NATIONAL TRANSPORTATION SAFETY BOARD

Office of Research and Engineering
Materials Laboratory Division
Washington, D.C. 20594

March 7, 2022

MATERIALS LABORATORY FACTUAL REPORT Report No. 21-003

A. ACCIDENT INFORMATION

Place : Coolidge, Arizona
Date : August 15, 2021
Vehicle : 30-inch natural gas transmission pipe operated by Kinder Morgan
NTSB No. : PLD21FR003
Investigator : Kim West (RPH)[1]

B. COMPONENTS EXAMINED

The following pieces were torch cut from the pipe and submitted for examination:

(a) Piece "1" measured approximately 4-foot long by 0.7-foot wide and contained a longitudinal fracture that was adjacent the double submerged arc weld (DSAW) longitudinal seam.

(b) Piece "2" contained a fracture that mated with that of piece "1". This piece was approximately the same size as that of piece "1".

(c) Piece "3" measured approximately 3.3-foot-long by 1-foot wide and contained a fracture that extended nearly parallel and approximately 3 inches away from the longitudinal weld seam.

(d) Piece "4" is a 3-foot-long ring segment of the pipe that was torch cut between 29.5 and 32.5 feet south of the south end of the ejected pipe segment.

C. DETAILS OF THE EXAMINATION

1. Pipeline Specification

The ruptured pipe segment was manufactured to American Petroleum Institute (API) Standard 5L, Grade X70; as 30-inch nominal outside diameter (OD); 0.281-inch nominal wall thickness; longitudinal seam submerged arc welded pipe (also referred to in the industry as double submerged arc welded [DSAW] longitudinal seam pipe. The pipe rupture was located in Line 2000. The pipe in Line 2000 was installed in 1985. At the time of construction, the pipeline segment in the area of the rupture was owned and operated by All American Pipeline. At the time of the accident, the pipeline in the area of the rupture was owned and operated by Kinder Morgan. Based on installation records of Kinder Morgan, the pipe for Line 2000 in the area of the rupture was manufactured

[1] The Investigator-in-Charge (IIC) onsite was Sara Lyons.

between 1984 and 1985, by either Bergrohr (Herne, Germany) or Vallourec (Sedan, France). Based on onsite inspection, the outer surface of the pipe was coated with primer (a liquid adhesive). The coating consisted of a layer of adhesive, anti-corrosion spiral wrap tape, followed by a mechanical protection layer of a spiral wrap tape (inside to outside). The adhesive was black. The inner spiral wrap tape was black on all sides. The outer spiral wrap layer was black on the inner face and white on the outer face. The outer layer was also referred to as a “rock shield” layer. Corrosion control of the pipe was augmented by impressed current cathodic protection. The gas was flowing north.

2. Weld Joint Design

The joint for the DSAW longitudinal seam was specified as double V-groove butt-joint (see Figure 7). The process for making the pipe joint starts with a flat steel plate that is formed into a cylinder shape. The edges of the rolled plate are formed with double V-shaped grooves on the interior and exterior surfaces at the location of the longitudinal seam. An automated arc welder makes a single pass on the inner V-groove forming the inner longitudinal weld bead. This process is repeated on the outer V-groove forming the outer longitudinal weld bead. The outer face of the longitudinal weld seam contains a toe[2] portion at both edges of the weld. Similarly, the inner face of the longitudinal weld seam contains a toe portion at both edges of the weld.

3. On-site Examination of the Ruptured Pipe

On-site examination revealed an approximately 47-foot-long segment fractured from the pipeline (see figures 1 through 3). The fracture was predominately through the toe portions of the DSAW longitudinal seam. Details of the on-site examination are documented in Appendix 1. Pieces of interest were submitted to the NTSB Materials Laboratory for examination.

4. NTSB Materials Laboratory Group Examination

Metallurgical group examination of the submitted pipe pieces was performed between September 16 and 17, 2021 at the Safety Board’s Materials Laboratory, Washington, D.C. The following personnel participated in the group examination:

Frank Zakar	NTSB	Senior Metallurgist
Ed Komarnicki	NTSB	Technician
Kim West	NTSB	Investigator-in-Charge
Fred Hafner	Kinder Morgan	Metallurgical Engineer

Examination of the pipe pieces continued after the group examination.

[2] According to the American Welding Society, toe of the weld is the junction of the weld metal and base metal. Also, it can be described as the portion where the edge of the weld meets the base metal.

4.1 As-received Pipe Pieces

Figures 3 through 6 show photographs of four pieces that were torch-cut from the pipeline and submitted to the NTSB Materials Laboratory for examination. The submitted pipe pieces were arbitrarily labelled pieces “1” through “4”. The outer surface of piece “1” contained a longitudinal fracture that intersected the toe portions of the DSAW longitudinal seam, as shown in figure 4. The fracture face of piece “2” mated with that of piece “1”. Piece “3” contained a fracture that extended nearly parallel and approximately 3 inches away from the DSAW longitudinal seam. Piece “3” was torch cut from an area that was located downstream of piece “1”. The faces of pipe pieces “1” through “3” exhibited a blue tint and oxidation scale, consistent with exposure to heat from a fire. Piece “4” is a 3-foot-long ring portion of the pipe segment that was torch cut between 29.5 feet and 32.5 feet south of the south end of the ejected pipe segment. The ring segment was excavated from an area of the pipeline that showed no evidence of heat damage on the exterior coatings (the ring segment was reserved for testing of the pipe wall and DSAW longitudinal seam). Prior to detailed visual examination, pieces “1” through “3” were brush cleaned with Alconox, a commercial detergent, and force-dried with air supplied from an air compressor pump.

4.1.1 Examination of Piece “1”

Detailed visual examination of piece “1” revealed the outer face (that included the longitudinal weld, toe portions of the longitudinal weld, and base metal) showed evidence of pitting corrosion. The fracture face showed evidence of ratchet fracture features, indication of multiple origins, that emanated from the outer surface of the pipe at the toe portions of the DSAW longitudinal seam, in the area indicated by bracket “O” in figures 2, 3, 4 and 8. The origin of the fracture incorporated three separate fracture regions, indicated by brackets “O1”, “O2”, and “O3” in figure 8. Fracture region “O1” extended between 12.3 feet and 13.4 feet upstream of GW256360, measuring a length of 1.1 feet. Fracture region “O2” extended between 11.5 feet and 12.3 feet upstream of GW256360, measuring a length of 0.6 feet. Fracture region “O3” extended between 13.4 feet and 14 feet upstream of GW256360, measuring a length of 1.4 feet. The downstream (north) end of the 1.1-foot-long fracture region was connected to the upstream (south) end of fracture region “O2” by a transverse fracture that crossed over the DSAW longitudinal seam. The upstream (south) end of the 1.1-foot-long fracture region was connected to the downstream end of fracture region “O3” by another transverse fracture that crossed over the DSAW longitudinal seam.

4.1.1.1 Bench Binocular Microscope Examination of Piece “1”

Bench binocular microscope examination of the fracture face in the area corresponding to fracture regions “O1” and “O2” in figure 8 revealed evidence of multiple and continuous ratchet fracture features, indication of multiple origins, that emanated at the outer surface of the toe portion of the weld (see figure 9). The ratchet fracture regions were oriented perpendicular to the outer face of the pipe (on a radial-longitudinal plane). The fracture face in the area that corresponded to fracture region “O3” in figure 8 showed evidence of intermittent (non-continuous) regions of ratchet fracture features, that emanated at the outer surface of the toe portion of the weld. Intermittent in this report indicates the outer boundaries (upstream and downstream ends) of the ratchet fracture regions were not connected to each other. The longitudinal distance between the outer boundaries of the intermediate ratchet fracture regions varied. The ratchet features in the three fracture regions extended 0.1 inch below the outer surface. The fracture face within the ratchet fracture region showed no evidence of progressive crack features, such as fatigue cracking. The fracture face in areas outside of the continuous and intermittent rachet fracture feature regions exhibited rough texture features on a slant plane typical of overstress separation. The transverse fracture faces exhibited rough texture features typical of overstress separation with no evidence of ratches fracture features at the outer surface.

4.1.1.2 SEM Examination of Piece “1”

A 4.5-inch-long portion of the fracture face was cut from fracture region “O1” in figure 8 and ultrasonic cleaned with Alconox, a commercial detergent, followed by immersing the piece in “Evapo-Rust”, a commercial rust (corrosion) cleaner. The cleaning procedure removed oxide scale from the exposed surfaces. Scanning electron microscope (SEM) examination of the fracture face after the cleaning procedure revealed ratchet marks emanated from the outer surface of the pipe. Branch cracks were found within the ratchet feature regions and at the terminus of the ratchet fracture feature regions (see figures 10 and 11). The depth of the ratchet fracture features was similar to those observations made by bench binocular microscope. The areas located outside of the ratchet regions exhibited micro-void coalescent features typical of overstress separation, see figures 10 and 11.

4.1.1.3 Metallurgical Section of Piece “1”

A transverse section (longitudinal-radial section) was made through fracture region “O1”, in the orientation indicated by section line “O-O” in figure 8. The section was polished and etched with 2% Nital reagent. Examination of the etched section revealed the fracture face in the area near the outer surface exhibited a branch crack, indicated by arrow “F1” in figure 12. The other toe portion of the weld contained a branch crack, indicated by arrow “T1” in figure 12, that extended approximately 0.07 inch below the surface. The outer surface of the pipe in the base metal portion also contained a branch crack, indicated by arrow “B1” in figure12, that extended as deep as 0.06 inch below the surface.

4.1.2 Pieces “2” and “3”

Bench binocular microscope examination of piece “2” revealed the fine fracture features were obliterated from exposure to heat from the fire. Examination of piece “3” revealed the fracture face was on a slant place consistent with overstress separation, with no evidence of ratchet fracture features.

5. Evaluation of MPI indications on the Outer Surface of the Pipe After Grit Blast Cleaning

The NTSB Materials Laboratory contracted the American Stripping Company, Manassas, Virginia, to clean the outer surfaces of pieces “1” through “3” by grit blast method. This process was carried out prior to detailed examination of the fracture faces at the NTSB Materials Laboratory. The outer surfaces were blasted with 70 grit garnet to a white finish (NACE No.1/SSPC-SP5 White Metal Blast Cleaning standard). A one-inch-wide portion along the fracture face of each piece was masked with tape and covered with rubber insulation (to protect the fracture face from the grit blasting procedure).[3] After the grit blast cleaning operation, the outer faces were inspected at the Manassas facility by fluorescent magnetic particle inspection (MPI) method. The fluorescent MPI was performed by Testing Technologies, Woodbridge, Virginia, under contract by NTSB. Both operations were conducted on the same day. The rubber insulation and tape were removed from the fracture faces to facilitate the fluorescent MPI method.

The fluorescent MPI method revealed the outer surface of the three submitted pieces contained evidence of multiple colonies of longitudinal linear indications that were parallel to each other, consistent with stress corrosion cracking (SCC). The outer boundaries of each region of SCC colony were marked by a rectangle pattern (see Appendices 2A through 2B) to indicate the extent of a SCC colony. The size of each rectangle pattern (general size of a SCC colony) was measured. Piece “1” contained a total of 14 separate regions of SCC colonies; piece “2” contained a total of 4 separate regions of SCC colonies; and piece “3” contained a total of 9 separate regions of SCC colonies. Piece 3 contained the largest region of a SCC colony and it measured approximately 16.3 inches in length by 4 inches in circumference. The general size of each colony of longitudinal linear indication is tabulated in Appendix 2. Examples of a typical colony of longitudinal linear indications are shown in Appendices 2C through 2F.

The three pipe pieces were returned to the NTSB Materials Laboratory to determine whether the colony of longitudinal linear indications were surface breaking cracks. A transverse metallurgical section was made through the wall (base metal) of piece “1”, in the orientation indicated by section line “1A-1A” in Appendix 2A, a region that MPI exposed colonies of longitudinal linear indications. The photograph in Appendix 2G shows four of the many surface-breaking cracks that were found in section “1A-1A”. The location of the surface breaking cracks corresponded to colonies of linear indications. The shallow portion of the cracks propagated through the wall by intergranular crack path (see Appendices 2H through 2J). The deeper cracks were filled with iron oxide (verified by X-ray energy dispersive spectroscopy [EDS] analysis). The cracks in the base metal as observed in section “1A-1A” extended as deep as 0.016 inch below the surface.

Follow-up fluorescent MPI of the outer surface of piece “3” disclosed evidence of linear crack indications at the toe portion of the longitudinal weld in the same two areas identified on-site by MPI as having linear indications (indicated by brackets “L1” and “L2”

[3] A flexible rubber tube (water hose) was used as rubber insulation. A longitudinal cut was made along the length of the tube and the pipe fracture was inserted into the longitudinal cut portion of the hose to protect the fracture face.

in Appendices 1A through 1C). A cross section was made through linear indication “L2” in the orientation indicated by section line “3B-3B in Appendix 1C and 2B. The section was prepared and etched with 2% Nital reagent (see Appendix 2K). Examination of section “3B-3B” revealed the crack at the toe portion of the weld, indicated by arrow “B” in Appendices 2K through 2M, extended 0.06 inch below the surface.

Another section was made through a linear indication at the toe portion of the weld in the orientation indicated by section line“3E-3E” in Appendix 2B (discovered by fluorescent MPI and unrelated to crack indications “L1” and “L2”). Appendix 2N shows a photograph of section “3E-3E”. The crack at the toe portion of the weld, indicated by arrow “E” in Appendices 2N through 2P, extended 0.14 inches below the surface.

The typical microstructure of the base metal from the ejected pipe segment is shown in Appendix 2Q. For comparison, the typical microstructure of the base metal from the 3-foot-length ring segment is shown in Appendix 2R.

