NATIONAL TRANSPORTATION SAFETY BOARD
Office of Research and Engineering
Materials Laboratory Division
Washington, D.C. 20594

May 22, 2008

MATERIALS LABORATORY FACTUAL REPORT Report No 08-035

A. ACCIDENT

Place : Carmichael, Mississippi
Date : November 1, 2007
Vehicle : Dixie Pipeline Company
NTSB No. : DCA08MP001
Investigator : Rod Dyck

B. COMPONENTS EXAMINED

Ruptured 12¾-inch outside diameter liquid propane transmission pipe segment that failed a hydraulic test.

C. DETAILS OF THE EXAMINATION

Background

The pipe was subjected to a hydrostatic pressure test that resulted in a longitudinal rupture (gaping crack). Figure 1 show photographs of the as-received pipe segment. Upon receiving this pipe segment, the fracture faces were sprayed with WD-40 lubricant to preserve the fracture. The length of the as-received portion of the pipe measured approximately 219 inches (18 feet and 3 inches) and the length of the gaping crack measured approximately 126 inches (10 feet and 6 inches).

Purchase records provided by Dixie Pipeline Company indicated that the pipe was manufactured to American Petroleum Institute (API) Standard 5LX, 9th edition[1], dated February 1960, grade X52[2], as 12¾-inch outside diameter, 0.250 inch nominal wall thickness, electric resistance weld (ERW) steel pipe. The pipe was ordered in May 1961 from Lone Star Steel Company (now owned by U.S. Steel), and rolling was scheduled from June 22, 1961 through July 3, 1961. A representative from U.S Steel indicated that at the time the pipe was ordered, the weld seam would have been made by the low frequency ERW process and reportedly would have been fully normalized after welding.

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1 Standard that was in effect at the time of purchase and manufacture.
2 Grade X52 indicates the steel for the pipe should have minimum yield strength of 52,000 pounds per square inch.

Laboratory Group Examination

Metallurgical group examination of the hydrostatic failed portion of the pipe was held between January 14 and 18, 2008, at the Safety Board's Materials Laboratory. This examination was attended by:

Frank Zakar	NTSB
Rod Dyck	NTSB
Alan Kushner	NTSB
Joshua Johnson	US DOT, PHMSA
John Sullivan	Dixie Pipeline Company
Carmen Seal	Dixie Pipeline Company
Phil Miller	U.S. Steel
Ron Scrivner	Stress Engineering Services Inc (consulting metallurgist for Dixie)
Dennis Johnson	Kiefner and Associates, Inc

The fracture faces of the pipe were brushed cleaned with Alconox, a detergent solution. Examination of the pipe with a magnifying glass and portable binocular microscope revealed that the faces of the longitudinal fracture for the most part were flat and oriented on a longitudinal plane aligned at 90 degrees to the outside diameter surface of the pipe. The fracture faces showed no evidence of radial lines associated with an origin area or crack arrest marks[3]. The flat fracture face in many areas contained longitudinal, narrow, island-like fracture features that extended either above or below the flat fracture face. An island feature that extended above the flat fracture face contained a flat-topped ridge with cliff-like sides. An island feature that extended below the flat fracture face contained a valley with a flat bottom. The longitudinal flat fracture face contained many isolated island features that intersected the inside diameter and/or outside diameter surfaces as well as some that were closer to the center of the wall thickness. The texture of the flat-bottom or flat-top portion of the island features for the most part appeared smooth compared to the rough texture on the flat longitudinal fracture face. Photographs of typical island features are shown in Materials Laboratory Factual Report No. 07-122, a report that documented the condition of the accident pipe.

The wall of the pipe on the outside diameter at the downstream end contained a minor longitudinal weld depression consistent with a trim[4] of an ERW seam at the 6 o'clock position looking downstream. The longitudinal rupture was within the area of the ERW seam. Metallographic cross sections (sections 1-1, 2-2, and 3-3) of the pipe later showed that the longitudinal mating fracture faces were through the material affected by the ERW process, and that the flat top portion of the ridge or flat bottom portion of the valley of an island feature actually were fractured along the curved portion of the upturned grains created when the edges were upset (deformed) during welding. Details of how the ERW seam fracture was found in discussed in the section titled "Metallurgical Sections of Intact and Fractured ERW Seams".

[3] A crack arrest mark is a "step" on the fracture surface and indicates an intermittent stopping point during fracture propagation.
[4] Excess flash on the outside faces of the wall is trimmed (removed) after the welding process.

For the purpose of this report, the fracture face on the right side of the pipe looking downstream was referred as the "B" face. The mating fracture face was referred as the "A" face. To facilitate examination of the fracture faces, four ring sections, the length of each measuring approximately 18 inches, were cut from the pipe segments in the area near the center of the gaping crack. Approximately 2-inch wide strip portions that incorporated the "B" face of the fracture and another set of 2-inch strip portions that incorporated the "A" face of each ring piece were cut from the ring pieces. Bench binocular microscope examination of the "B" faces of the fractures revealed black-gray tinted deposits that extended between the outside diameter surface and an area located below the outside surface. The black-gray tinted deposit contained a minor luster compared to other areas of the fracture. Eleven black-gray deposits were identified and were labeled "1" through "11" in table 1. The measured distance of each black-gray deposit relative to the upstream girth weld, their calculated length, and depth are indicated in table 1. Figure 3 shows photographs of a portion of the black-gray deposit "9". The length of deposit "9" measured approximately 3 inches, and this deposit extended as much as approximately 0.05 inch below the outside diameter surface, as shown in figure 3. On May 2005, a GE Ultrasonic Crack Detection Tool performed an inspection of the pipe and detected a crack-like feature on the outside diameter surface of the pipe at approximately 13.57 feet (162.84 inches) downstream from the upstream girth weld. According to the results from the May 2005 inspection, the length of this crack-like feature was estimated to be approximately 3.5 inches and the depth was estimated to be between 25% and 40% of the wall thickness. The location of this crack-like feature coincided with deposit "9" in this report.

A 1-inch long piece of face "B" of the fracture that contained black-gray deposit "9" in table 1 was excised from the 2-inch wide strip portion of the pipe. Scanning electron microscope examination of the 1-inch long piece revealed the black-gray deposit was smooth compared to the surrounding fracture features; see the bottom photograph in figure 3. The deposit areas contained cracks in several areas, not visible in figure 3. The sample was rotated to view the fractured edges of the deposit. The thickness of the deposit measured approximately 10 micrometer (0.0004 inch). X-ray energy dispersive spectroscopy analysis of the smooth deposit produced a spectrum that contained major elemental peaks of iron and oxygen, consistent with iron oxide, and minor elemental peaks of carbon, manganese and silicon, see figure 5.

