

BETA LAB NO.M10198- CS4-01/ LS3 BOTTOM, REV. 1	TESORO REFINING AND MARKETING COMPANY ANACORTES REFINERY 10200 W. MARCH POINT ROAD T91WA4428 ANACORTES, WA 98221	CUSTOMER P.O. NO.: 4501667904
PART: 6600-E HEAT EXCHANGER CS4 01/BOTTOM PART 18/14		DATE: SEPTEMBER 20, 2010
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THE FOLLOWING CHANGES/ADDITIONS ARE MADE IN THIS REPORT:

1. Added source references to the Tables 2, 3 and 4
2. Changed Table 1
3. Added the results of the bundle guides angle evaluation – chemistry, Rockwell hardness, and microphotographs (Figures 21 through 23).

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 photos.

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On June 5, 2010 the heat exchanger arrived at Halvorsen Company's warehouse, in a June 11, 2010 meeting locations were selected for sample removal and on June 12, 2010 samples were cut by Halvorsen for submittal to BETA laboratory. The results of the receipt inspection for the heat exchanger at Halvorsen Companies warehouse are contained in FirstEnergy's Report titled M10198- Receipt Inspection dated July 29, 2010.

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 fifth in a series of the reports 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 | M10198 LS2-CS3 Tee Indications Findings
Aug. 13, 2010 |

TEST PERFORMED: The tests on the exchanger parts included visual examination, chemical analysis via Vacuum Spectrometry, SEM/EDS and LECO carbon, macro and micro-hardness measurements, 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 previously labeled as shown in Figure 1 and the same labeling was used for this report.

The piece labeled 18 with a part of the weld CS4, as well as a matching small piece labeled 19E from the Can 4 are subjects of evaluation in this report. The parts are shown on Figures 2 through 4.

Four locations were selected, by others, for metallurgical mounting. The locations on pieces and the photos of the etched mounts are shown in Figures 5 and 6. 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 7 through 33. On Figures 34 and 35 the micro-hardness graphs and tables are shown.

Later the evaluation of the angle irons (the bundle guides, sample 18 M2) base metal and welds was performed and the results have been added to this report.

The chemical composition of the base metal of the cans 3 and 4, as well as the chemistry of the SC4 weld metal are in Table 2. The Rockwell hardness of the cans 3 and 4 base metal in Table 3. Table 4 shows the spread of the micro-hardness in the cans 3 and 4 base metal, HAZ, and weld metal. The chemistry of the weld metal attaching the bundle guides to the I.D. of the can 3 as well as the micro-hardness are in Table 5.

The chemical composition of the bundle guide base metal, and Rockwell hardness are in Table 6.

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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 AND M. BRIDAVSKY	HALVORSEN & BETA, VARIOUS	TEST RESULTS
CHEMICAL ANALYSIS	THERMO ARL-3460 OE SPECTROMETER	M. TASCAR	BETA, 6/25/2010	TABLE 2, 6
Carbon Analysis	Leco Carbon/Sulfur Determination CS-444	M. Belviso	BETA, 7/26/2010	Table 2, 6
ROCKWELL HARDNESS	Wilson Rockwell 524THardness Tester	M, Tascar	BETA, 7/26/10	Table 3, 6
KNOOP/VICKERS, SEMI-MACRO VICKERS	INSTRON TUKON 2100B HARDNESS TESTER, MODEL T2100BR1942	M. TASCAR	BETA, 7/31/2010	TABLES 4 & 5 FIGURES 34 & 35
OPTICAL METALLOGRAPHY	LECO PMG-3 OPTICAL MICROSCOPE	M. BRIDAVSKY	BETA, VARIOUS	FIGURES 11-33

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

SAMPLE IDENTIFICATION	CHEMICAL COMPOSITION, WT. %											
	C	SI	P	S	MN	NI	CR	MO	V	CU	CO	AL
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