Table 1 provides a summary of crack depth for all metallurgical sections prepared and discussed in this report. In summary, the deepest crack in the pipe was located at the toe portion of a longitudinal weld and it extended approximately 0.14 inch below the surface. The base metal in areas adjacent to the toe of the weld contained a network of cracks and one of those cracks extended approximately 0.07 inches below the surface. The base metal in areas located approximately 3 inches away from the toe of the longitudinal weld contained cracks that were shallower (extending as deep as 0.016 inch below the surface) compared to those adjacent to the toe of the longitudinal weld.

Table 1. Depth of Surface Cracks Found in Metallurgical Cross Sections

Piece Number	Metallurgical Cross Section	Location of Crack	Maximum Depth of Crack (Inches)	Reference Image(s)
1	O-O	Surface crack at the toe portion of the weld (located opposite the one containing the fracture origin)	0.07	Fig. 12
1	O-O	Surface crack in the base metal (located approximately 0.12 inch laterally away from the toe portion of the weld)	0.06	Fig. 12
1	1A-1A	Surface crack in the base metal	0.014	Appx. 2G
1	1A-1A	Surface crack in the base metal	0.005	Appx. 2H
1	1A-1A	Surface crack in the base metal	0.009	Appx. 2I
1	1A-1A	Surface crack in the base metal	0.016	Appx. 2J
3	3B-3B	Surface crack adjacent to toe of weld	0.06	Appx. 2K-2M
3	3E-3E	Surface crack at toe portion of weld	0.14	Appx. 2N-2P

6. Chemical Composition of Ejected Pipe Segment and Ring Sample

As indicated earlier, the pipe was installed in 1985. API Standard 5L, 34th edition, dated May 31, 1984, would have been the standard that was in affect at the time the pipe was installed. The chemical composition was determined for the base metal of the ejected pipe segment and 3-foot-long ring sample using Optical Emission Spectroscopy (OES) and for all elements greater than 0.001% by weight, including carbon and sulfur.[4] The chemical analysis was performed by Energy Systems Inc (ESi), Peachtree Corners, Georgia. The results of the chemical analysis indicated the composition of the base metal for the ruptured pipe and 3-foot-ring segment were within the limits indicated in the 34th issue of API 5L, for grade X70 pipe (shown in table 2).

For information purpose, chemical analysis was also performed on the inner and outer bead of the longitudinal weld seam from the 3-foot-long ring sample. Table 2 shows the chemical results of the chemical composition for the outer and inner weld portion of the longitudinal welds.

7. Ring Sample

7.1 Tensile Testing

API Standard 5L, 34th edition, indicated that for welded pipe, in sizes 8 and 5/8 inch and larger, the tensile properties shall be determined by tests on transverse[5] specimens. The transverse body-tensile specimens shall be taken from an area that is located opposite the weld and shall represent the full wall thickness of the pipe from which the specimen was cut. In the transverse weld-tensile specimens the weld shall be located at the center of the tensile specimen. The specification also indicated that transverse weld specimens shall be tested for ultimate tensile strength only. The yield strength and elongation values for the weld were recorded for information purpose.

A total of 6 transverse tensile specimens were machined from the ring sample - three transverse body-tensile specimens and three transverse weld-tensile specimens. Each tensile specimen was machined with a gage length of 2 inches and a gage width of 1.5 inches, in accordance with API 5L and American Society for Testing and Materials (ASTM) A370, “Standard Methods and Definitions for Mechanical Testing of Steel Products”. Tensile specimens were machined and tested at ESi, Peachtree Corners, Georgia.

Table 3 shows the results of the tensile properties for the base metal. The measured ultimate tensile strength, yield strength, and elongation were greater than the minimum specified values. Table 4 shows the results of the ultimate tensile strength (UTS) of the longitudinal weld seam (only the UTS values are required to be reported). The measured UTS for the longitudinal weld seam tensile specimens were greater than the minimum specified value (82,000 psi).

[4] With the exception that Boron was measured to 0.0001% by weight.
[5] Oriented circumferential with respect to the length of the pipe.

7.2 Charpy V-Notch Impact Testing

Purchasing records from Kinder Morgan indicated the pipe was ordered to API 5L Supplementary Requirement SR5, which specifies 35% minimum shear fracture appearance per set of three Charpy specimens per heat and 50% minimum all-heat average shear fracture appearance. Testing temperature for Charpy specimens was 32 degrees Fahrenheit (° F). According to ASTM A370 and Specification for Line Pipe – API Specification 5L, 34th edition, transverse[6] Charpy specimens prepared from longitudinal weld seam pipe are to be removed from an area that is located 90 degrees circumferentially away from the longitudinal weld seam. Sub-size Charpy specimens (approximately 1/2 the thickness of a standard specimen) were prepared to accommodate the wall thickness of the pipe (0.281 inch [7.14 mm]).[7]

Charpy V-notch specimens were prepared from the base metal and the longitudinal weld seam of the ring sample. A total of 12 Charpy V-notch transverse specimens were prepared. Six Charpy V-notch samples were tested from the base metal and 6 transverse samples were tested from the longitudinal weld seam. Three specimens from the base metal and 3 specimens from the longitudinal seam weld were tested at 32° F. The other three specimens from the base metal and 3 specimens from the longitudinal seam weld were tested at 50° F. Tables 5 and 6 shows the results of the Charpy V-notch impact tests. All the Charpy specimens that were tested did not completely fracture, so the lateral expansion and percent shear values were not reported.

There was no evidence that the pipe was ordered to API 5L Supplementary Requirement SR8, which would have specified a Charpy absorbed energy requirement. The pipe body Charpy test absorbed energy results in the factual report were well above the 44 foot-pound (ft-lb) full-size equivalent minimum required to achieve ductile fracture arrest based on the referenced equations in ASME B31.8 Section 841.1.2.[8] The average Charpy energy value for the longitudinal weld seam specimens that were tested at 32° F was slightly lower than the full-size equivalent minimum required to achieve ductile fracture arrest, but the average energy value for specimens tested at 50° F was well above full-size equivalent minimum required to achieve ductile fracture arrest.

[6] Length of a Charpy specimen is parallel to the circumference of the pipe.

[7] The size of a standard Charpy specimen is about 0.394 inch x 0.394 inch x 6.67 inch (10 mm x 10 mm x 55 mm). Half size Charpy specimens (10mm x 5mm x 55 mm) were machined to adjust for the thickness of the pipe.

[8] The calculated Charpy V-notch (CVN) minimum energy was based on Battelle Columbus Laboratories (BCL) (AGA) formula that resulted in a calculated value of 44 ft-lbs for full size specimens. Calculations were based on maximum allowable operating pressure (MAOP) of 944 psig, calculated hoop stress of 50.3 kilopounds per square inch (ksi), radius of 15-inch, and wall thickness of 0.281-inch. The API 5L specification further states that when using subsize specimens, the specification values shall be reduced proportionally with the reduction in cross sectional area. For ½ size specimens that were tested, the Charpy energy values must be equal to or greater than 22 ft-lbs.

7.3 Wall Thickness

According to API 5L, 34th edition, the specified wall thickness for a 0.281-inch nominal wall pipe is between 0.259 inch and 0.336 inch. Samples of the plastic wrap tape materials were removed (peeled away) onsite from the ring piece. The wall thickness of the ring piece without the exterior coatings measured between 0.287 inch and 0.289 inch, which was within the specified range. The outside diameter of the ring segment measured approximately 30 inches, which was consistent with the specified outside diameter.

7.4 Spiral Wrap Tape

According to All American Pipeline original construction Field Book #2553, the pipeline was coated with Kendall Polyken 919 primer (a liquid adhesive), 950-15 tape (inner layer), and 980-15 tape (outer layer). The coating was applied in the field using 6-inch-wide tape with one-half to one inch overlap. The contractor that applied the tape was not determined. The technical data sheet for Polyken 950-15 tape and Polyken 919 primer were not posted online.

The technical data sheet for Polyken-980-15 tape shows the tape is offered in three different thicknesses (15 mils, 20 mils, 25 mils, and 30 mils).[9] The number following the 980 designation indicates the total thickness of the tape. For example, Polyken-980-15 indicates the tape as having a total thickness of 15 mils. The data sheet further states Polyken-980 as having 9 mils of backing and 6 mils of adhesive. A sample of the inner and outer spiral wrap tape was removed on-site from the 3-foot-long ring sample. The thickness of each tape was measured with a micrometer. The thickness of the inner wrap tape layer (black on all sides) measured approximately 0.016 inch, and the thickness of the outer wrap tape layer (black inside face and white outer face) measured approximately 0.015 inch. The thickness of each collected tape sample was consistent with the thickness specified for each respective tape layer.

Report prepared by:

Frank Zakar
Senior Metallurgist

[9] One mil is equivalent to 0.001 inch. For example, 9 mils is equivalent to 0.009 inch.

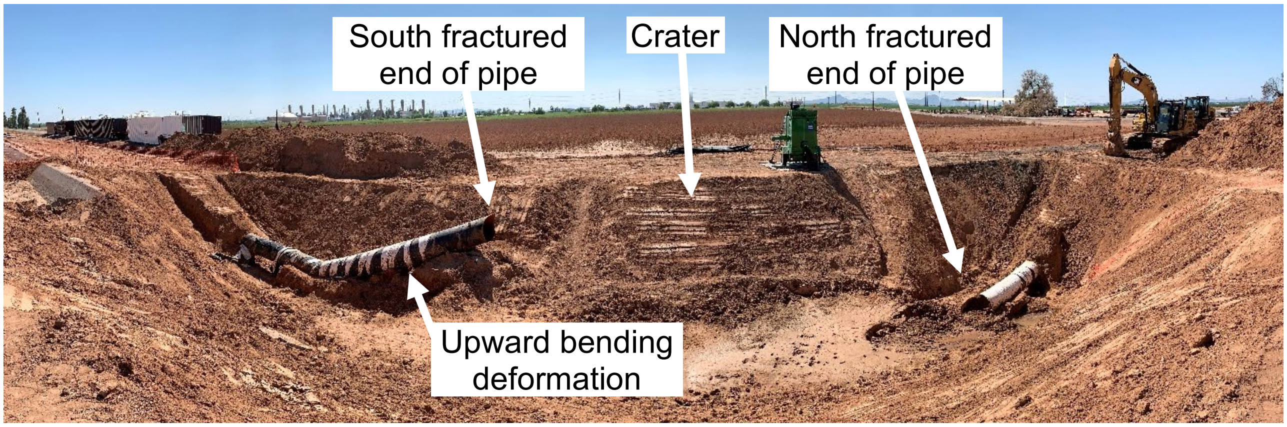


Figure 1. Photograph of the two fractured ends of the ruptured gas pipe located within the crater, after excavation crew exposed portions of the underground pipe.

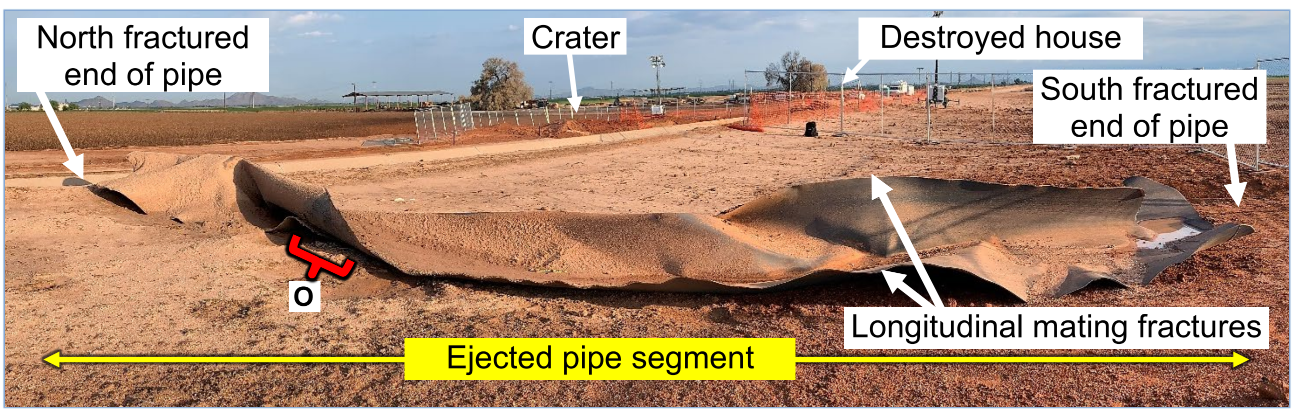


Figure 2. Photograph of the approximately 47-feet ejected segment of pipe. The origin of the fracture was ultimately determined to be located in the general area indicated by bracket "O".