Figure 4 shows photographs of the black-gray deposit "8". The length of deposit "8" measured as long as 3.1 inches, and the depth measured as deep as 0.01 inch. Over most of its length, deposit "8" was found on a secondary crack adjacent to the outside diameter surface. The secondary crack and portion of the deposit that extended into the secondary crack are indicated in figure 4. The deposit was found on at least 90% of the length of the secondary crack.

The tint and texture of black-gray deposits "1" through "8", and "10" were similar to the tint and smooth texture of black-gray deposit "9", consistent with iron oxide. These iron oxide deposits were located on the fracture face adjacent to the outside diameter surface.

Metallurgical Sections of the ERW Seams

A transverse metallurgical section was made through the wall of the pipe in an area that contained a longitudinal ERW trim at the outside diameter surface, location and orientation indicated by section line “1-1” in figure 2. The trim was located at approximately the 6 o’clock position.[5] Examination of the prepared section revealed the pipe contained a microstructure of ferrite and pearlite typical for low alloy steel. Away from the ERW seam, the pipe exhibited a minor banding[6] structure that was parallel to the inside and outside diameter surfaces and followed the circumference of the pipe. The ERW seam appeared in the microstructure as a white line and extended radially between the inside and outside diameter. In the area of the ERW seam, the grains in the base metal flowed toward the weld at the center of the wall thickness then fanned out (curved) toward the inside diameter and outside diameter surfaces. The grains were nearly parallel to the ERW seam at the outside and inside diameter surfaces. For the purpose of this report, the portion of the grains near the ERW seam that turn/curve toward the inside or outside diameter surfaces are referred as upturned grains.[7] The ERW seam coincided with the longitudinal ERW trim and showed no evidence of incomplete fusion.

The largest separation between the fracture faces was located approximately 148 inches downstream from the upstream girth weld, and the separation between the fracture faces in this area measured approximately 1.1 inches. A transverse metallurgical section was made through the mating fracture faces near the largest separation between the fracture faces, location and orientation indicated by section line “2-2” in figure 2. Section “2-2” was located approximately 146.5 inches from the upstream girth weld. Another transverse metallurgical section was made through the mating fracture faces that contained the black-gray deposit (iron oxide) in the deposit area “9”, location and orientation is indicated by section line “3-3” in figure 2. Section “3-3” was located approximately 164.5 inches downstream from the upstream girth weld. The prepared sections were etched with 2% Nital reagent. Figures 6 and 7 show photographs of the etched sections. Examination of sections “2-2” and “3-3” revealed a portion of the fracture at the outside diameter surface was parallel or nearly parallel to the ERW seam and extended partially around the upturned grains, resembling the outline of the letter “J”. The depth of the “J” portion of the fracture when measured from the outside diameter surfaces was expressed as a percent of the wall thickness, noted in the appropriate figures that contained a “J” fracture. The fracture adjacent to the inside diameter surface partially intersected several of the upturned grains but did not continuously follow the path of an upturned grain. Because of this the fracture adjacent to the inside diameter surface was not categorized as a “J” fracture.

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[5] The top of the pipe was referred as the 12 o’clock position.
[6] Banding is segregated structure consisting of alternating nearly parallel bands of different composition, typically aligned in the direction of primary hot working.
[7] Not to be confused with the term “upturned fiber imperfection or “hook cracks” that according to API Standard 5T1, titled “Standard on Imperfection Terminology”, dated November 1996, refer to metal separation, resulting from imperfections at the edge of the plate or skelp, parallel to the surface, which turn toward the I.D. or O.D. pipe surface when the edges are upset during welding.

The microstructure in the wall portion of the sections “2-2” and “3-3” appeared as fine grain. The grains in the ERW seam for the most part appeared uniform, and their size appeared similar to the size of the grains in the wall of the pipe. The wall of the pipe in the area of the ERW showed no evidence of an hour glass-like heat-affected-zone on both sides of the ERW. These observations are consistent with an ERW seam that was subjected to heat treatment at a normalizing temperature.

Chemical Composition

At the time the pipe was ordered, steel for the pipe would have been produced by the open-hearth, non-expanded process, according to a representative from U.S. Steel. The check chemical composition for the pipe is carbon 0.34 max, manganese 1.40 max, phosphorus 0.05 max, and sulfur 0.06 max. Chemical analysis was performed by the Safety Board’s Materials Laboratory using a LECO model GDS500 Glow Discharge Optical Emission Spectrometer on the prepared surface of section “1-1”. Two analyses were made on the surface of section “1-1”. The results of the analyses and the calculated average of the two results are indicated in table 2. The calculated average composition of the ruptured pipe was within the limits described in the 1960 issue of API 5LX, for grade X52 pipe.

Dimensions of the Pipe

The thickness of the wall at the upstream cut end of pipe was measured with a point micrometer. The wall thickness of the ruptured and intact pipe pieces measured between 0.250 inches and 0.260 inches, which was within the specified tolerances for 0.250-inch nominal wall thickness pipe (0.219 and 0.288 inch). The circumference of the outside diameter of the intact pipe at the cut southwest end measured approximately 3 feet, 4 inches and 3/8 inches. This calculates to an outside diameter of 12.86 inches, which was within the API 5LX specified range (between 12.62 and 12.88 inches).

Tensile Testing

The March 1960 issue of API Standard 5LX indicated that the ultimate tensile strength, yield strength (at 0.5% of gage length when measured with an extensometer), and elongation for grade X52 pipe should be no less than 66,000 pounds per square inch (psi), 52,000 psi, and 18%, respectively. The API specification indicated that for welded pipe, in sizes 8 and 5/8 inch and larger, the tensile properties shall be determined by tests on transverse specimens. The transverse body-tensile specimens shall be taken from an area that is located opposite the weld. Transverse weld specimens shall be taken with the weld at the center of the specimen. The specification also indicated that transverse weld specimens shall be tested for ultimate tensile strength only.

A ring portion of pipe was excised approximately between 9 inches and 35 inches downstream from the upstream girth weld. Two transverse[8] body-tensile specimens and

[8] Oriented circumferential with respect to the length of the pipe.

two transverse weld-tensile specimens were machined from the ring portion of the pipe. Each tensile specimen was manufactured with a gauge length of 2 inches and a width of 1.5 inches at the gauge length area, in accordance with API and American Society for Testing and Materials (ASTM) A370, titled "Standard Methods and Definitions for Mechanical Testing of Steel Products". Tensile specimens were machined and tested at Lehigh Testing Laboratories, New Castle, Delaware.