SAMPLE IDENTIFICATION	CHEMICAL COMPOSITION, WT. %											
	C	SI	P	S	MN	NI	CR	MO	V	CU	CO	AL
19E CAN 4	0.285	0.25	0.008	0.031	0.65	0.11	0.10	0.03	<0.001	0.13	0.01	0.005
19E CAN 4 CLAD	0.067	0.61	0.016	0.012	1.67	13.02	17.37	2.3	0.06	0.14	0.32	0.002
SA- 515 GRADE 70	0.31	0.13- 0.45	0.035 MAX	0.035 MAX	1.30 MAX	NS	NS	NS	NS	NS	NS	NS
SA 240 TYPE 316 S31600▲	0.08 MAX	0.75 MAX	0.045 MAX	0.030 MAX	2.00 MAX	10.00- 14.00	16.00- 18.00	2.00- 3.00	NS	NS	NS	NS

▲N - 0.10 MAX MEASURED 0.04

19W CS4 OD CROWN	0.08	0.53	0.011	0.020	1.07	0.06	0.07	0.02	0.001	0.13	0.001	0.005
19W CS4 ID SURFACE	0.05	0.69	0.14	0.16	1.18	12.37	19.42	2.80	0.03	0.05	0.05	ND
SFA 5.1 (E7016, E7018)*	NS	0.75 MAX	NS	NS	1.60 MAX	0.30 MAX	0.20 MAX	0.30 MAX	0.08 MAX	NS	NS	NS
SFA 5.17 (EM11K)	0.07- 0.15	0.65- 0.85	0.030	0.025	1.00- 1.50	NS	NS	NS	NS	0.35	NS	NS
SFA 5.17 (EL12)	0.04- 0.14	0.10 MAX	0.030 MAX	0.030 MAX	0.25- 0.60	NS	NS	NS	NS	0.35	NS	NS
SFA 5.17 (EM12K)	0.05- 0.15	0.10- 0.35	0.030 MAX	0.030 MAX	0.80- 1.25	NS	NS	NS	NS	0.35	NS	NS

NOTES: NS = NOT SPECIFIED, ND = NOT DETECTED

NO ALLOYS OR WELD WIRE GRADES WERE SPECIFIED SO TYPICAL ARE PRESENTED

* TOTAL OF MN+NI+CR+MO+V 1.75 MAX

SA-515 SPECIFICATION FOR PRESSURE VESSEL PLATES, CARBON STEEL, FOR INTERMEDIATE-AND HIGHER-TEMPERATURE SERVICE – JULY 2003 ADDENDUM

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

SFA 5.1 SPECIFICATION FOR CARBON STEEL ELECTRODES FOR SHIELD METAL ARC WELDING-JULY 2003 ADDENDUM

SFA 5.17 SPECIFICATION FOR CARBON STEEL ELECTRODES AND FLUXES FOR SUBMERGED ARC WELDING- JULY 2003 ADDENDUM

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

SAMPLE IDENTIFICATION	HARDNESS			
	MINIMUM	MAXIMUM	AVERAGE	NUMBER OF INDENTATIONS
CAN 4	79.3	80.2	79.8	7
CAN 3	82.5	83.7	83.1	7

TABLE 4
SPREAD OF MICRO-HARDNESS MEASUREMENTS
VICKERS 500Gm (HV₅₀₀)
(THE DATA ARE FROM PREVIOUS REPORT M10198-LS3 BOTTOM FINDINGS JULY 30, 2010)

Location	CS4
Base Metal Can 3	141-226
Base Metal Can 4	146-172
HAZ Can 3	145-218
HAZ Can 4	138-221
Weld Metal	161-242
Notes: HAZ = heat Affected Zone	

TABLE 5*
CHEMISTRY (BY SEM/EDS) AND MICROHARDNESS HV₅₀₀ OF
WELD METAL OF THE BUNDLE GUIDES TO THE CAN 3 I.D. JOINT

Test Objects	Chemical Composition, wt. %					Hardness			
	Si	Cr	Mn	Fe	Ni	Minimum	Maximum	Average	Number of Indentations
18 – M1 Weld Metal	0.4	0	0.8	98.8	0	189	215	205	9
18 – M2 Weld Metal	0.4	13.6	1.0	76.3	8.8	172	391	283	9

* The transverse hardness readings of the welding joint are on Figures 34 and 35 of this report