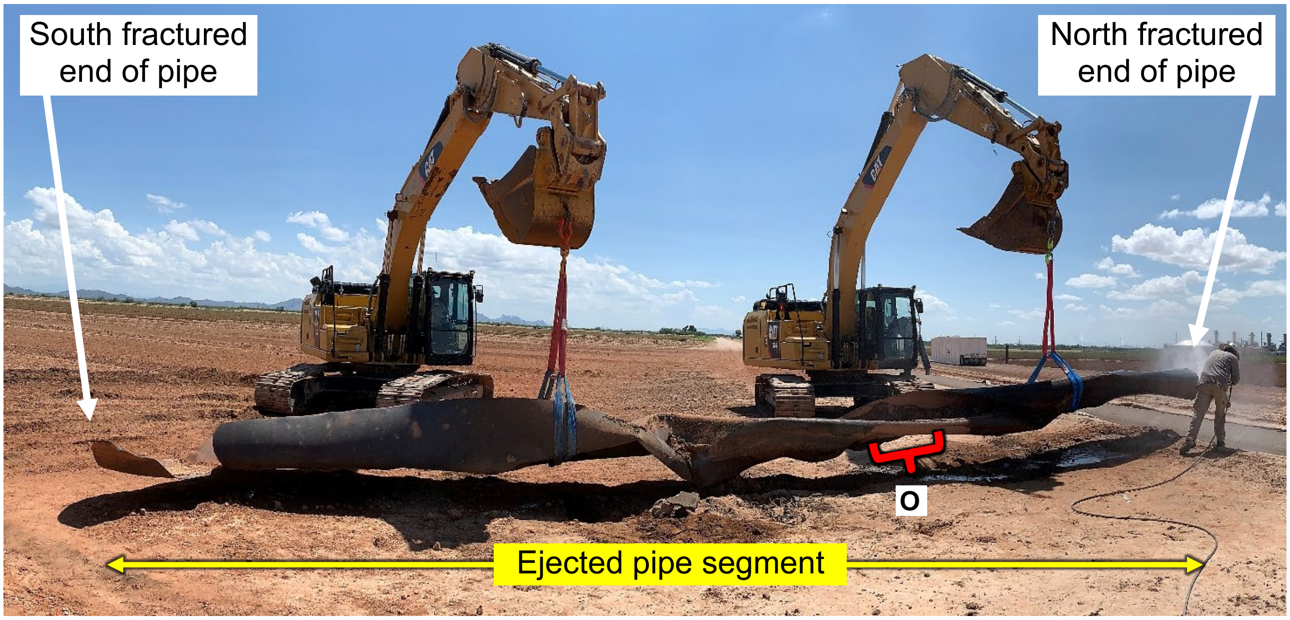


Figure 3. Two track hoes lifting approximately 47-feet of the ejected pipe segment for power-wash cleaning with water prior to inspection by NTSB. The origin of the fracture was ultimately determined to be located in the general area indicated by bracket “O”.

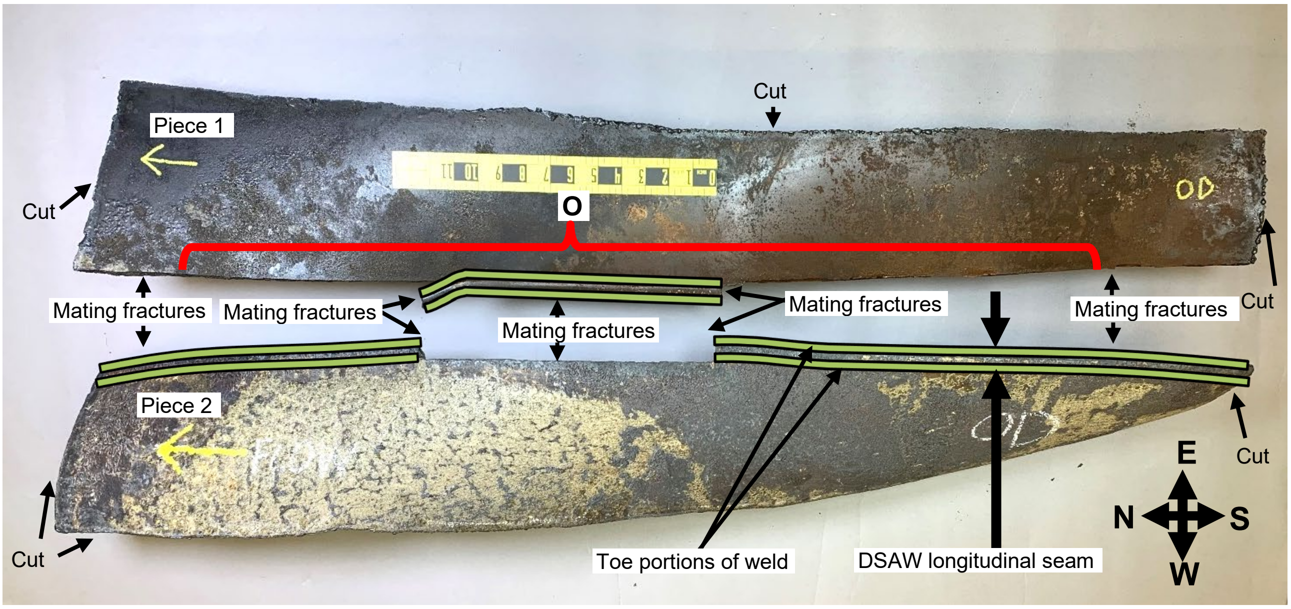


Figure 4. As-received pieces arbitrarily labelled “1” and “2” that were torch cut from the pipe showing the outer face with the mating fractures facing each other. The fracture intersected the toe portions of the DSAW longitudinal seam. The fracture faces contained evidence of ratchet fracture features, indication of multiple origins, that emanated from the outer surface, in the general area indicated by bracket “O” in this figure and by bracket “O” in figures 2 and 3. The location of the toe portions of the weld are indicated by green lines. At the time of the accident, gas was flowing north in the direction indicated by a yellow arrow.

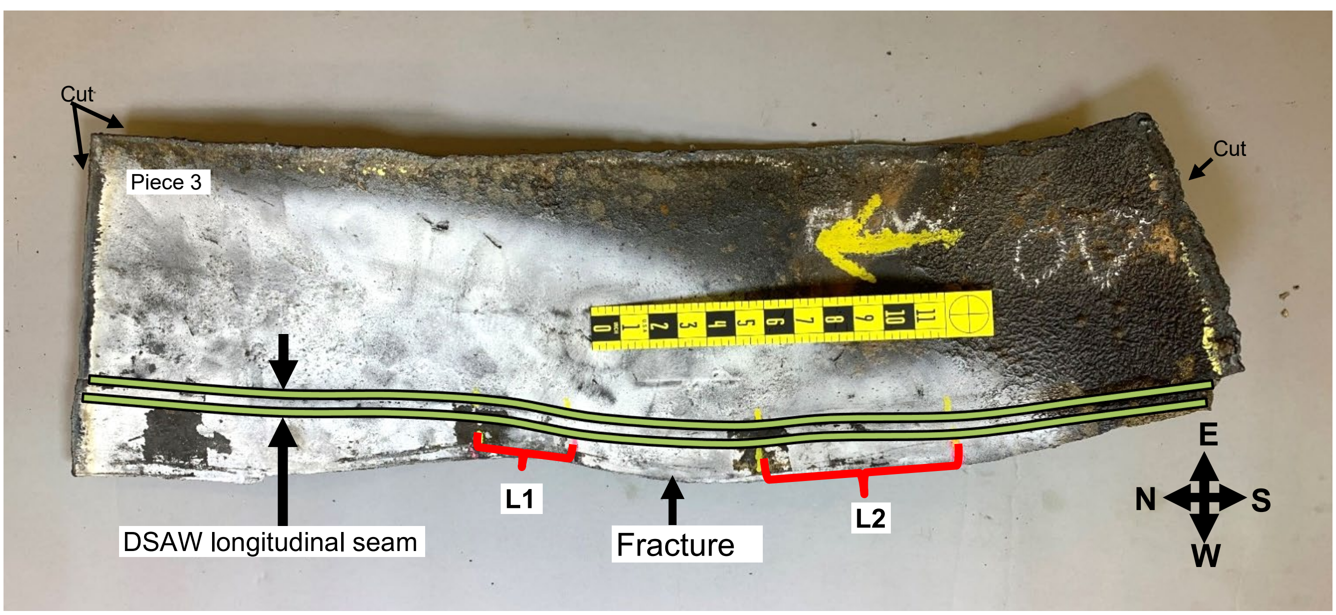


Figure 5. As-received piece “3” that was torch cut from the pipe showing the outer face. The toe portions of the DSAW longitudinal seam are located in areas marked by green lines. Portion of the outer surface was painted white to enhance magnetic particle inspection (MPI). On-site MPI found linear indications at the toe of the longitudinal weld seam (the toe portion closest to the fracture face) in the areas indicated by bracket “L1” and “2”.

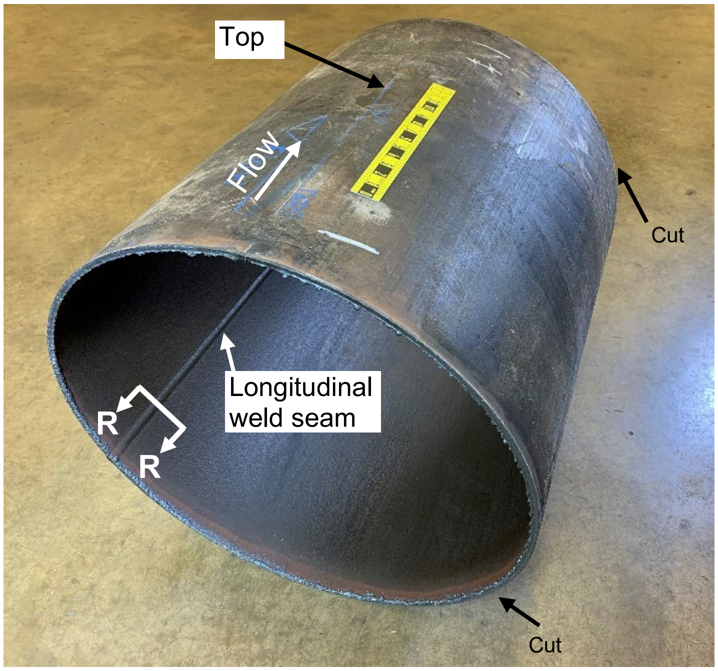


Figure 6. As-received 3-foot-long ring portion of a pipe segment that was located upstream of the ejected pipe segment. The exterior coatings were removed on-site in preparation for cutting out tensile and Charpy V-notch specimens.

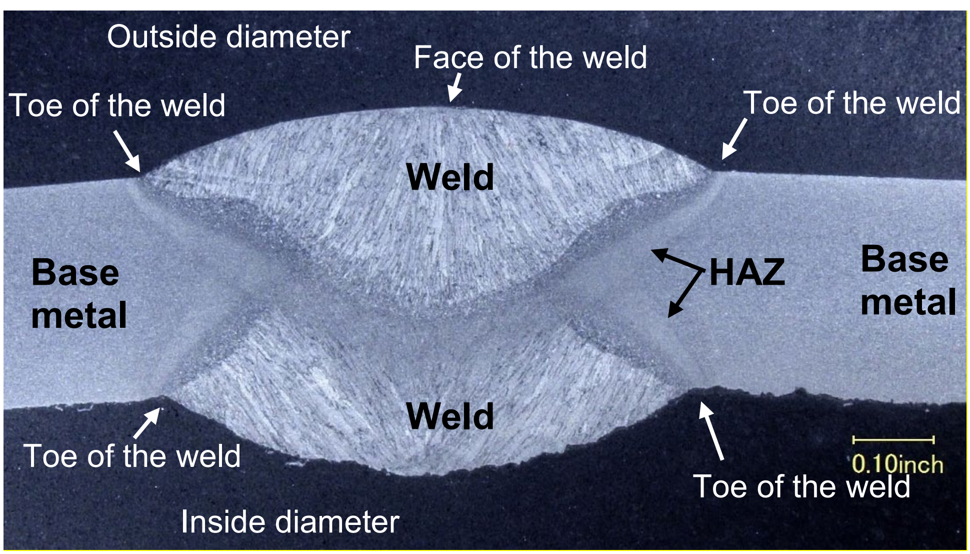


Figure 7. Cross section of the DSAW longitudinal seam from the ring portion looking south (upstream), in the orientation indicated by section line “R-R” in figure 6, showing various parts of the weld, such as location of the toe portions of the welds, base metal, and heat affected zones (HAZ). Etched with 2% Nital reagent.

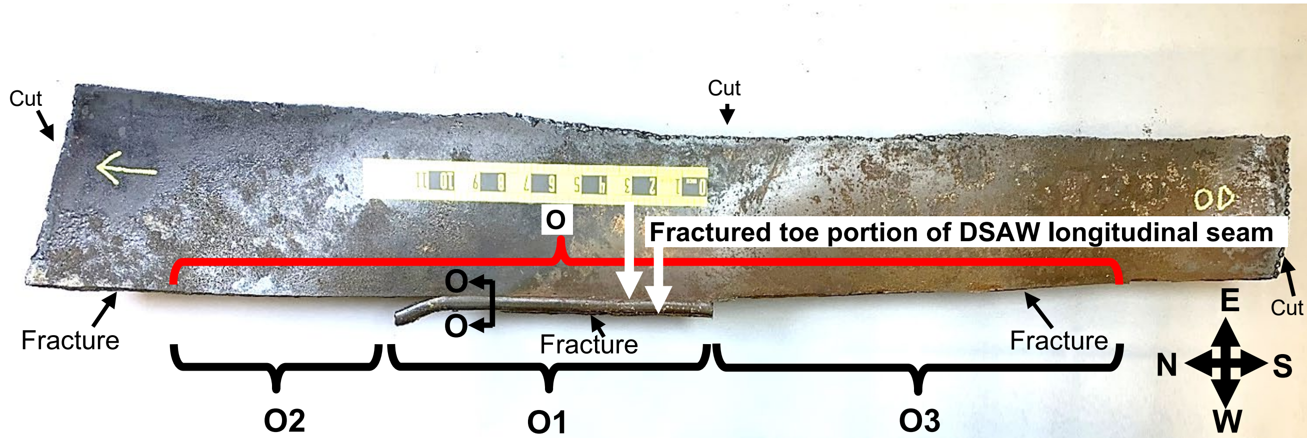


Figure 8. As-received pipe piece “1” showing the outer face and fracture that intersected the toe portions of the DSAW longitudinal seam. The origin of the fracture indicated by bracket “O” incorporated three separate fracture segments indicated by brackets “O1”, “O2”, and “O3”.