The results of the tensile testing are shown in table 3A for the base metal and table 3B for the ERW seam. The measured ultimate tensile strength and yield strength for the two base metal tensile specimens was within the specified range. The measured elongation values for the two base metal tensile specimens were greater than the minimum specified value (18%). The measured ultimate tensile strength for the two ERW seam tensile specimens was within the specified range. As indicated earlier, testing for the yield strength and elongation of the ERW seam was not required, but was recorded for information purpose. The measured yield strength of the ERW seam tensile specimens was within the range that was specified for the base metal, but the measured elongation value of the two tensile specimens (6% and 5%) was significantly less than the minimum elongation that was specified for the base metal (18%).

Charpy V-Notch Impact Testing

March 1960 issue of API Standard 5LX did not specify Charpy V-notch impact testing and minimum values for Charpy V-notch specimens. In order to gain information on the impact properties of the pipe, Charpy V-notch specimens were prepared from the base metal and the ERW seam. ASTM A370-07a and Specification for Line Pipe - API Specification 5L, 43rd edition, March 2004, indicated that for ERW seam pipe, transverse[9] Charpy specimens for the base metal are to be prepared from an area of the pipe that is located 90 degrees circumferentially away from the ERW seam. Sub-size Charpy specimens (approximately 1/3 the thickness of a standard specimen) were prepared to accommodate the wall thickness of the pipe (0.250 inch [6.35 mm]).[10] Specimens were machined to 3.3 mm x 10 mm x 55mm. The specimens were tested at room temperature (approximately 68 degrees Fahrenheit). Non-notch specimens also were prepared from the ERW seam (same size and orientation as the sub-size Charpy specimens (but without the notch). API does not specify testing of non-notch specimens. The test specimens were prepared and tested by Lehigh Testing Laboratories, New Castle, Delaware. The results from the impact tests are shown in table 4. The values shown in table 4 are for sub-size specimens (1/3 the thickness of standard size specimens).

Frank P. Zakar
Senior Metallurgist

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[9] Length of a Charpy specimen is parallel to the circumference of the pipe.
[10] The size of a standard Charpy specimen is about 0.394 inch x 0.394 inch x 6.67 inch (10mm x 10mm x 55mm).

Table 1. Location of Black-Gray Deposits Found on "B" Face of Fracture

Cut-Out Ring Piece No	Deposit No.	Measured Distance Downstream From Upstream Girth Weld (Inches)	Calculated Length Of Deposit (inches)	Maximum Depth Of Deposit: Measured From Outer Surface (Inches)	Maximum Depth Of Deposit: Percent of Wall Thickness (**)
Upstream End of Crack		70.5	--	--	--
Saw Cut		101.6	--	--	--
1	1	107.5 - 108.0	0.3	0.03	12
1	2	108.2 - 108.5	0.3	0.02	8
1	3	108.8 - 109.0	0.2	0.02	8
1	4	113.8 - 114.3	0.5	0.01	4
Saw Cut		119.5	--	--	--
2	5	123.3 - 123.9	0.6	0.02	8
2	6	131.6 - 131.8	0.2	0.02	8
Saw Cut		137.4	--	--	--
3	7	144.0 - 144.4	0.4	0.02	8
3	Reference Point *	148	--	--	--
Saw Cut		155.4	--	--	--
4	8	155.4 - 158.5	3.1	0.01	4
4	9	162.5 - 165.5	3.0	0.05	20
4	10	165.8 - 166.3	0.5	0.02	8
4	Approx. location of crack-like feature detected by GE ultrasonic ILI tool in May 2005	Estimated to be located between 162.8 – 166.3 inches	Estimated Length was 3.5 inches	--	Estimated to be between 25-40% of wall thickness
Saw Cut		173.5	--	--	--
Downstream End of Crack		196.5	--	--	--

Notes:

(*) All measurements were made relative to the 148-inch mark that was found on the pipe that indicated the maximum opening of the rupture (gaping crack).

(**) Based on a 0.25 inch wall thickness.

Table 2. Chemical Composition of Coupons

Element	Specified For Open Hearth, Killed Deoxidized Non-Expanded Pipe (weight %)	Analysis #1 (weight %)	Analysis #2 (weight %)	Calculated Average (weight %)
Aluminum	Not specified	0.00	0.00	0.00
Boron	Not specified	0.00	0.00	0.0005
Carbon	**0.34 max**	**0.315**	**0.287**	**0.301**
Chromium	Not specified	0.036	0.036	0.036
Copper	Not specified	0.392	0.399	0.3955
Manganese	**1.40 max**	**1.27**	**1.26**	**1.265**
Molybdenum	Not specified	0.013	0.012	0.0125
Niobium[11]	Not specified	0.00	0.00	0.00
Nickel	Not specified	0.078	0.075	0.0765
Phosphorus	**0.05 max**	**0.030**	**0.026**	**0.028**
Sulfur	**0.06 max**	**0.037**	**0.032**	**0.0345**
Silicon	Not specified	0.041	0.040	0.0405
Tin	Not specified	0.003	0.00	0.0015
Titanium	Not specified	0.003	0.001	0.002
Vanadium	Not specified	0.001	0.001	0.001
Iron	Remainder	Remainder	Remainder	Remainder

[11] Formerly know as the element columbium.

Table 3A. Tensile Properties of the Base Metal[12]

Property	**Minimum Specified**	Specimen #1 **Measured**	Specimen #2 **Measured**
Yield Strength, 0.5% EUL (psi)[13]	52,000	64,800	67,900
UltimateTensile Strength (psi)	66,000	90,700	91,900
Elongation, (%)	18	23	24

Table 3B. Tensile Properties of the ERW Seam

Property	**Minimum Specified**	Specimen #1 **Measured**	Specimen #2 **Measured**
Yield Strength, the stress required to produce a total elongation of 0.5% of the gage length (psi)	Not required for a weld	67,900	67,100
UltimateTensile Strength (psi)	66,000	85,000	84,500
Elongation, (%)	Not required for a weld	6	5

Table 4. Impact Properties (tested at 68^{O}F)

Specimen Type	Specimen Identification	Impact Energy (ft-lbs)	Lateral Expansion (Mils)	Shear (%)
Notched ERW Seam	A	8	23	100
	B	6	18	90
	C	9	26	100
	D	9	26	100
Not Notched ERW Seam	A	6	12	90
	B	4	9	90
	C	12	17	100
	D	12	16	100
Notched Base Metal	1	8	19	100
	2	8	18	100
	3	8	18	100

[12] Results are for the pipe portion that was located downstream from the downstream girth weld.
[13] Extension under load (EUL) method - stress required to produce a total elongation of 0.5% of the gage length.

