEMI-MICRO VICKERS 500g (HV^{500}) MEASUREMENTS OF TRAVERSES CONVERTED TO ROCKWELL SCALE B

2B-LH3

See Graphs on Figure 47

Line	Zone	Hardness, HV^{500}			Number of Indentations
		Minimum	Maximum	Average	
1 - (OD)	BM Can 3	83	90	87	11
	HAZ 3	90	100	94	10
	Weld	81	93	87	55
	HAZ 3	87	97	93	10
	BM Can 3	84	90	87	10
2 (Middle)	BM Can 3	80	86	83	11
	HAZ 3	81	89	85	11
	Weld	82	87	84	23
	HAZ 3	79	86	83	9
	BM Can 3	79	86	83	10
3 - (ID)	BM Can 3	82	92	82	12
	HAZ 3	84	94	84	12
	Weld	73	92	76	51
	HAZ 3	86	93	90	11
	BM Can 3	84	90	86	9

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TABLE 8

SEMI-MICRO VICKERS 500g (HV^{500}) MEASUREMENTS OF TRAVERSES CONVERTED TO ROCKWELL SCALE B

3B-CH3

See Graphs on Figure 48

Line	Zone	Hardness, HV^{500}			Number of Indentations
		Minimum	Maximum	Average	
1 - (OD)	BM Can 2	85	92	88	12
	HAZ 2	88	96	93	6
	Weld	82	96	88	56
	HAZ 3	88	100	93	9
	BM Can 3	84	87	86	11
2 (Middle)	BM Can 2	82	89	85	13
	HAZ 2	85	87	86	4
	Weld	80	84	82	21
	HAZ 3	85	89	87	3
	BM Can 3	78	86	82	10
3 - (ID)	BM Can 2	89	89	87	12
	HAZ 2	90	94	92	14
	Weld	86	93	89	23
	HAZ 3	86	90	87	8
	BM Can 3	84	91	88	11

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TABLE 9

SUMMARY OF MICRO-HARDNESS NUMBERS FROM TABLES 6, 7, and 8 VICKERS 500g (HV^{500}) CONVERTED TO ROCKWELL SCALE B

Location	MIN	MAX	AVERAGE
Base Metal Can 4	**73**	**79**	**76**
Base Metal Can 3	**71**	**92**	**82**
Base Metal Can 2	**82**	**92**	**87**
HAZ Can 4	**73**	**79**	**76**
HAZ Can 3	**72**	**100**	**86**
HAZ Can 2	**82**	**94**	**88**
Weld Metal CW4 (CH4)	**73**	**88**	**79**
Weld Metal LW3 (LH3)	**81**	**94**	**85**
Weld Metal CW3 (CH3)	**80**	**96**	**86**

TABLE 10
TENSILE PROPERTIES OF CW4 WELDED JOINT
(See Figures 49 -53, Appendix 4)

TEST	SAMPLE	TENSILE, K.S.I.	YIELD, K.S.I.	ELONGATION IN 2", %	FAILURE LOCATION
Set 1	T4 Full Thickness	40.0	NA	NA	Base Metal
	T4 Full Thickness	44.0			Base Metal
Set 2	T4 – 1 Reduced Thickness from I.D. *	63.0	35.3	11	Base Metal/HAZ
	T4 – 2 Reduced Thickness from I.D. *	56.5	34.5	9.5	Base Metal/HAZ
SA- 515 GRADE 70		70 - 90	38 min	21 min	NA

* Sample is approximately 1/3 of wall thickness with 2/3 of the thickness removed from the I.D.

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TABLE 11
CHEMICAL ANALYSIS OF BASE METAL AND WELD DEPOSITS

SAMPLE IDENTIFICATION		CHEMICAL COMPOSITION, WT. %											
		C	SI	P	S	MN	NI	CR	MO	V	CU	CO	AL
CAN4 (PART 1B – N4)		0.27	0.25	0.008	0.030	0.66	0.11	0.10	0.03	0.000	0.13	0.009	0.006
CAN3 (PART 2B – N3)		0.25	0.23	0.008	0.020	0.60	0.12	0.13	0.02	0.000	0.18	0.01	0.008
CAN2 (PART 3B – N2)		0.28	0.23	0.009	0.021	0.62	0.12	0.13	0.03	0.000	0.18	0.01	0.006
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
WELD CW4 AT CAP (OD) - C4		0.15	0.43	0.010	0.019	0.99	0.08	0.09	0.02	0.000	0.15	0.01	0.007
WELD LW3 – L3	AT CAP (OD)	0.09	0.55	0.011	0.018	1.15	0.06	0.07	0.01	0.001	0.14	0.007	0.007
	AT ROOT (ID)	0.12	0.45	0.011	0.020	1.03	0.08	0.08	0.02	0.001	0.15	0.01	0.008
WELD CW3 – C3	AT CAP (OD)	0.09	0.57	0.011	0.018	1.13	0.06	0.07	0.01	00.001	0.15	0.007	0.006
	AT ROOT (ID)	0.09	0.60	0.012	0.020	1.29	0.05	0.06	0.01	0.002	0.13	0.007	0.007
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 12
DEPTH AND LOCATION OF THE DAMAGE

SAMPLE	DAMAGE DEPTH FROM ID				DAMAGE LOCATION**		WIDTH AT THE DEEPEST DAMAGE, MM			
	LEFT OF WELD		RIGHT OF WELD		LEFT OF WELD	RIGHT OF WELD	COARSE GRAIN HAZ		FINE GRAIN HAZ	
	MM	%*	MM	%*			LEFT OF WELD	RIGHT OF WELD	LEFT OF WELD	RIGHT OF WELD
CH4 (1B-CW4)	5.14	24	S.S. CLAD		BM	S.S. CLAD	0.38	NA	1.12	NA
LH3 (2B-LW3)	13.94	64	5.02	23	FL/CG	FL/CG	0.46	1.90	1.50	5.05
CH3 (3B-CW3)	2.49	11	3.74	17	FL/CG	FL/CG	0.66	0.87	1.62	1.07
LM3 (3B-LW3)	1.71	8	1.91	9	FL/CG	FL/CG	1.45	2.44	3.40	2.73

CG - Coarse Grain Heat Affected Zone (HAZ)
FL - Fusion Line
BM – Base Metal
CG – the damage is located in CG beyond the first two grains of the CG
*** Percentage is based on the average wall thickness of 21.8 mm**
**** See definitions on Figure 12**

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6600-B HEAT EXCHANGER
IN AS UNPACKED CONDITION.
INITIAL RECEIPT

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Figure 1
Exchanger on the warehouse floor

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Figure 2
Manufacturers' plates

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Figure 3 Shell as received

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Figure 4 Shell as received

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Figure 5 Shell as received

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Figure 6 Shell as received

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Figure 7 Tube bundle as received

BETA LAB NO.M10329, TESORO EXCHANGER E6600B EXAMINATION DATA	TESORO REFINING AND MARKETING COMPANY ANACORTES REFINERY 10200 W. MARCH POINT ROAD T91WA4428 ANACORTES, WA 98221	CUSTOMER P.O. NO.: 4501667904, CHANGE ORDER #1
PARTS: 6600B HEAT EXCHANGER, PARTS 1B, 2B, AND 3B		DATE: DECEMBER 27, 2010
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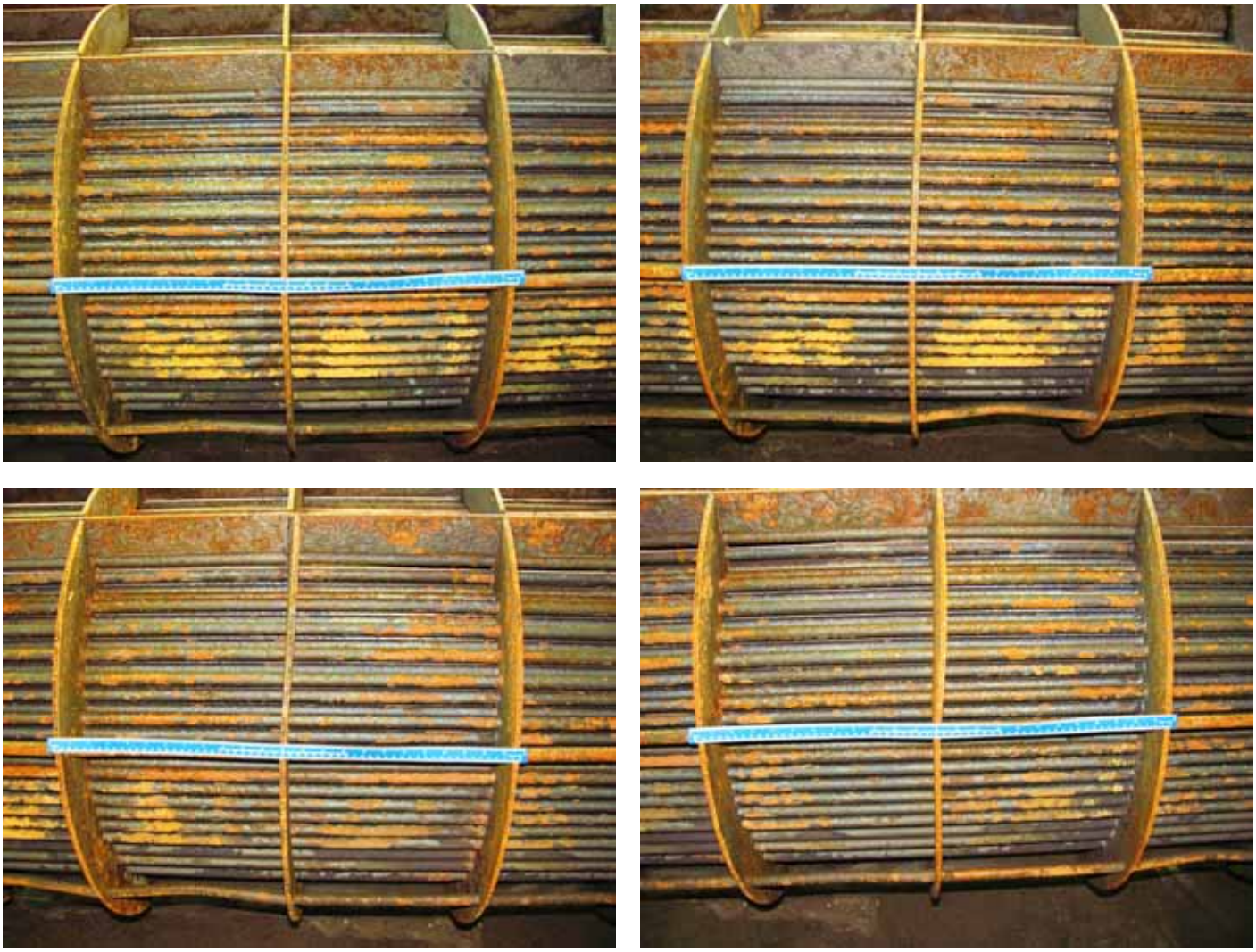

Figure 8 Tube bundle as received

BETA LAB NO.M10329, TESORO EXCHANGER E6600B EXAMINATION DATA	TESORO REFINING AND MARKETING COMPANY ANACORTES REFINERY 10200 W. MARCH POINT ROAD T91WA4428 ANACORTES, WA 98221	CUSTOMER P.O. NO.: 4501667904, CHANGE ORDER #1
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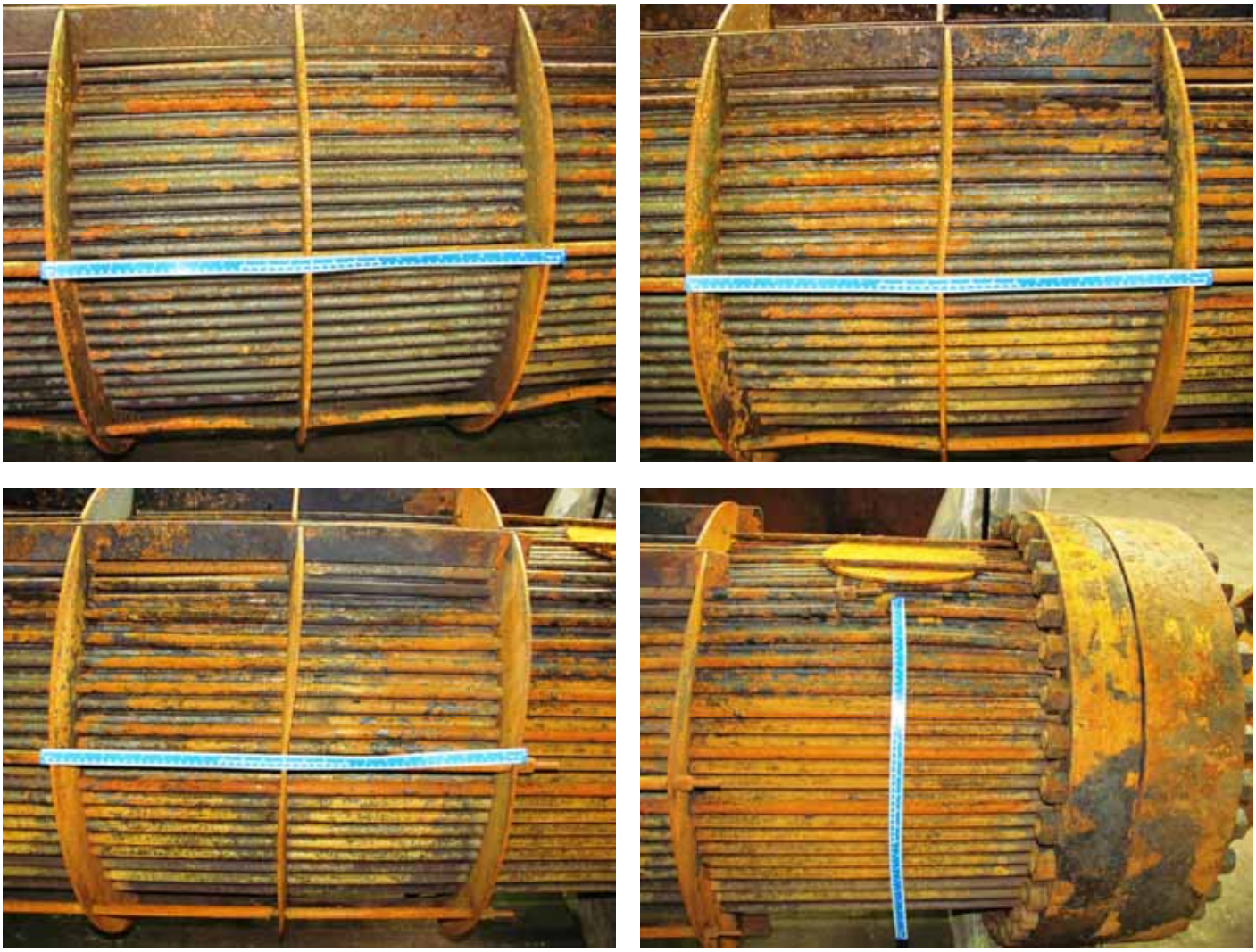

Figure 9 Tube bundle as received

BETA LAB NO.M10329, TESORO EXCHANGER E6600B EXAMINATION DATA	TESORO REFINING AND MARKETING COMPANY ANACORTES REFINERY 10200 W. MARCH POINT ROAD T91WA4428 ANACORTES, WA 98221	CUSTOMER P.O. NO.: 4501667904, CHANGE ORDER #1
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Figure 10 Tube bundle as received

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6600-B HEAT EXCHANGER SHELL SAMPLES CUT, PT AND SPECIMENS LAYOUT

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TESORO Exchanger E6600B as received at Halvorsen

The areas of the interest marked by others and are ready to be cut out

Figure 11.Shell

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Figure 12. Part 1B

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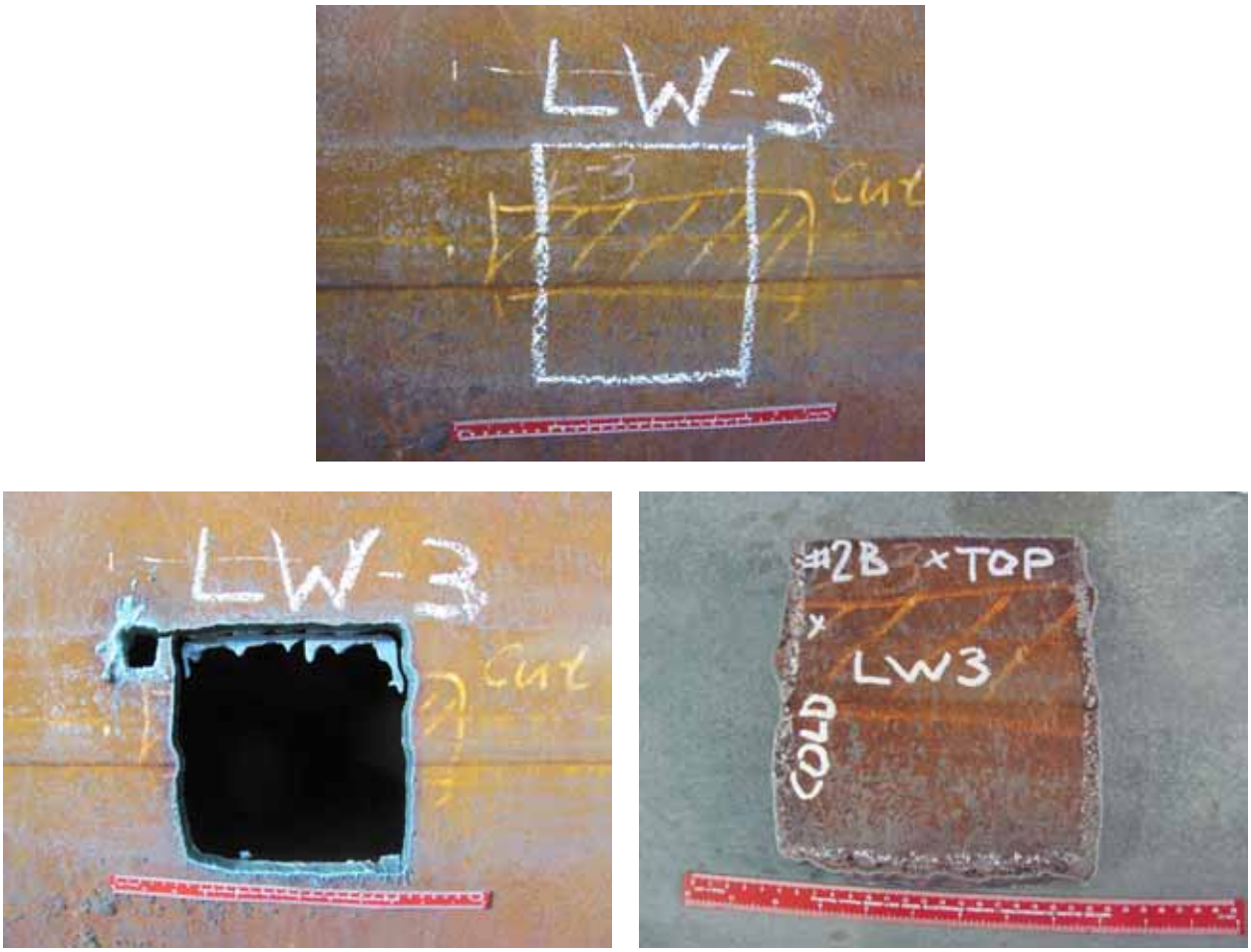

Figure 13. Part 2B

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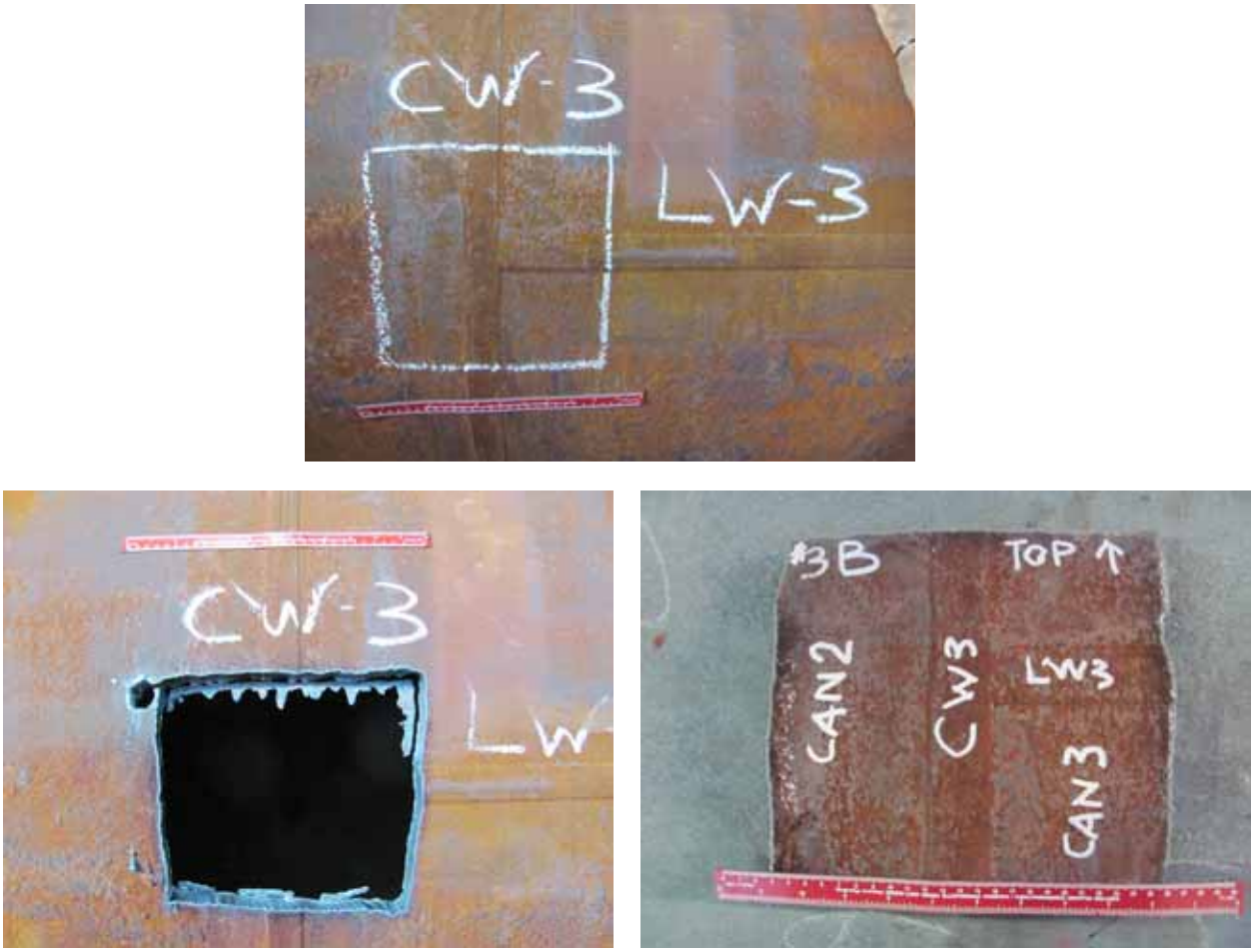

Figure 14. Part 3B

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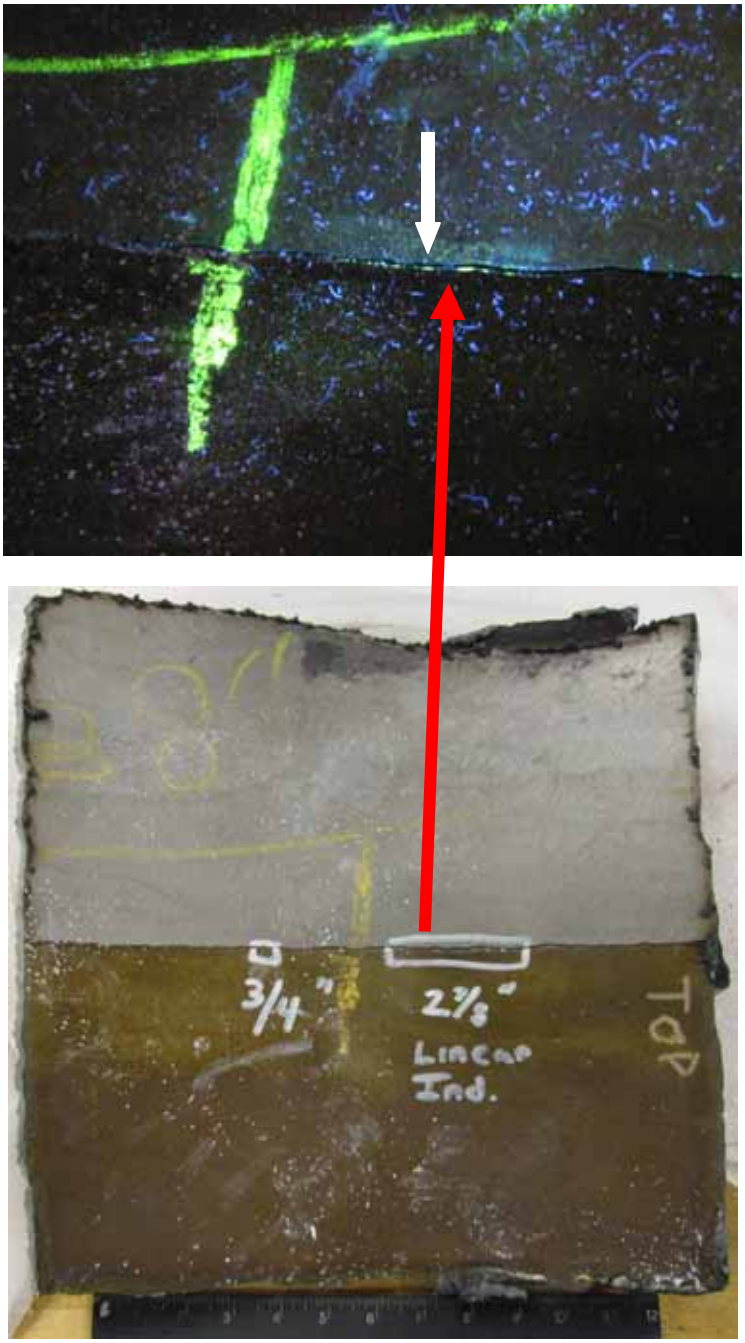

Figure 15. PT results of Part 1B. You are looking at ID. The s.s. clad is at the top portion of the sample on this picture.