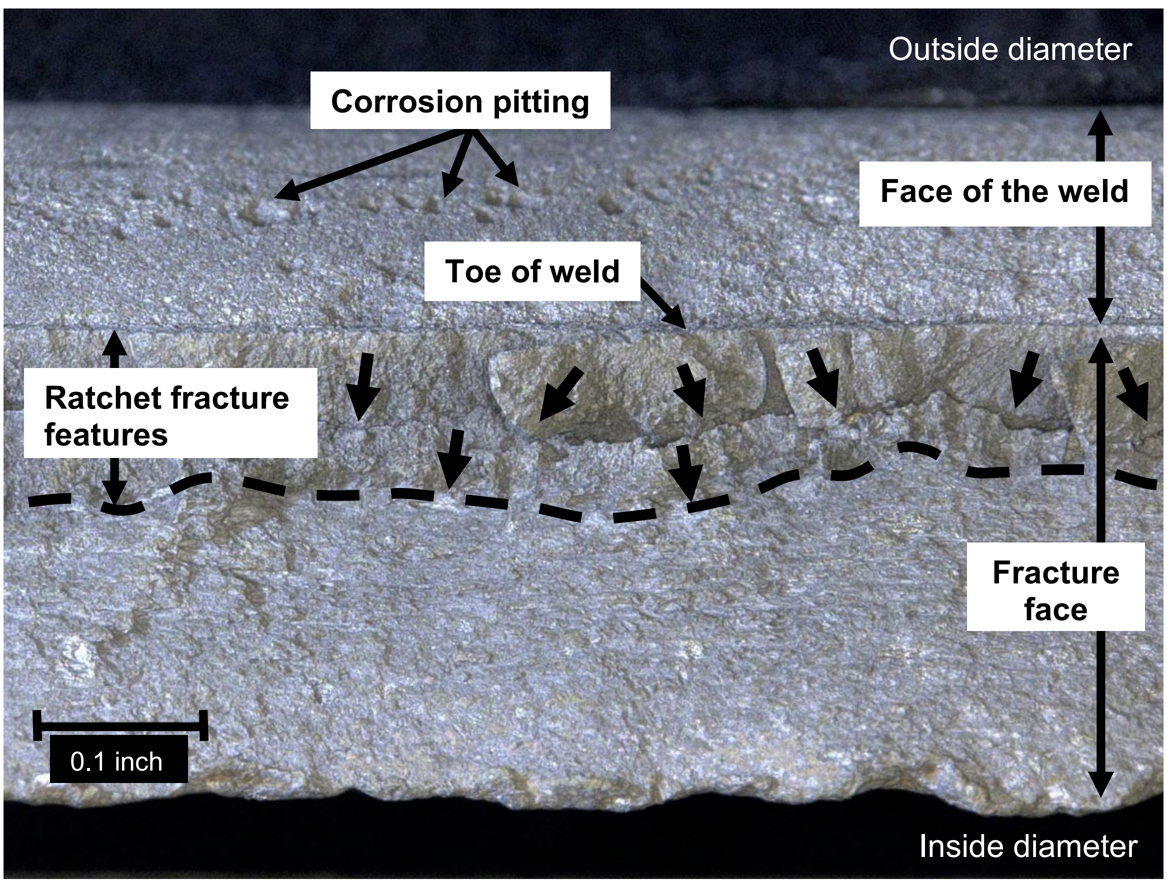


Figure 9. Optical photograph of a portion a fracture face showing typical ratchet fracture features that emanated from the toe of the weld at the origin of the fracture in the area indicated by bracket “O” in figures 2, 3, 4, and 8. General direction of fracture propagation is indicated by arrows. The ratchet features extended approximately 0.1 inch below the toe of the DSAW longitudinal seam to the areas indicated by a dashed line.

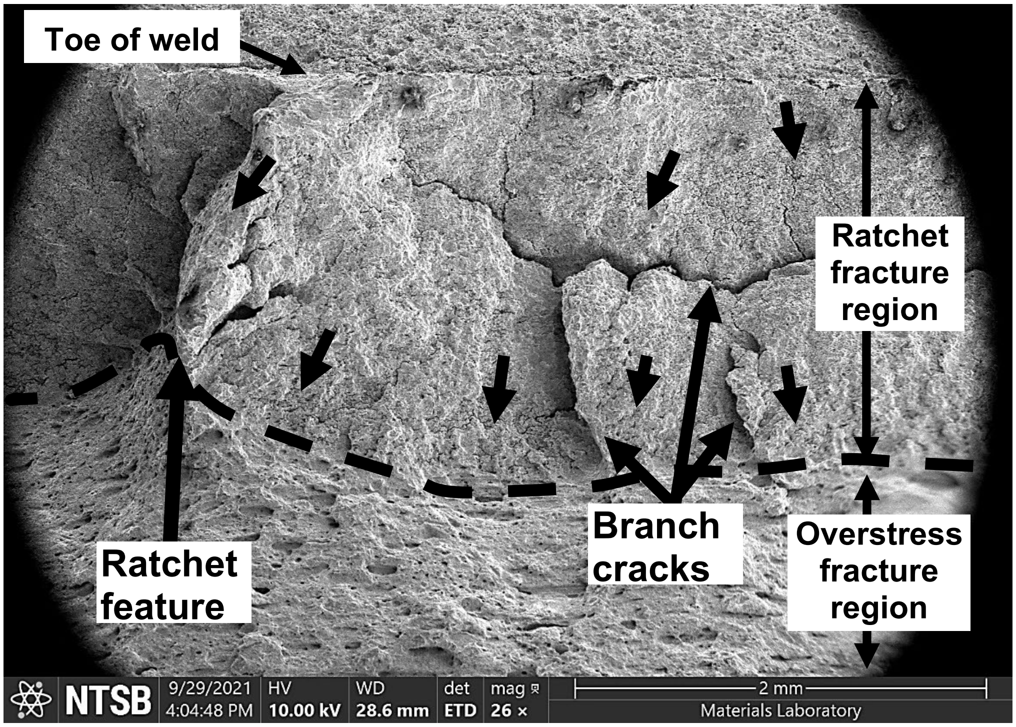


Figure 10. SEM photograph of the fracture face located within the origin of the fracture indicated by bracket “O” in figures 2, 3, 4, and 8. Arrows indicate the general direction of fracture propagation within the ratchet fracture region.

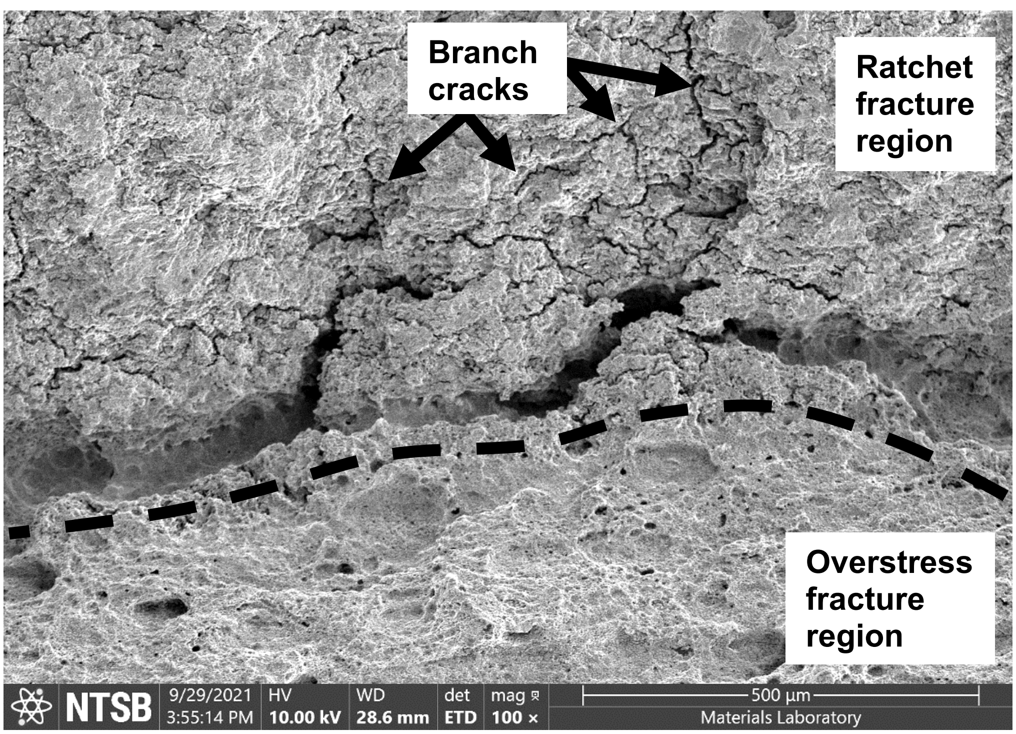


Figure 11. SEM photograph of the fracture face showing a typical transition region between the ratchet region and the overstress region (micro-void coalescence features). The ratchet fracture region contained several branching cracks.

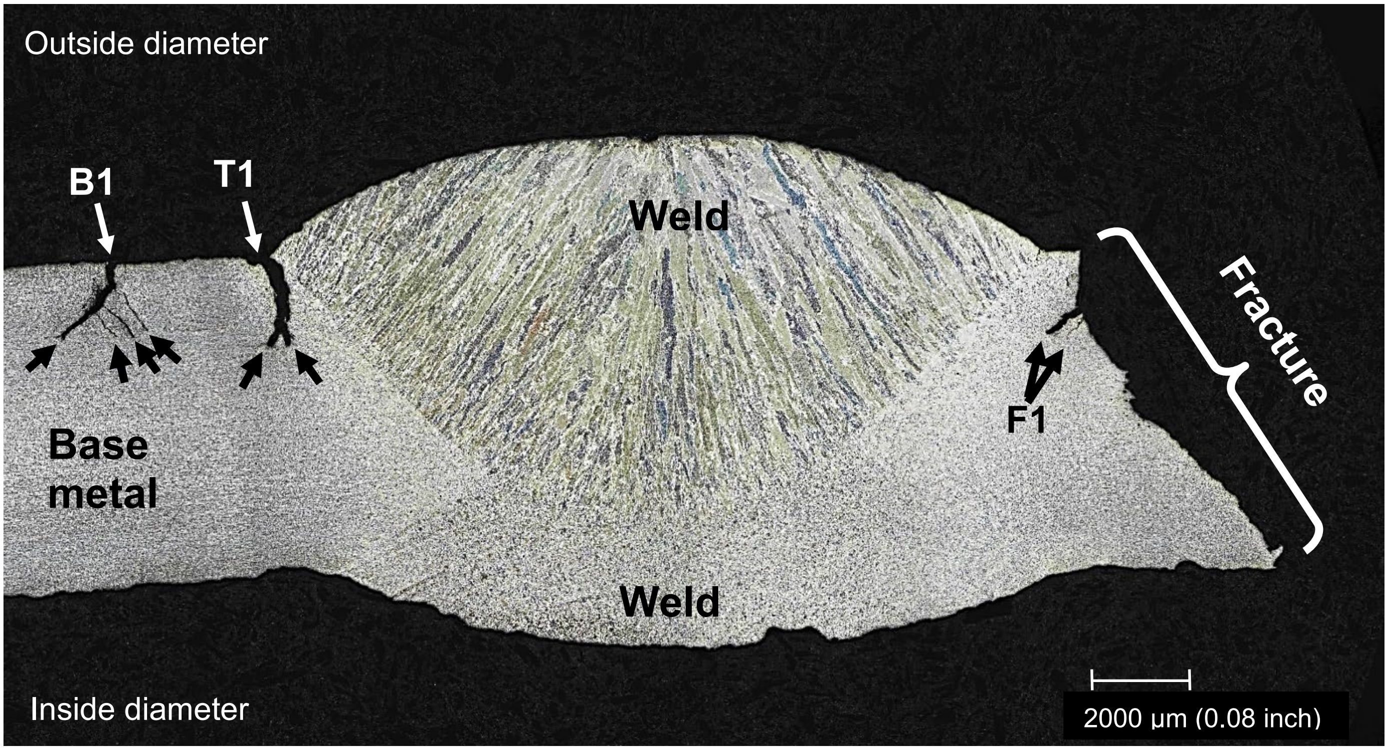


Figure 12. Metallurgical cross section O-O showing the fracture face; a branch crack extending from the fracture face in the area indicated by arrows “F1”; a branch crack indicted by arrow “T1” (approximately 0.07 inches deep) that intersected the toe of the weld; and a branch crack indicated by arrow “B1” (approximately 0.06 inches deep) that extended into the base metal. Crack “B1” was located approximately 0.12 inch laterally away from crack “T1”. The ends of the branch cracks are indicated by arrows. Etched with 2% Nital reagent.

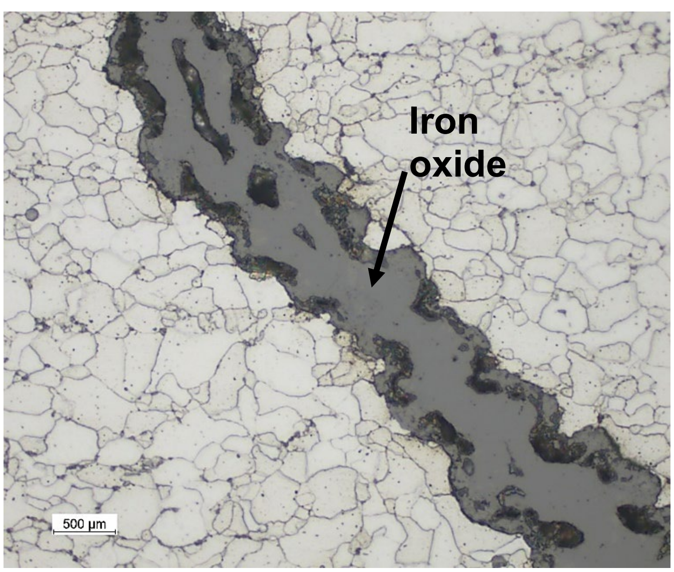


Figure 13. Iron oxide deposit (light grey area) within a branching crack “B1” in figure 12. Etched with 2% Nital reagent.