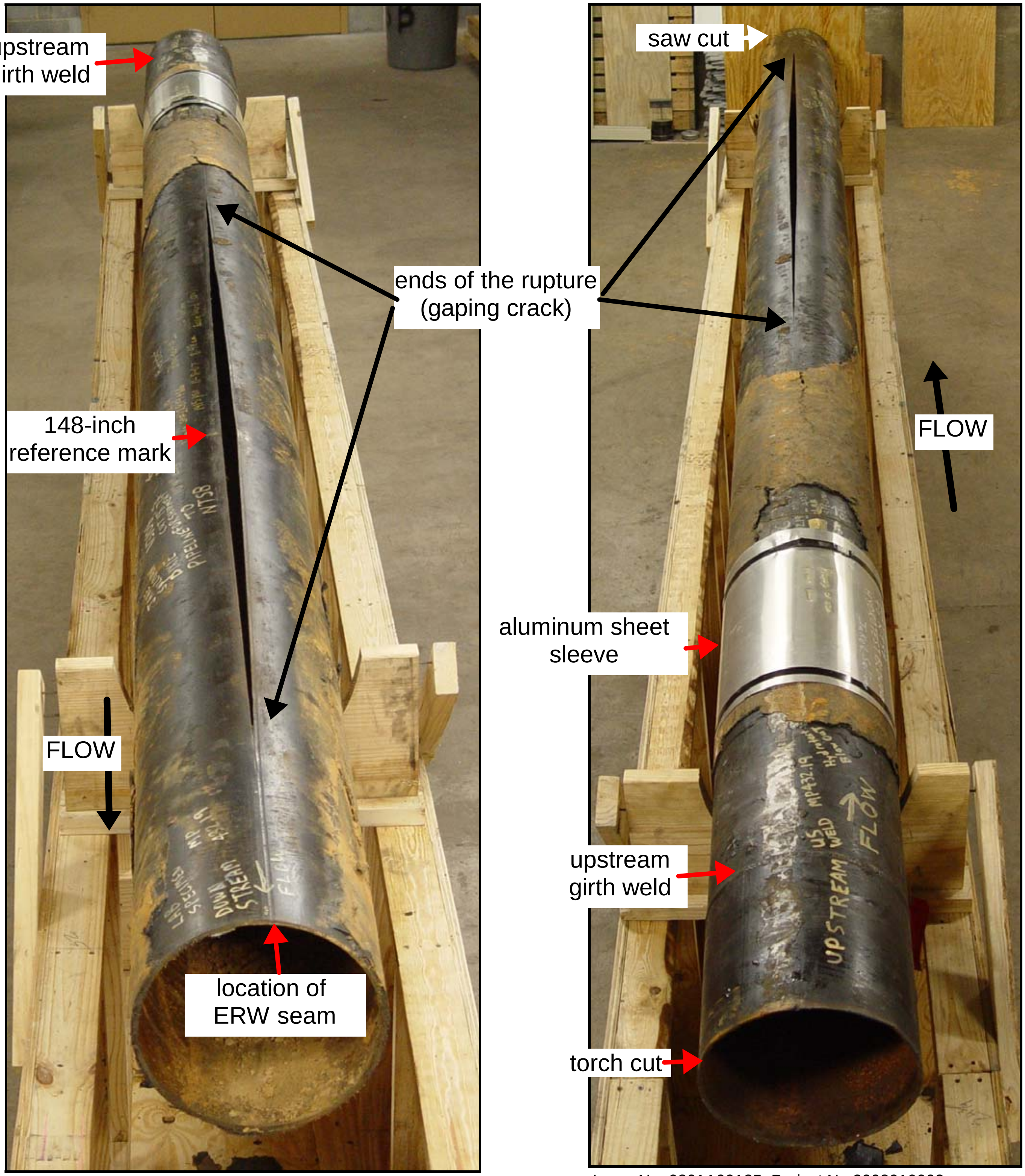

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Figure 1. Photographs of the as-received pipe segment showing the downstream cut end (left side of page) and the upstream end (right side of page). An aluminum sheet sleeve with identification information was placed over the pipe in the area near the upstream girth weld prior to shipping.