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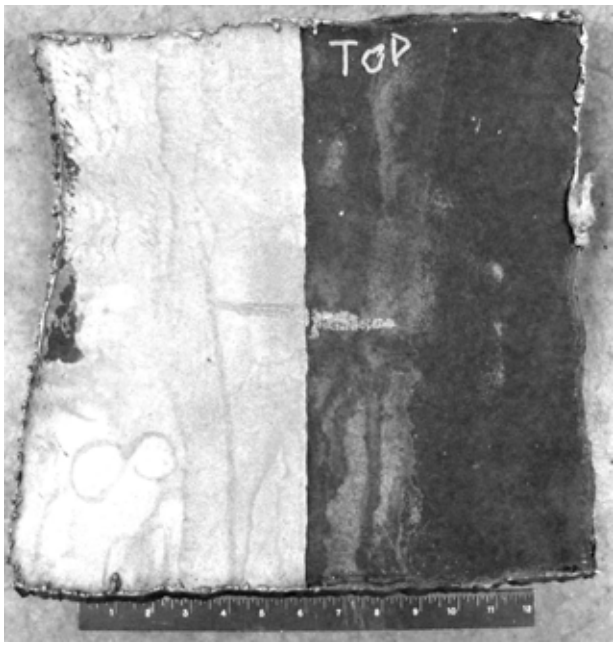
O.D.



I.D.

#1B - CW4

SAMPLE IDENTIFICATION	TEST
N4	CHEMISTRY OF BASE METAL (BM) CAN 4
C4	CHEMISTRY OF WELD METAL (WM) CW4
CH4	METALLOGRAPHY AND TRAVERSE HARDNESS OF CW4 (ARROW POINTS AT MOUNTED FACE)
CS4	FRACTOGRAPHY OF OPENED CRACK
R4	ROCKWELL HARDNESS OF BM CAN 4
T4	MECHANICAL PROPERTIES (TENSILE TEST)

Figure 16a. Specimens layout and labeling and test to be performed

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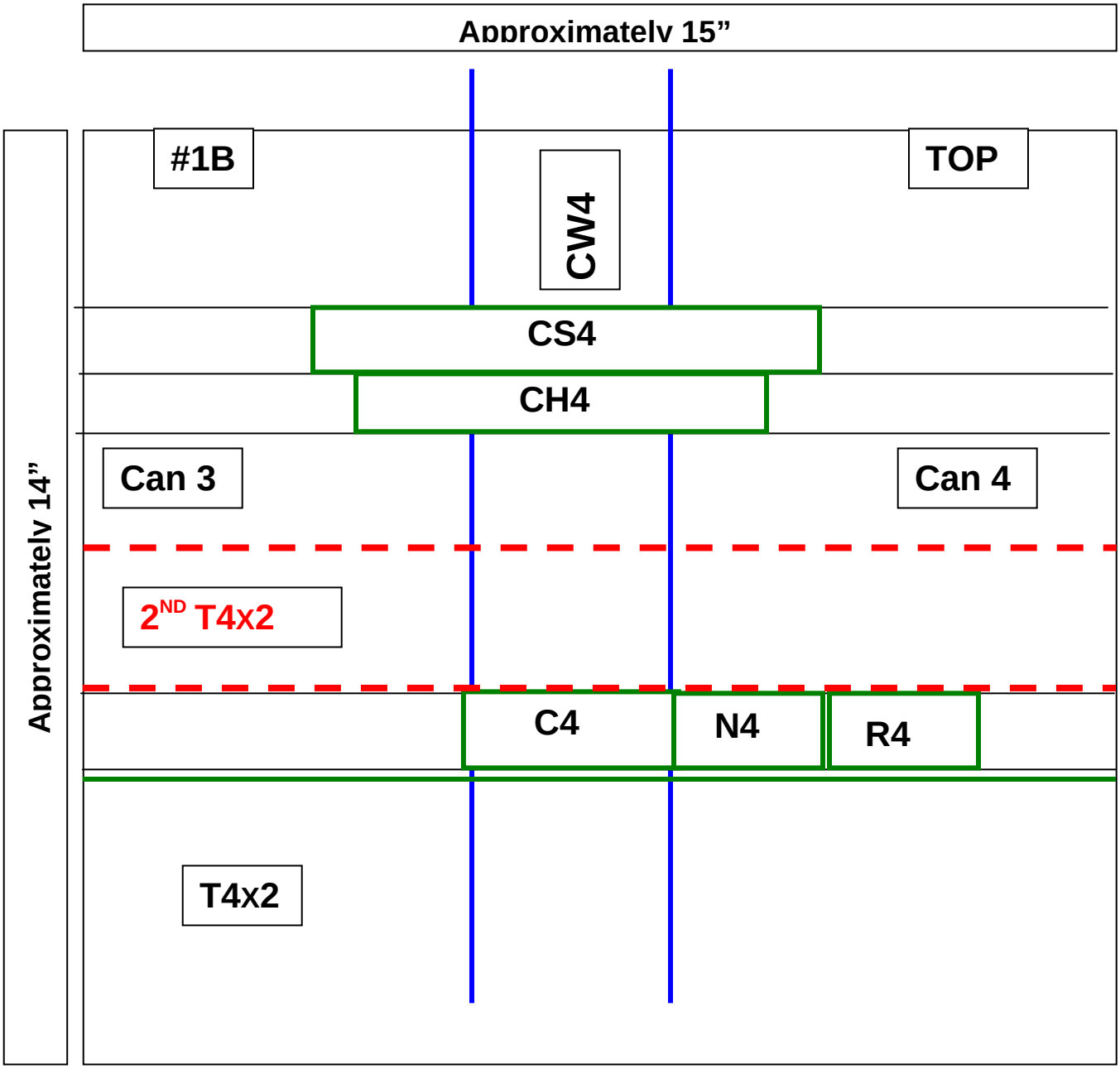
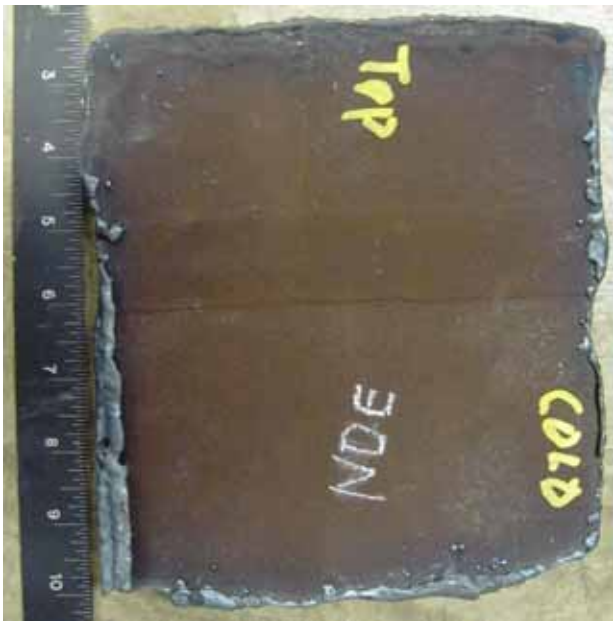


Figure 16b. 1B CW4 samples layout sketch. For labels explanation see Table on Figure 16a above.
You are looking at O.D.
There are two coupons for the tensile test T4 because the first one was not tested properly.

LABORATORY REPORT

O.D.



I.D.

2B - LW3

SAMPLE IDENTIFICATION	TEST
N3	CHEMISTRY OF BM CAN 3
L3	CHEMISTRY OF WM LW3
LH3	METALLOGRAPHY AND TRAVERSE HARDNESS OF LW3 (ARROW POINTS AT MOUNTED FACE)
LS3	FRACTOGRAPHY OF OPENED CRACK
R3	ROCKWELL HARDNESS OF BM CAN 3

Figure 17a. Specimens layout and labeling and test to be performed

LABORATORY REPORT

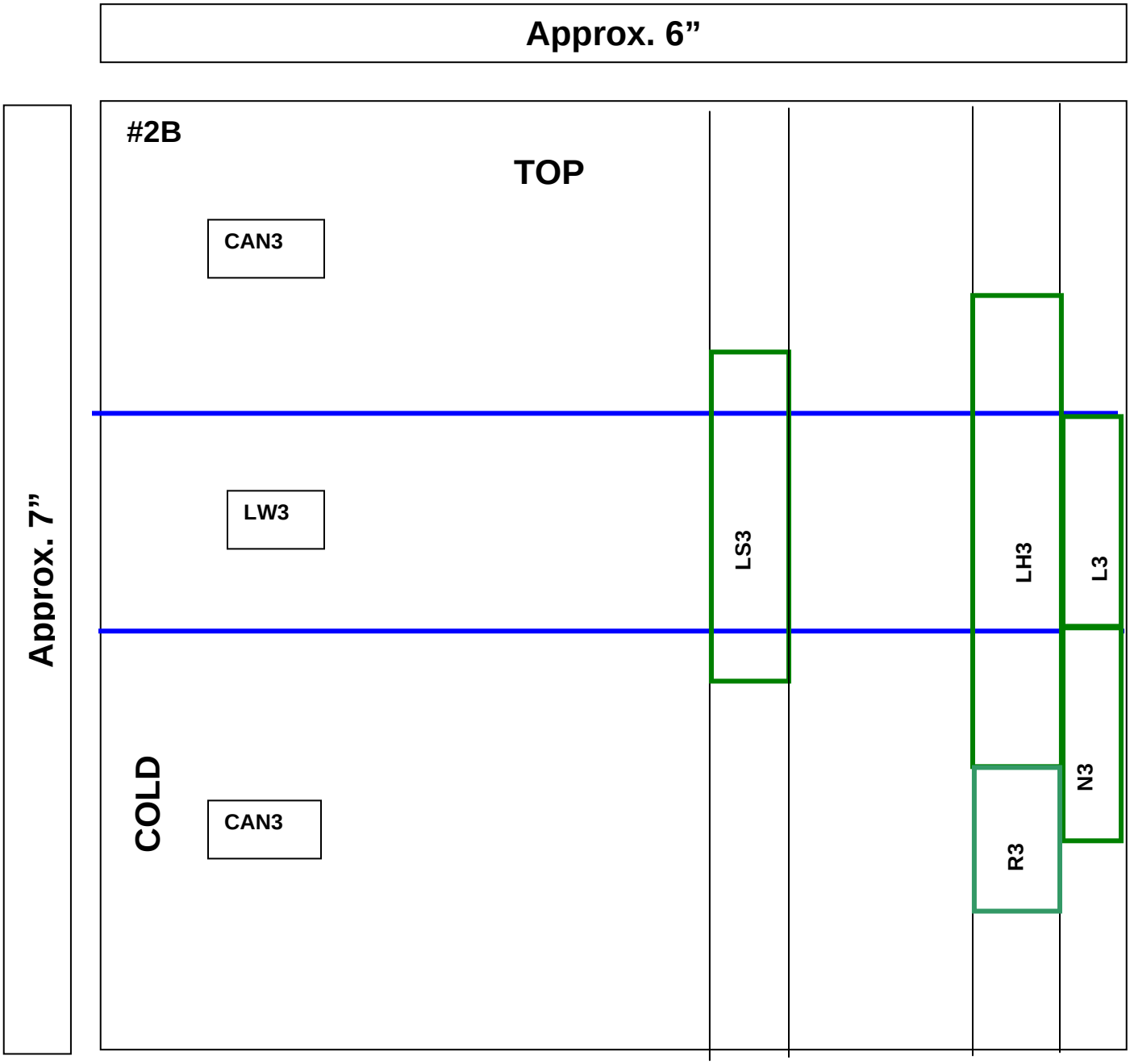
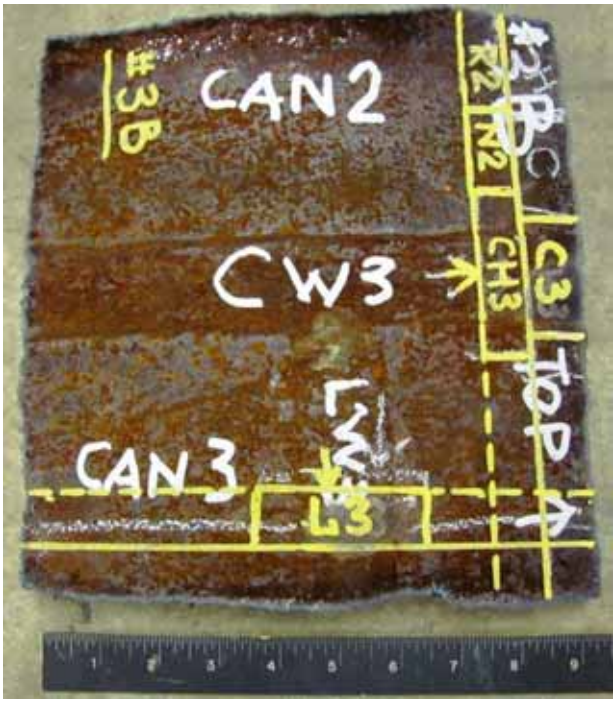


Figure 17b. 2B LW3 samples layout sketch. For labels explanation see Table on Figure 17a above.
You are looking at O.D.

LABORATORY REPORT



O.D.

I.D.

#3B - CW3-LW3

SAMPLE IDENTIFICATION	TEST
N2	CHEMISTRY OF BM CAN 2
C3	CHEMISTRY OF WELD METAL CW3
CH3	METALLOGRAPHY AND TRAVERSE HARDNESS OF CW3 (ARROW POINTS AT MOUNTED FACE)
LM3	METALLOGRAPHY AND HARDNESS (LW3) (ARROW POINTS AT MOUNTED FACE)
R2	ROCKWELL HARDNESS OF CAN 2

Figure 18a. Specimens layout and labeling and test to be performed

LABORATORY REPORT

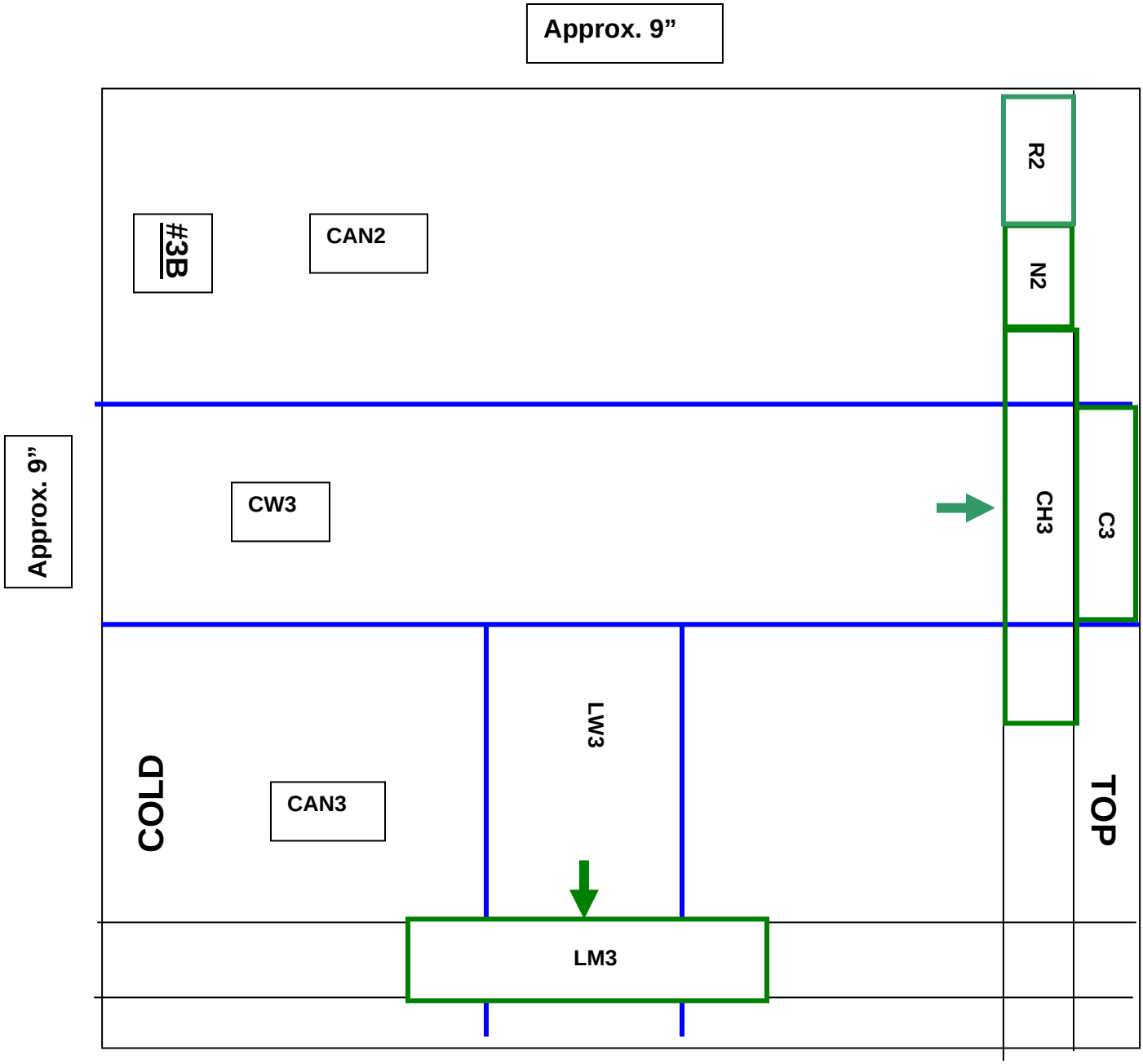


Figure 18b. **3**B LW3-CW3 samples layout sketch. For labels explanation see Table on Figure 18a above. You are looking at O.D.

LABORATORY REPORT

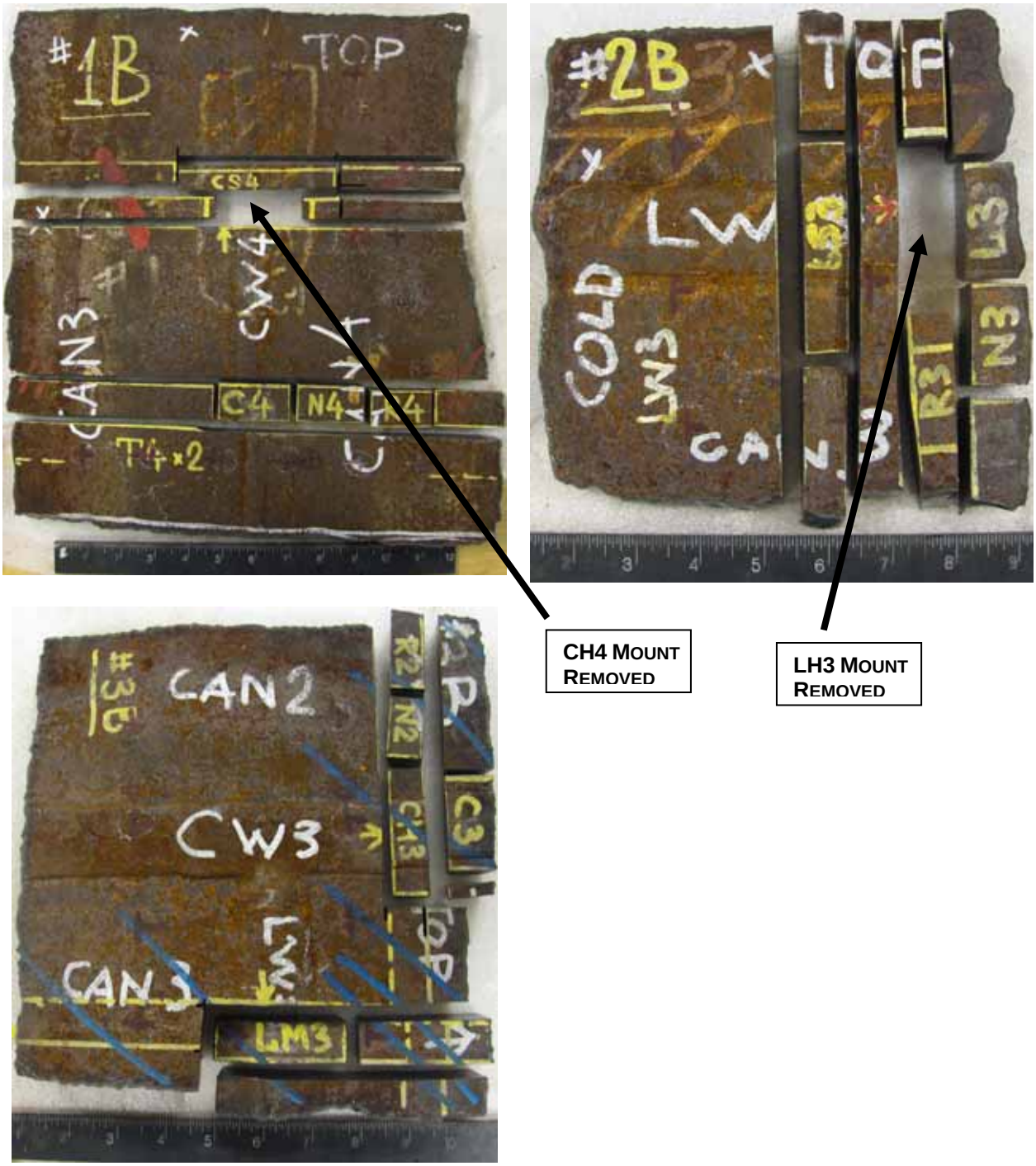
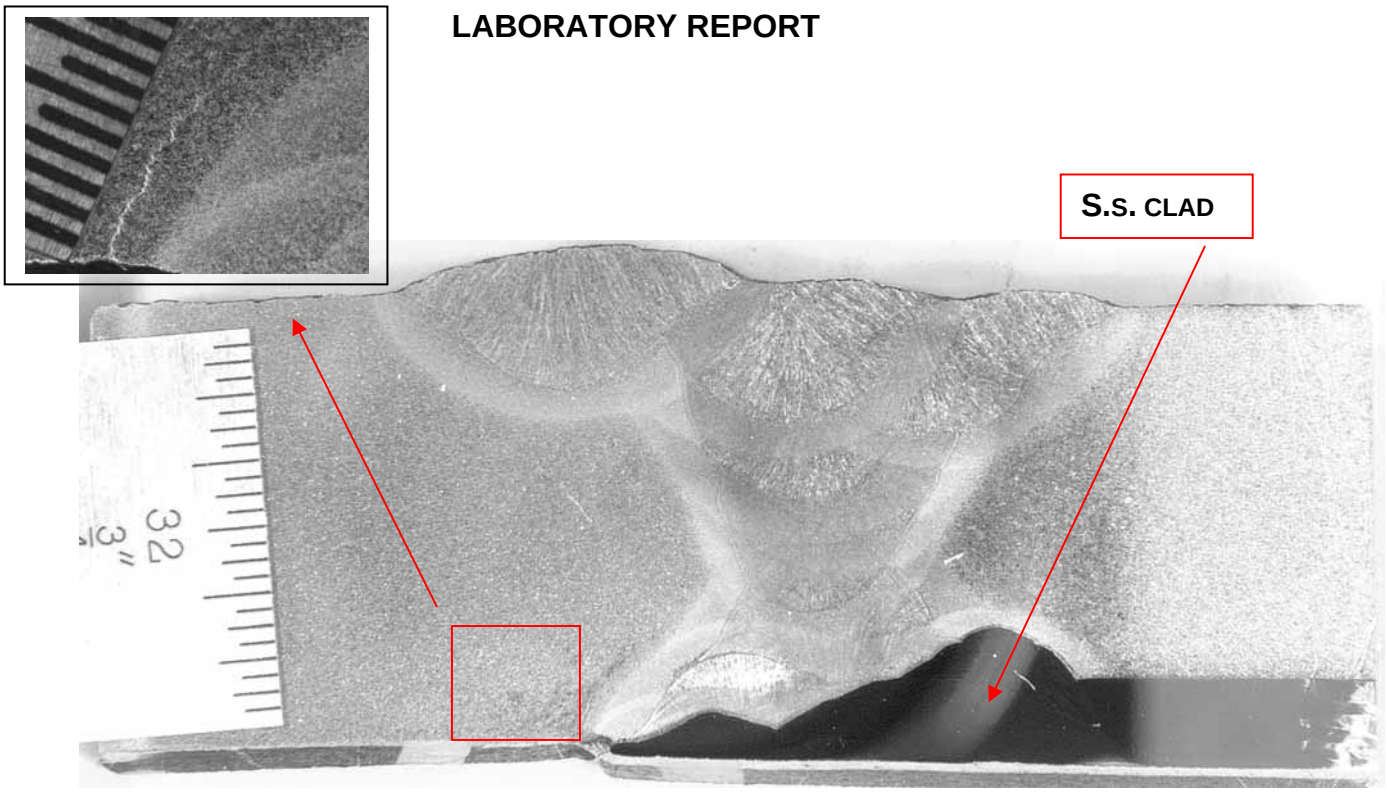


Figure 19. All three specimens cut.