APPENDICES

APPENDIX 1

Onsite Work

On-site Examination of the Ruptured Pipe

An in-service rupture occurred on El Paso Natural Gas Line 2000, leaving a crater in the ground in the area of the pipeline fracture. The ruptured segment of pipe was ejected from the pipeline. Gas was flowing from south to north direction. On-site examination of the fractured pipe was conducted by Frank Zakar (NTSB), Wesley Mathews (PHMSA), and Fred Hafner (Kinder Morgan).

Crater

Two fractured ends of the pipeline were exposed in the crater. The south end fracture had an exposed length of approximately 3-feet. Reportedly, on the day of the accident, the North end fracture had an exposed length of approximately 1-foot. On the following day soil and water had accumulated at the bottom of the crater and covered the north end fracture. No pipe fragments were found in the crater.

Examination of Ejected Pipe Segment

The ejected pipe segment was visually examined. The majority of the external coating had been consumed by fire, leaving most of the external surface bare. The inner and outer surface, and fracture faces of the ejected pipe exhibited blue tint consistent with heat exposure. Major portions of the ejected pipe segment were covered with dry mud (result of rain shower after the accident). The ejected piece was power washed with water to facilitate follow-up examination of the welds and fracture faces.

The ejected segment of pipe contained two girth welds (GW). The GW at the south end was identified as GW 256350 and GW 256360 at the north end, based on in-line inspection records. The length of the longitudinal seam welds on the ejected pieces were measured, as well as the circumferential distance between the seam welds on adjacent sides of the girth welds. The longitudinal weld seam between the two girth welds measured approximately 39.4 feet in length. The longitudinal seam welds were submerged arc welds with weld passes from both the inside and outside, as specified in the original installation records. The fracture continued 2.4 feet upstream of GW 256350 and 5.1 feet downstream of GW 256360. The total length of the ejected piece was 46.9 feet.

Visual examination of girth weld at the south end of the ejected piece identified the “weld buttons”, indicating approximately the 6 o’clock and 12 o’clock position of the pipe. The location of longitudinal weld was based on clock position looking north, in the direction of gas flow. Between GW 256350 and 256360, the longitudinal weld seam was located at the 5 o’clock position relative to the top of the pipe. The longitudinal weld seam upstream of GW 256350 was located at the 8:30 o’clock position, and the longitudinal weld seam downstream of GW 256360 was located at 8 o’clock position.

The fracture propagation direction was determined by visual examination of the fracture surfaces. Chevron features were found on the fracture face indicating the fractures terminated at the north and south end of the ejected pipe segment with the origin located in an area between north and south ends. The ejected piece contained a longitudinal fracture. Between GW 256350 and an area located approximately 9.3 feet upstream of GW 256360 (calculated length of 30.1 feet), the longitudinal fracture intersected the toe portions of the longitudinal seam weld. Between 9.3 feet upstream of GW256360 and GW 256360, the fracture was propagating in the base metal nearly parallel and located approximately 3 inches away from the longitudinal seam weld. The longitudinal fracture extended through approximately 76% of the pipe joint length (length between the two girth welds). The ejected pipe segment showed no evidence of mechanical damage, such as gouge damage.

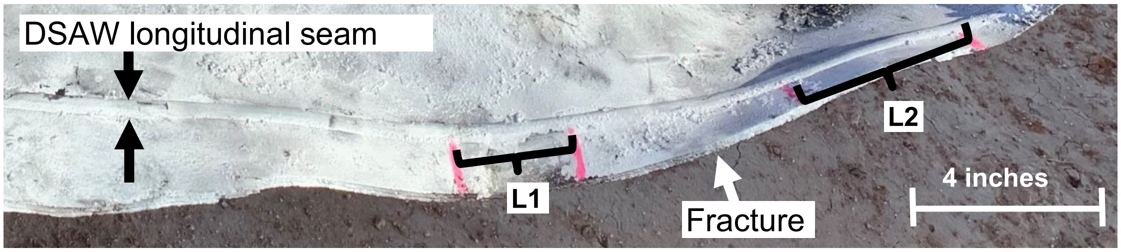
The profile of the pipe in the area of the longitudinal fracture portion appeared to follow a straight and level path between 11 feet and 15.9 feet upstream from GW 256360. The fracture face in this area appeared irregular. Inspection of the irregular fracture region with a magnifying glass revealed what appeared to be ratchet-like fracture features that emanated from the outer surface of the pipe (in the area indicated by bracket "O" in figure 2 of the Materials Laboratory Factual Report). A 4-foot-length portion of the fracture that incorporated the irregular fracture area was torch cut from the pipe and submitted to the NTSB Materials Laboratory for detailed examination. The longitudinal profile of the pipe that extend out and away from the ends of the straight fracture area contained a wave pattern (similar to a sinusoidal wave pattern) and exhibited evidence of a shear fracture.

The ejected piece also contained four through-wall tears in the pipe body in areas that exhibited severe mechanical deformation (bending and twisting deformation). These tears were arbitrarily labelled "A" through "D". Tear "A" was nearly longitudinal and located approximately between 9.2 and 9.5 feet downstream of GW 256350. Tear "B was nearly longitudinal and located between 10.4 and 10.7 downstream from GW 256350. Tears "C" was nearly transverse (circumferential) and located 6 feet upstream from GW 256360. Tear "D" was nearly longitudinal and located between 2.3 feet and 2.5 feet upstream from GW 256360.

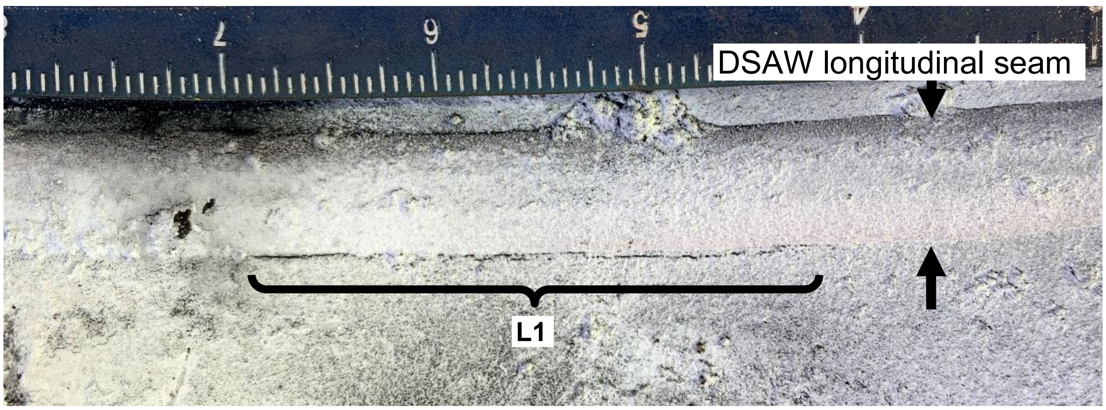
On-site Magnetic Particle Inspection

As indicated earlier, the fracture in the area between GW 256360 and 9.3 feet upstream of GW 235360 was propagating in the base metal nearly parallel and located approximately 3 inches away from the longitudinal seam weld (see appendix 1A). The outer surface of the longitudinal weld in the area between 6 feet and 9.3 feet from GW256360 (3.3 foot-length) was inspected by black on white magnetic particle inspection (MPI). MPI was conducted by IAG Integrity Services (contractor for Kinder Morgan). Linear indications were noted in several areas that followed the toe of the weld on the outer surface of the pipe, but no indications were found on the base metal. A linear indication was located between 7.3 feet and 7.6 feet upstream of GW 256360 (see area indicated by bracket "L1" in Appendices 1A and 1B) and another linear indication was located between 8.2 feet and 8.6 feet upstream of GW 256360 (see area indicated by bracket "L2" in Appendices 1A and 1C). A 3.3-foot-length portion of the pipe that contained the intact longitudinal weld was torch cut and submitted to the NTSB Materials Laboratory for detailed examination.

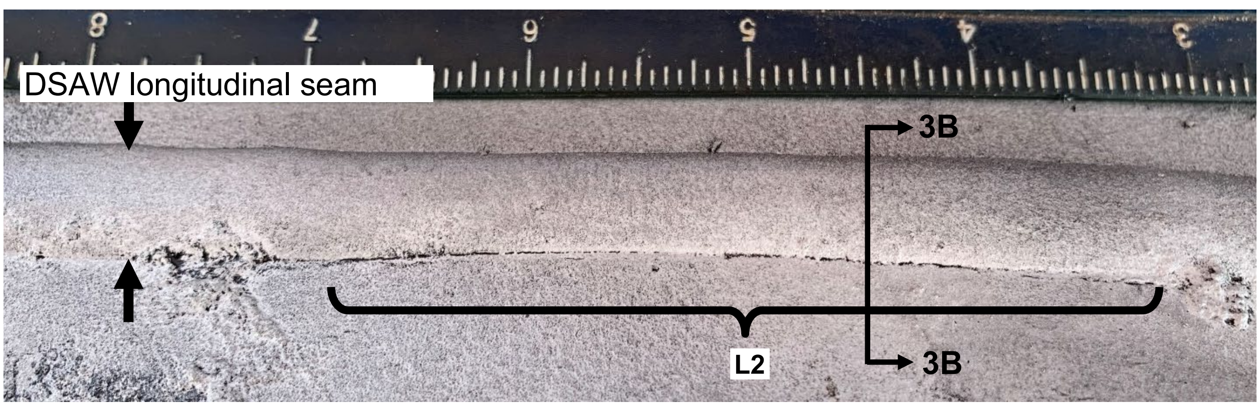
IAG Integrity Services also conducted ultrasonic wall thickness measurements in all four quadrants of the pipe immediately upstream and downstream of GW 256350 and 256360. Wall thickness measurements ranged from 0.297 to 0.309 inches.



Appendix 1A. On-site photograph of the outer face of the pipe showing MPI linear indications that were found at the toe portions of the longitudinal weld, in the areas indicated by brackets "L1" and "L2".



Appendix 1B. Close-up photograph of MPI linear indication "L1" in Appendix 1A.



Appendix 1C. Close-up photograph of MPI linear indication "L2" in Appendix 1A.

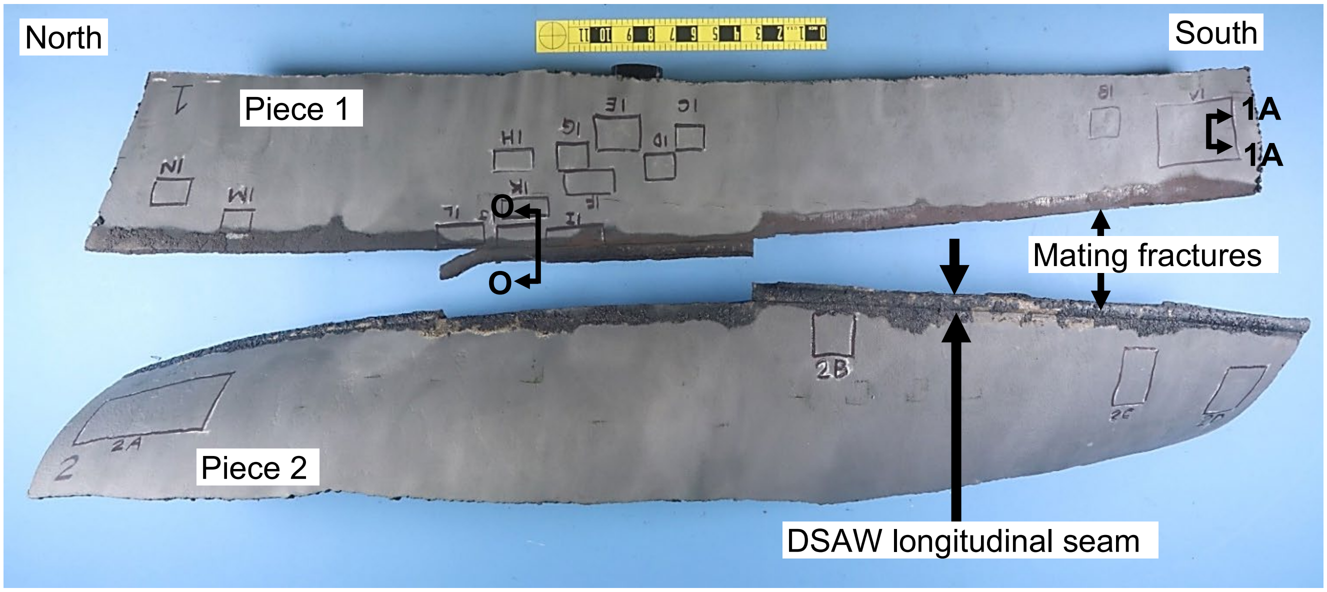
Ring Sample for Material Properties Testing

Excavation crew (track-hoe and crew with shovels) removed soil from the crater in the area along the length of the pipe to expose longer segments of the pipe. The excavation crew exposed approximately a 37-foot length of the pipe at the south end of the fracture. Post-excavation examination revealed approximately a 21-foot length portion of the pipe at the south fractured end was bend up (see figure 1).