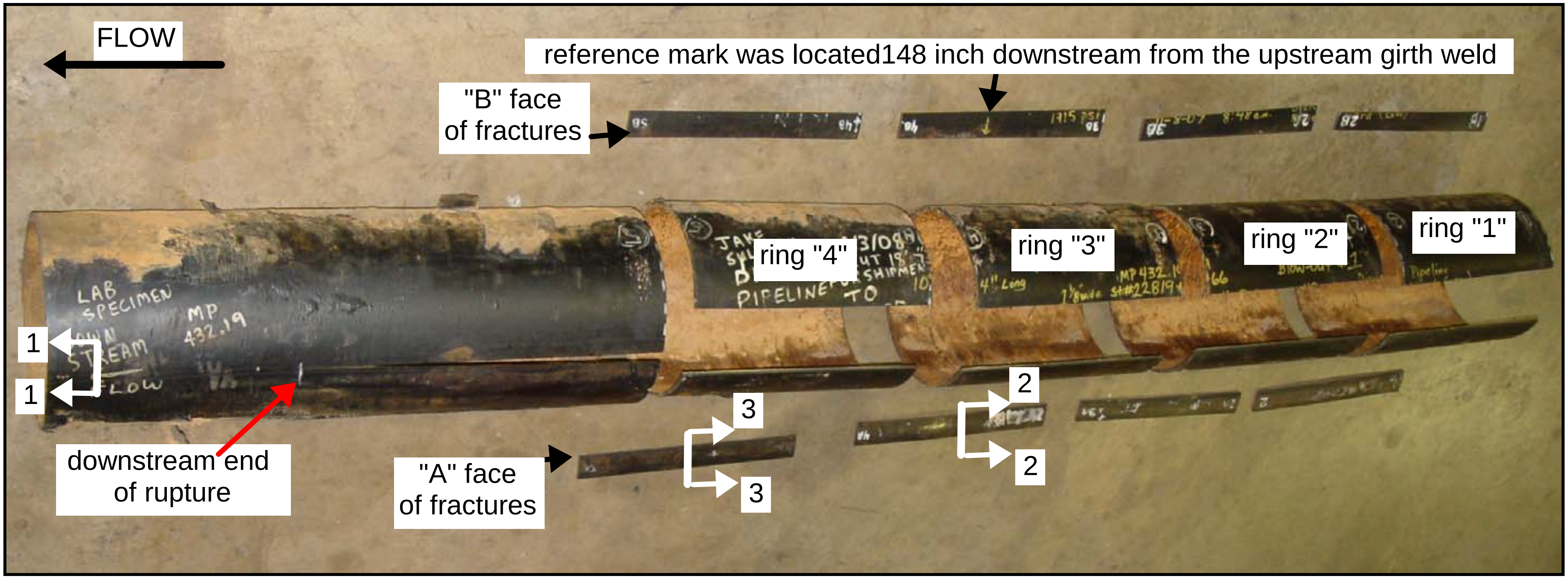

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Figure 2. Photograph of the downstream end of the pipe after four ring pieces were cut from the downstream end of the gaping crack. Two inch wide strip portions that contained the fracture faces were cut from each ring piece and were placed next to their respective ring piece. The "B" face portion of the fracture faces are on the top side of the photograph and the mating fractures ("A" face) are shown on the bottom side of the photograph. The widest opening in the gaping grack was found approximately 148 inches downstream from the upstream girth weld. The upstream end of the gaping crack is not shown in this photograph.

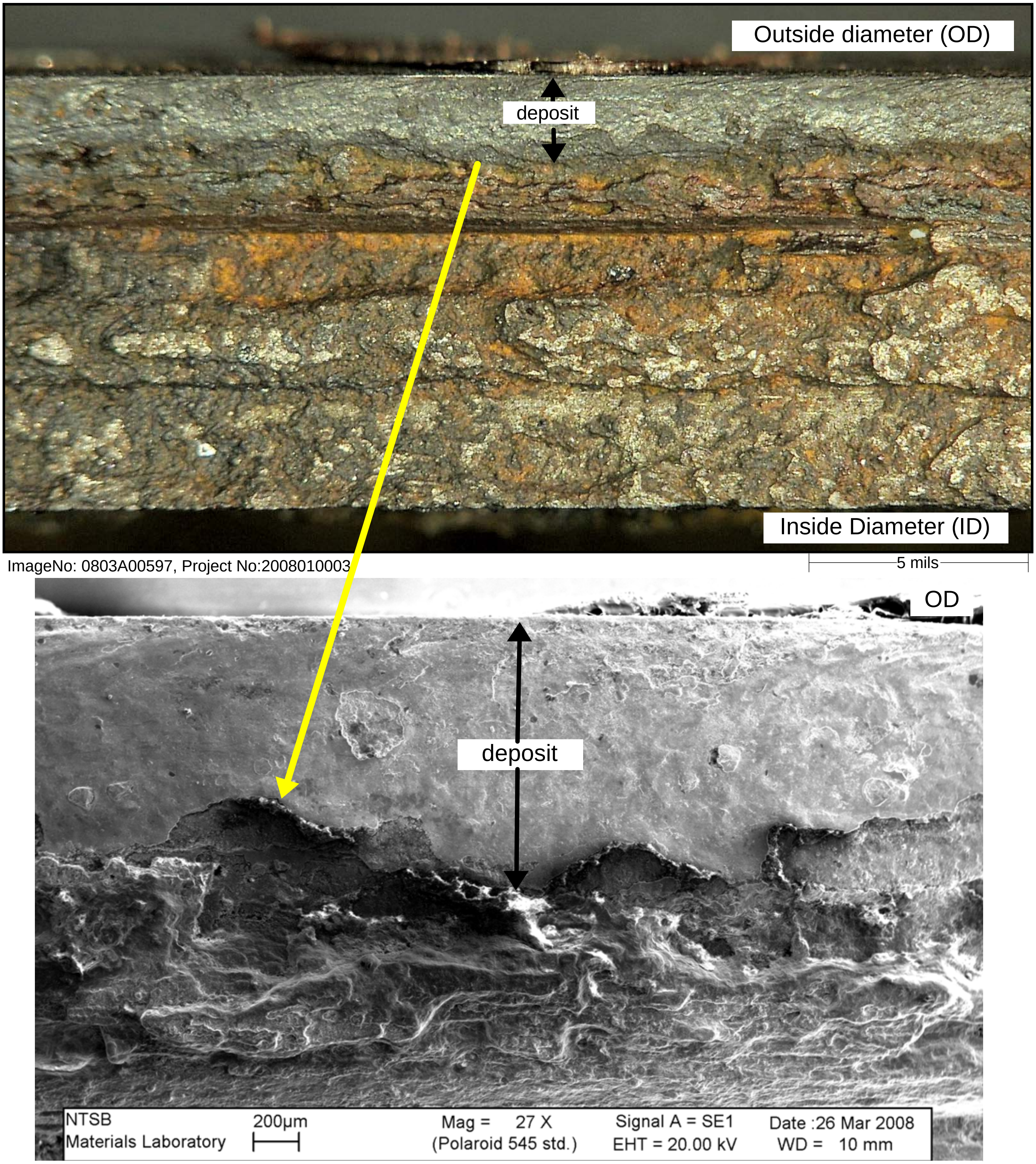

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Figure 3. Photograph of a portion of the fracture from ring piece "4" showing the "B" face in an area that contained a black-gray deposit adjacent to the outside diameter surface. A scanning electron microscope photograph of the same general area is shown in the bottom side of the page. Note the smooth texture of the deposit compared to the rough texture of the fracture. The black-gray deposit is indicated as deposit "9" in table 1.