LABORATORY REPORT



A

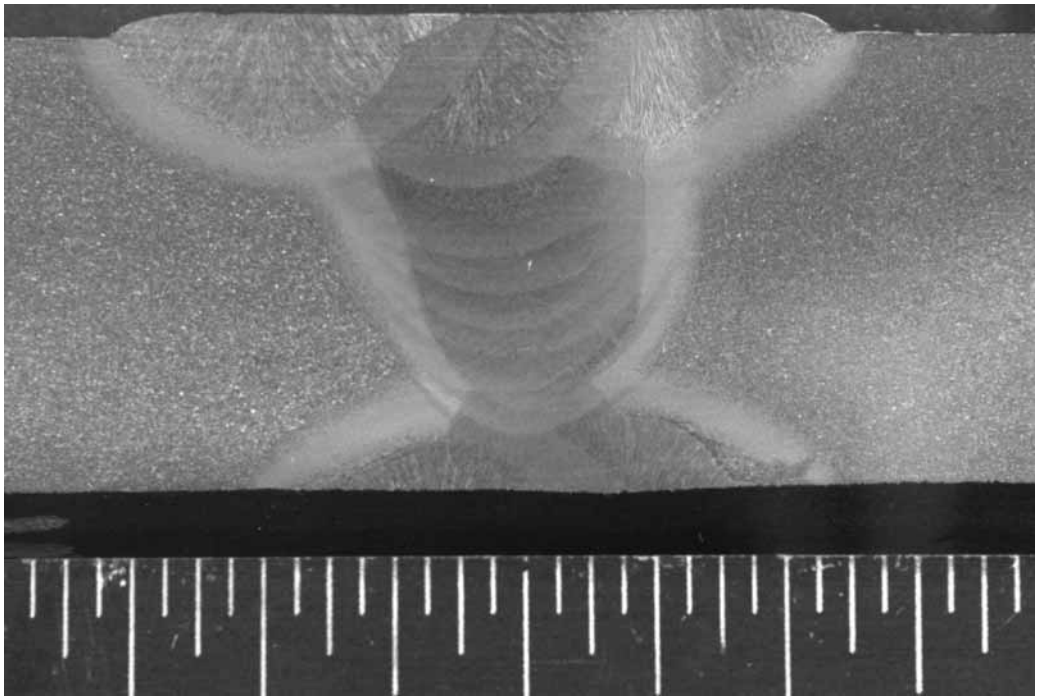
Part 1B. CH4 mount. Inset shows the crack at higher magnification. The ruler increment in inset is 1/64 inch.

B

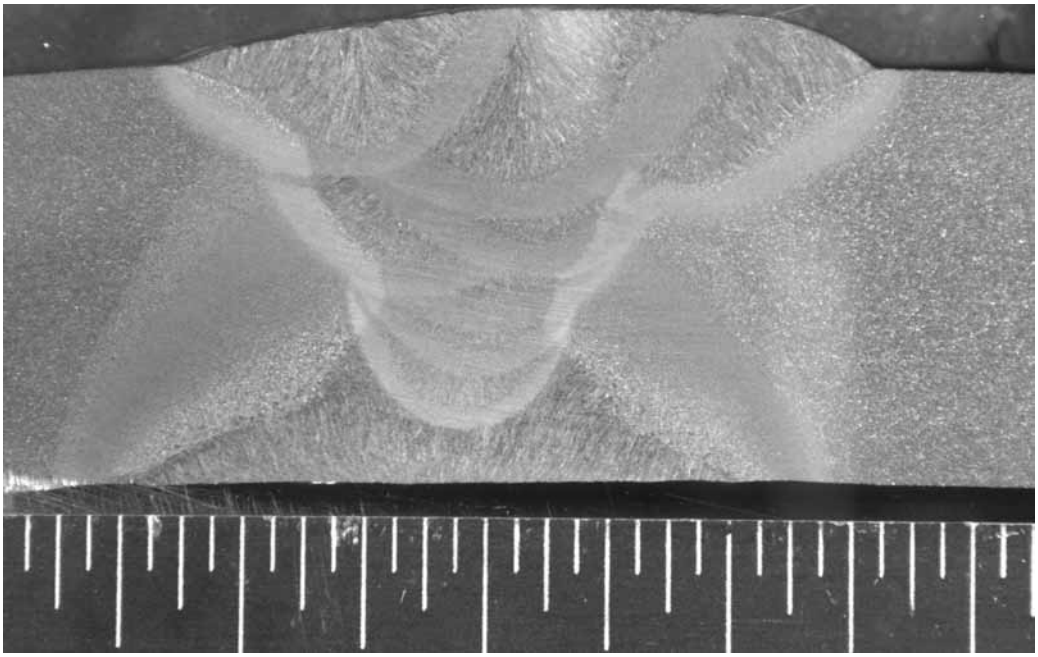
Part 2B. LH3 mount.

Figure.20. O.D. is on the top.

LABORATORY REPORT



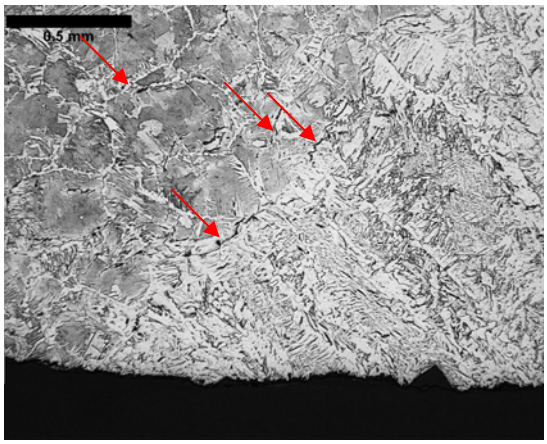
A. Part 3B. CH3 mount. The ruler increment is 1/16 inch.



B. Part 3B. LM3 mount. The ruler increment is 1/16 inch

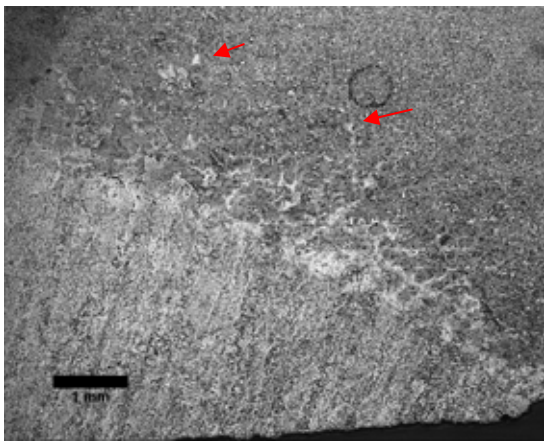
Figure 21. O.D. is on the top.

LABORATORY REPORT



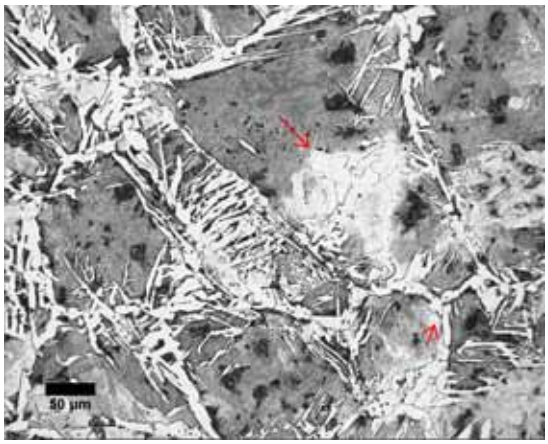
A

When the observed damage is located at the fusion line (FL) or at the 1st or 2nd grain of the CG HAZ (Coarse Grain of the Heat Affected Zone, CG everywhere in this report), it is marked as "**FL**"



B

It is typical to find damage beyond the FL and the 2nd grain of the CG, as it shown on the micrographs at left. The arrows at the microphotograph [B] show a decarburized spot indicative of the damage well deep in the CG, away from the FL. On microphotograph [C] the damage is in the 21st – 22nd grain inside the CG.



C

If this is observed, the location of the damage is defined as **"CG".**

If both, fusion line and coarse grain area are affected (which is most often the case), the location is defined as **"FL/CG"**

Figure 22. Definitions of the damage locations (devised by others) used in Table 11 and in the text

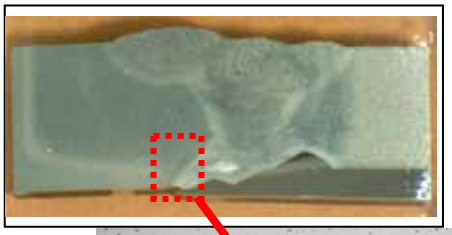
LABORATORY REPORT

METALLOGRAPHY

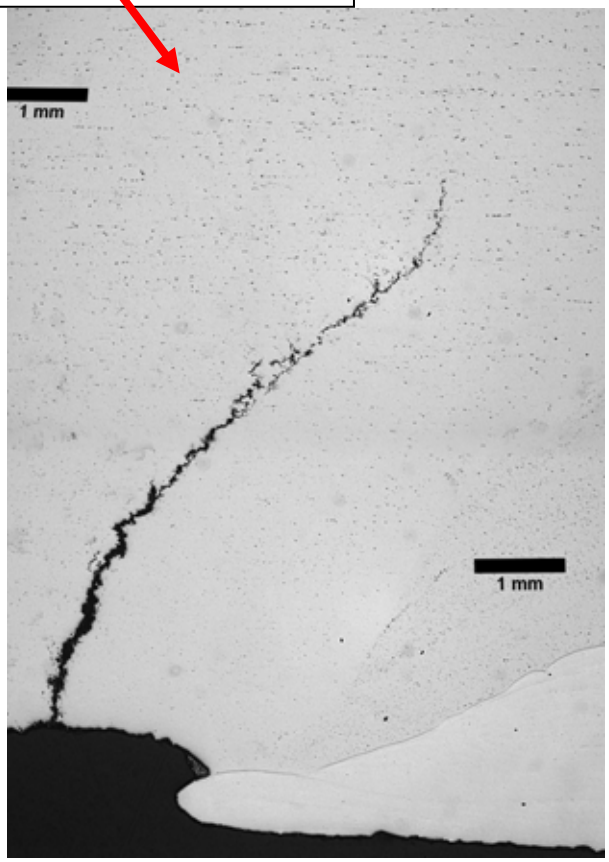
PART 1B
WELD CW4
SAMPLE CH4

ON ALL PHOTOGRAPHS I.D. IS ON THE BOTTOM.

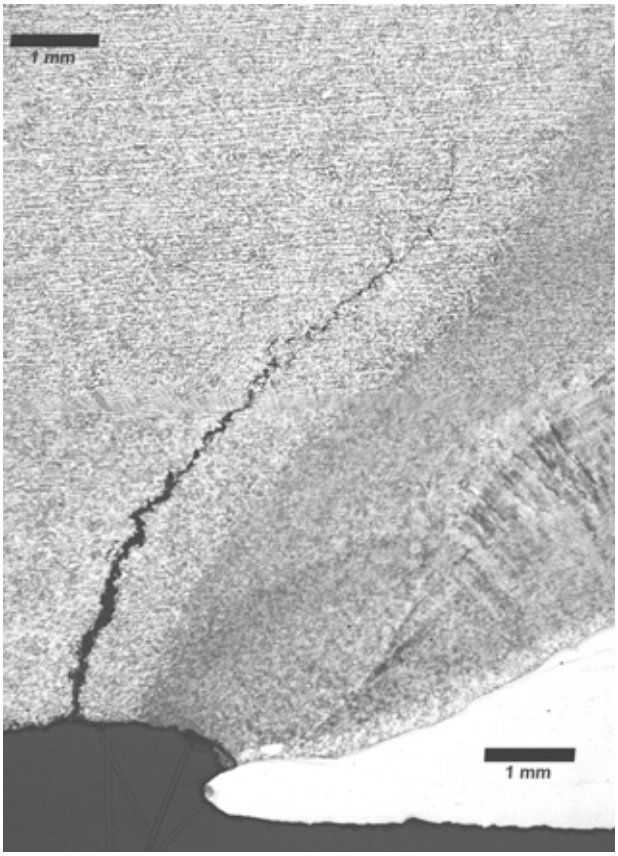
LABORATORY REPORT



PART 1B, WELD CW4, SAMPLE CH4. METALLOGRAPHY



Crack in the Base Metal. Un-etched



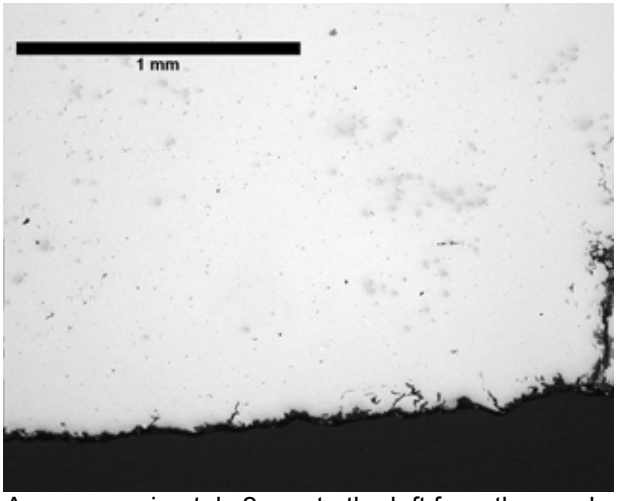
Same as at left. Etched

Figure 23.

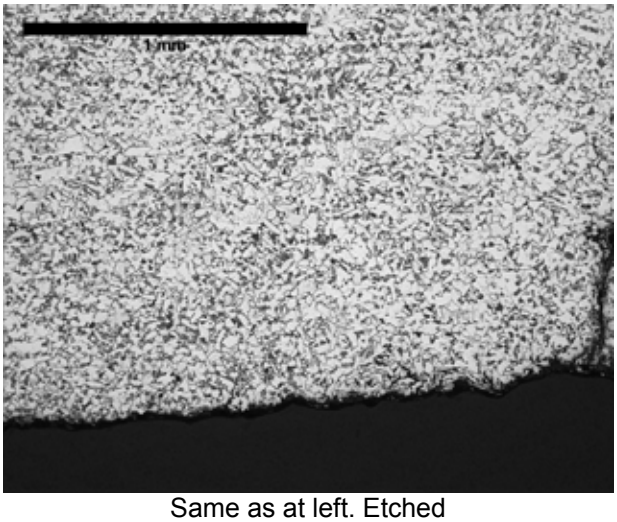
BETA LAB NO.M10329, TESORO EXCHANGER E6600B EXAMINATION DATA	TESORO REFINING AND MARKETING COMPANY ANACORTES REFINERY 10200 W. MARCH POINT ROAD T91WA4428 ANACORTES, WA 98221	CUSTOMER P.O. NO.: 4501667904, CHANGE ORDER #1
PARTS: 6600B HEAT EXCHANGER, PARTS 1B, 2B, AND 3B		DATE: DECEMBER 27, 2010
		PAGE 42 OF 91

LABORATORY REPORT

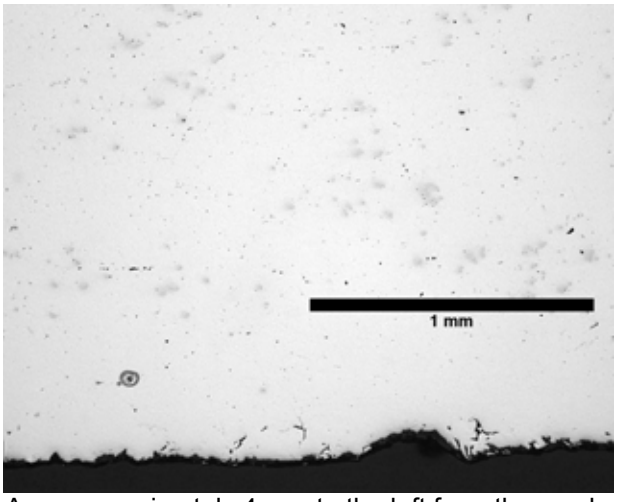
PART 1B, WELD CW4, SAMPLE CH4. METALLOGRAPHY



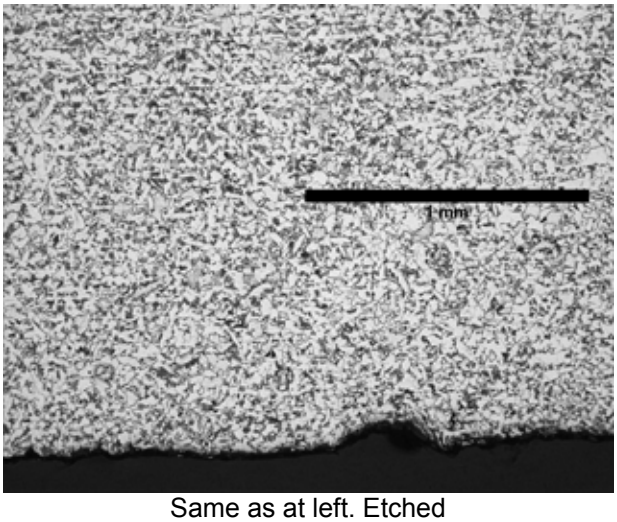
Area approximately 2 mm to the left from the crack. Un-etched



Same as at left. Etched



Area approximately 4 mm to the left from the crack. Un-etched

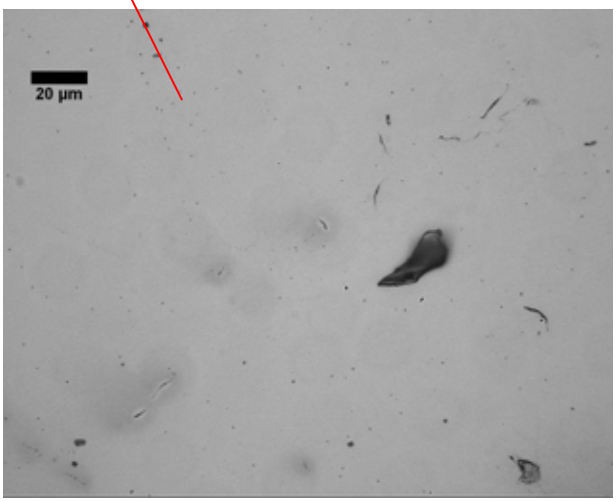


Same as at left. Etched

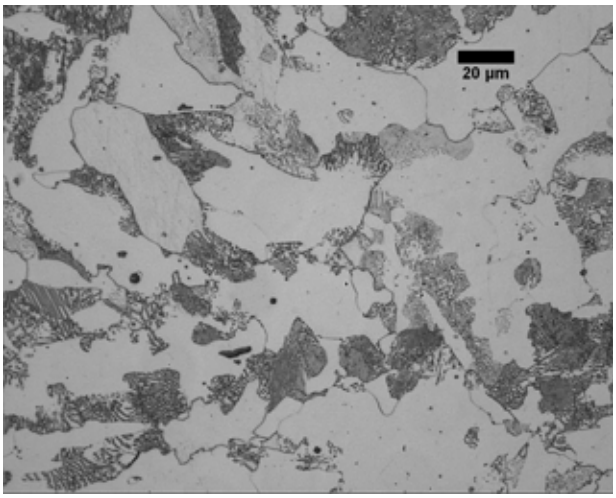
Figure 24

LABORATORY REPORT

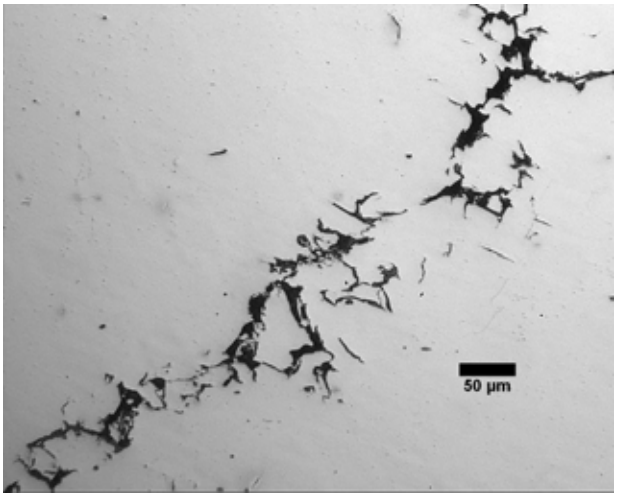
PART 1B, WELD CW4, SAMPLE CH4. METALLOGRAPHY



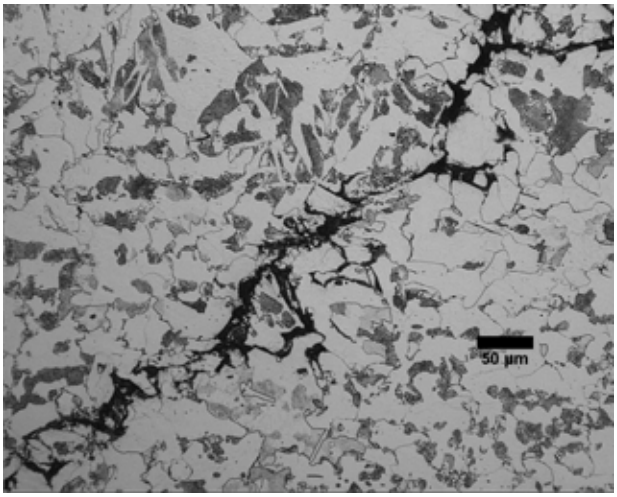
Area 4 mm from the crack to the left of the crack. Un-etched



Same as at left. Etched



Area near the tip of the crack. Un-etched

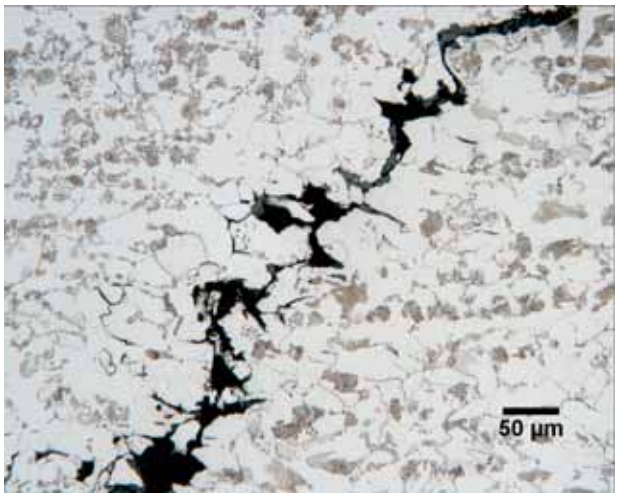


Same as at left. Etched

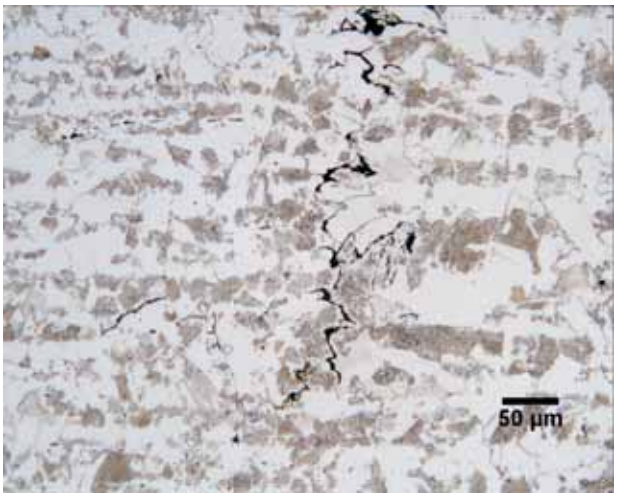
Figure 25

LABORATORY REPORT

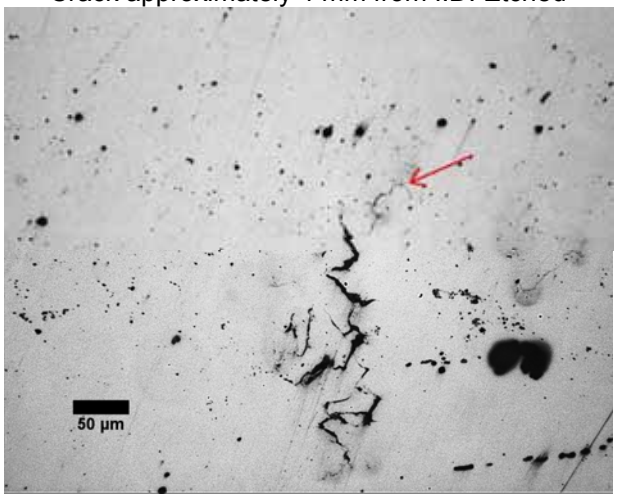
PART 1B, WELD CW4, SAMPLE CH4. METALLOGRAPHY



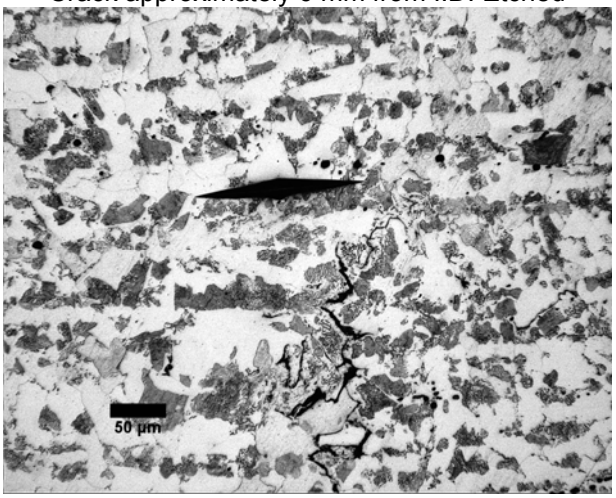
Crack approximately 4 mm from I.D. Etched



Crack approximately 6 mm from I.D. Etched



Tip of the crack and the last (deepest) damage observed. Un-etched.



Same as at left. The diamond is an identification of the deepest damage location. The measurements are in Table 12. Etched

Figure 26

LABORATORY REPORT

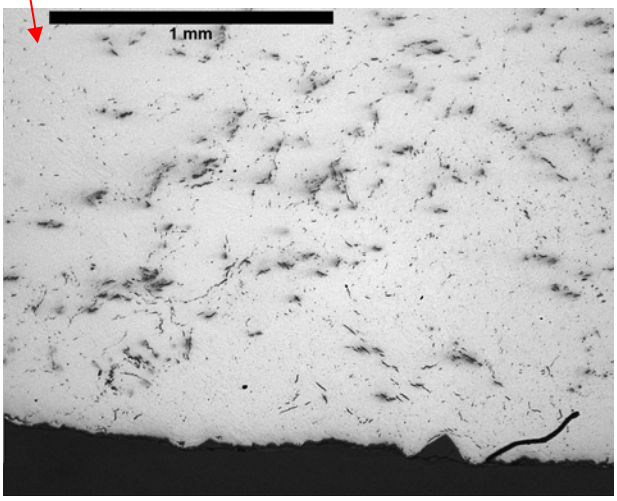
METALLOGRAPHY

PART 2B
WELD LW3
SAMPLE LH3

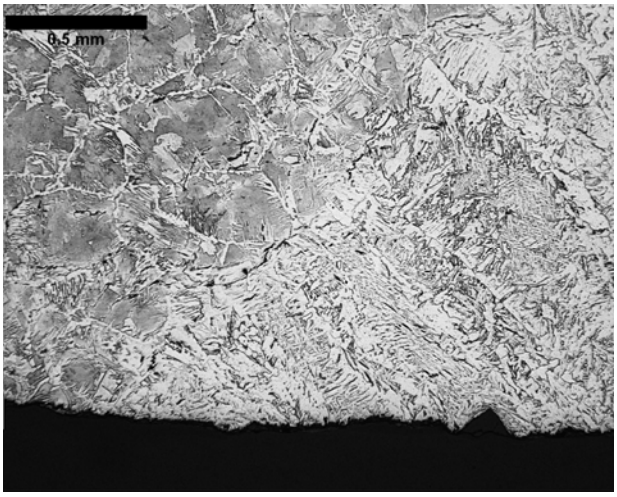
ON ALL PHOTOGRAPHS I.D. IS ON THE BOTTOM.