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TABLE 6

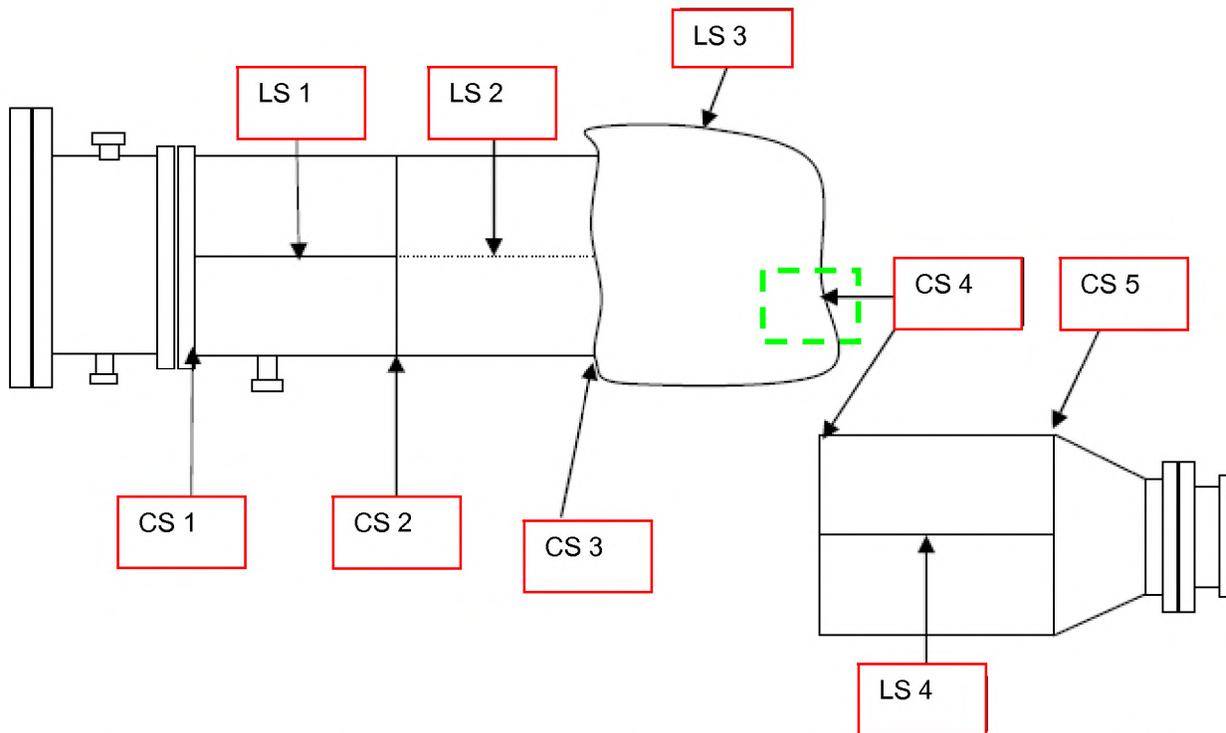
**CHEMISTRY (BY VACUUM SPECTROMETR, CARBON BY LECO CARBON/SULFUR
DETERMINATION CS-444) OF THE BUNDLE GUIDE ANGLE AND ROCKWELL HARDNESS**

Test Object	Chemical composition, wt.%					Hardness, HRB (converted from HRA)			
	C	Si	S	P	Mn	Min	Max	Average	Number of indentations
Sample 18 M2 Angle Base Metal	0.14	0.07	0.014	0.006	0.58	30	57	48	8
ASTM A 36-00, Standard Specification for Carbon Structural Steel	0.26 max	0.40 max	0.05 max	0.04 max	NS	NA	NA	NA	NA