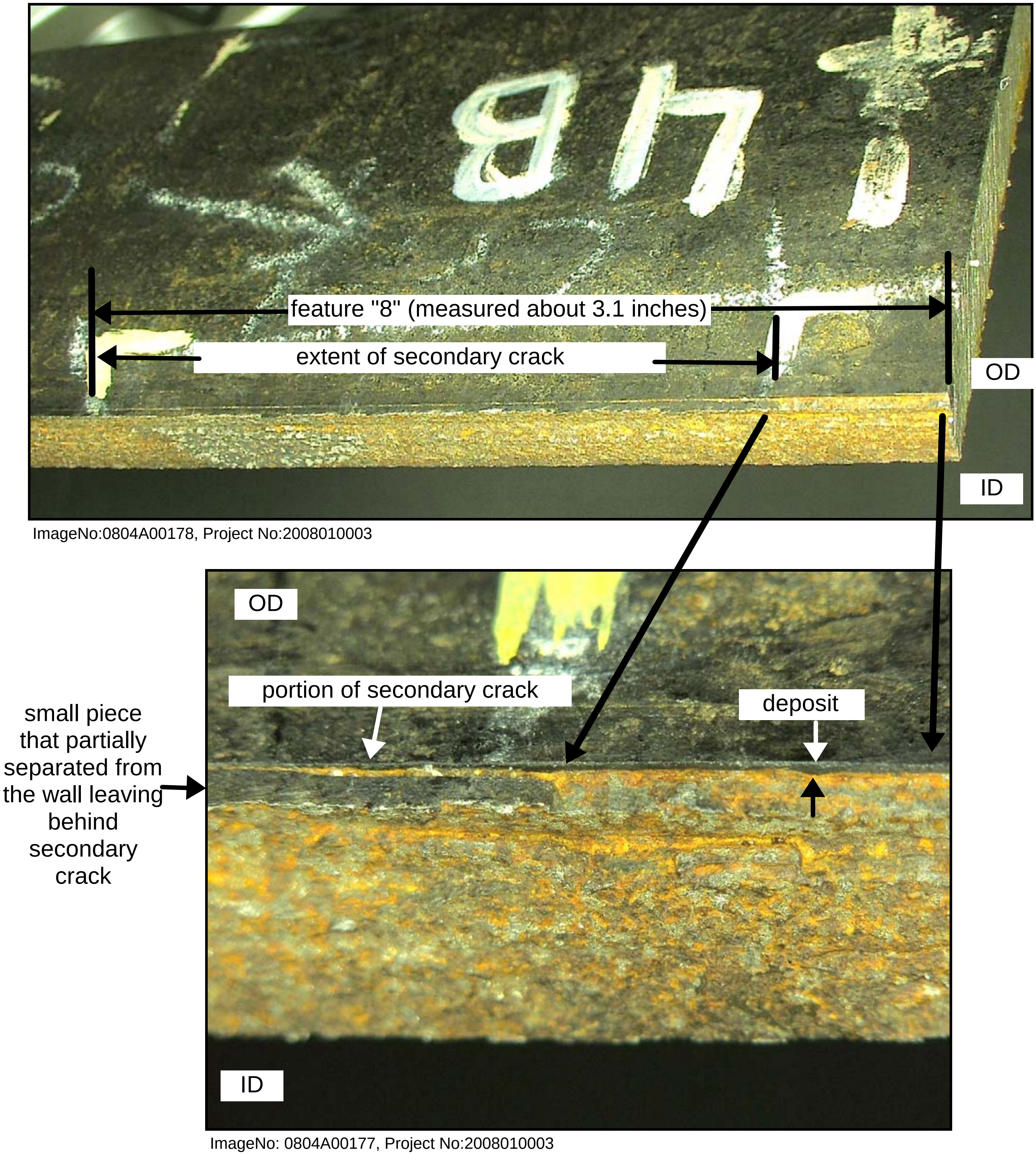

Figure 4. Photograph of a portion of the fracture from ring piece "4" showing the "B" face in an area that contained a black-gray deposit adjacent to the outside diameter surface. A close-up photograph of the same area where the deposit extended into a crack on the outside surface is shown at the bottom side of the page. The black-gray deposit is indicated as deposit "8" in table 1.