LABORATORY REPORT

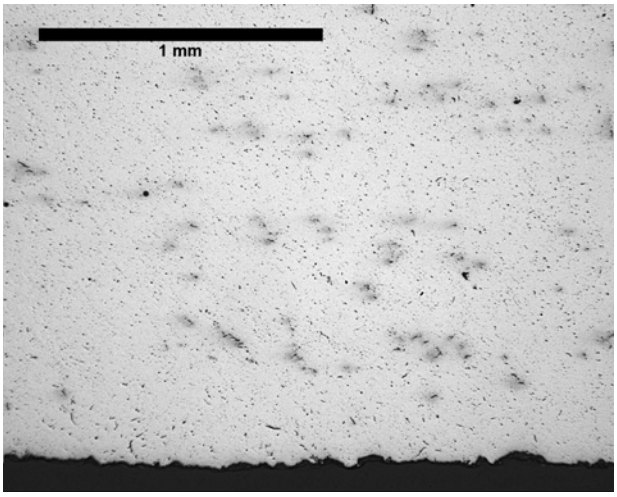
PART 2B, WELD LW3, SAMPLE LH3. METALLOGRAPHY



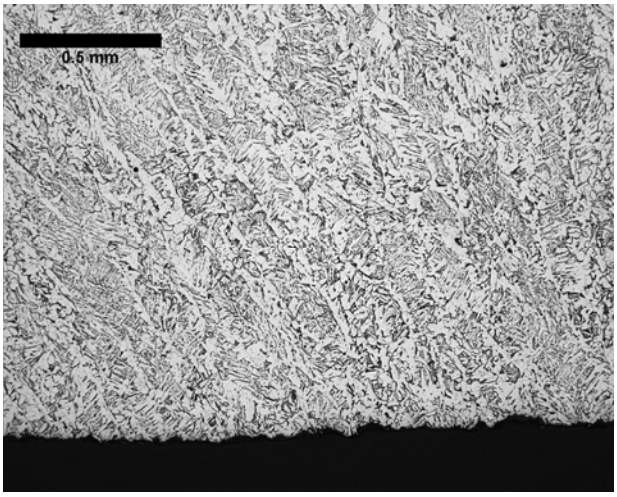
Left of the weld. Area at the toe of the weld at I.D. Un-etched



Same as at left. Etched



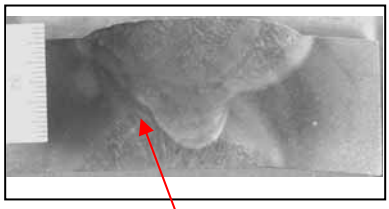
Typical damage in the weld at I.D. Un-etched



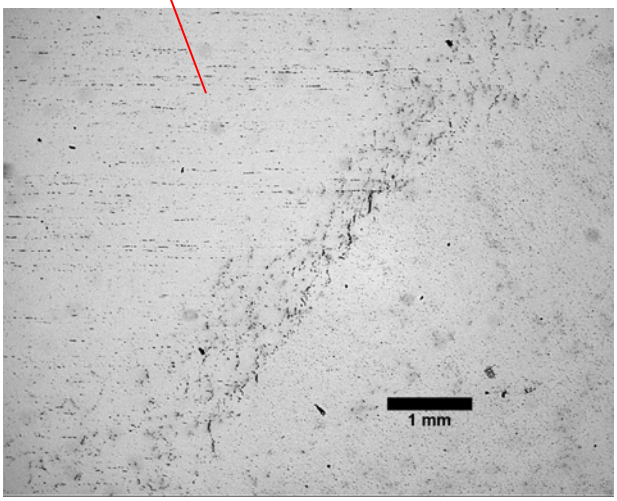
Same as at left. Etched

Figure 27.

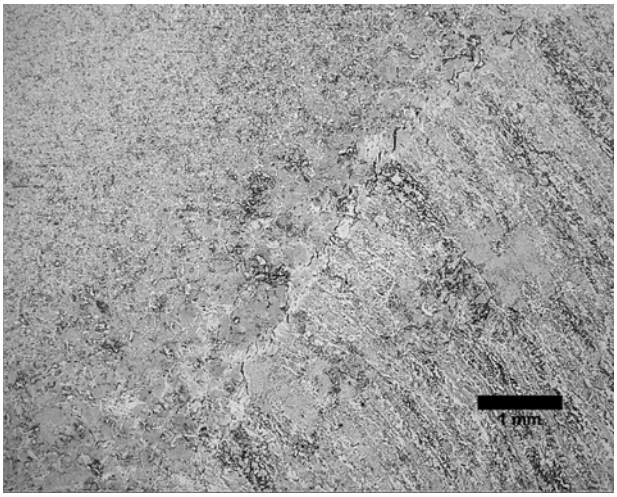
LABORATORY REPORT



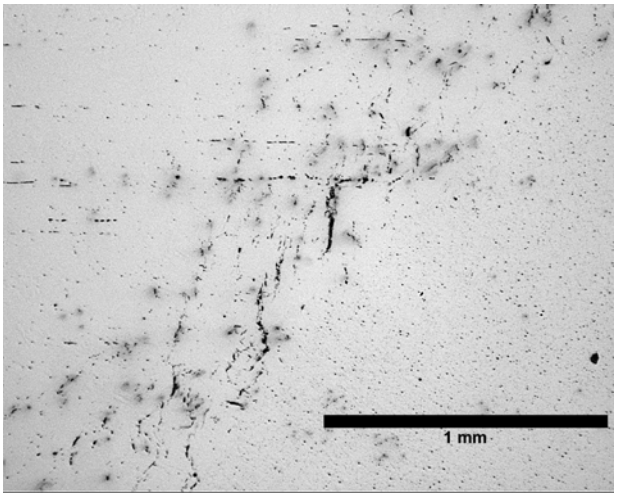
PART 2B, WELD LW3, SAMPLE LH3. METALLOGRAPHY



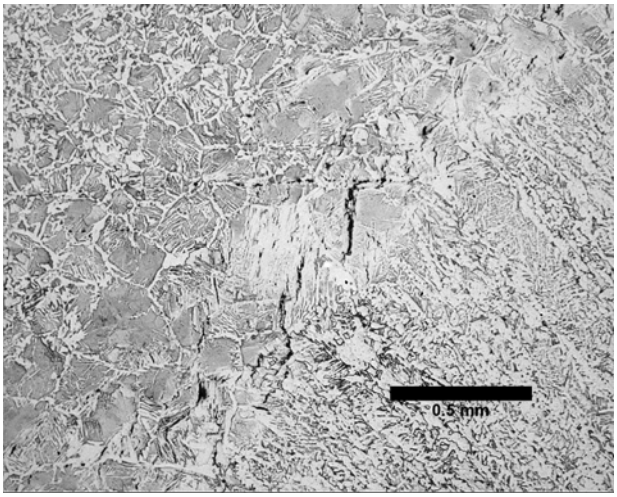
Left of the weld. Area below the weld cusp. Un-etched



Same as at left. Etched



Same as above at higher magnification. Un-etched

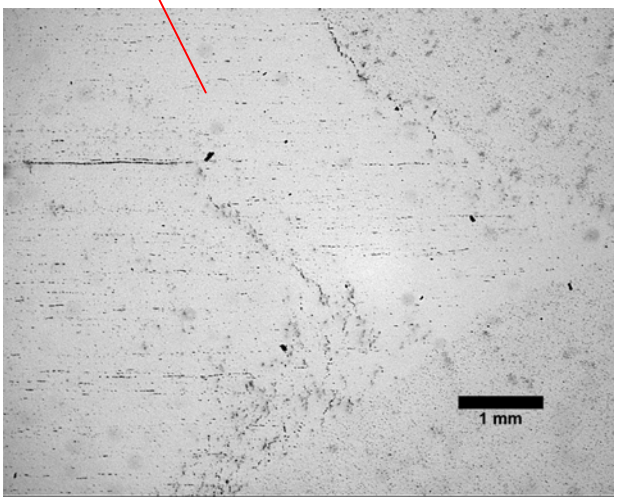


Same as at left. Etched

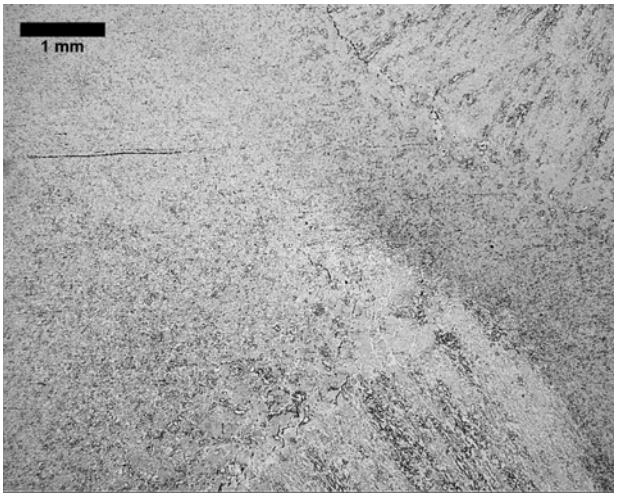
Figure 28

LABORATORY REPORT

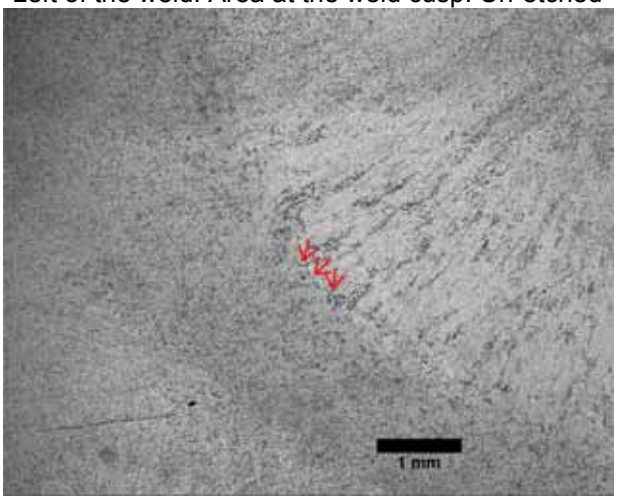
PART 2B, WELD LW3, SAMPLE LH3. METALLOGRAPHY



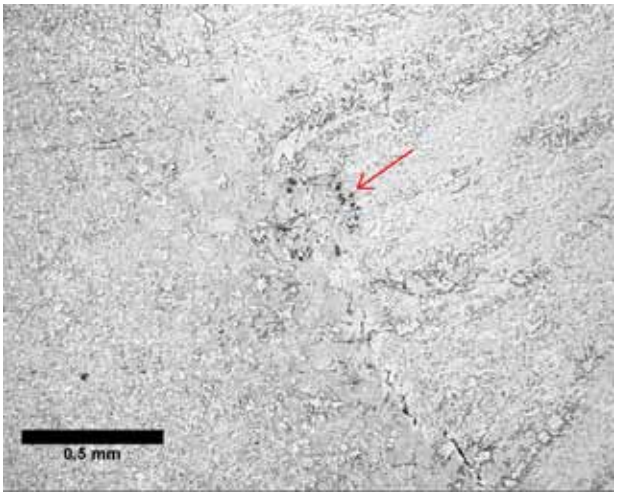
Left of the weld. Area at the weld cusp. Un-etched



Same as at left. Etched



The deepest damage at the left side of the weld. Etched



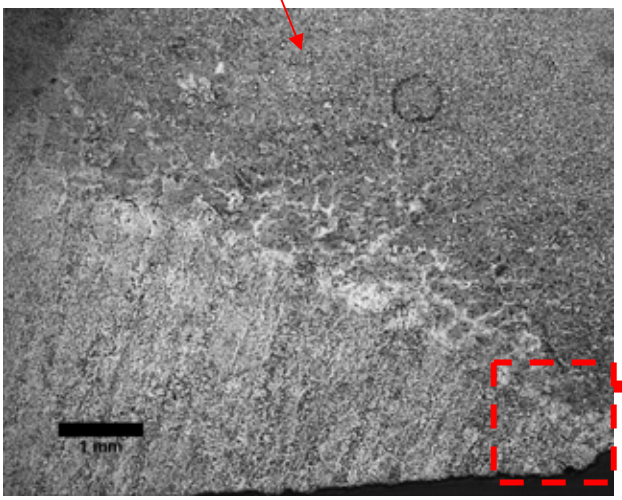
Same area as at left, enlarged. Etched

Figure 29

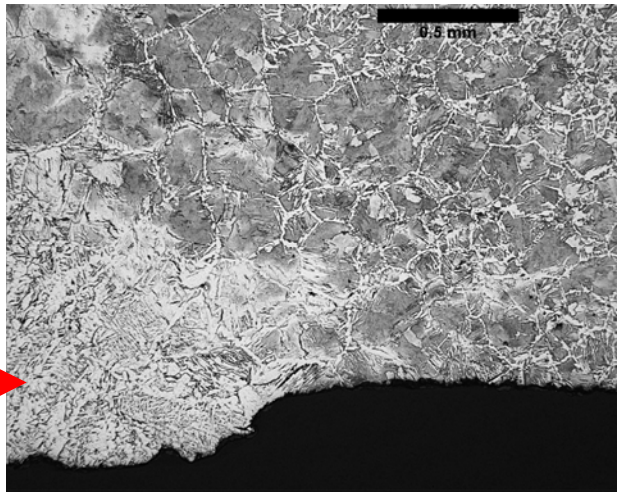
BETA LAB NO.M10329, TESORO EXCHANGER E6600B EXAMINATION DATA	TESORO REFINING AND MARKETING COMPANY ANACORTES REFINERY 10200 W. MARCH POINT ROAD T91WA4428 ANACORTES, WA 98221	CUSTOMER P.O. NO.: 4501667904, CHANGE ORDER #1
PARTS: 6600B HEAT EXCHANGER, PARTS 1B, 2B, AND 3B		DATE: DECEMBER 27, 2010
		PAGE 49 OF 91

LABORATORY REPORT

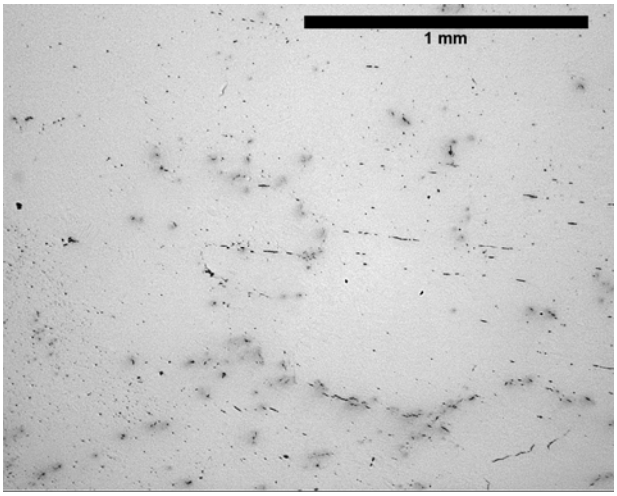
PART 2B, WELD LW3, SAMPLE LH3. METALLOGRAPHY



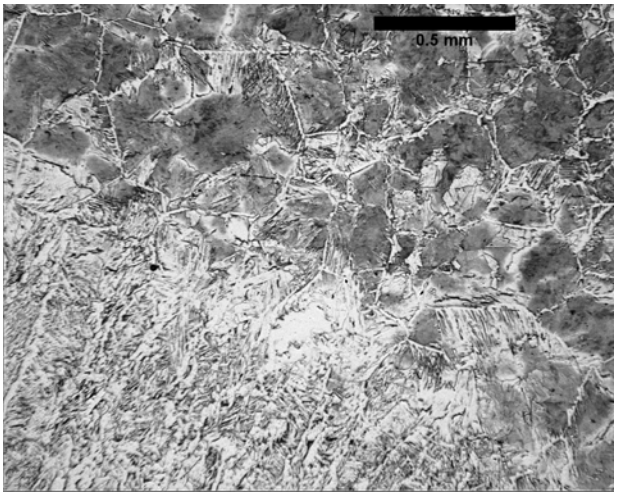
Right side of the weld near the toe at the I.D. Etched



Right side of the weld at the toe. Etched



Right side of the weld near the cusp. Un-etched.

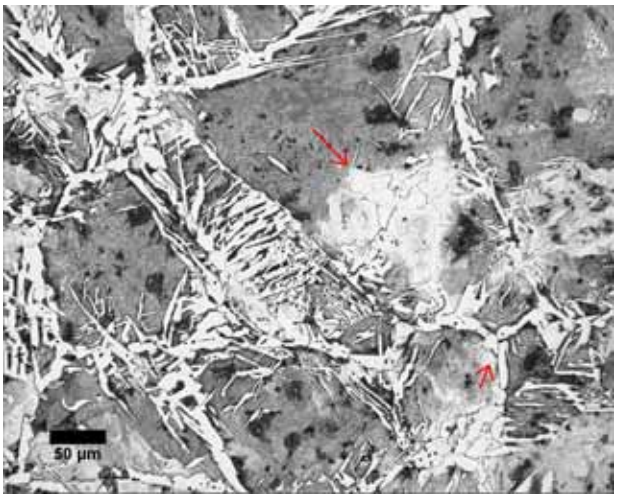


Same as at left. Etched

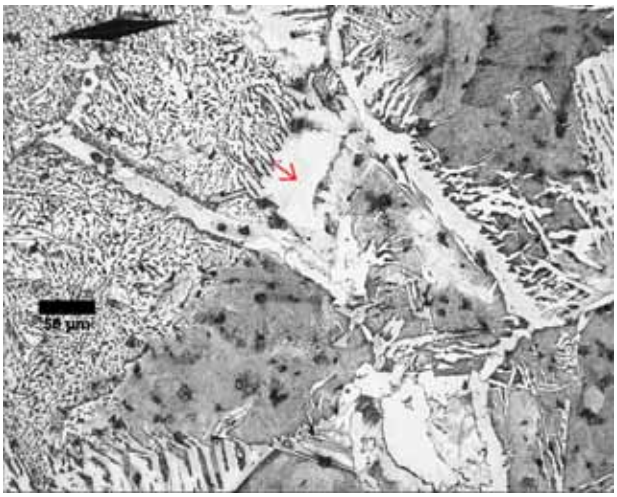
Figure 30

LABORATORY REPORT

PART 2B, WELD LW3, SAMPLE LH3. METALLOGRAPHY



Right side of the weld. Damage of the 21st – 22nd grain in the coarse grain area of the heat affected zone.



The deepest observed damage at the right side of the weld. See Table 12 for measurements.

Figure 31

BETA LAB NO.M10329, TESORO EXCHANGER E6600B EXAMINATION DATA	TESORO REFINING AND MARKETING COMPANY ANACORTES REFINERY 10200 W. MARCH POINT ROAD T91WA4428 ANACORTES, WA 98221	CUSTOMER P.O. NO.: 4501667904, CHANGE ORDER #1
PARTS: 6600B HEAT EXCHANGER, PARTS 1B, 2B, AND 3B		DATE: DECEMBER 27, 2010
		PAGE 51 OF 91

LABORATORY REPORT

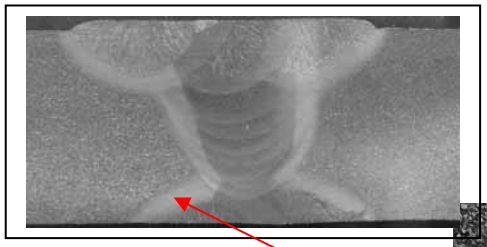
METALLOGRAPHY

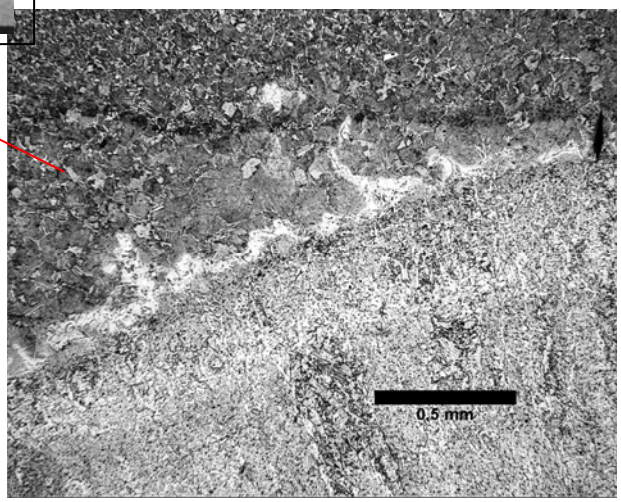
PART 3B
WELD CW3
SAMPLE CH3

ON ALL PHOTOGRAPHS I.D. IS ON THE BOTTOM.

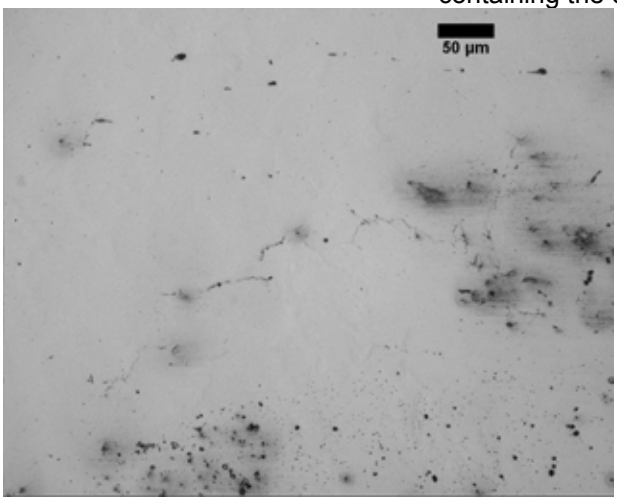
LABORATORY REPORT

PART 3B, WELD CW3, SAMPLE CH3. METALLOGRAPHY

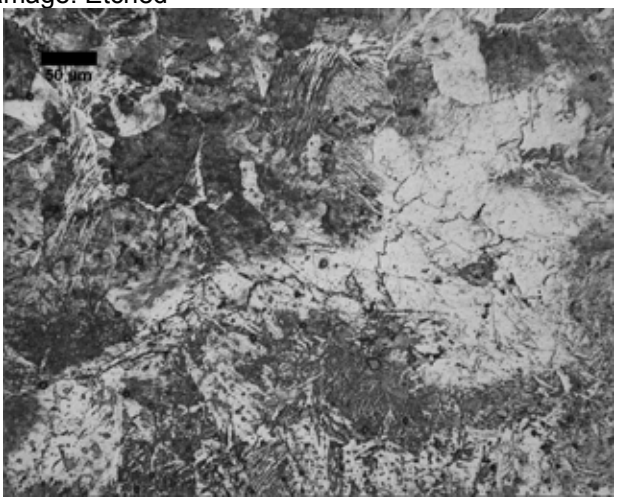




Left side of the weld at I.D. Decarburized area containing the damage. Etched



Left of the weld. Area at the toe at I.D. Un-etched



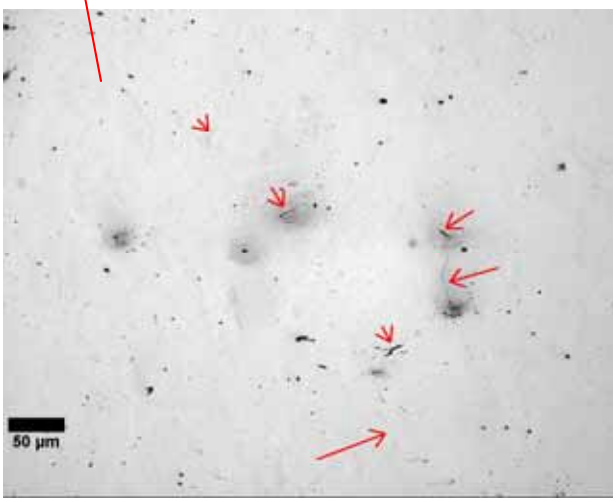
Same as at left. Etched

Figure 32

BETA LAB NO.M10329, TESORO EXCHANGER E6600B EXAMINATION DATA	TESORO REFINING AND MARKETING COMPANY ANACORTES REFINERY 10200 W. MARCH POINT ROAD T91WA4428 ANACORTES, WA 98221	CUSTOMER P.O. NO.: 4501667904, CHANGE ORDER #1
PARTS: 6600B HEAT EXCHANGER, PARTS 1B, 2B, AND 3B		DATE: DECEMBER 27, 2010
		PAGE 53 OF 91

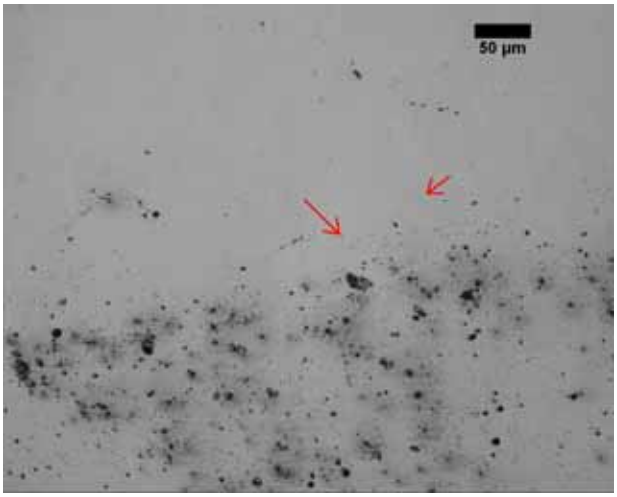
LABORATORY REPORT

PART 3B, WELD CW3, SAMPLE CH3. METALLOGRAPHY

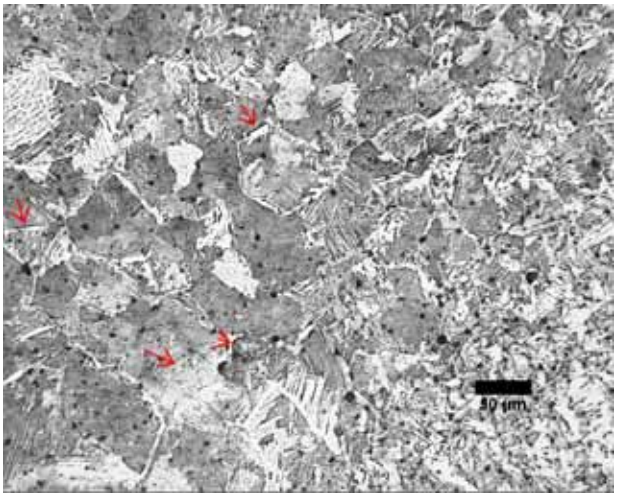


Left side of the weld. Damage in the CG HAZ. Un-etched

Same area as at left. Etched



Left of the weld. Area close to the end of the damaged HAZ. Un-etched

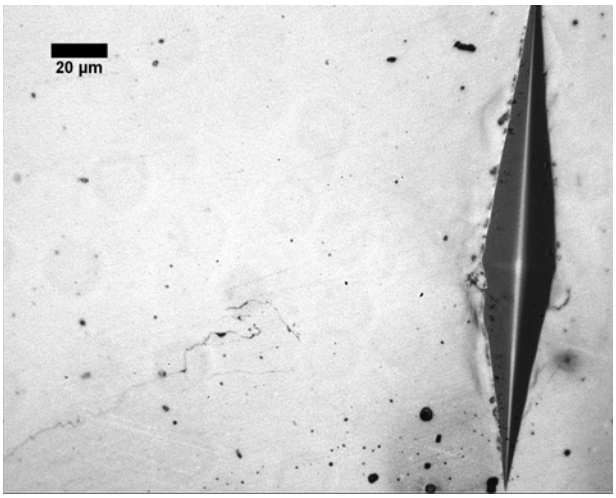


Same as at left. Etched

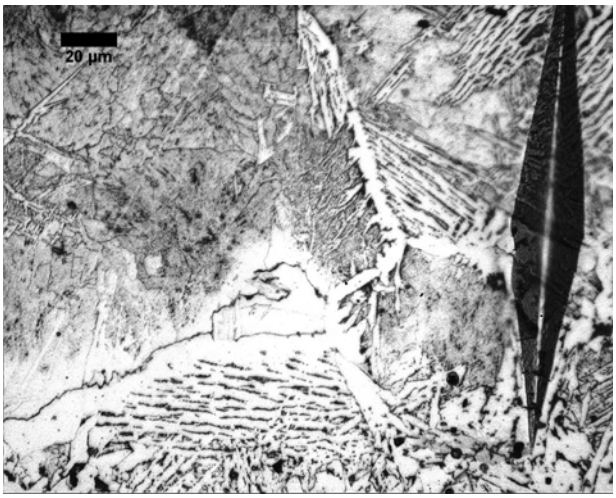
Figure 33.