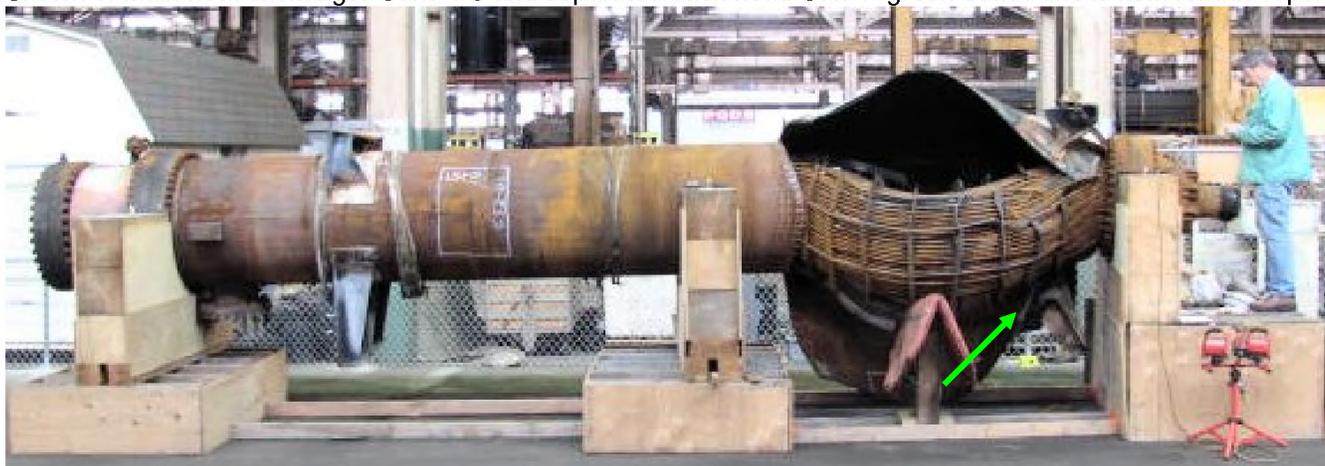
NA – not applicable
NS – not specified

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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

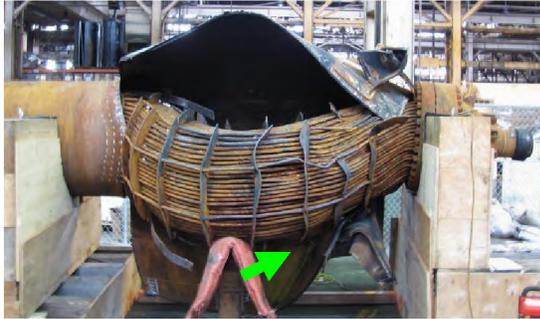


Location for CS4-01 item

Figure 1 Un-packed Main Heat Exchanger part of the 6600E heat exchanger

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Location of CS4-01 part (green arrow)



View in place form ID, marked for a cut



View from OD with CS4 on top and deformed saddle below



View during cutting from OD with CS4 on top and deformed saddle below which had to be cut along the fillet attachment weld to relieve sample

Figure 2

BETA LAB No.M10198- CS4-01/ LS3 BOTTOM, REV. 1	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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**CS4-01 ID VIEW. SAMPLES MARKED FOR
 REMOVAL**