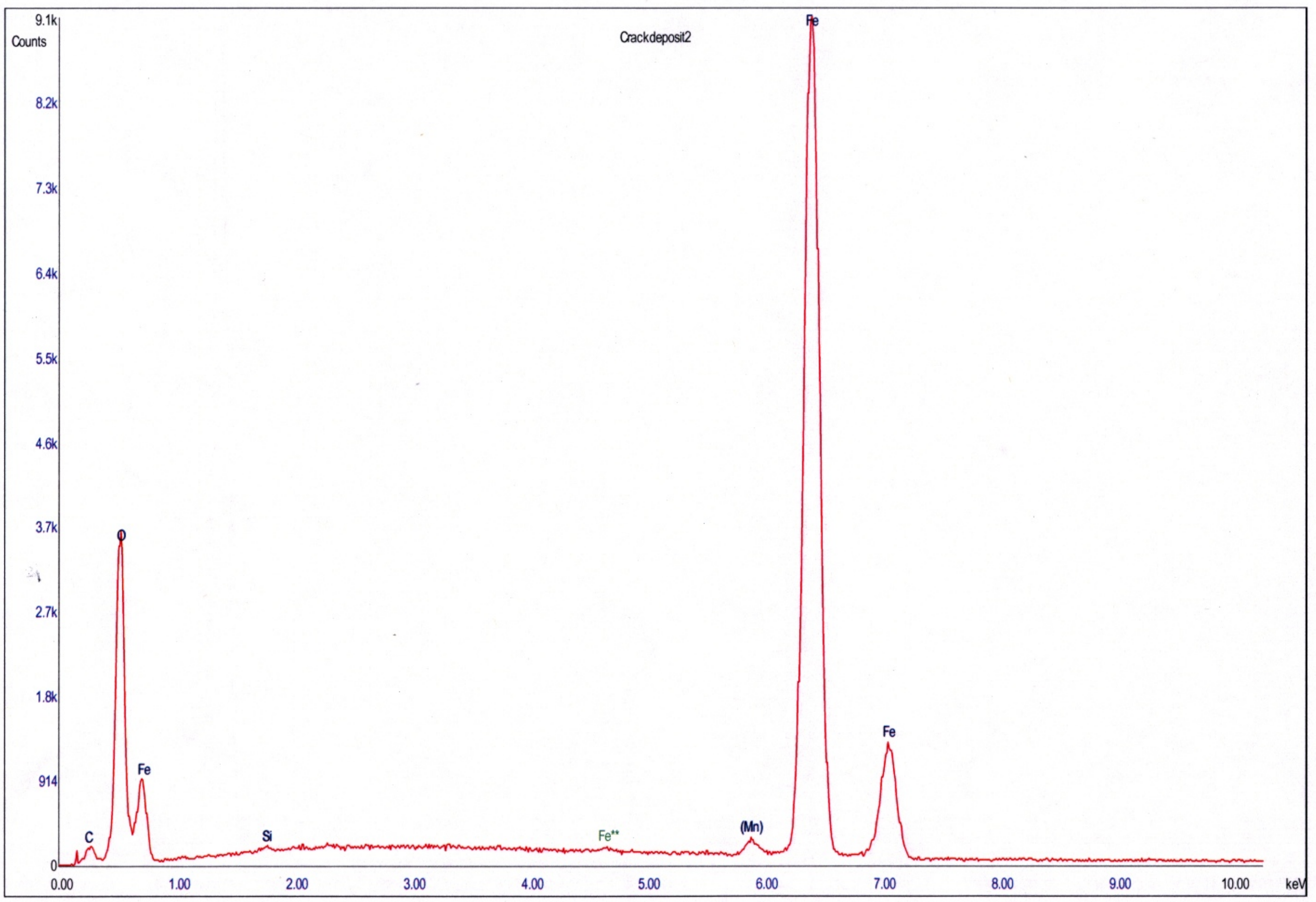

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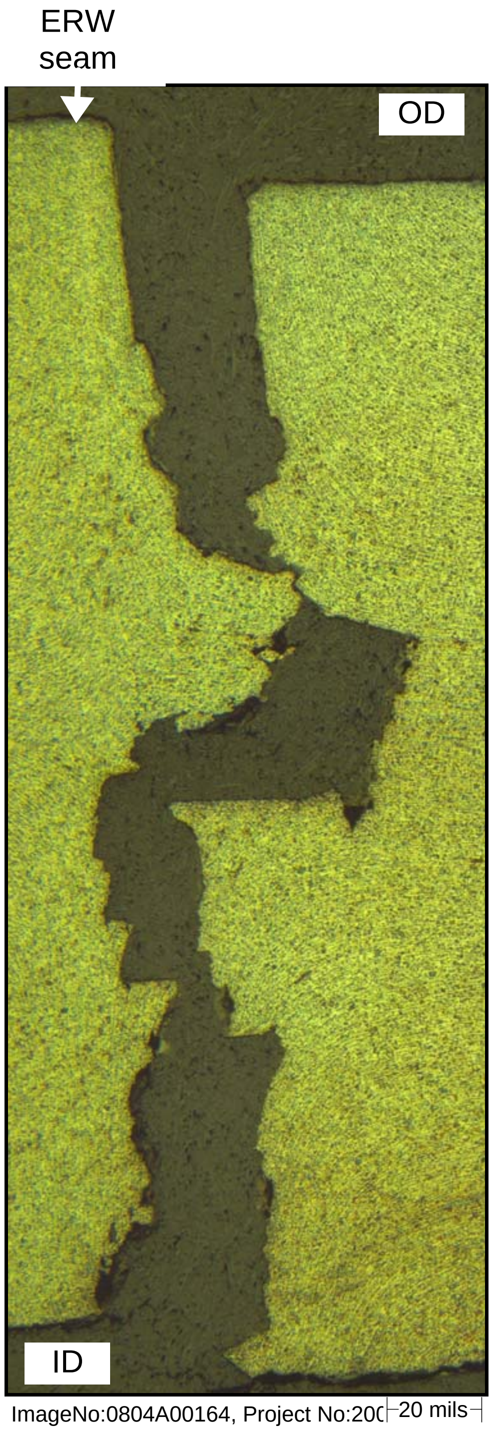
Figure 5. Energy dispersive spectrum of the black-gray deposit shown in figure 3.



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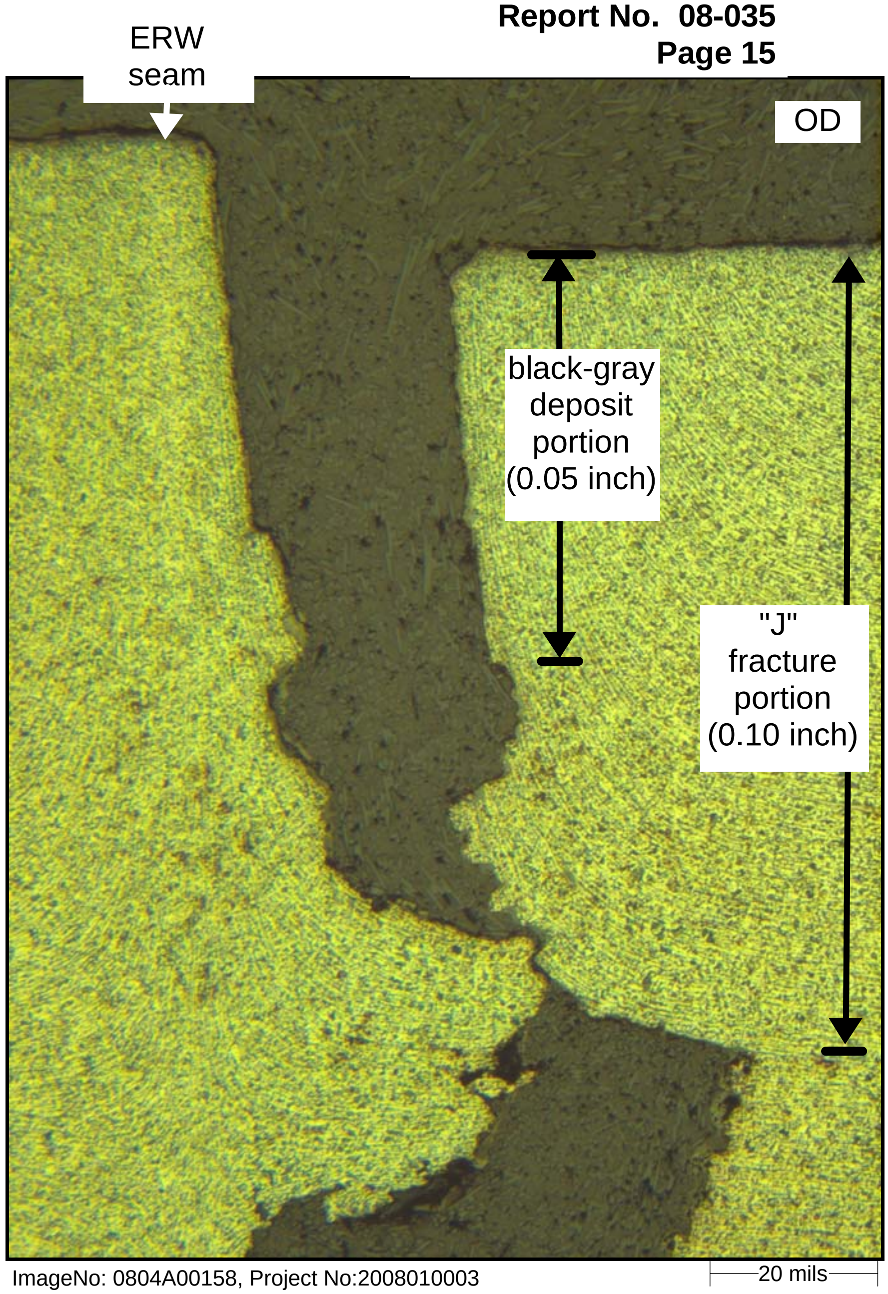