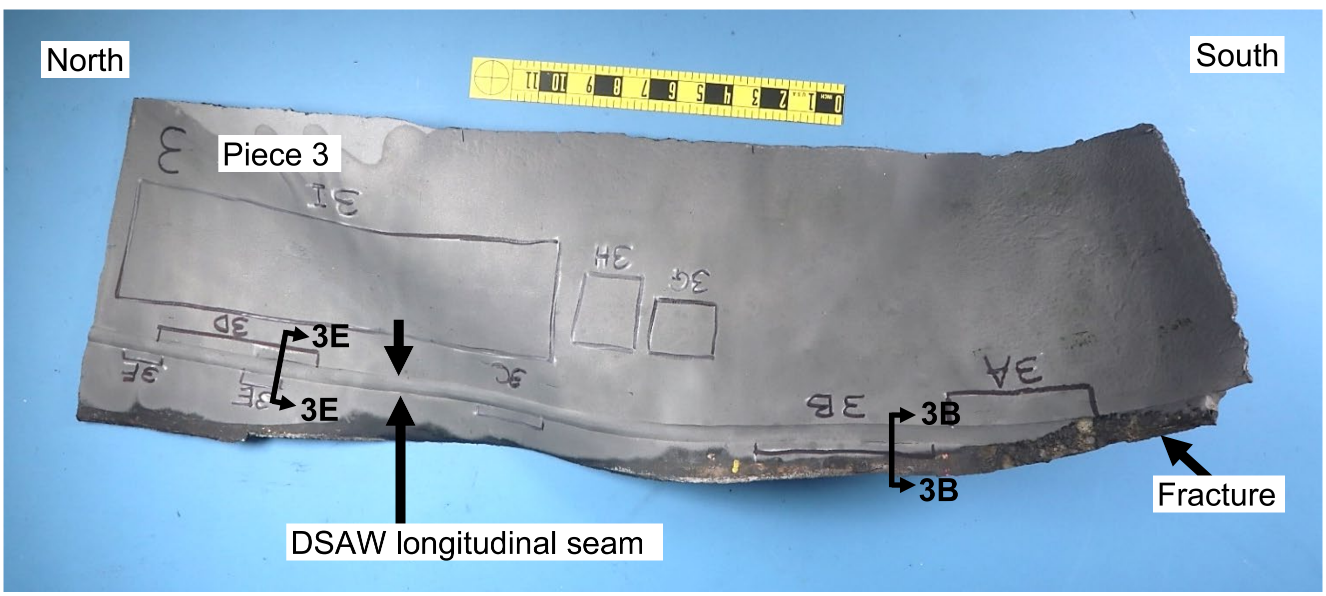
The exposed portions of the pipe were covered with spiral wrap tape. A 3-foot-long ring piece (approximately between 29.5 feet and 32.5 feet from the south fractured end) was torch cut from an area that showed no evidence of heat damage (areas where the tape wrap showed no evidence deformation related to heat from a fire). Prior to torch cutting the 3-foot-long ring piece from the pipeline, a cut was made with a box cutter on top of the pipe in the longitudinal orientation that penetrated the exterior coating. The pipe was covered with more than one layer of spiral wrap tape. The spiral wrap tape layers were peeled apart by hand. The examination revealed the pipe was covered with an inner black adhesive coating, followed by a middle layer of plastic spiral wrap tape (black on both sides of the tape), and an outer layer of plastic spiral wrap tape (white on the outer surface and black on the inner surface of the tape). The ring sample was shipped to the NTSB Materials Laboratory for testing.

APPENDIX 2

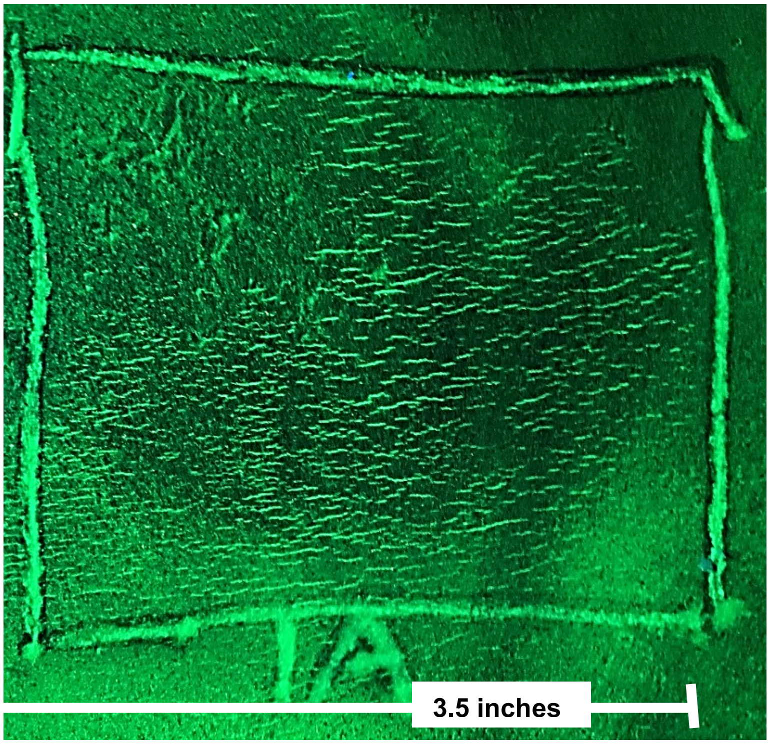
EVALUATION OF MPI INDICATIONS
ON
THE OUTER SURFACE OF THE PIPE
AFTER
GRIT BLAST CLEANING



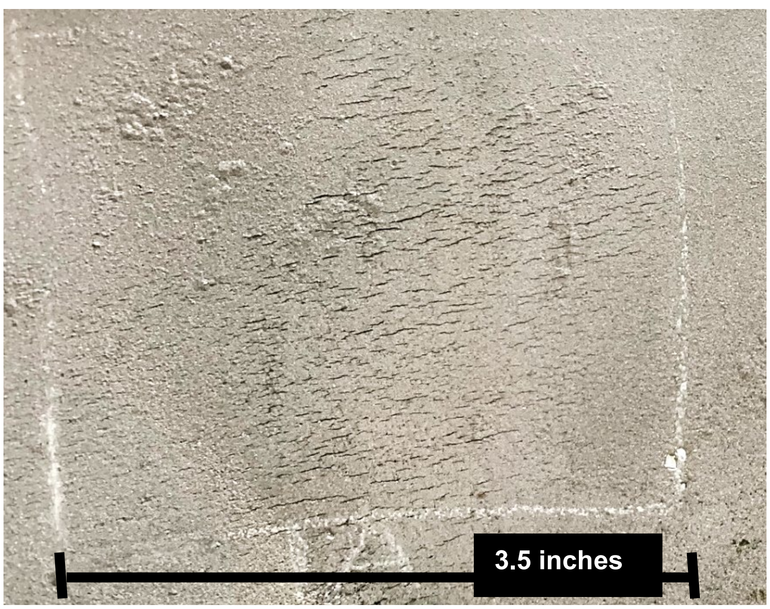
Appendix 2A. Outer face of the pieces “1” and “2” after grit blast cleaning. On piece “1”, areas showing cluster of MPI linear indications were arbitrarily identified by regions “1A” through “1N”. On piece “2”, areas showing cluster of MPI linear indications were arbitrarily identified by regions “2A” through “2D”. A one-inch-wide portion along the fracture face of each piece was masked to protect the fracture face from the grit blasting procedure). Pieces are shown after removing masking material. Section “O-O” was made approximately 1.5 feet from the north cut end. Section “1A-1A” was made approximately 0.2 feet from the south cut end.



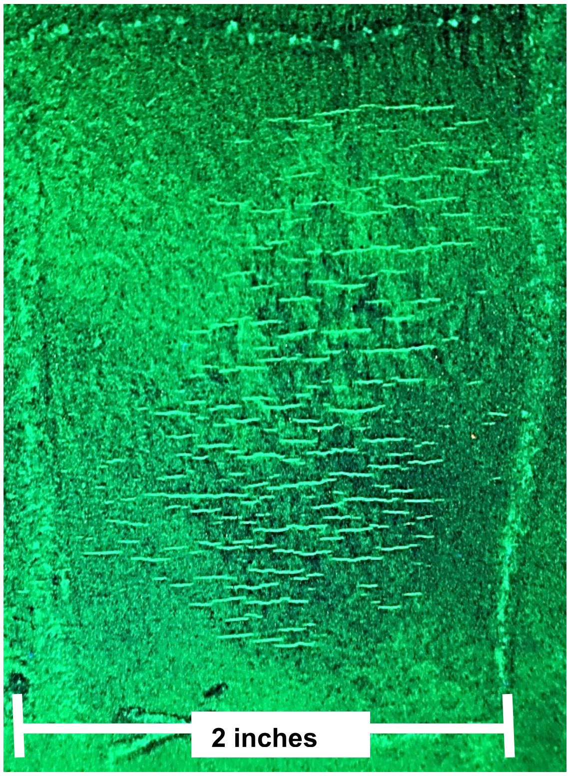
Appendix 2B. Outer face of the piece “3” after grit blast cleaning. Areas showing MPI linear indications are indicated by regions “3A” through “3F”. A one-inch-wide portion along the fracture face of each piece was masked to protect the fracture face from the grit blasting procedure). Piece is shown after removing masking material. Section “3E-3E” was made approximately 0.7 feet from the north cut end. Section “3B-3B” was made approximately 3 feet from the north cut end.



Appendix 2C. Outer surface of piece 1 showing region 1A when viewed with black (ultraviolet) light during fluorescent MPI. This area contained colonies of longitudinal crack indications consistent with SCC. Surface was grit blasted prior to MPI.



Appendix 2D. Outer surface of region 1A when viewed with incandescent light showing surface breaking cracks that coincided with colonies of longitudinal crack indications. Photograph taken after grit blast cleaning and MPI. Pitting corrosion is present in the general area.



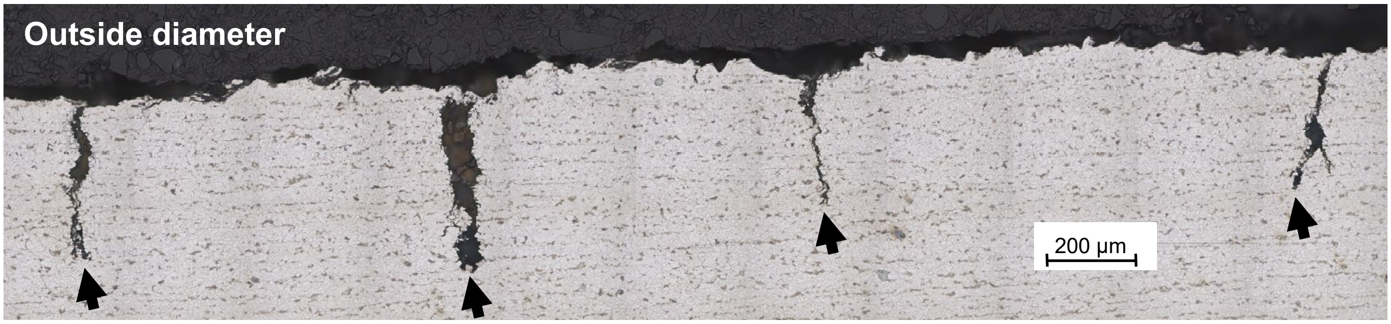
Appendix 2E. Outer surface of piece 2 showing region 2D when viewed with black (ultraviolet) light during fluorescent MPI. The area contains longitudinal colonies of crack indications consistent with SCC. Surface was grit blasted prior to MPI.

Appendix 2F. Outer surface of piece 2 showing region 2D showing when viewed with incandescent light showing surface breaking cracks that coincided with colonies of longitudinal crack indications. Photograph taken after grit blast cleaning and MPI. Pitting and general corrosion is present in the general area.

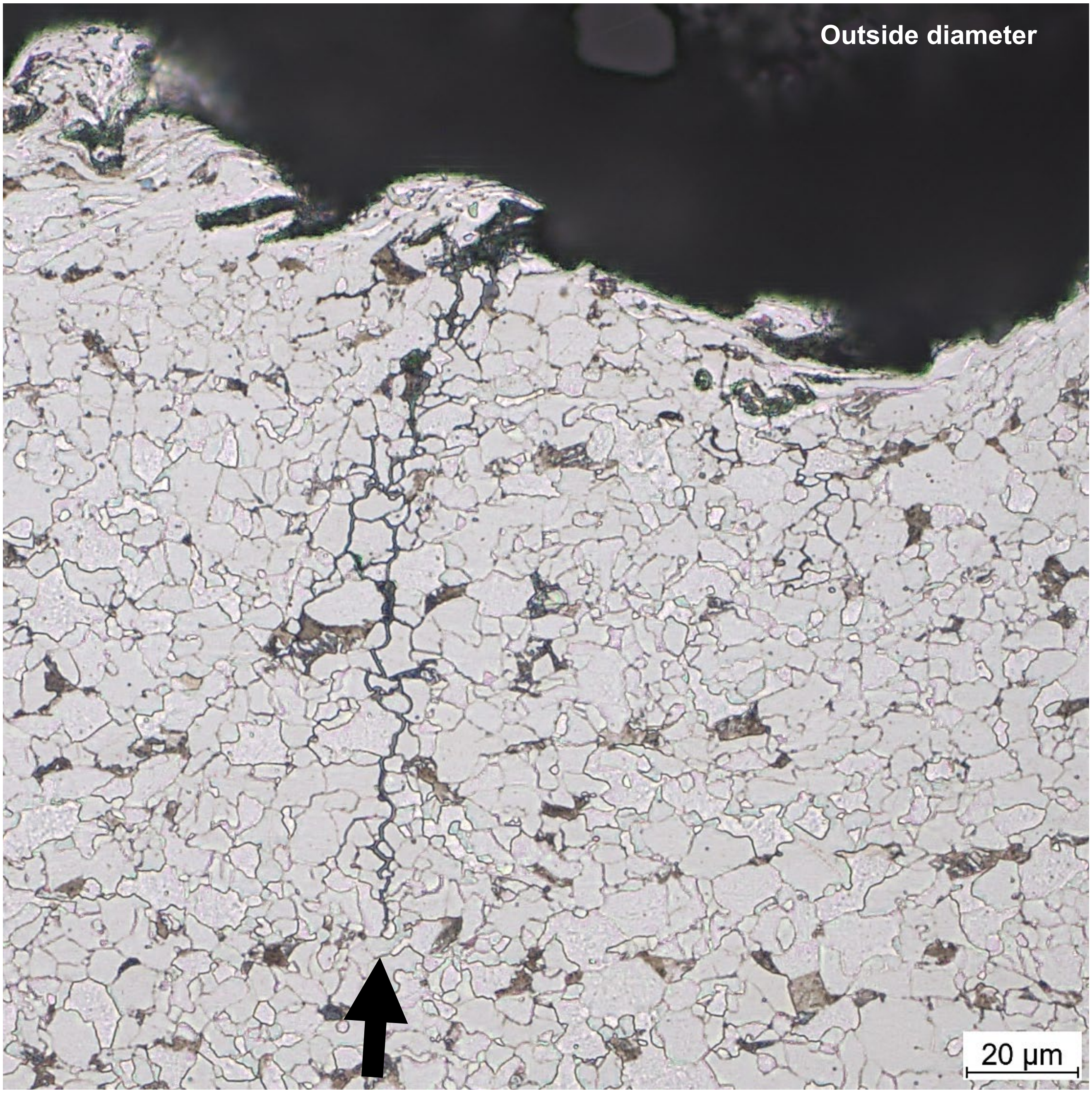
Table W.
Results of Fluorescent Magnetic Particle Inspection, After Grit Blast Cleaning