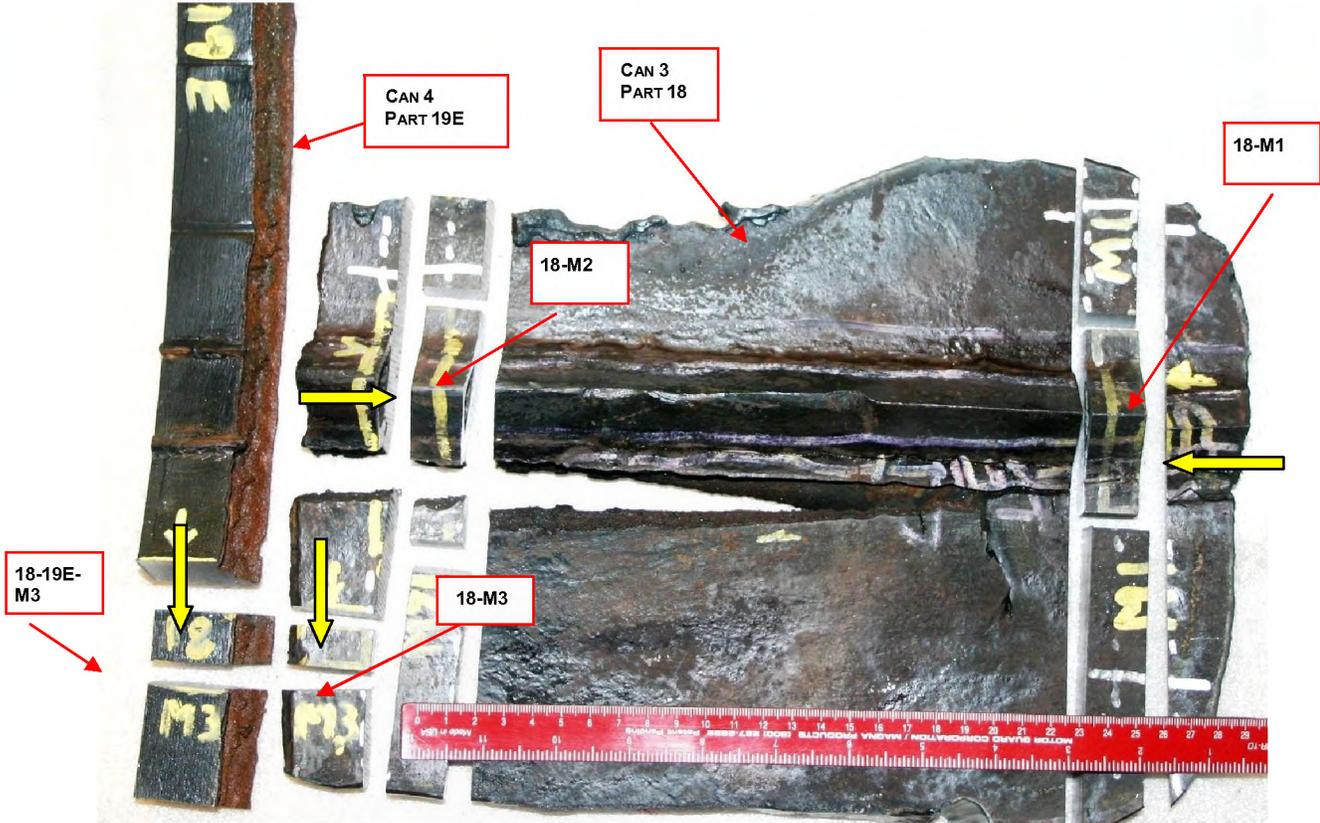


SAME AS ABOVE BUT OD VIEW

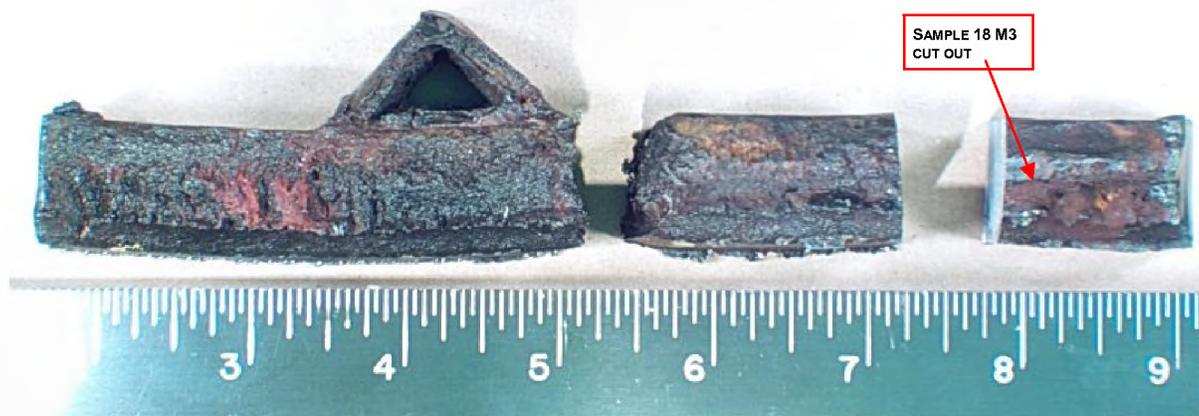
Figure 3

BETA LAB NO.M10198- CS4-01/ LS3 BOTTOM, REV. 1	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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LAY OUT OF THE CUT SAMPLES. YELLOW ARROWS INDICATE THE PLAIN TO BE POLISHED.