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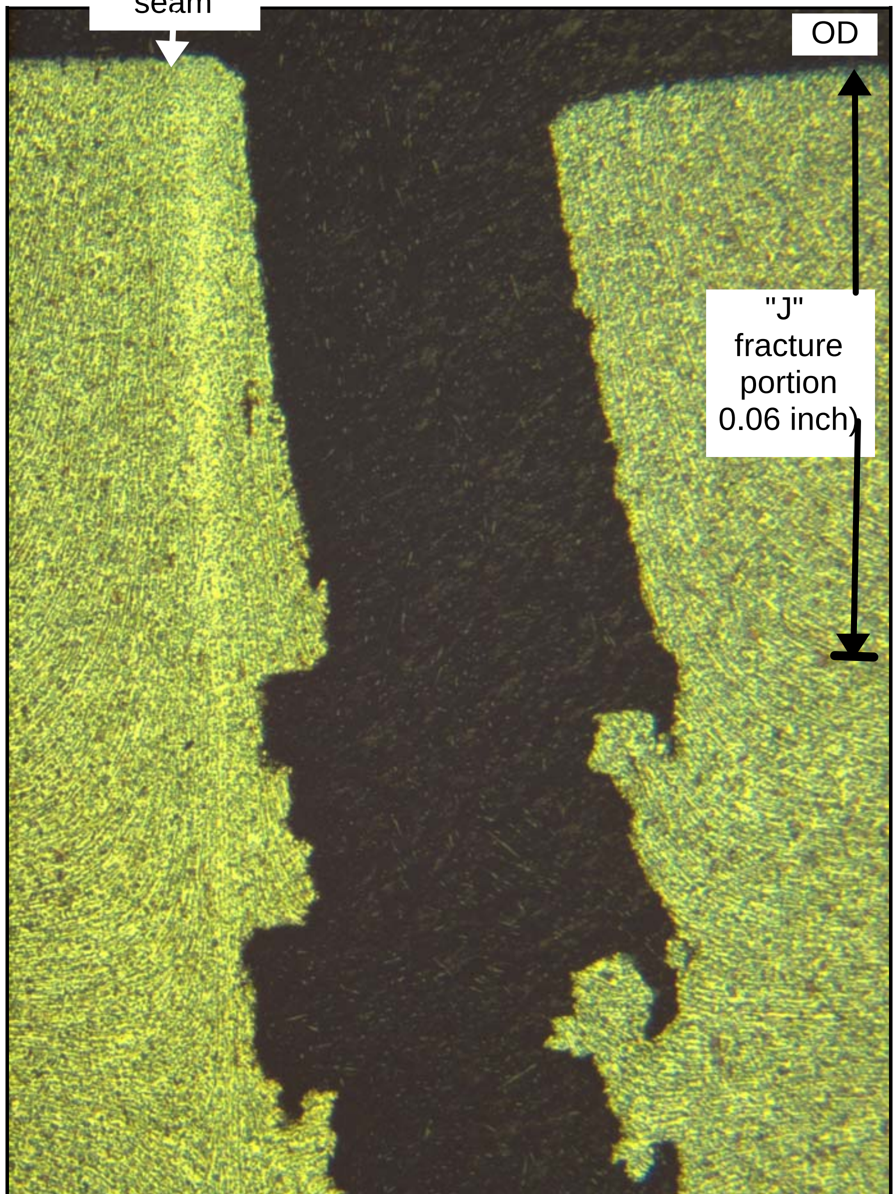
Figure 6. Composite photograph of a portion of metallurgical section "3-3" showing the mating fractures (left side of page) and a close-up photograph of the "J" portion of the fracture (right side of page). The "J" portion of the fracture and portion that contained the black-gray deposit (iron oxide) region is indicated on the photograph. The depth of the "J" portion of the fracture was calculated to be as deep as approximately 40% of the wall thickness. The black-gray deposit, labeled deposit "9" in table 1, extended as deep as 20% of the wall thickness. Etched with Nital reagent.



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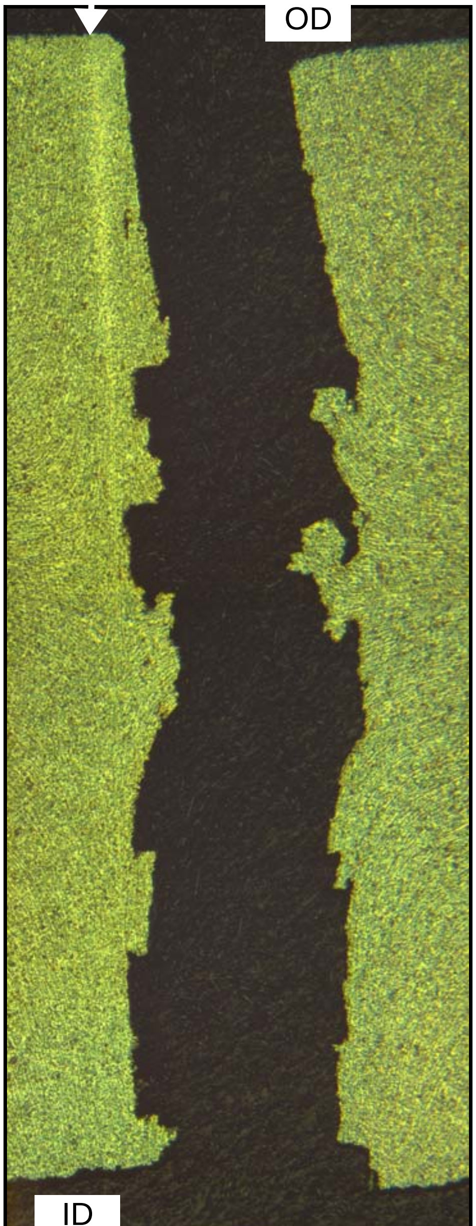

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Figure 7. Composite photograph of a portion of metallurgical section "2-2" showing the mating fractures (left side of page) and a close-up photograph of the "J" portion of the fracture (right side of page). The depth of the "J" portion of the fracture was calculated to be as deep as approximately 24% of the wall thickness. Etched with Nital reagent.