Piece Number	Regions containing colonies of longitudinal linear indications***	Size of region containing colonies of longitudinal linear indications, length x circumference (inches)
1	1A	3.5 x 2.5
	1B	1.5 x 1.3
	1C	1.3 x 1.0
	1D	1.3 x 1.0
	1E	2.0 x 1.5
	1F	2.0 x 1.0
	1G	1.3 x 1.0
	1H	1.5 x 1.0
	1I	2.5 x 1.0
	1J	1.8 x 1.3
	1K	2.0 x 1.0
	1L	2.0 x 1.0
	1M	1.3 x 1.0
	1N	1.5 x 1.3
2	2A	6.5 x 3.0
	2B	1.5 x 1.8
	2C	1.5 x 2.8
	2D	2.0 x 2.8
3	3A	4.0 x 1.0
	3B	5.8 x 0.3
	3C	2.5 x 0.3
	3D	6.0 x 0.3
	3E	1.5 x 0.3
	3F	1.8 x 0.3
	3G	2.3 x 1.8
	3H	2.3 x 2.5
	3I	16.3 x 4.0

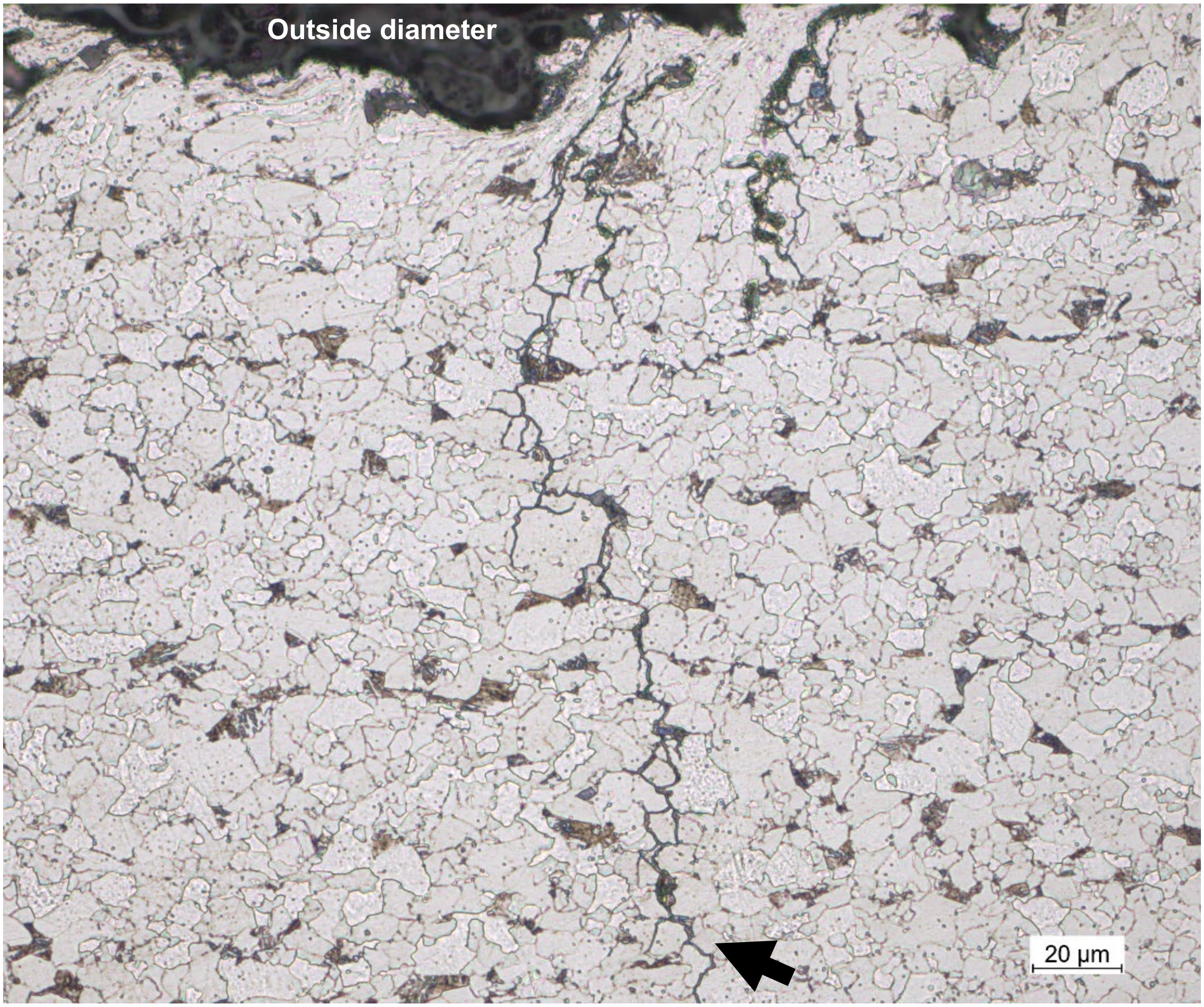
Note: *** Appendices 2A and 2B show photographs of the regions containing colonies of longitudinal linear indications. The regions are labelled “1A” through “3I”.



Appendix 2G. Portion of cross section 1A-1A showing four separate surface breaking cracks in the base metal, in the areas indicated by arrows. These cracks are part of the colonies of cracks that were detected by fluorescent MPI. In this view, the maximum depth of the surface cracks measured approximately 0.014 inch.

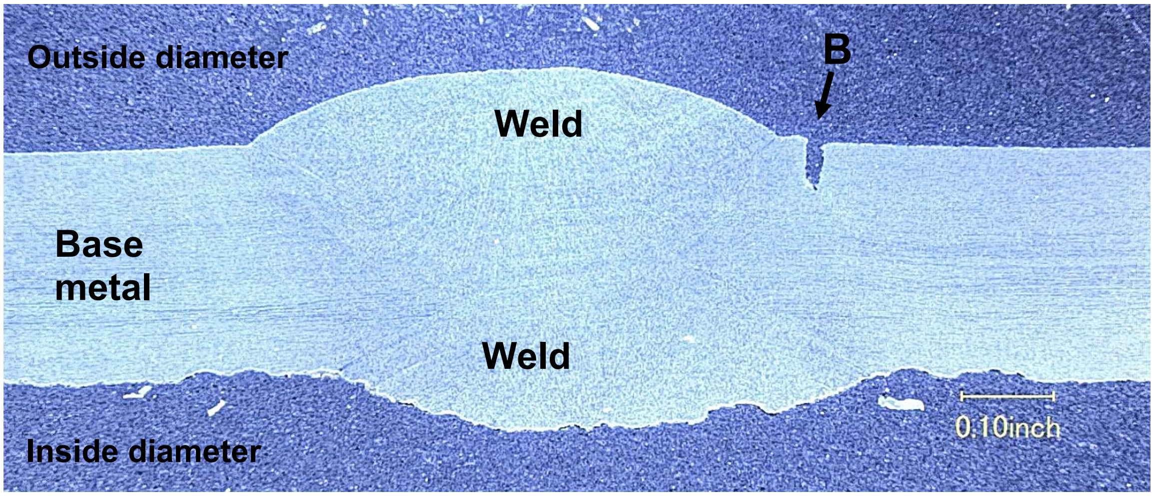


Appendix 2H. . Portion of cross section 1A-1A showing a surface breaking crack, indicated by an arrow, at the outer face of the pipe. These are part of the colonies of cracks that were detected by fluorescent MPI. In this micrograph, the maximum depth of the crack measured approximately 0.005 inch. The crack appears to be propagating by intergranular mode.

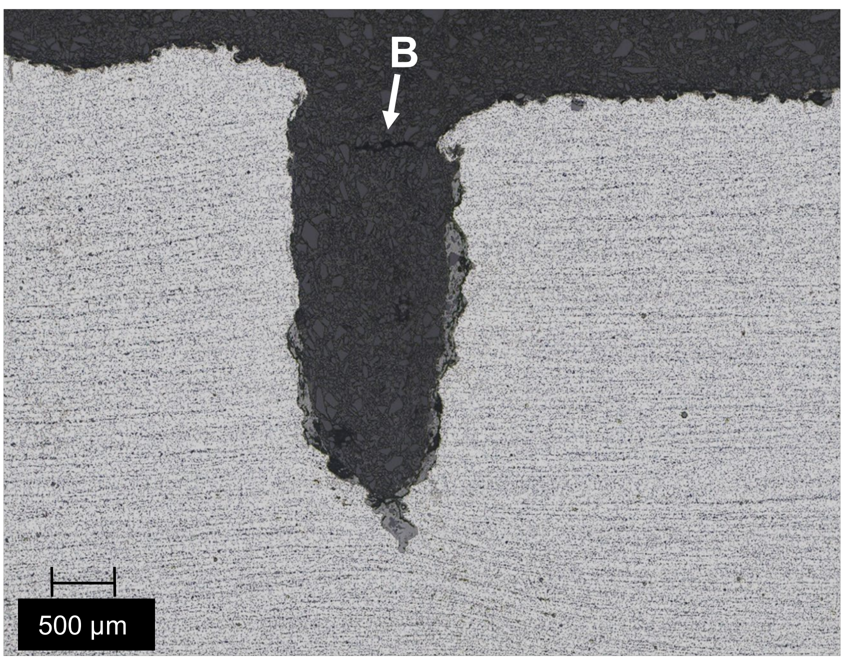


Appendix 2I. Portion of cross section 1A-1A showing a surface breaking crack, indicated by an arrow, at the outer face of the pipe. These are part of the colonies of cracks that were detected by fluorescent MPI. In this micrograph, the maximum depth of the crack measured approximately 0.009 inch. The crack appears to be propagating by intergranular mode.

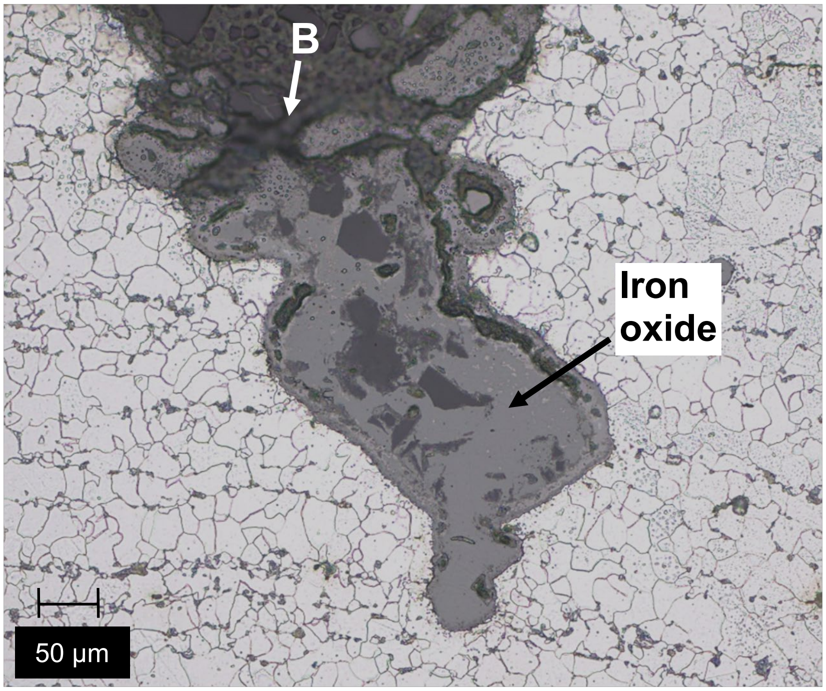
Appendix 2J. Portion of cross section 1A-1A showing two separate surface breaking cracks, indicated by arrows, at the outer face of the pipe. These are part of the colonies of cracks that were detected by fluorescent MPI. In this micrograph, the maximum depth of the cracks measured approximately 0.07 inch. The crack appears to be propagating by intergranular mode.



Appendix 2K. Metallurgical cross section 3B-3B showing a crack indicted by arrow “B” (approximately 0.06 inch deep) that intersected an area adjacent to the toe portion of the weld. Etched with 2% Nital reagent.



Appendix 2L. Close-up micrograph of the crack arrowed “B” in section 3B-3B showing that the edges of the crack cavity contained iron oxide scale. Etched with 2% Nital reagent.