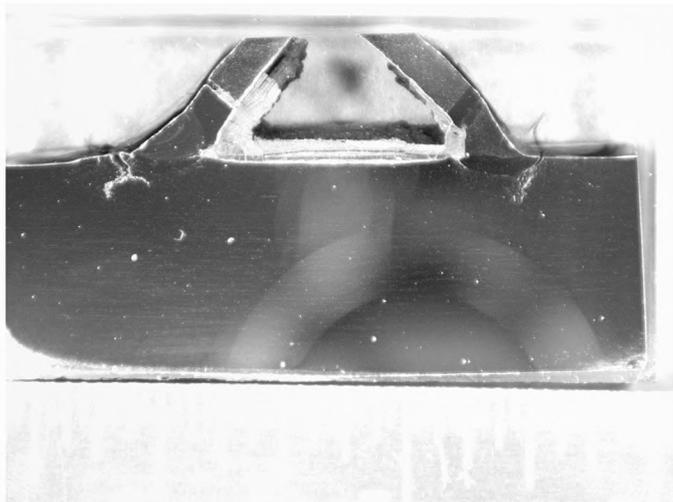
Fracture surface of Part 18.

CS4-01 FRACTURE SURFACE (PART 18)

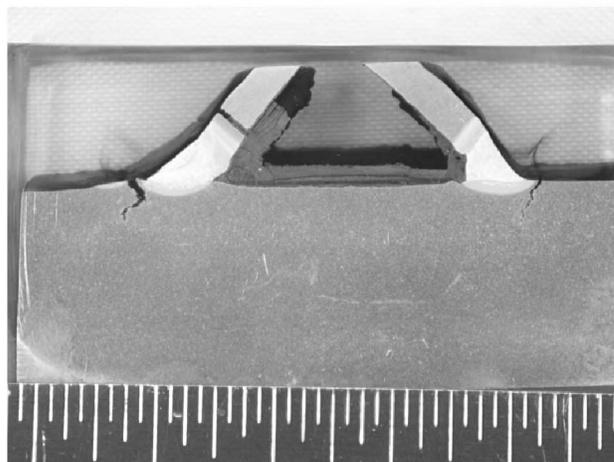
Figure 4

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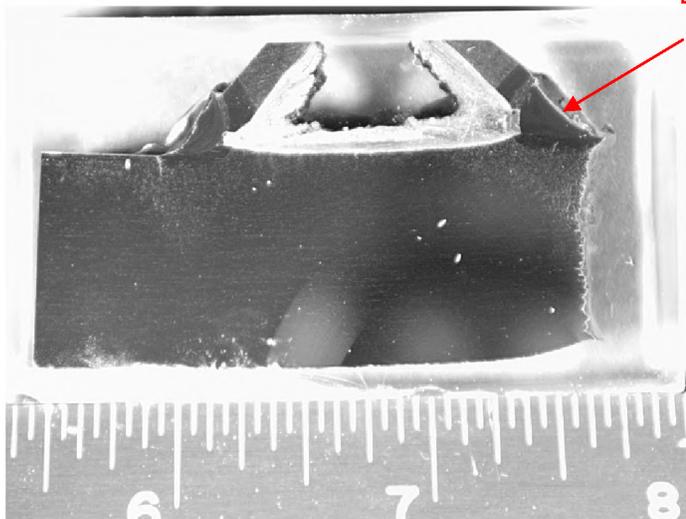
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SAMPLE 18-M1 UN-ETCHED-RING IS LIGHT ARTIFACT

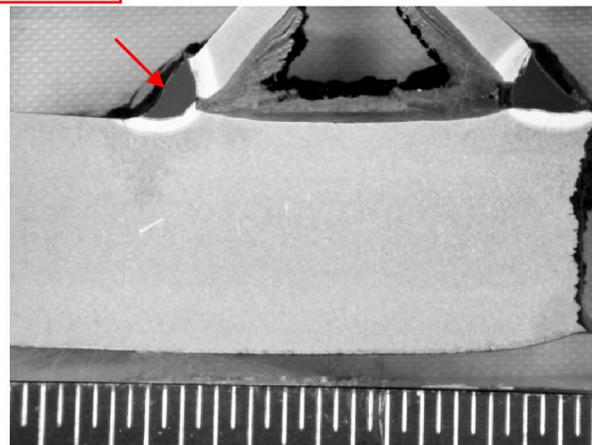


SAMPLE 18-M1 ETCHED



SAMPLE 18-M2 UN-ETCHED-RING IS LIGHT ARTIFACT

SS Welds



SAMPLE 18-M2 ETCHED

Figure 5- ID on top