LABORATORY REPORT

PART 3B, WELD CW3, SAMPLE CH3.
METALLOGRAPHY



Left side of the weld. The deepest damage observed marked by a diamond indentation. Un-etched.

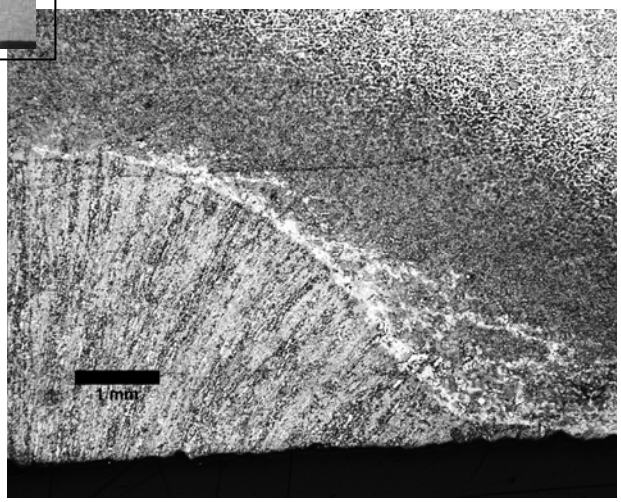


Same as at left. Etched.
The measurements are in the Table 12.

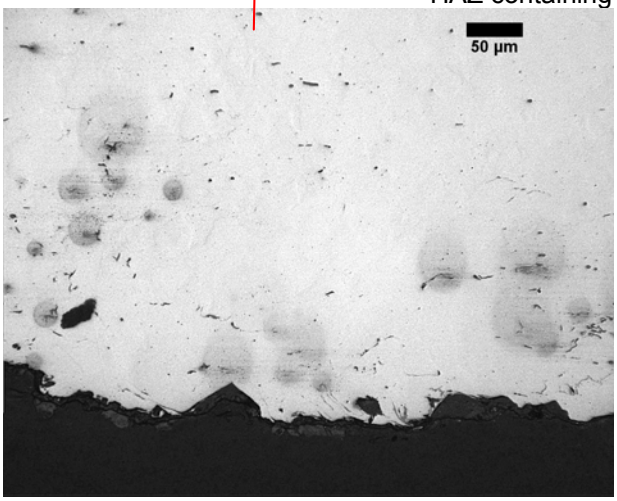
Figure 34

LABORATORY REPORT

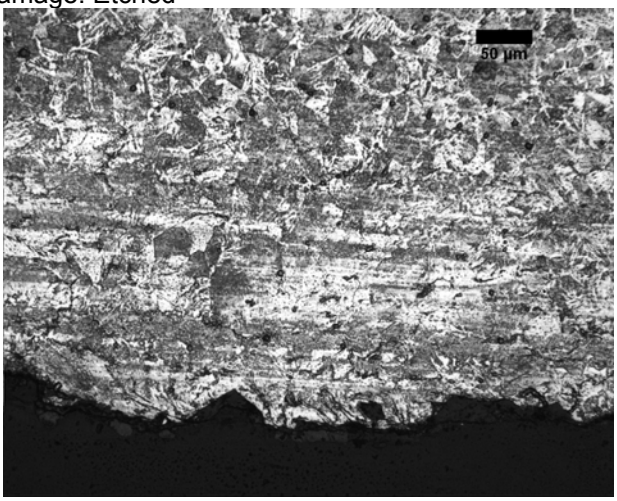
PART 3B, WELD CW3, SAMPLE CH3. METALLOGRAPHY



Right side of the weld. Decarburized layer in CG HAZ containing damage. Etched



Right side of the weld. Area near the toe of the weld. Un-etched

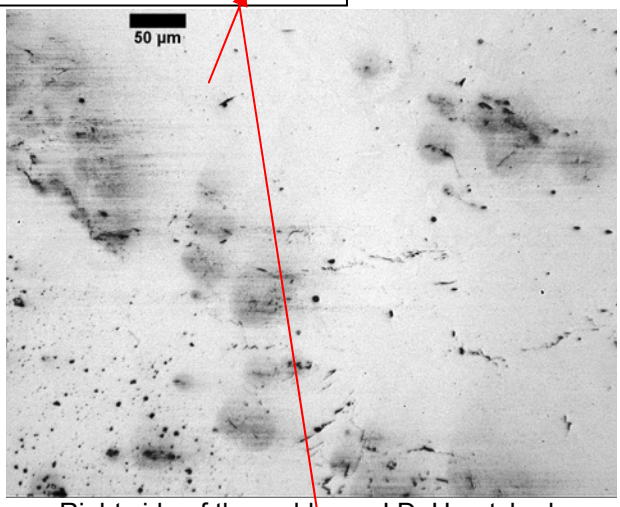


Same as at left. Etched.

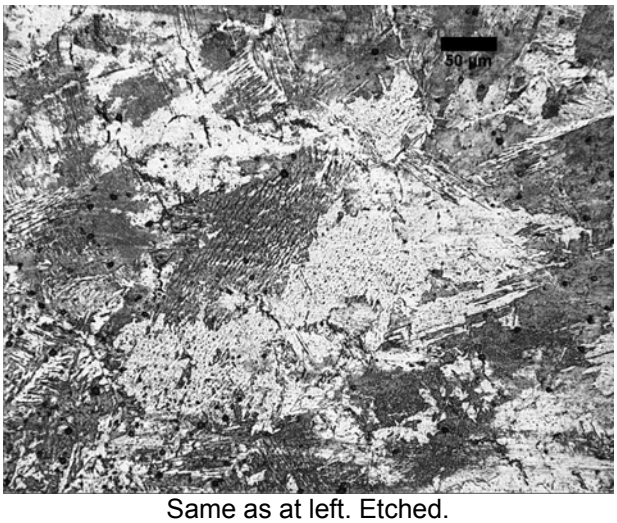
Figure 35

LABORATORY REPORT

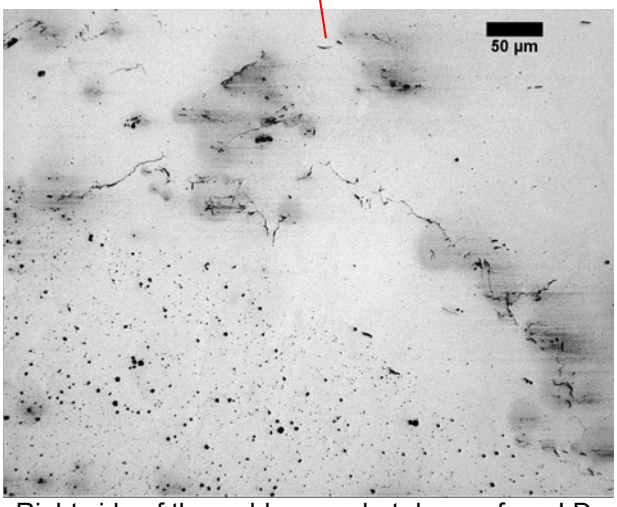
PART 3B, WELD CW3, SAMPLE CH3. METALLOGRAPHY



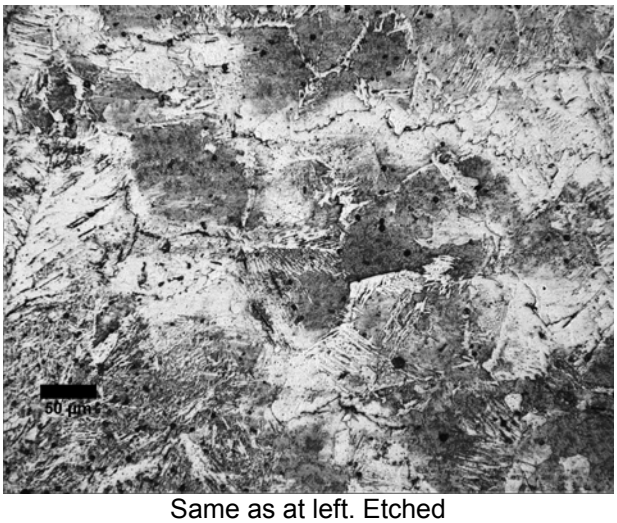
Right side of the weld near I.D. Un-etched.



Same as at left. Etched.



Right side of the weld somewhat deeper from I.D. than the area above. Un-etched.

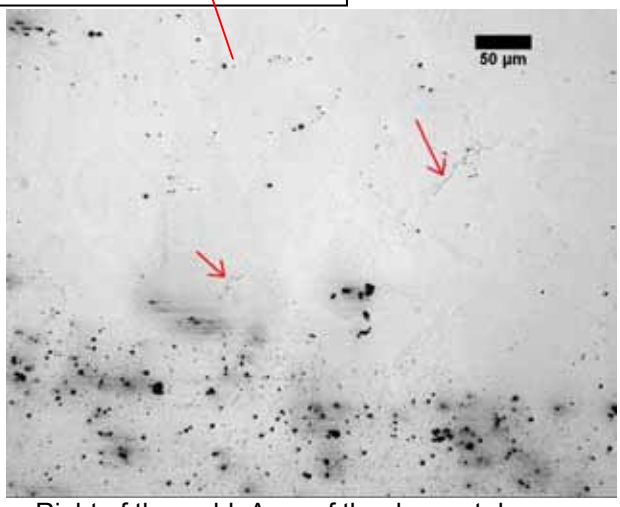


Same as at left. Etched

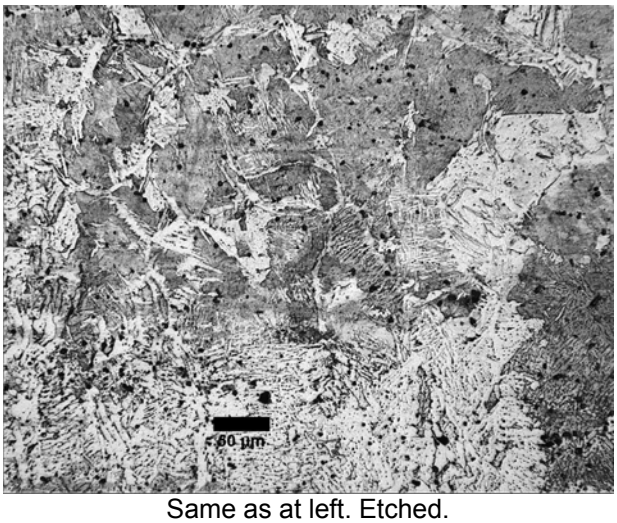
Figure 36

LABORATORY REPORT

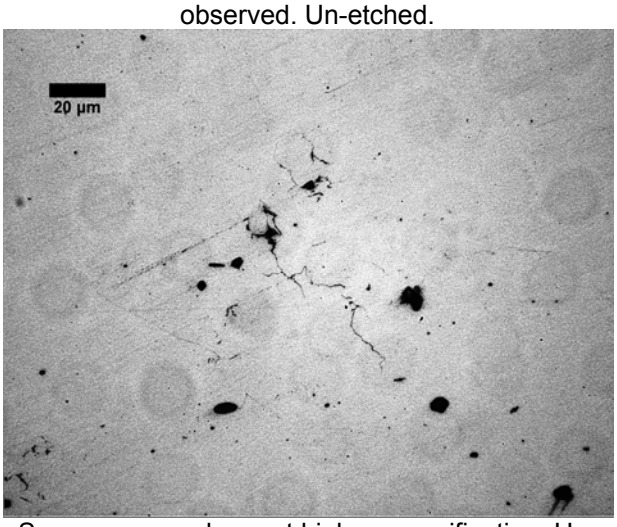
PART 3B, WELD CW3, SAMPLE CH3. METALLOGRAPHY



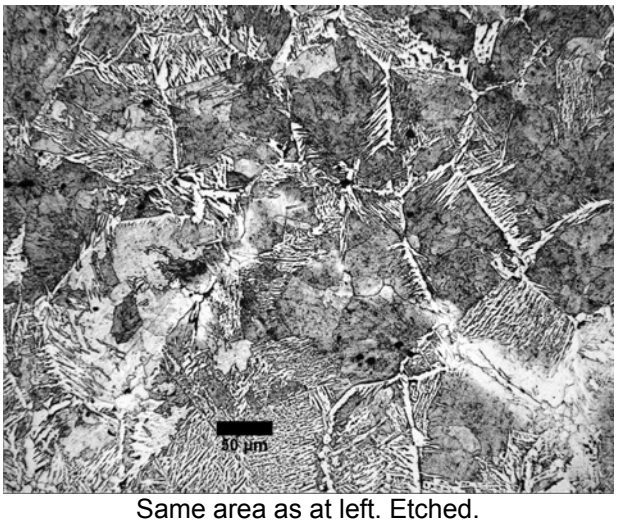
Right of the weld. Area of the deepest damage observed. Un-etched.



Same as at left. Etched.



Same area as above at higher magnification. Un-etched.



Same area as at left. Etched.

Figure 37

LABORATORY REPORT

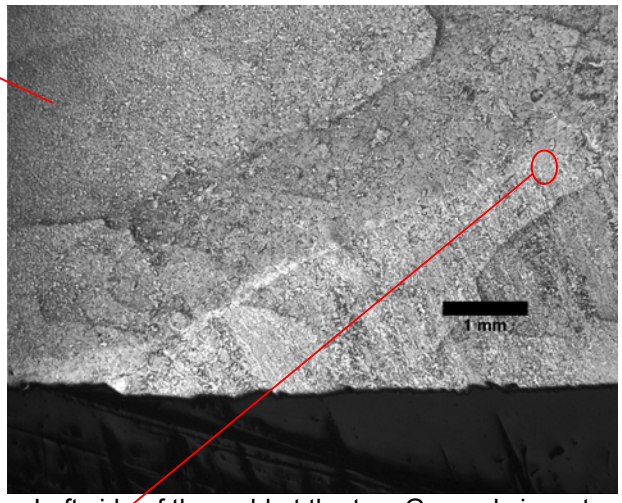
METALLOGRAPHY

PART 3B
WELD LW3
SAMPLE LM3

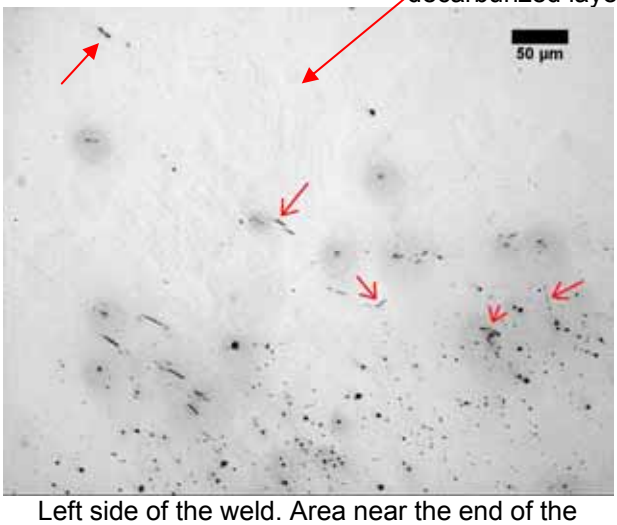
ON ALL PHOTOGRAPHS I.D. IS ON THE BOTTOM.

LABORATORY REPORT

PART 3B, WELD LW3, SAMPLE LM3. METALLOGRAPHY



Left side of the weld at the toe. General view at decarburized layer in CG HAZ. Etched



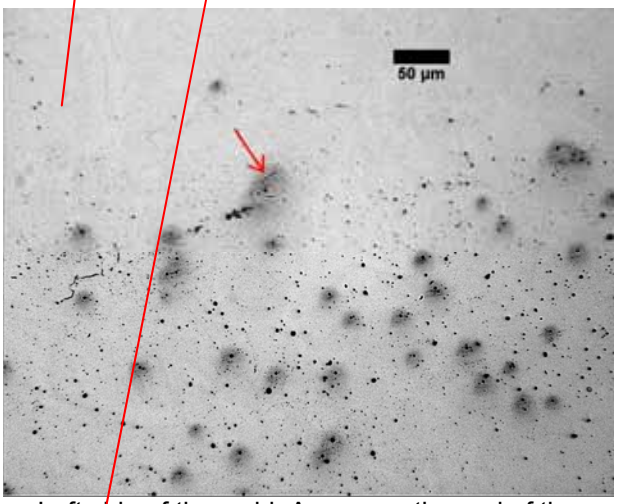
Left side of the weld. Area near the end of the damaged zone. Un-etched

Same as at left. Etched

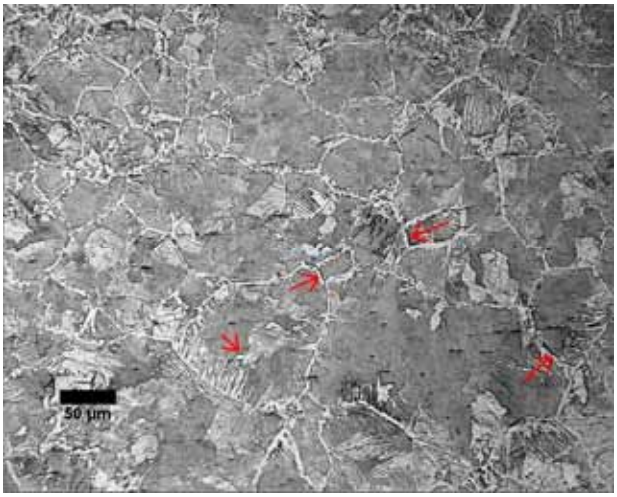
Figure 38

LABORATORY REPORT

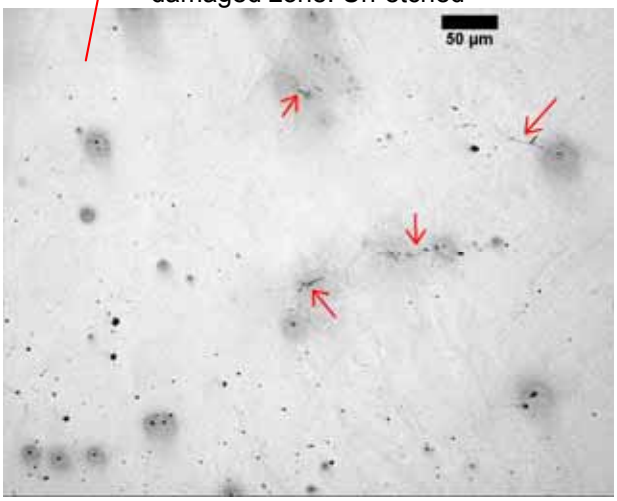
PART 3B, WELD LW3, SAMPLE LM3. METALLOGRAPHY



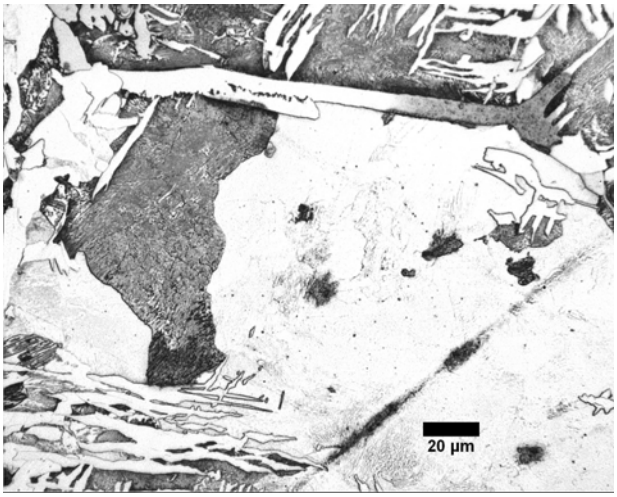
Left side of the weld. Area near the end of the damaged zone. Un-etched