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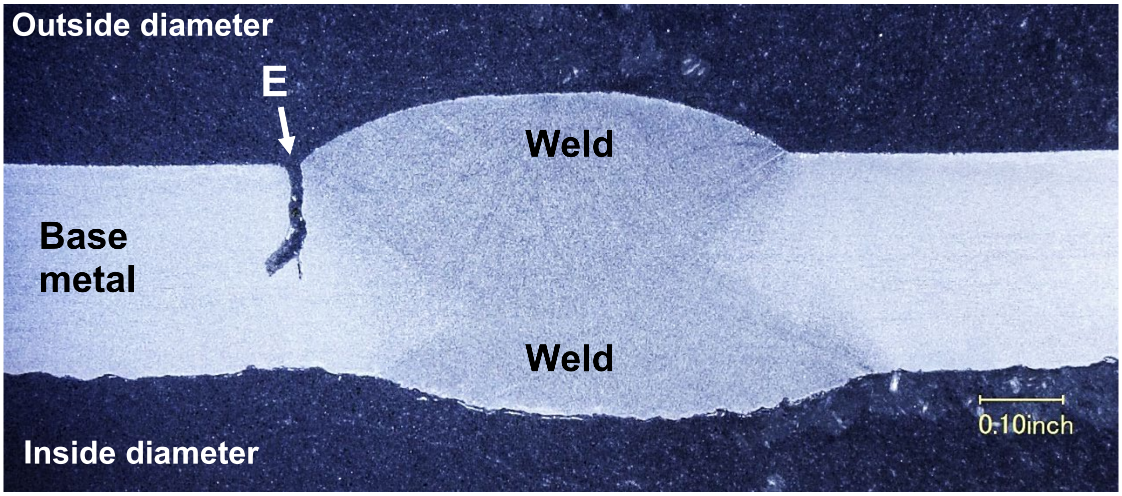
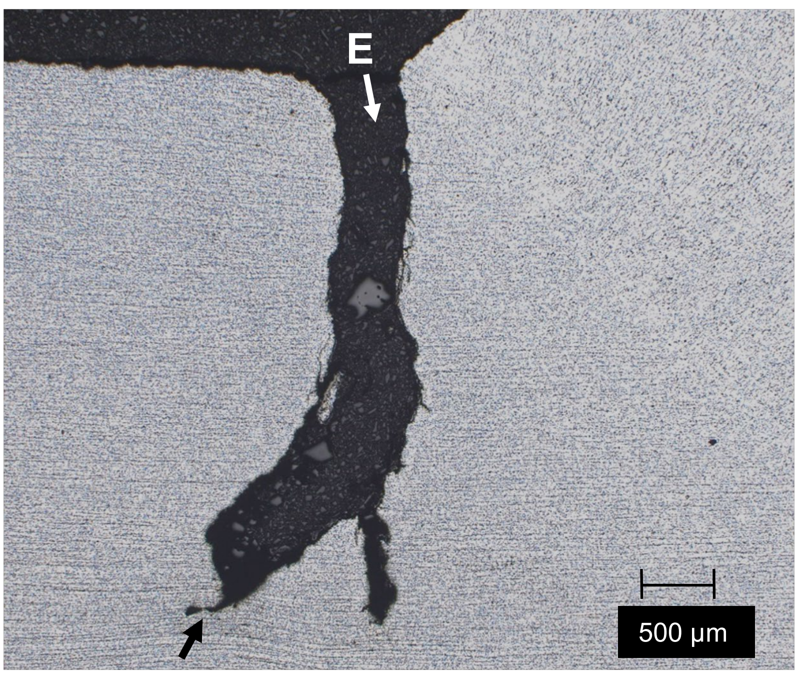
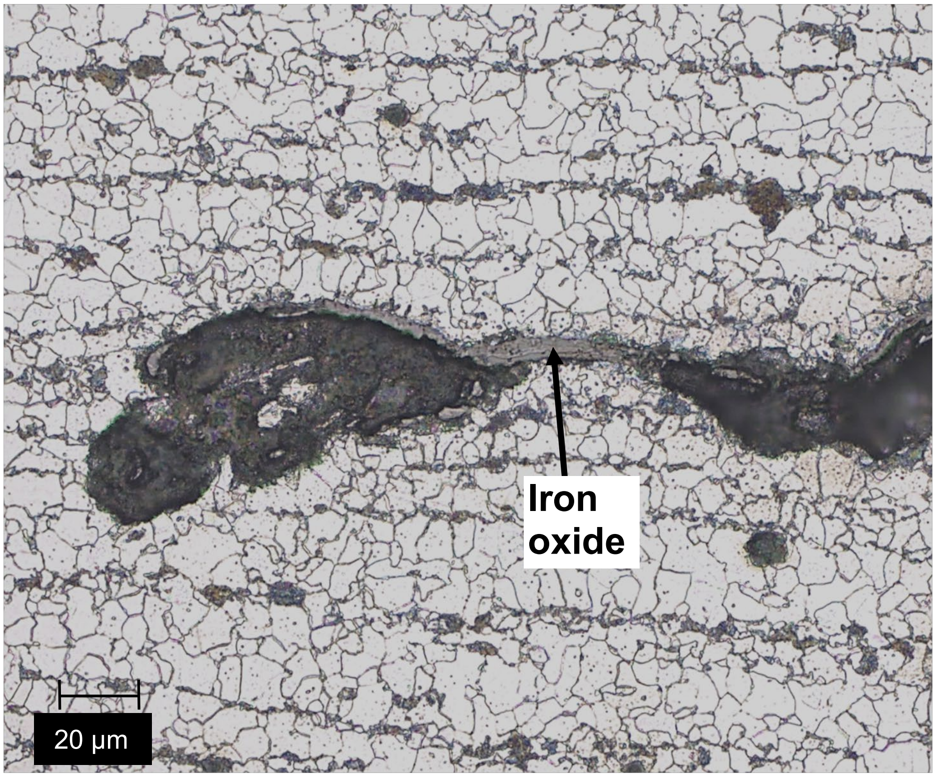
Appendix 2M. Bottom of crack “B” in section “3B-3B” showing deposit of iron oxide (light grey color).



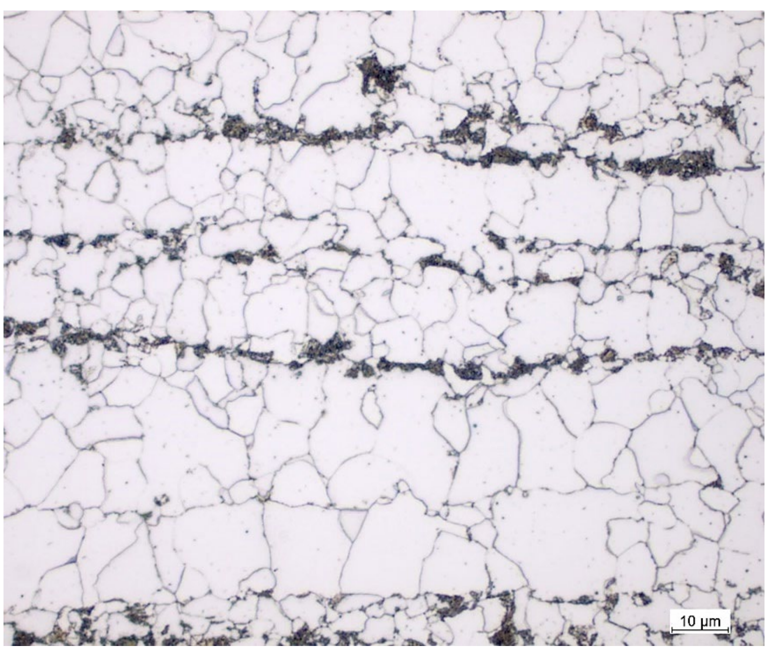
Appendix 2N. Metallurgical cross section 3E-3E showing a branch crack indicted by arrow “E” (approximately 0.14 inch deep) that intersected the toe portion of the weld. Etched with 2% Nital reagent.



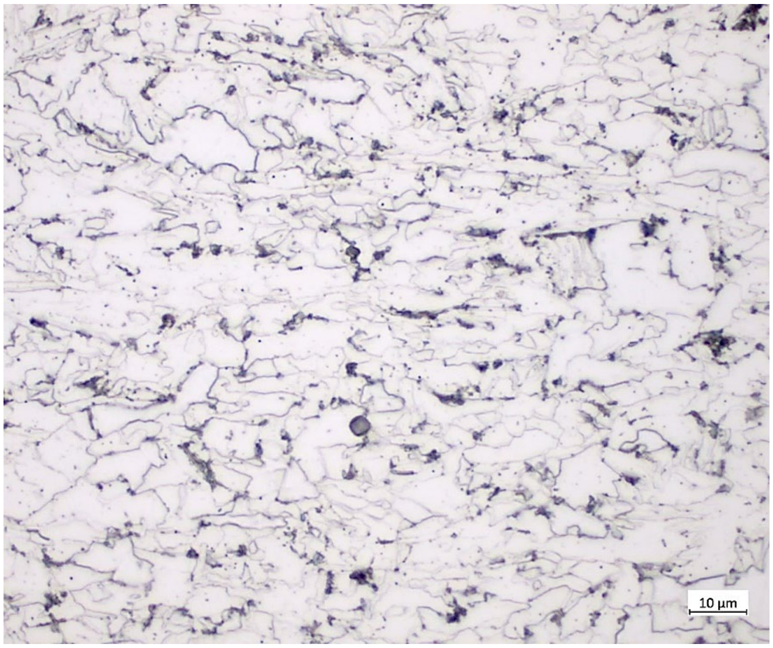
Appendix 2O. Close-up micrograph of the crack arrowed “E” in section 3E-3E showing that the cavity within the crack contained iron oxide scale in the area indicated by a black arrow. Etched with 2% Nital reagent.



Appendix 2P. Bottom of crack “E” in section “3E-3E” showing a deposit of iron oxide (light grey color).



Appendix 2Q. Cross section 3E-3E showing the base metal microstructure of ferrite and pearlite. Etched with 2% Nital reagent.



Appendix 2R. Typical microstructure of the wall portion (base metal) of the 3-foot-long ring segment, in the orientation indicated by section line "R-R" in figure 5. The base metal showed a microstructure of ferrite and pearlite. Etched with 2% Nital reagent.

APPENDIX 3

Chemical Composition

Table 2 Chemical Composition for 30-Inch Diameter Pipe, API 5L Grade X70 [10] Weight Percent					
Element	Specified For WELDED Pipe Non-expanded or Cold-Expanded	Ejected Pipe Piece 1 Base Metal	Ring Sample Base Metal	Ring Sample Weld ID	Ring Sample Weld OD
		Measured			
Aluminum	Not specified	0.034	0.032	0.026	0.025
Arsenic	Not Specified	0.003	0.007	0.019	0.024
Boron	Not specified	0.0004	0.0004	0.0004	0.0005
Carbon	**0.23 max**	**0.06**	**0.06**	**0.06**	**0.06**
Chromium	Not specified	0.03	0.04	0.03	0.03
Copper	Not specified	0.11	0.09	0.10	0.10
Manganese	**1.6 max**	1.49	1.49	**1.05**	**1.14**
Molybdenum	Not specified	0.02	0.01	0.01	0.01
Niobium[11]	Not specified	0.026	0.039	0.023	0.022
Nickel	Not specified	0.07	0.06	0.05	0.05
Phosphorus	**0.04 max**	**0.024**	**0.036**	**0.037**	**0.039**
Sulfur	**0.05 max**	**0.004**	**0.001**	**0.005**	**0.005**
Silicon	Not specified	0.43	0.23	0.35	0.41
Tin	Not specified	0.003	0.003	0.003	0.003
Titanium	Not specified	0.002	0.003	0.012	0.012
Vanadium	Not specified	0.058	0.002	0.004	0.005
Iron	Remainder	Remainder	Remainder	Remainder	Remainder

[10] API Std 5L, 34th Edition, dated May 31, 1984. Chemistry values for grade X-52 pipe in both editions were the same.
[11] Formerly known as the element columbium.

APPENDIX 4

Tensile and Charpy V-Notch Properties

Table 3. Tensile Properties of the Base Metal API 5L Grade X70 Pipe				
	Minimum	Specimen #1	Specimen #2	Specimen #3
	Specified	Measured		
Yield Strength, 0.5% EUL (psi)[12]	70,000	79,000	75,000	74,000
Ultimate Tensile Strength (psi)	82,000	89,000	87,500	86,500
Elongation, (% in 2 inch)	20	28	29	29

Note: In following the API convention of reporting significant figures, the measured tensile values were rounded off and reported to the nearest hundreds of psi.

Table 4. Tensile Properties of the Longitudinal Weld (psi)				
Property	Minimum	Specimen #1	Specimen #2	Specimen #3
	Specified	Measured		
Ultimate Tensile Strength	82,000	93,500	94,000	93,500

[12] Extension under load (EUL) method - stress required to produce a total elongation of 0.5% of the gage length.

Table 5. Charpy V-Notch Impact Properties (1/2 size specimens) tested at 32° F in the Transverse Orientation			
Specimen Type	Specimen Identification	Measured Impact Energy (ft-lbs)	
		Each	Average[13]
Longitudinal Weld Seam	1 2 3	21 22 21	21
Base Metal	6 7 8	39 51 49	43

Table 6. Charpy V-Notch Impact Properties (1/2 size specimens) tested at 50° F in the Transverse Orientation			
Specimen Type	Specimen Identification	Measured Impact Energy (ft-lbs)	
		Each	Average[14]
Longitudinal Weld Seam	1 2 3	32 44 40	39
Base Metal	6 7 8	51.5 53 48	51

[13] Average impact energy rounded to a whole number.
[14] Average impact energy rounded to a whole number.