Same area as at left. Etched

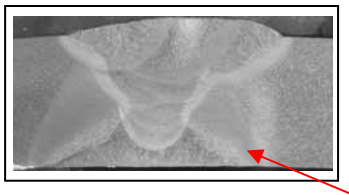


Right side of the weld. Area near the end of the damaged zone. Un-etched



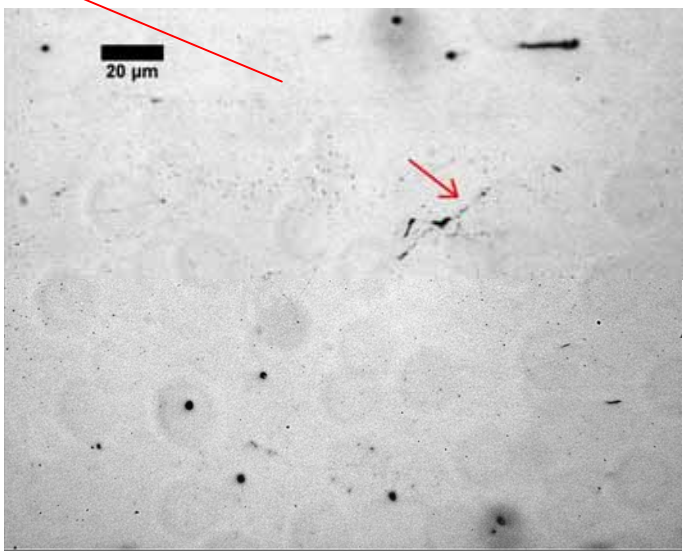
Same area as at left. Etched

Figure 39

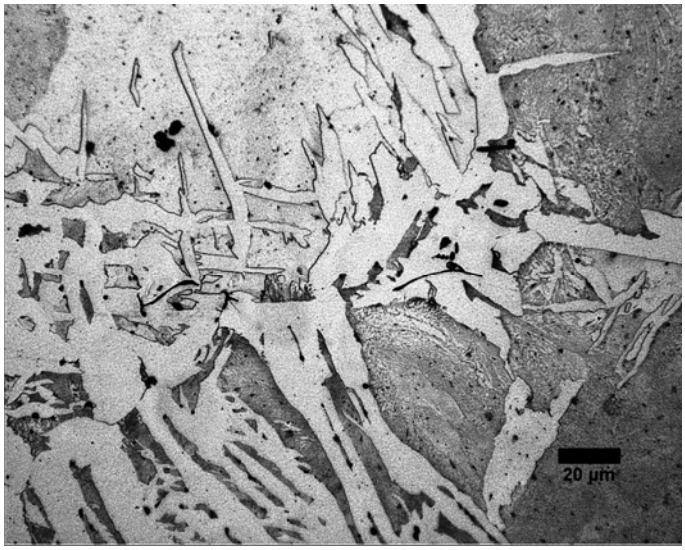


LABORATORY REPORT

PART 3B, WELD LW3, SAMPLE LM3. METALLOGRAPHY



Right side of the weld. Area near the deepest damage. Un-etched



Same area as above. Etched

Figure 40

LABORATORY REPORT

SEM FRACTOGRAPHY OF LABORATORY FAILED SPECIMENS

LABORATORY REPORT

PART 1B, WELD CW4, SAMPLE CS4
AND
PART 2B, WELD LW3, SAMPLE LS3

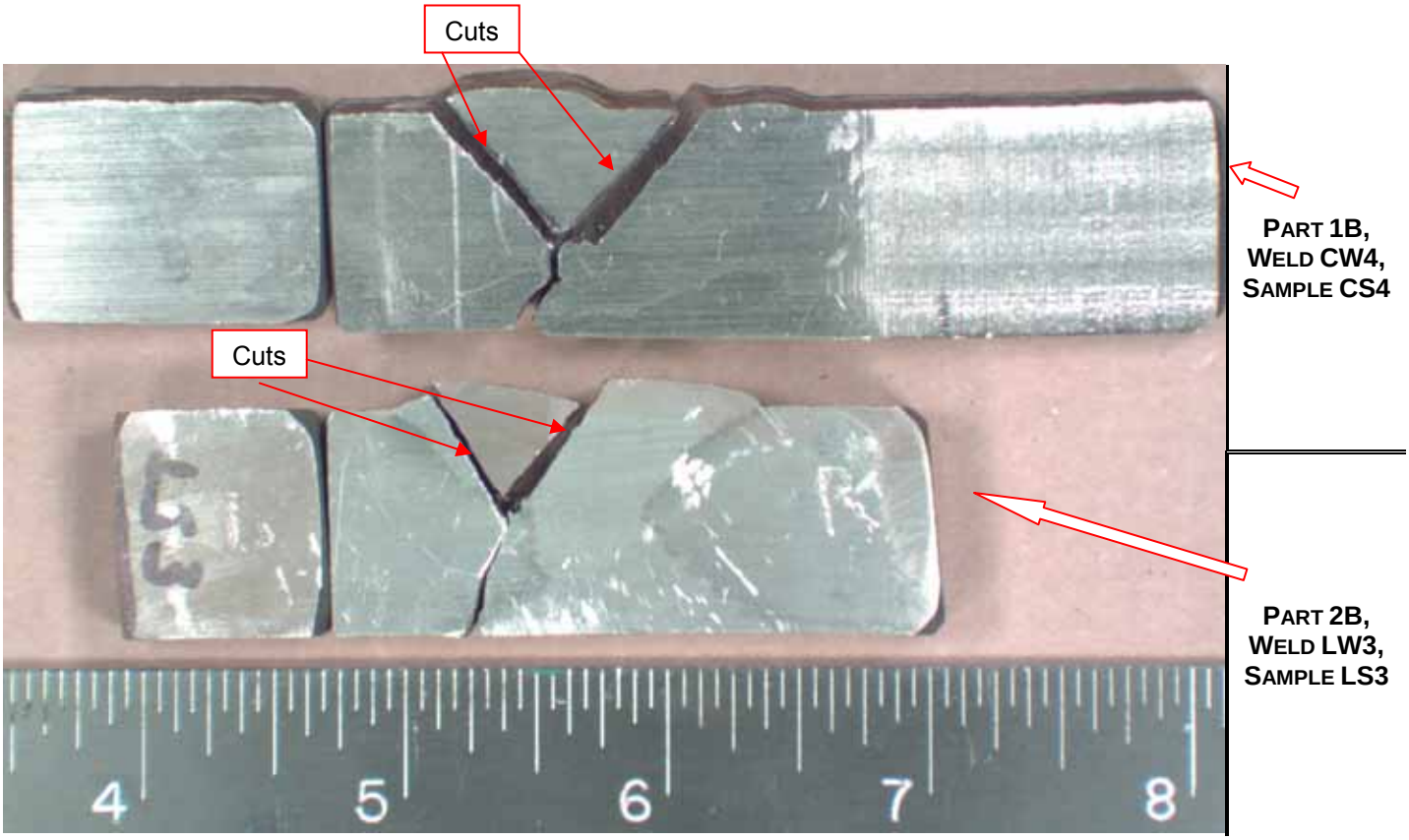


Figure 41. Two samples failed in the Lab for Fractography in Scanning Electron Microscope (SEM)

I.D. is on the bottom

LABORATORY REPORT

PART 1B, WELD CW4, SAMPLE CS4.
SEM FRACTOGRAPHY

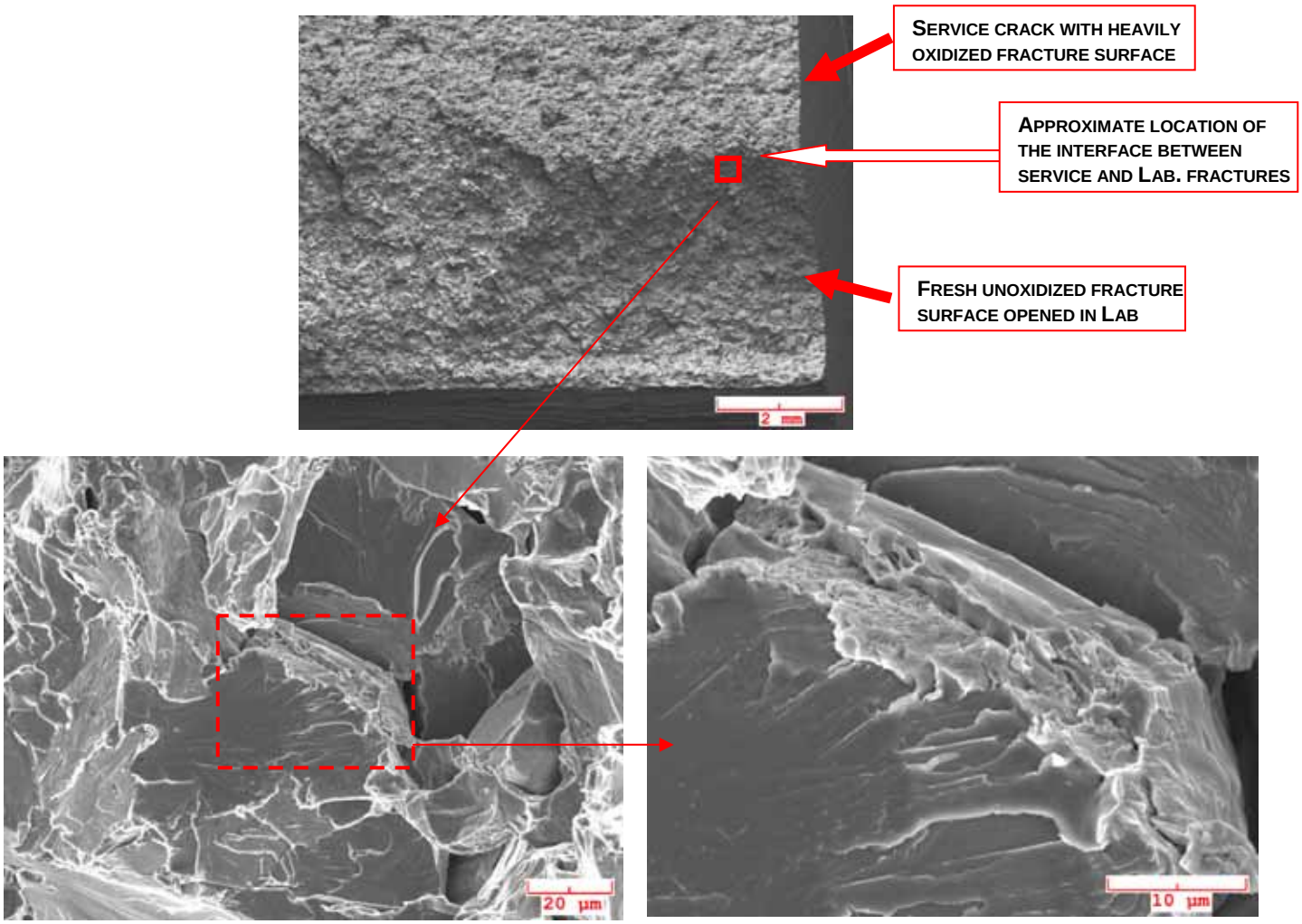


Figure 42. Fracture features of an area in the fresh fracture but near the tip of the service crack. The I.D. is at the top of the pictures.

LABORATORY REPORT

PART 1B, WELD CW4, SAMPLE CS4
SEM FRACTOGRAPHY

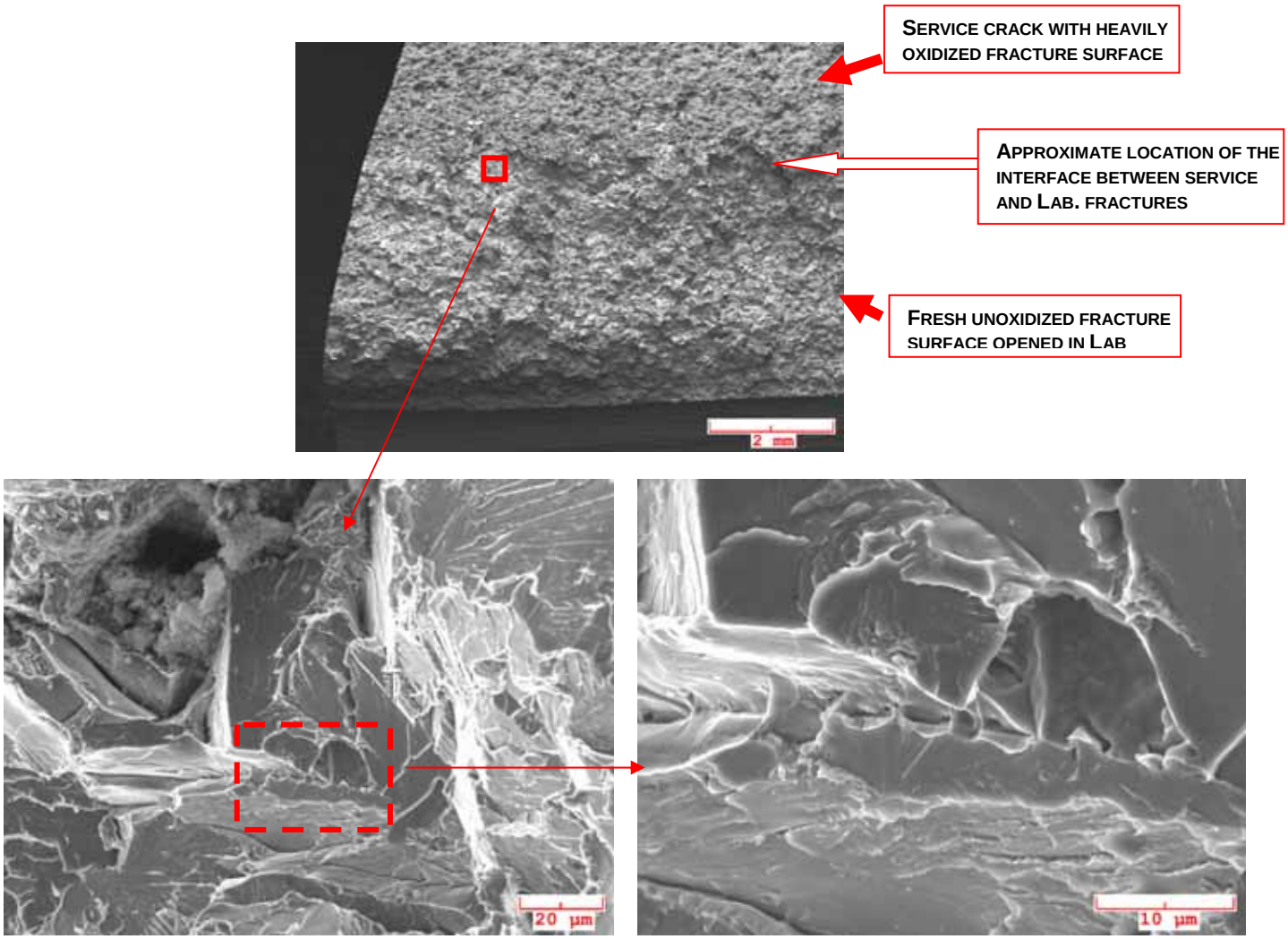


Figure 43. Fracture features of an area in the fresh fracture but near the tip of the service crack. The I.D. is at the top of the pictures.

LABORATORY REPORT

PART 2B, WELD LW3, SAMPLE LS3
SEM FRACTOGRAPHY

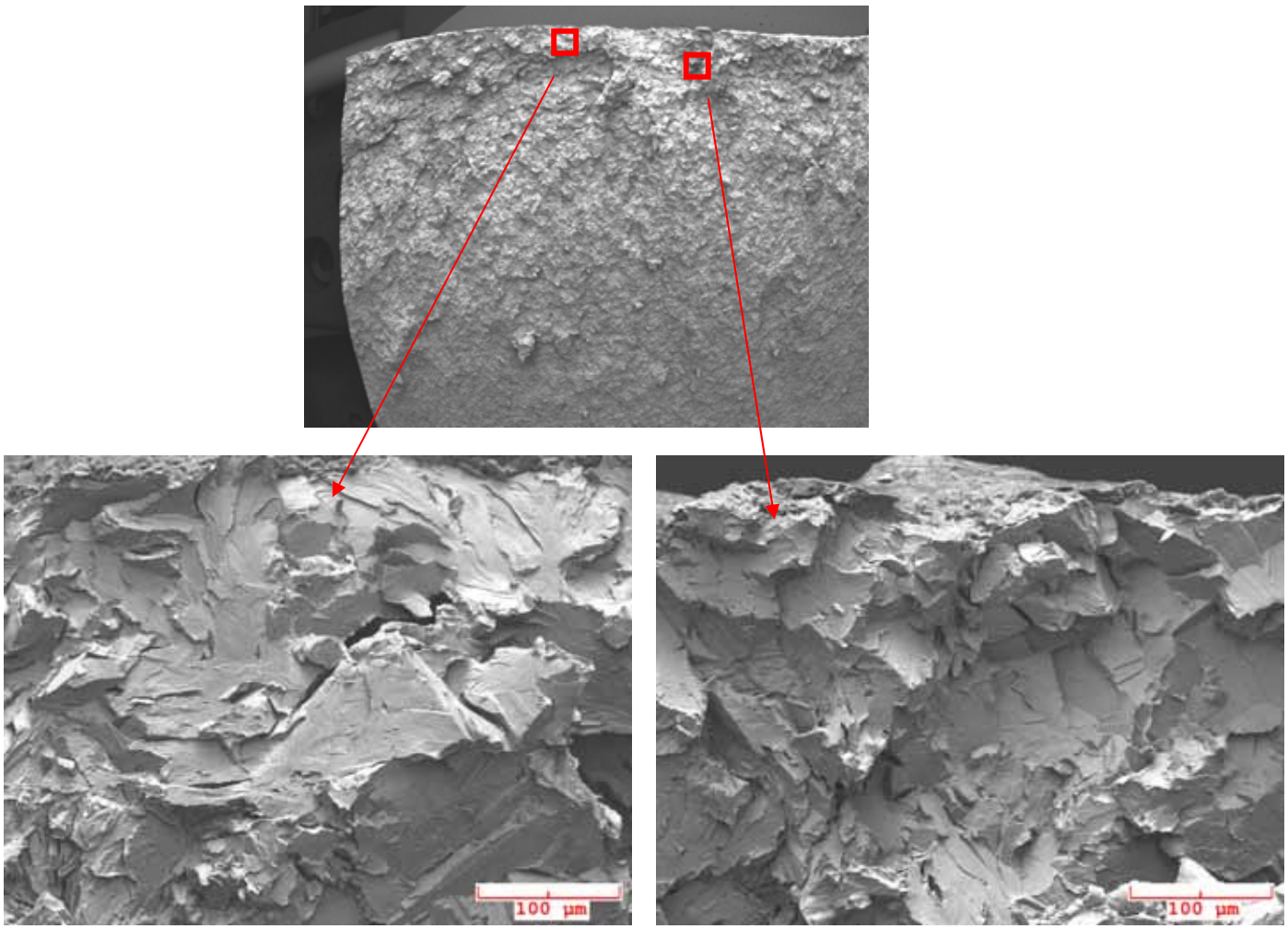
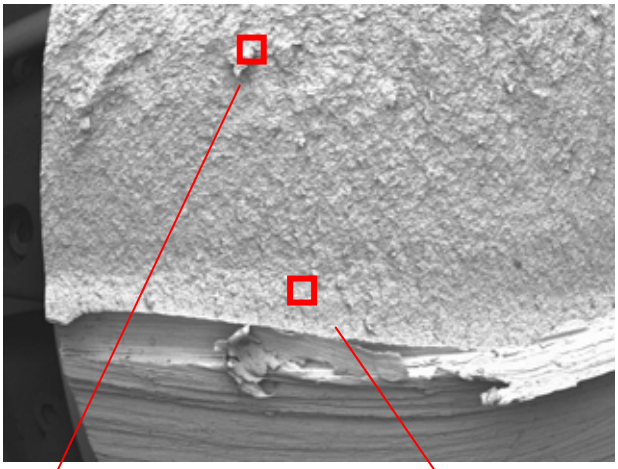
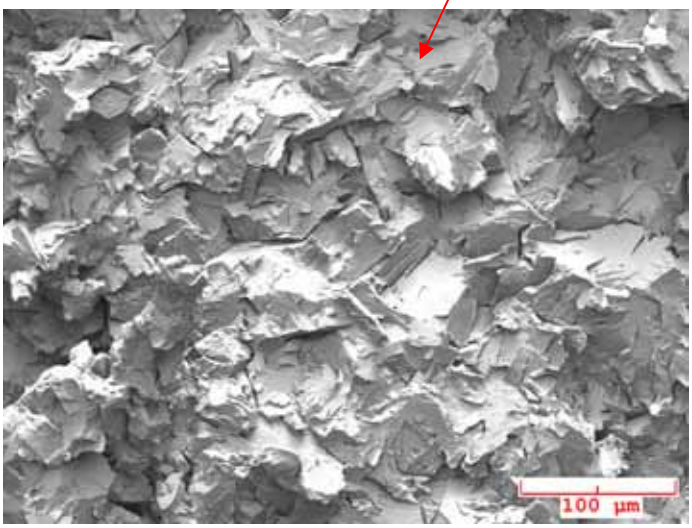


Figure 44. Fracture surface features at the I.D. The squares indicate the approximate location of the fractures shown. I.D. is at the top of the pictures.

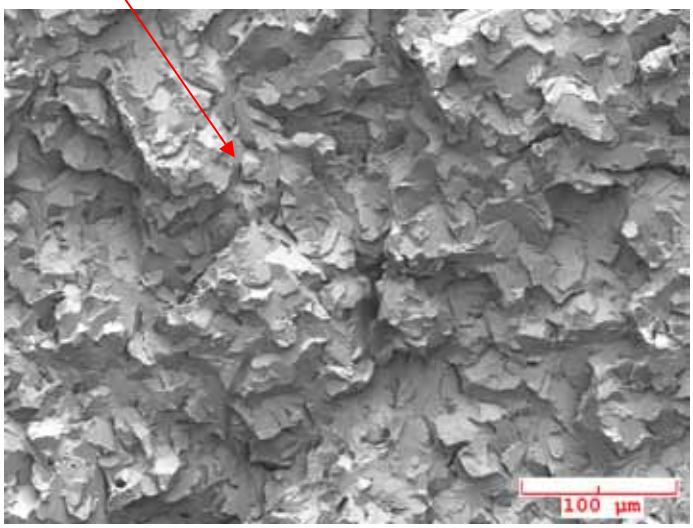
LABORATORY REPORT

PART 2B, WELD LW3, SAMPLE LS3
SEM FRACTOGRAPHY





Fracture features near the middle of the fracture surface



Fracture features near the bottom of the V-cut

Figure 45. The squares indicate the approximate location of the fractures shown.
The I.D. is at the top of the photographs.

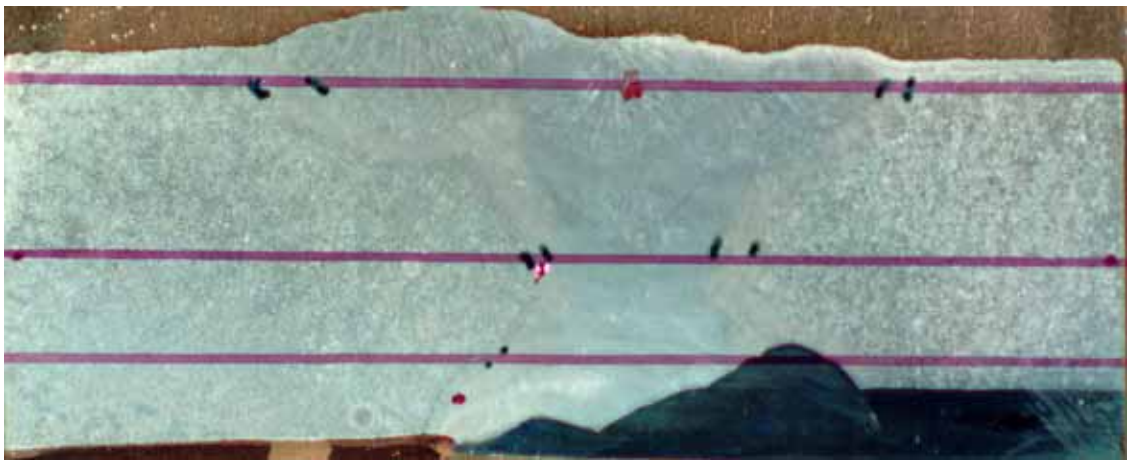
LABORATORY REPORT

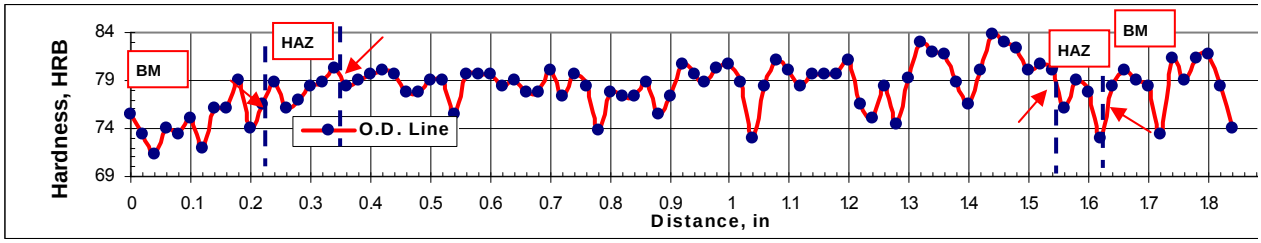
MECHANICAL PROPERTIES OF WELDED JOINTS

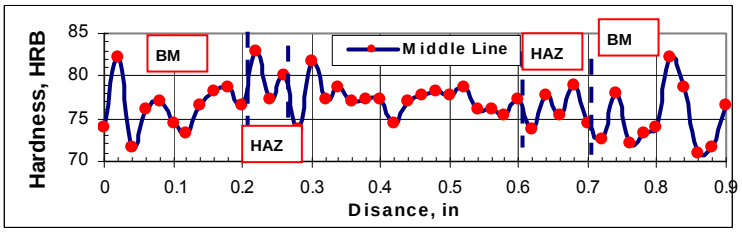
(FOR HARDNESS NUMBERS SEE TABLES 5 THROUGH 9, FOR TENSILE DATA SEE TABLE 10)

LABORATORY REPORT

PART 1B, WELD CW4, SAMPLE CH4.
HARDNESS TRAVERCES







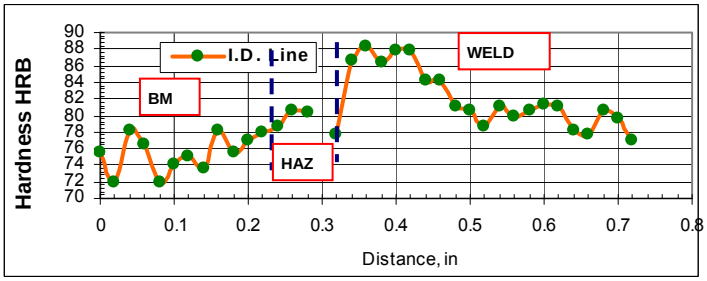
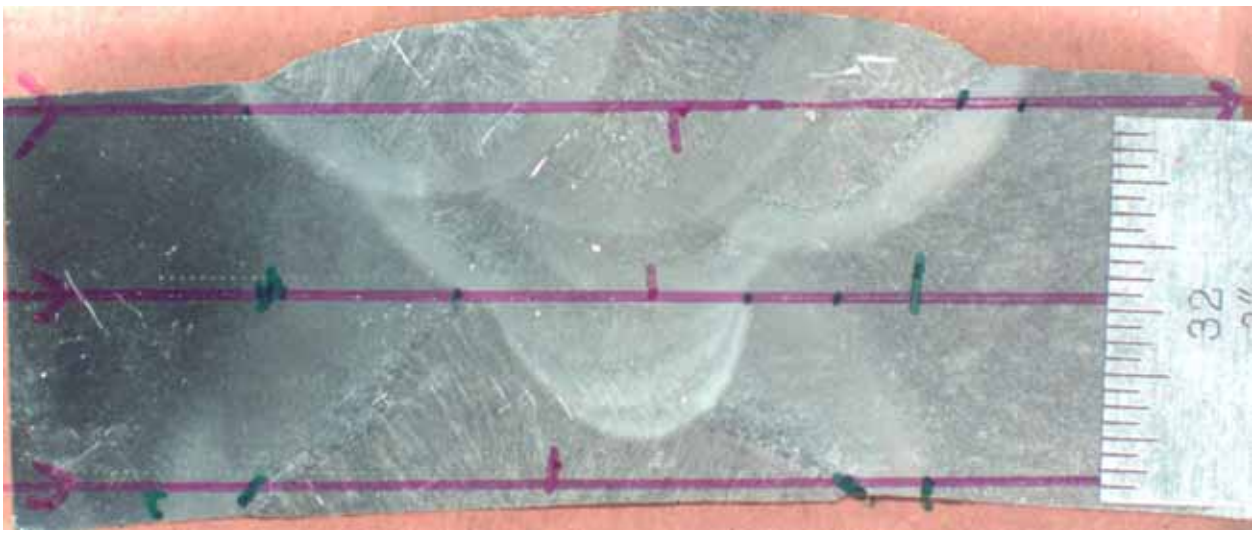
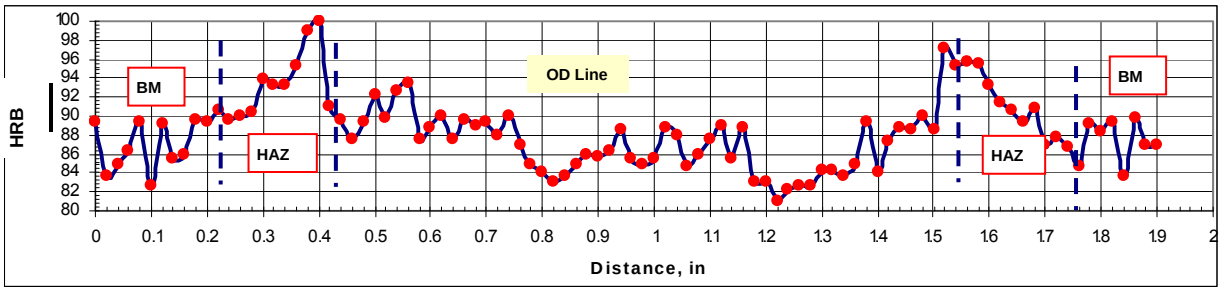


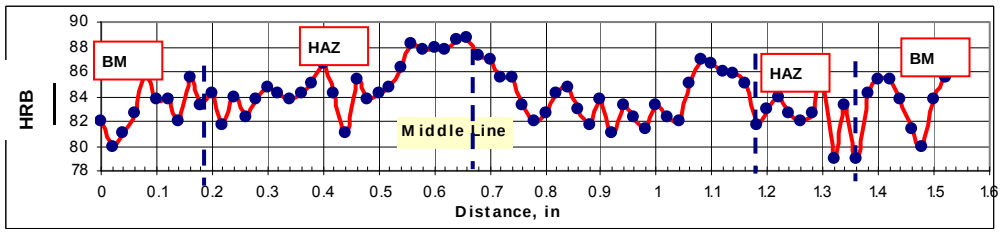
Figure 46

LABORATORY REPORT

PART 2B, WELD LW3, SAMPLE LH3.
HARDNESS TRAVERCES







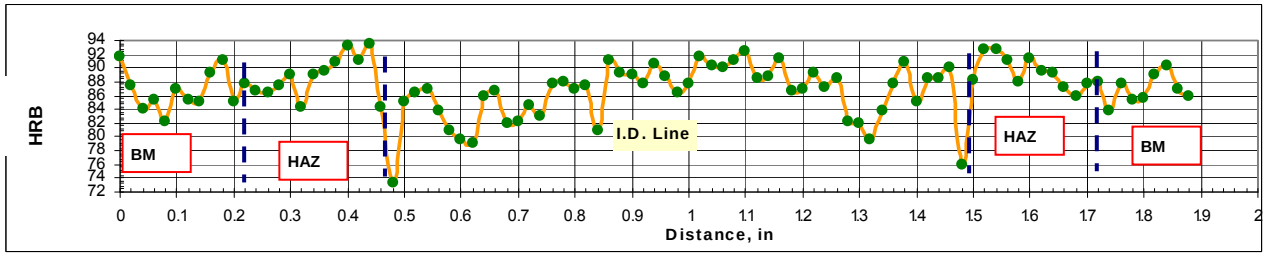
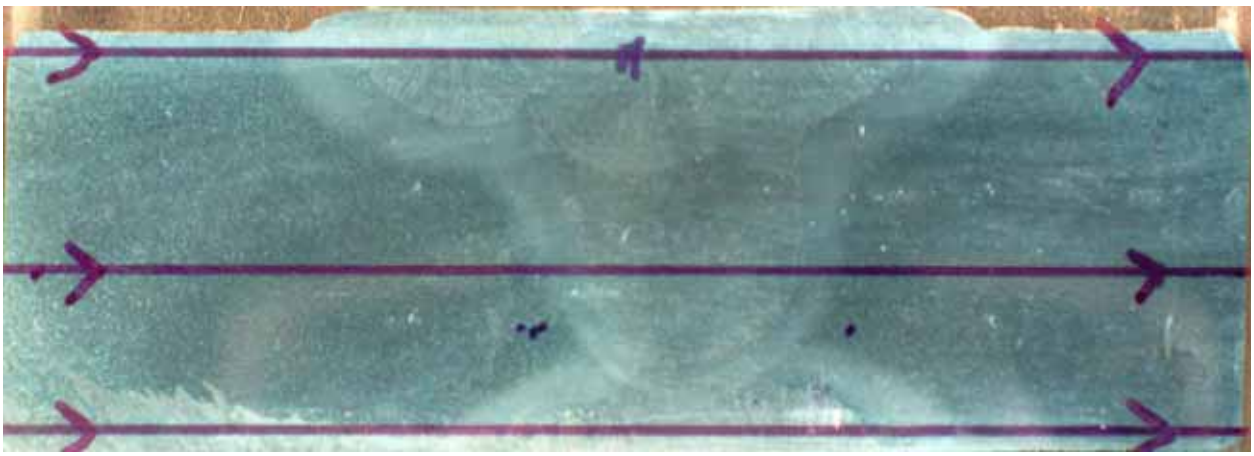
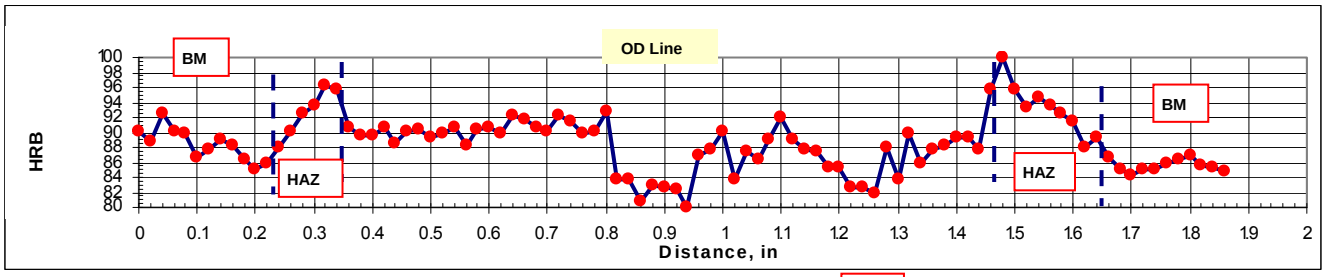


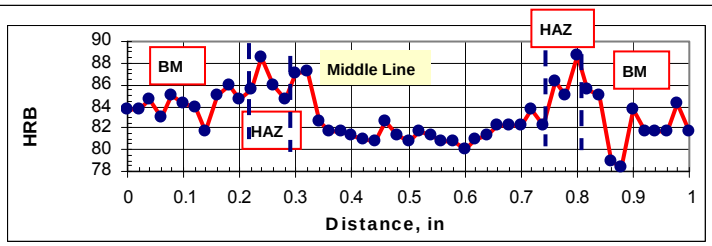
Figure 47

LABORATORY REPORT

PART 3B, WELD CW3, SAMPLE CH3.
HARDNESS TRAVERCES







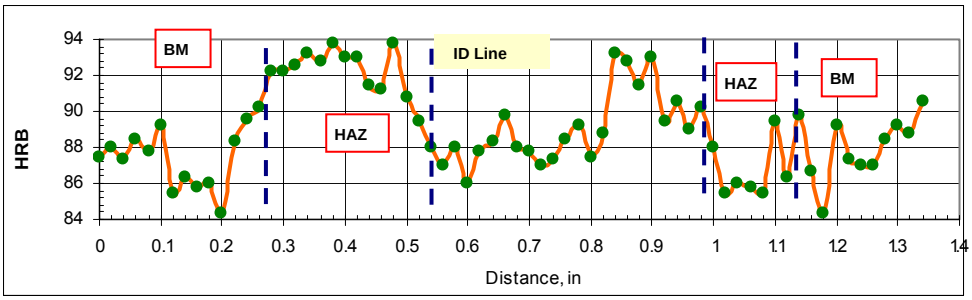
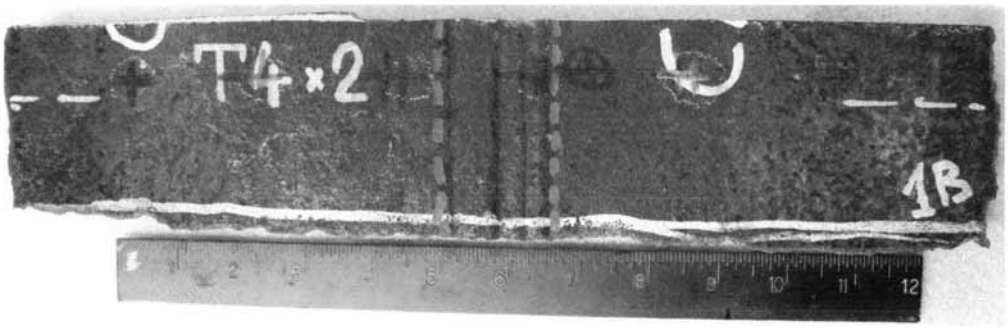


Figure 48

LABORATORY REPORT

PART 1B, WELD CW4, SAMPLE T4.
TENSILE TEST COUPON

BETA M10329 Coupon for two tensile test specimens marked T4



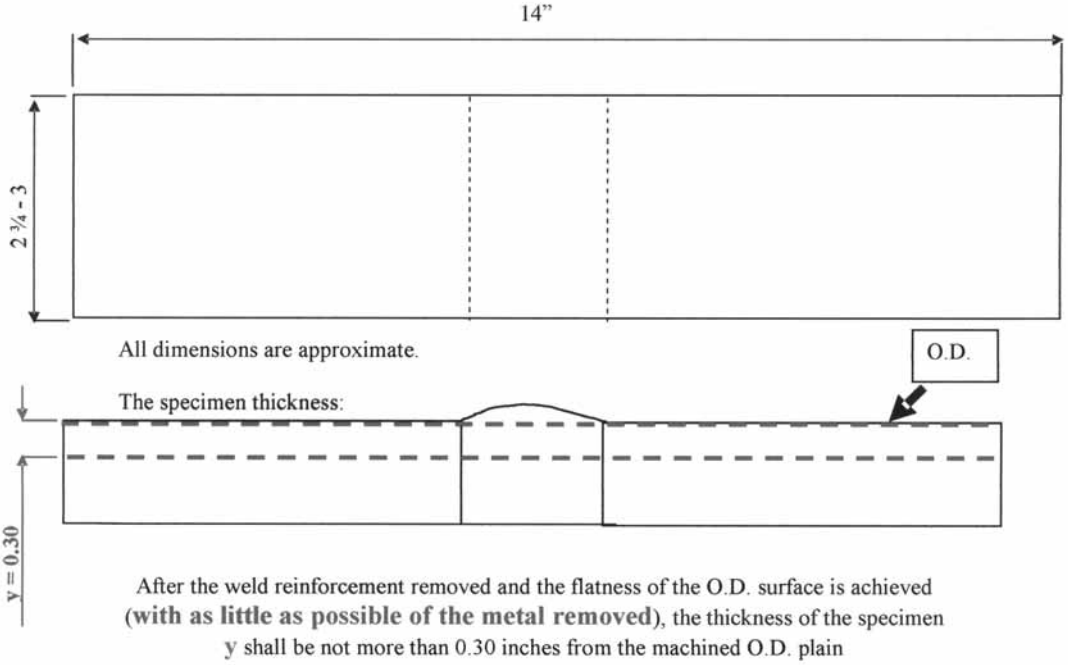
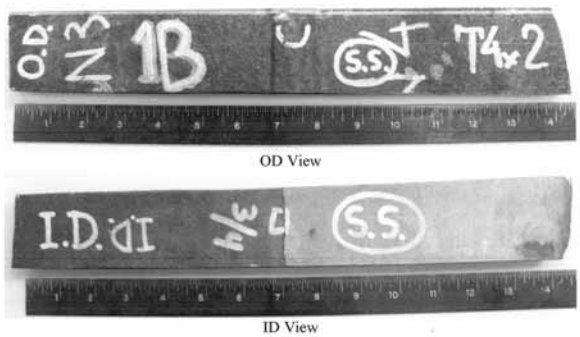


Figure 49. The document explaining how to prepare the samples and how to test. The requirements were not executed and the specimens were tested at full thickness. Test results are in Table 10 and Appendix 4.

LABORATORY REPORT

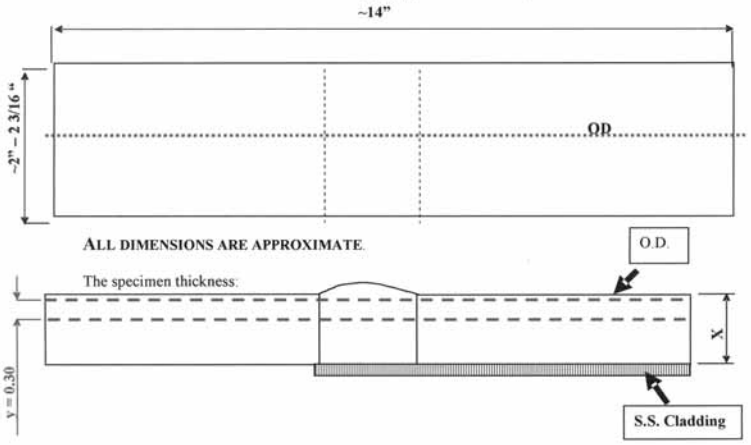
PART 1B, WELD CW4, SAMPLE T4. TENSILE TEST COUPON

BETA M10329 Coupon for two tensile test specimens marked T4



OD View

ID View



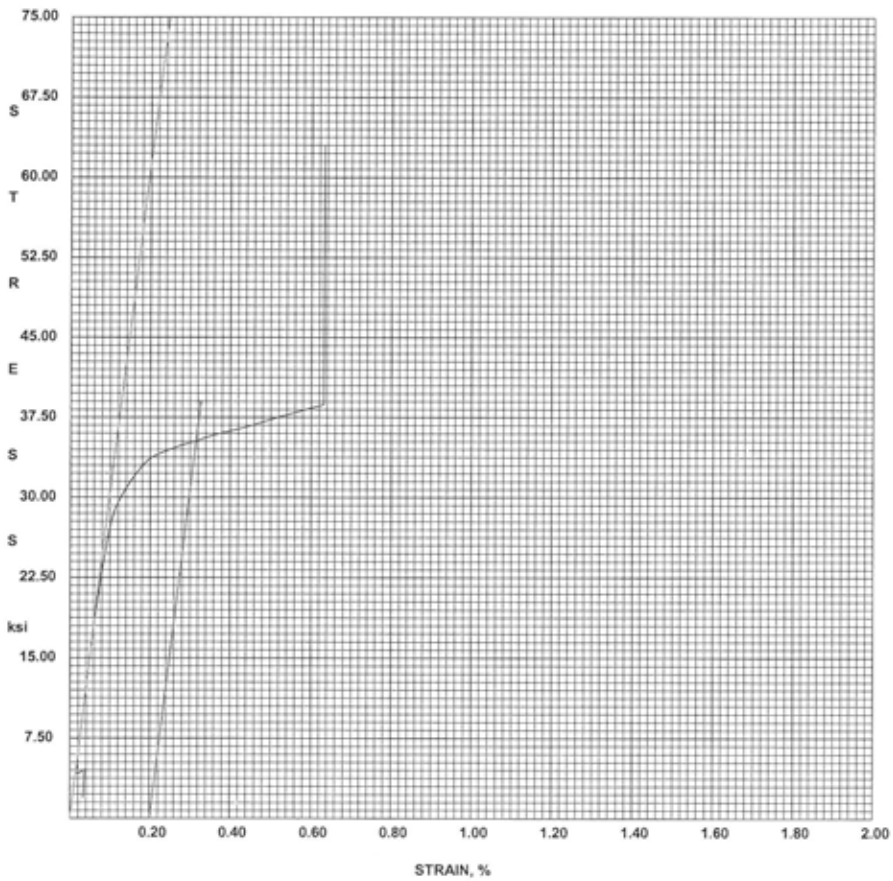
SEQUENCE OF THE SAMPLES MACHINING

1. FROM TH OD OF THE COUPON: REMOVE THE WELD REINFORCEMENT AND ACHIEVE THE FLATNESS REMOVING AS LITTLE OF THE MATERIAL AS POSSIBLE.
2. FLIP THE COUPON PLACING IT ON THE MACHINED OD SURFACE AND MACHINE OFF THE BODY OF THE COUPON LEAVING THE SAMPLE THICKNESS EQUAL 0.30 IN.
3. SPLIT THE MACHINED COUPON IN TWO EQUAL SAMPLES ACROSS THE WELD
4. MACHINE THE TEST SAMPLES IN ACCORDANCE WITH ASME SECTION IX, QW 151.1 AND QW 462.1(a).
5. THE DATA SHALL INCLUDE THE TENSILE STRENGTH, YELD, AND ELONGATION. TENSILE CURVES SHALL BE SUPPLIED WITH THE TEST RESULTS AS WELL.

Figure 50. The document with the expended requirements for the second coupon tensile test. Test results are in Table 10 and Appendix 4.

LABORATORY REPORT

PART 1B, WELD CW4, SAMPLE T4-1, 2ND TEST.



Tensile Testing
4520 Willow Pkwy
Cleveland OH 44125
216.641.3290

Preliminary Results

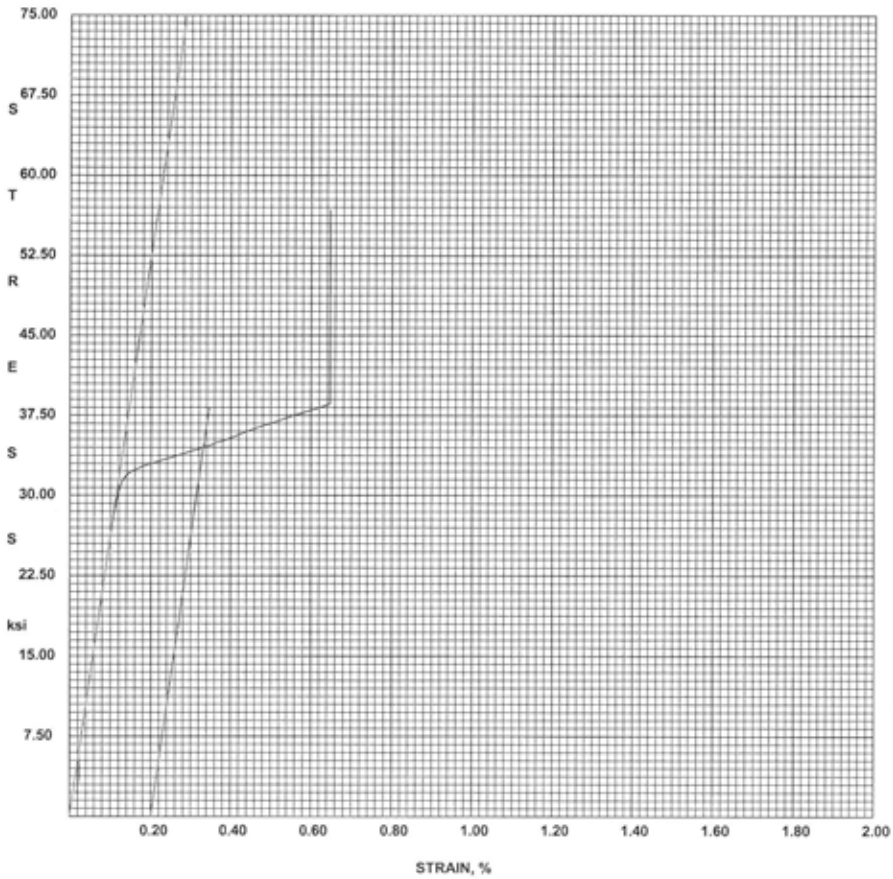
Customer	FIRST ENERGY
Contact	
PO	55102614
Order Ref	NA
Order Ref	M10329 T4
TTML Job#	JB0294-007
Test Date	11/10/2010
Operator	42
Test Setting	290M-TeFl-Weld TYE
Instrumentation	TO213762-4%-2.0"
Item Reference:	M10329 RP
..:	T4
..:	
Sample:	1
Width, in:	0.746
Thickness, in:	0.288
Ult Load, lbf:	13510
Tensile, psi:	63000
OS @ .2, psi:	35300
Elong, %:	11
Failure Type:	Brittle
Failure Location:	Base

Nov 29, 2010 11:00:01 AM
SN: 224307-R2 V7.02.10

Figure 51.

LABORATORY REPORT

PART 1B, WELD CW4, SAMPLE T4-2, 2ND TEST



Tensile Testing
4520 Willow Pkwy
Cleveland OH 44125
216.641.3290

Preliminary Results

Customer	FIRST ENERGY
Contact	
PO	55102614
Order Ref	NA
Order Ref	M10329 T4
TTML Job#	JB0294-007
Test Date	11/10/2010
Operator	42
Test Setting	290M-TeFl-Weld TYE
Instrumentation	TO213762-4%-2.0"
Item Reference:	M10329 RP
,,:	T4
..:	
Sample:	2
Width, in:	0.738
Thickness, in:	0.286
Ult Load, lbf:	11980
Tensile, psi:	56500
OS @ .2, psi:	34500
Elong, %:	9.5
Failure Type:	Ductile
Failure Location:	Base

Nov 29, 2010 11:00:08 AM
SN: 224307-R2 V7.02.10

Figure 52

BETA LAB NO.M10329, TESORO EXCHANGER E6600B EXAMINATION DATA	TESORO REFINING AND MARKETING COMPANY ANACORTES REFINERY 10200 W. MARCH POINT ROAD T91WA4428 ANACORTES, WA 98221	CUSTOMER P.O. NO.: 4501667904, CHANGE ORDER #1
PARTS: 6600B HEAT EXCHANGER, PARTS 1B, 2B, AND 3B		DATE: DECEMBER 27, 2010
		PAGE 76 OF 91

LABORATORY REPORT

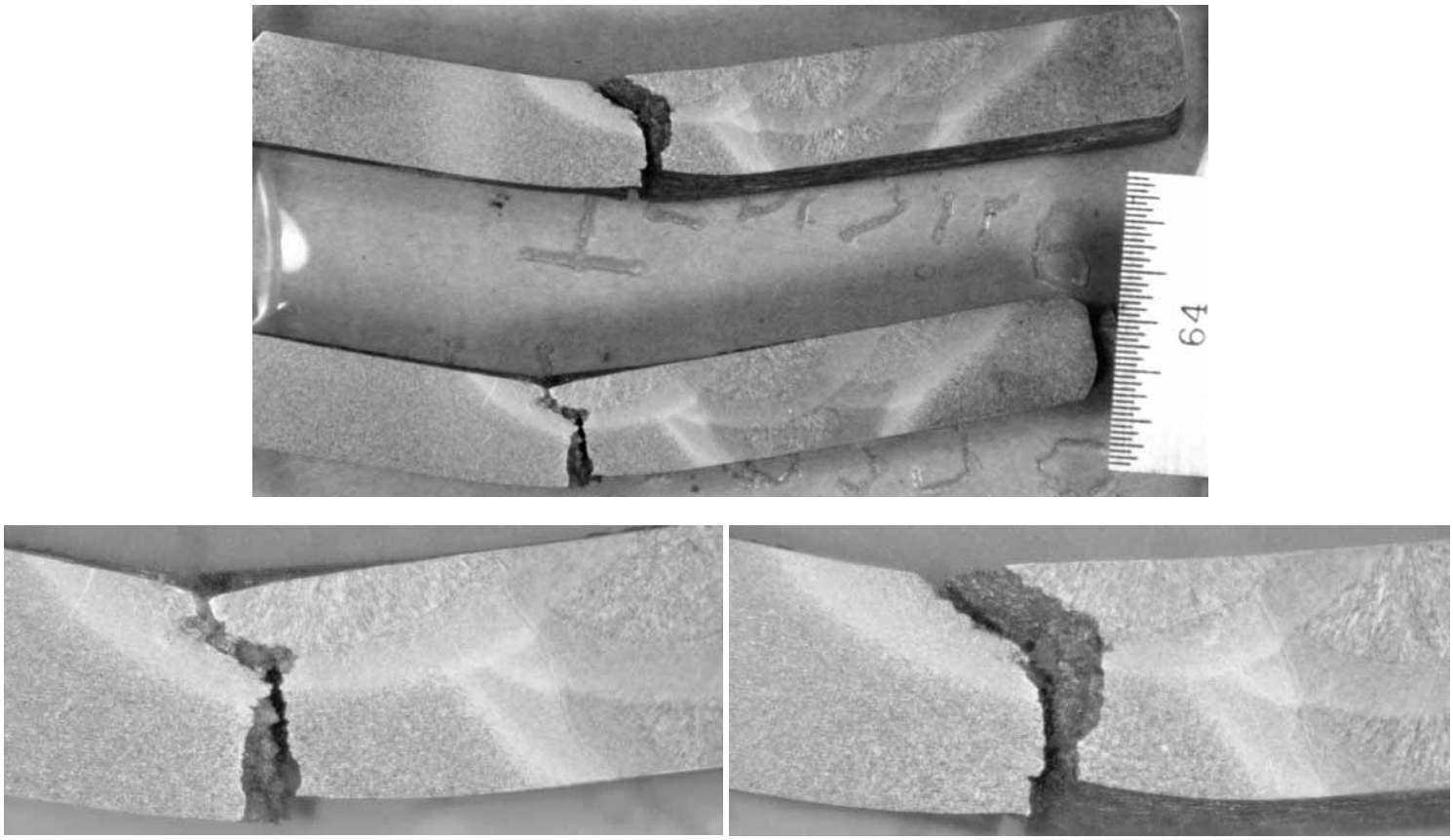


Figure 53. Tensile specimens after test. Side view. O.D. is on the top.

LABORATORY REPORT

ATTACHMENT 1 – TEST PROTOCOL AND ADDENDUM

Tesoro Exchanger B Shell Laboratory Examination Protocol

This protocol sets forth specified destructive testing on the shell of Heat Exchanger E6600-B.

Signature parties to this agreement shall receive at least 72 hour notice by the selected laboratory prior to laboratory testing per this protocol with notice by email or by emailed notice of activities in order for signature parties to have the opportunity to be present and observe testing.

1. *Material Preparation for Shipment and Receipt*
   - The E6600-B exchanger shall be submitted to the laboratory as exists in the evidence laydown yard at the Tesoro refinery.
   - The exchanger shall be secured to a transport trailer, suitably protected for transport.
   - ABS shall create a detailed shipping list and copies of pictures to assist in identification, and generate a chain of custody form signed off by a Tesoro representative.
   - ABS shall provide shipping details to the selected laboratory.
   - The selected laboratory shall be present at receipt of the exchanger and removal of the exchanger from the transport trailer.
   - The selected laboratory shall photograph or have photographed the as received condition of the exchanger and document any shipping damage.
   - The exchanger and any collected samples shall be stored in a secure indoor location at a Halvorsen warehouse in the Cleveland OH area. A Halvorsen representative will sign the chain of custody form for the exchanger upon receipt and maintain possession of the original form.

2. *Sample Cutting*
   - Two samples of interest from the B exchanger shell will be removed by air or plasma arc cutting by Halverson. One sample is Circ Weld 4 (CW-4) and extends a minimum of six (6) inches on both sides of this weld. The other sample is Longitudinal Weld 3 (LW-3) and also extends a minimum of six (6) inches on both sides of this weld). Locations for welds LW-3 and CW-4 and a description of indications of interest within these welds can be found in CISI Report dated June 24, 2010.
   - Cuts will be made on lines marked on the exchanger by Tesoro or their designated representative at locations consistent with previous language above.
   - Subsequent to cut line marking and receipt of the exchanger by Halvorsen, notification of intent of cutting shall be made to all signature parties by Halvorson or the laboratory and cutting shall not commence until three business days have passed since notification to permit review of cut line placement by all signature parties and provide the opportunity to be present to observe the cutting operation.

3. A tagging protocol and laboratory chain of custody form shall be developed by the selected laboratory to use for transfer of custody. The laboratory shall use the approved protocol and chain of custody form to take custody of the cut out samples from Halvorsen.

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Tesoro Exchanger B Shell Laboratory Examination Protocol

4. *Documentation of Samples – All work to be performed by the selected laboratory*
   - Lay out each cut out sample in a separate location.
   - Take initial photographs of "as received" condition of each sample, include tag and reference measurement ruler as appropriate.
   - Examine each sample for specific details in as received condition and document with photographs.

Laboratory NDE Examinations

NDE

1. Take caliper readings or UT readings for thickness at all edges of the samples and document. If there is pitting corrosion damage, use a pit gauge to measure the pit depth of the worst areas of pitting. Take macro hardness readings of each plate in the samples.
2. Inspect the reportedly internally exposed cracked section on CW-4 using dye penetrant (PT). Document the examinations photographically.

Marking and Sample Selection for Analysis

1. Examine each tagged sample for areas where sections will be removed for further detailed analysis. The signature parties or their representatives that are present in the lab shall determine the areas to sample for all analyses. Any and all NDE identified in the previously approved Tesoro Exchanger B Examination Protocol for Field Visual and Nondestructive Examination may be performed as directed by the signature parties or their designated representatives present in the lab to assist in the selection of sections for further laboratory examination.

2. Mark all areas chosen for further examination. Include specimen side to be exposed when mounted.

3. Document those areas chosen with macrophotographs, showing areas to be removed, ID tag, and reference measurements.

4. Mark all remote areas to be taken for general chemical analysis and mechanical tests, including base metal, welds, and Heat Affected Zones (HAZ). The signature parties or their representatives that are present in the lab shall determine areas for analysis and tests.

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Tesoro Exchanger B Shell Laboratory Examination Protocol

Fractographic/Metallographic Examination

1. Saw selected cutout sections on CW-4 to be mounted or looked at with Macroscope, maintaining tag traceability and side to be examined. Cut back material sufficiently near crack like indications of CW-4 to permit breaking. Cool sections in liquid nitrogen, place in vice and break away material as necessary to exposed crack surfaces on CW-4 selected sections.

2. Examine sections from (1) above with Macroscope and take pictures of all exposed fracture surfaces.

3. Examine un-mounted and unpolished fracture surfaces of interest in an SEM at 5, 50, 100, 500, 1000 and/or 5000X directed by the signature parties or their representatives present in the lab to look for potential initiation sites and clearly describe the fracture surface morphology. Any deposit areas shall be analyzed with EDS analysis as directed by the signature parties or their representatives present in the lab.

4. Cold mount sample pieces from both CW-4 and LW-3 in areas of interest as determined by the signature parties or their representatives present in the lab for metallography using a clear epoxy.

5. Etch control numbers on each mount corresponding to original tags.

6. Grind and polish the surface of each sample using a series of progressively finer grit papers and polishing wheels to obtain a surface suitable for examination under a metallurgical microscope with magnification at 50X, 100X, 200X, 500X, 1000X, and 1500X.

7. Examine each mount in the unetched condition under a Macroscope at 5 to 50X magnification as directed by the signature parties or their representatives present in the lab at the time.

8. Take photomicrographs and document any areas of interest as determined by the signature parties or their representatives present in the lab at the time.

9. Examine each mount under a metallurgical microscope for a higher magnification view of any areas on the sample as directed by the signature parties or the representatives present in the lab at the time.

10. Photograph any areas of interest as determined by the signature parties or their representatives present in the lab at the time.

11. Surface etch each mount with a Nital 2% etch solution (for carbon steel) and reexamine using both the macro and microscopes.

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Tesoro Exchanger B Shell Laboratory Examination Protocol

12. Photograph and document all areas of interest as directed by the signature parties or their representatives present in the lab at the time.

13. The signature parties or their representatives present in the lab at the time shall decide if any mounts are to be further examined using a Scanning Electron Microscope (SEM) either in the etched or unetched condition in the case of the mounts.

14. Photograph and document all areas of interest as determined by the signature parties or their representatives present in the lab at the time.

15. Perform EDS analysis of any scale or weld/base metal zone on the polished mount samples as directed by the signature parties or their representatives present in the lab at the time.

16. All weld joint cross section specimens shall be given a series of microhardness tests starting in base metal and traveling through the weld HAZ and weld metal at locations determined by the signature parties or their representatives present in the lab at the time.

Mechanical Properties

Testing shall be performed to determine the mechanical properties of the heat exchanger shell at locations determined by the signature parties or their representatives present in the lab at the time. These mechanical tests shall at least include the following:

- Tensile Testing
- Charpy V-notch Impact Testing
- Chemical Analysis

1. Tensile Testing

Tensile test specimens shall be prepared and tested in accordance with ASTM A370 (Mechanical Testing of Steel Products) for the shell base metal and weld seams to measure yield strength, ultimate tensile strength, and elongation. The shell base metal shall, at a minimum be tested in the transverse direction, and weld seam specimens should be taken across the weld seam. Tensile testing in the transverse direction is interpreted as transverse to the original plate rolling direction.

2. Charpy V-notch Impact Testing

Charpy V-notch (CVN) specimens should be prepared and tested in accordance with ASTM E23 (Notched Bar Impact Testing of Metallic Materials) to determine the toughness characteristics of in the transverse direction. Impact testing in the transverse direction is interpreted as transverse to the original plate rolling direction. Transition curves shall be produced with three (3) specimens at each temperature. Results from CVN testing may be reported in some or all of the following forms depending on the testing results:

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Tesoro Exchanger B Shell Laboratory Examination Protocol

- Upper-Shelf Energy (in ft-lbs)
- Lower-Shelf Energy (in ft-lbs)
- Ductile-to-Brittle Transition Temperature (in °F) determined from graphical representation of testing results
- Fracture Appearance Transition Temperature (in °F) corresponding to 50 % shear
- Lateral expansion (to measure notch toughness)

In some steels it may be difficult to measure percent shear because of "woody" fracture surfaces. In these cases it would be more appropriate to use lateral expansion and absorbed energy measurements to obtain a more accurate transition temperature.

3. Chemical Analysis

Chemistry samples representative of all components at locations as determined by the signature parties or their representatives shall be taken and analyzed per standard lab confirmation compared to ASME Section II material specifications. Perform Leco analysis for carbon content. A determination of carbon equivalent for each test shall be made.

Laboratory Results Reporting/Sample Retention

1. All laboratory tests, including photographs or sketches, should be documented and summarized in a single complete Level 2 lab report which contains descriptive text and captioned photos with the resultant assembly time being a function of the amount of data obtained but is typically 2-3 weeks. No analysis or conclusions shall be provided in the lab report. Any signatory party, its representative, or other party permitted to witness the laboratory testing may have the opportunity to see the data so long as there is no disruption to lab work but no one can have or make any copies of the laboratory work product prior to the Laboratory issuing the test report to the signatory parties.

2. No party shall have the opportunity to review the lab report in advance or the other parties. Any party requesting clarification or correction of anything in the report shall submit their request to the lab and all parties.

3. The Laboratory Report should be signed by a P.E from the laboratory.

4. All samples that are cut, whether used or not and all samples analyzed shall be saved and stored in a manner that minimizes corrosion, by retaining in a container filled with desiccant or wrapping in plastic, etc.

5. The chain of custody form should be signed at all stages where the samples are handled within the lab or removed from the lab for any reason. Any markings/tags should be visible and retained.

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LABORATORY REPORT

Tesoro Exchanger B Shell Laboratory Examination Protocol

James Darnell
Vice President, Health and Safety
Tesoro Companies

Signature — Date: 22 July 2010

Robert Parker
Compliance Manager
Division of Occupational Safety and Health

Signature — Date

Robert J. Hall
Investigator-in-Charge
U.S. Chemical Safety Board

Signature — Date: 27 July 2010

Exchanger B Shell Laboratory Examination Protocol, Rev. 0 — 7/20/2010

Page 6 of 6

LABORATORY REPORT

Tesoro Exchanger B Shell Laboratory Examination Protocol
Addendum – 1: Revisions/Clarifications Sample Cutting

This Addendum 1 to Exchanger B Shell Laboratory Examination Protocol sets forth revisions/clarifications to the Sample Cutting from the Exchanger E6600B and the Fractographic/Metallographic Examination. Except as revised herein, performance of work is to be in accordance with the Exchanger B Shell Laboratory Examination Protocol.

An outline drawing and designation of weld seams of E6600B, and references to the areas of indications discussed in this Addendum, can be found in the June 24, 2010 Spectrum Inspection Report titled: TESORO ANACORTES REFINERY EXCHANGER E6600B.

Areas chosen for metallurgical examination in this sample plan are shown in Figure 1 with cut lines that have been marked on the exchanger by Tesoro or its designated representative. Chosen locations are the longitudinal weld seam LW3 (Figure 2), circumferential weld seam CW4 (Figure 3), and the weld seam "T" junction of LW3/CW3 (Figure 4). Two of those areas (Figures 2 and 3) are listed as containing weld zone indications in the Spectrum Inspection Report dated June 24, 2010, and one area that was chosen, Figure 4, was free of any reported indications. The following detailed sample plan replaces the first two bullet points under item 2 of the Exchanger B Shell Laboratory Examination Protocol:

Detailed Sample Plan

Longitudinal Seam LW3

- Mark out an area on long seam LW3 approximately 6" along the seam and 6" wide.
- Center this sample location on the designated 10" continuous mid wall lack of fusion (LOF) indication listed in the Spectrum report and marked on the surface of the E6600B exchanger shell.
- Photograph the marked area prior to cutting out the sample plate.
- Cut the sample using the plasma arc or oxyacetylene process.
- Cut samples for weld metal and base metal chemistry.
- Cut one sample for a weld cross section metallurgical mount in the 10" LOF zone.
- Perform a weld and base metal hardness traverse across the cross section mount.
- Cut one sample in the 10" LOF zone for fractography.

Circumferential Seam CW4

- Mark out an area on circumferential seam CW4 approximately 12" long by 12" wide.
- Locate this area on the designated lack of fusion (LOF) zone.
- Photograph the marked area prior to cutting out the plate.
- Cut the sample using the plasma arc or oxyacetylene process.
- Cut samples for weld metal and base metal chemistry.
- Cut samples for two cross weld tensile tests, tests to be machined reduced size samples to provide areas of sound weld.
- Cut one sample for a weld cross section metallurgical mount.
- Perform a weld and base metal hardness traverse across the cross section mount.
- Cut one sample in the LOF zone for fractography.

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LABORATORY REPORT

Tesoro Exchanger B Shell Laboratory Examination Protocol
Addendum – 1: Revisions/Clarifications Sample Cutting

"T" Joint between Circumferential Seam CW3 and Longitudinal Seam LW3

- Mark out an area on the "T" joint of the circumferential seam CW3 and the longitudinal seam LW3 approximately 6" long by 6" wide.
- Center this area on the "T" joint intersection.
- Photograph the marked area prior to cutting out the plate.
- Cut the sample using the plasma arc or oxyacetylene process.
- Cut a sample for weld metal chemistry of CW3.
- Cut one sample for a weld cross section metallurgical mount of LW3 and one sample for a mount of CW3.
- Perform a weld and base metal hardness traverse across both cross section mounts.

James Darnell
Vice President, Health and Safety
Tesoro Companies, Inc.

Signature — Date: 16 SEPT. 2010

Robert Parker
Compliance Manager
Division of Occupational Safety and Health

Signature — Date: 9-16-10

Robert J. Hall
Investigator-In-Charge
U.S. Chemical Safety Board

Signature — Date: 9-23-10

Page 2 of 5
Addendum 1 Exchanger B Laboratory Protocol

LABORATORY REPORT

Tesoro Exchanger B Shell Laboratory Examination Protocol
Addendum – 1: Revisions/Clarifications Sample Cutting

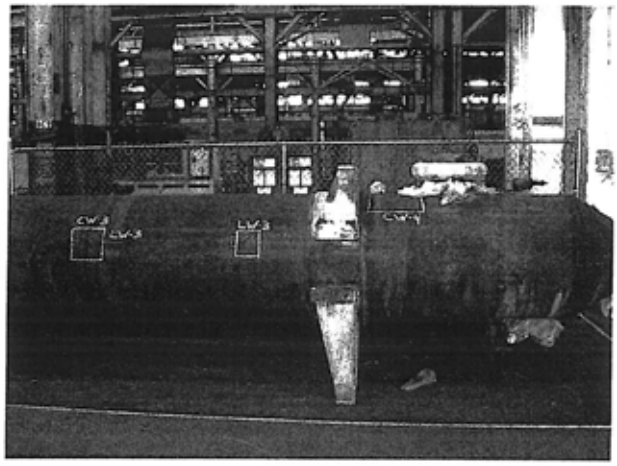

Figure 1: Overview of all three sample locations

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LABORATORY REPORT

Tesoro Exchanger B Shell Laboratory Examination Protocol
Addendum – 1: Revisions/Clarifications Sample Cutting

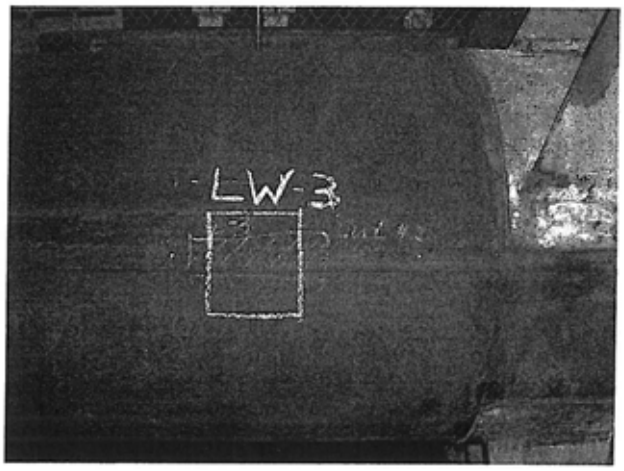

Figure 2: Long Seam Sample, LW-3

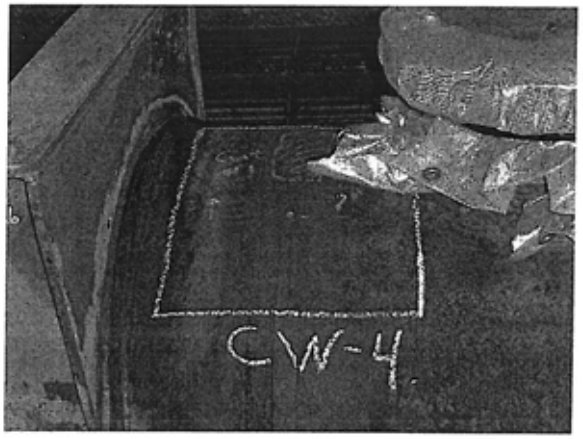

Figure 3: Girth Weld Sample, CW-4

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LABORATORY REPORT

Tesoro Exchanger B Shell Laboratory Examination Protocol
Addendum – 1: Revisions/Clarifications Sample Cutting

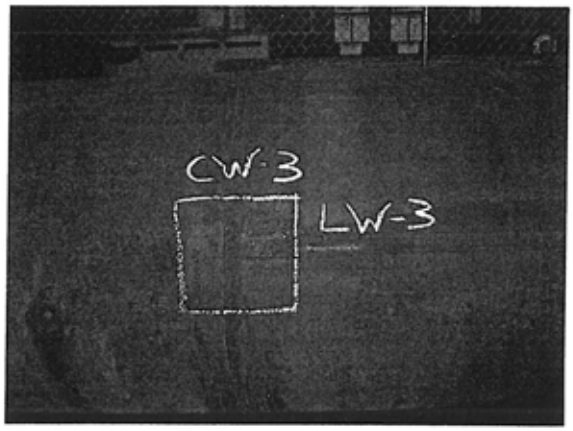

Figure 4: "T" Joint Weld Junction, CW-3/LW-3

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LABORATORY REPORT

Attachment2

TEST EQUIPMENT and PROCEDURES

TEST	INSTRUMENT & MODEL	CALIBRATION DUE DATE	BETA NO.	LSS PROCEDURE	
				NUMBER & TITLE	REV NO.
Failure Analysis	N/A	N/A	N/A	B0069 Failure Analysis	0
Chemical Analysis	Thermo ARL 3460 Optical Emission Spectrometer	Performance check prior to use	BETA 665	B0068 ARL 3460 Optical Emission Spectrometer Analysis	2
SEM/EDS	Amray Scanning Electron Microscope, Model: 1830T4, S/N: 18321002, with IXRF Energy Dispersive X-ray Spectrometer	*	BETA 386 BETA 755	B0064	*
SEM/EDS	Camscan Scanning Electron Microscope, Model: MV2300U, S/N: US0187039/VG0540181U with IXRF Energy Dispersive X-ray Spectrometer and x-ray Optics/AAT Detector	March 14, 2011	BETA 602 BETA 756	B0047 CAMSCAN/IXRF SEM/EDS System	8
Rockwell Hardness	Wilson Rockwell 524T Hardness Tester, Model 83259910	Performance check prior to use	BETA 400	D0027 Wilson Rockwell Model 524T Hardness Tester	5
Rockwell Hardness	NewAge NI300-C Hardness Tester, Model 8150 S/N 951480	Performance check prior to use	BETA 897	D0052	*
Knoop/Vickers Hardness	Buehler Micromet II Digital Microhardness Tester, Model B-D58222	Performance check prior to use	BETA 401	D0028	*
Knoop/Vickers Hardness by Image Analysis	Buehler Micromet II Digital Microhardness Tester, Model B-D58222 with Buehler OmniMet Analysis System Program Version 9.0 Rev 3	Performance check prior to use	BETA 401 BETA 977	D0028	*
Field Hardness	Proceq Equotip Hardness Tester, Model 25-819	Performance check prior to use	BETA 428	D0016	*
Knoop/Vickers, Semi-Micro Vickers Hardness	Instron Tukon 2100B Hardness Tester, Model T2100BR1942	Performance check prior to use	BETA 2006	D0068 Instron Tukon 2100B Hardness Tester	0
Reagent Preparation^	N/A	N/A	N/A	C0005 Metallurgical Reagents ▲	7
Linear Measurements by Optical Methods	LECO PMG-3 Inverted Metallograph with Buehler OmniMet Analysis System Program Version 9.0 Rev 3	6/1/2011	BETA 419 BETA 977	D0065	0
Average Grain Size	LECO PMG-3 Inverted Metallograph with Buehler OmniMet Analysis System Program Version 9.0 Rev 3	*	BETA 419 BETA 977	D0066	*
Dimensional	Starrett Micrometer Number 222	9/29/2011	BETA DLC-C-094	NA	NA
Dimensional	Starrett Vernier S/N 120 A	*	BETA 2005	NA	NA
Dimensional	Mitutoyo Digital Micrometer 342-361	*	BETA 884	NA	NA
Mass	Mettler AE-100 S/N C-31383	*	BETA 113	NA	NA
Carbon Analysis	Leco Carbon/Sulfur Determinator CS-444	Performance check prior to use	BETA 1061 BETA 1062	CST-19	*

*Denotes procedures or instruments not used in this report
▲ Etchant 5-1, 2% Nital

LABORATORY REPORT

Attachment 3

PT Report

TEAM® Industrial Services, Inc.
Providing Quality NDE and Heat Treating Services to Industries Worldwide

5901 Harper Road
Solon, OH 44139
(440) 498-9494

PT-FORM-08 Lab and Field Technique Sheet Rev 1

LIQUID PENETRANT EXAMINATION TECHNIQUE SHEET

Client: **First Energy** Technician: Gale Piercy
Facility: Mayfield Village Laboratory Date: October 12, 2010
Technique # n/a
Client PO# 45342412 Job # 13103291
Project Description: **FLP on Plates**

Item Data

☑ Weld ☐ Non-Weld ☐ Structural ☑ Initial Inspection ☐ Repair ☐ Final Inspection
☐ Other:

# of Parts 2 Base Metal C/S & S/S Filler Metal: S/A
Part Description: Part Number B1 Dimensions: 14"x 14"x 1"
Part Number B2 Dimensions: 7"x 6"x 1"

Inspection Data

Method: ☐ Visible Color Contrast ☑ Fluorescent ☐ Solvent Removable ☑ Water Wash ☐ Post Emulsifiable Surface Temp: Ambient

Pre Inspection Cleaning Method	Wire Brush and SKC-S		Batch #: 09E01K	Cleaner:	Spray and Wipe
Penetrant:	ZL-67 / 15 min (Dwell Time)		Batch #: 10A064	Application Method:	Brush
Emulsifier:	N/A / N/A (Emulsification Time)		Batch #: N/A	Application Method:	n/a
Remover:	Water / 10 min (Drying Time)		Batch #: N/A	Application Method:	Spray
Developer:	ZP-4B / 10 min (Developing Time)		Batch #: 08G072	Application Method:	Powder Bulb
Post Inspection Cleaning Method:	N/A		Batch #: N/A	Cleaner:	N/A
Black Light S/N:	1665145	Intensity: 2190 µw / cm²		Light Meter:	DSE 100X (Type) / 305603 (Serial No.)

Inspection Results

Procedure: PT.ASME.N2 Rev. 1 Acceptance Criteria: ASME Section III

Inspection Results Summary:

2 Pieces Inspected
Part Number B1 Had Two Linear Indications Measuring 3/4" and 2-7/8" long. Both Areas Were Identified
Part Number B2 Had No Indications Present at Time of Inspection

☐ Accept ☐ Reject ☐ See Attachments

Reported by: Gale Piercy LVII Reviewed by:
Supervisor: Contact:

NOTICE: This examination report reflects the actual NDT procedure which was conducted by TEAM personnel. Submission of this report is for informational purposes and does not reflect any guarantee of the part, inspection procedures, or standards and is subject to the limitations of each.

PT-FORM-08 Lab and Field Technique Sheet.xls

LABORATORY REPORT

ATTACHMENT 4

TENSILE TEST REPORTS
FULL THICKNESS TEST

TTML TENSILE TESTING
METALLURGICAL LABORATORY

A DIVISION OF J.T. ADAMS CO., INC.
4520 WILLOW PARKWAY
CLEVELAND, OHIO 44125
PHONE (216) 641-3290
FAX (216) 641-1223
www.tensile.com

CERTIFIED TEST REPORT

First Energy
6670 Beta
Mayfield OH 44143

Job No.: B0-294-007
Date: 11-1-10
Cust. PO#: 55102614

Attn: Mark Bridavsky

Description: 1 Welded Plate Lab# M10329 Receiving Order# 3271001 ID: T4

Base Metal Spec: ASME Section IX, QW 151.1 & QW 462.1(a)

TEST RESULTS

Width, in.	Thickness, in.	Ultimate Total Load lbs	Ultimate Unit Stress psi	Type of Failure & Location
0.752	0.800	24,060	40,000	Ductile/Base Metal
0.758	0.804	26,840	44,000	Ductile/Base Metal

Authorized Agent

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This Report May Not Be Reproduced Except In Full

This report represents Tensile Testing interpretation of the results obtained from the test and is not to be construed as a Guaranty or Warranty of the condition of the materials tested. Tensile Testing shall not be held liable for misinterpretation of conditions, loss, damage, injury or death arising from or attributable to delay preceding a test or subsequent to performance of a test.

ACCREDITED Cert No. 0161

LABORATORY REPORT

TENSILE TEST REPORTS
REDUCED THICKNESS TEST

From:Tensile Testing 12166411223 11/17/2010 12:05 #940 P.001/001

TTML TENSILE TESTING METALLURGICAL LABORATORY

A DIVISION OF J.T. ADAMS CO., INC.
4520 WILLOW PARKWAY
CLEVELAND, OHIO 44125
PHONE (216) 641-3290
FAX (216) 641-1223
www.tensile.com

CERTIFIED TEST REPORT

First Energy
6670 Beta
Mayfield OH 44143

Job No.: B0-294-007A
Date: 11-15-10
Cust. PO#: 55102614

Attn: Mark Bridavsky

Description: 1 Welded Plate Lab# M10329 Receiving Order# 3271001 ID: T4

Base Metal Spec: ASME Section IX, QW 151.1 & QW 462.1(a)

TEST RESULTS

Width, in.	Thickness, in.	Tensile, ksi	Yield, .2% ksi	Elong., % in 2"	Failure Type/Location
0.746	0.288	63.0	35.3	11	Brittle/Base Metal
0.738	0.286	56.5	34.5	9.5	Ductile/Base Metal

Authorized Agent

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ACCREDITED Cert No. 0151