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

February 6, 2020

MATERIALS LABORATORY FACTUAL REPORT Report No. 19-064

A. ACCIDENT INFORMATION

Place	:	Danville, Kentucky
Date	:	August 1, 2019
Vehicle	:	30-inch natural gas transmission pipe operated by Enbridge
NTSB No.	:	PLD19FR002
Investigator	:	Alexandria Colletti (RPH)

B. COMPONENTS EXAMINED

Ruptured 30-inch natural gas transmission pipeline that is operated by Enbridge.

C. DETAILS OF THE EXAMINATION

1. Pipeline Specification

Purchase records provided by Enbridge indicated that the pipe was manufactured to American Petroleum Institute (API) Standard 5LX, 6th edition, dated February 1956, grade X52, as 30-inch nominal outside diameter (OD), 0.375-inch nominal wall thickness, electric flash weld (EFW) longitudinal seam, ordered as cold-expanded welded steel plain end line pipe, and manufactured by A.O. Smith. The OD surface was coated with coal tar enamel. Corrosion control of the pipe augmented by impressed current cathodic protection.

2. On-site Examination of the Ruptured Pipe

Between August 1 and August 10, 2019, on-site examination of the ruptured pipe was performed by the NTSB Metallurgy Group. The group consisted of the following representatives.

Frank Zakar	NTSB
Gery Bauman	PHMSA
Gary Vervake	Enbridge

A visual survey of the accident location disclosed that the pipe at the rupture location was installed underground. The in-service rupture occurred on Tompkinsville to Danville Line 15, leaving a crater in the ground, see figure 1.[1] The size of the crater measured approximately 43.4 feet long, 30 feet wide, and 9.6 feet deep. The fractured ends of the pipe located within

[1] Tomkinsville to Danville (TOMP-DANV) Line 15 is the traditional flow orientation, and standard nomenclature used to identify the pipe segment that extended between the pumping stations at Tomkinsville and Danville. At the time of the accident, the line was operating under reverse flow conditions (gas was flowing from Danville to Tomkinsville).

the crater were exposed. For the purpose of this report, the fractured end of the pipe that extended from the Tomkinsville pumping station was referred to as the south end, and the fractured end of the pipe that extended from the Danville pumping station was referred to as the north end. The depth of cover at the south end of the crater measured approximately 40 inches. A 33.2 feet long segment of the pipe fractured and was ejected from the underground pipeline.[2] The ejected pipe segment was discovered approximately 481 feet from the crater, see figures 2 through 5.[3] The longitudinal length of the ejected pipe segment corresponded to the length between the two fractured pipe ends that were located inside of the crater.

Visual examination of the ejected pipe segment revealed the majority of the external coating had been consumed (removed) by the fire, leaving large regions of the external surface bare. The fracture propagation direction on the ejected segment was determined by visual examination of the fracture surfaces. The fracture faces contained evidence of a chevron pattern.[4] The chevron features pointed back to the origin area. The position of the origin was measured with a measuring tape relative to the position of a girth weld and the top dead center (TDC) of the pipe when looking north. The TDC was determined by finding the start position of a girth weld. The fracture origin area was located approximately 7.6 feet north from girth weld (GW) number 115430, at approximately the 4:00 clock position, in the area indicated by brackets “O” in figures 2, 3, and 5. The fracture faces showed no evidence of other fracture origin areas and contained no indication of crack arrest marks.[5] The fracture faces at the north and south ends of the ejected piece showed fracture features and longitudinal weld features that corresponded to those with the mating fracture faces.

Appendix 1 shows a diagram of the pipe with the relative position of the girth welds, longitudinal seam welds, clock position of the seam welds relative to the TDC when looking north toward Dansville, fractured ends of the pipe, and the approximate position of the crater. The longitudinal portion of the fracture intersected two girth welds (GW 115430 and GW 115440) but it did not intersect the longitudinal seam weld portions of the pipe. The longitudinal length between the two girth welds that were intersected by the fracture measured approximately 21.6 feet. The origin of the fracture was not associated with a girth weld or a seam weld.

During on-site work, the areas surrounding the crater (approximately 100 feet radius) and around the ejected piece (approximately 100 feet radius), and the areas between these two zones were scanned by metal detectors for possible missing pipe fragments. Once the crater was accessible, metal detector scan was performed at the base of the crater. No pipe fragments were found. Based on the length of the pipe, distance between the pipe ends in the crater, the appearance of the mating fractures, and the metal detector scan, all the pipe from the rupture was located and retrieved.

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[2] Measurements made at top-dead-center (TDC) between the two fracture ends within the crater measured approximately 33.2 feet in length, and this length corresponded to the longitudinal length of the ejected pipe piece.

[3] Distance is based on measurements made by NTSB drone, see NTSB UAS aerial imagery report.

[4] Chevron pattern is a fractographic pattern of radial marks (shear ledges) that look like nested letters “V”; sometimes called herringbone pattern. Chevron patterns are typically found on brittle fracture surfaces in parts whose widths are considerably greater than their thickness. The points of the chevrons can be traced back to the fracture origin.

[5] A crack arrest mark is a “step” feature on the fracture surface and indicates an intermittent stopping point during fracture propagation.

2.1 Hard Spot in Steel Pipe

A “hard spot” is an area in the pipe with a hardness level considerably higher than that of the surrounding metal, usually due to localized quenching.[6] The 6th edition of API Standard 5LX did not address or define a “hard spot” and did not provide a reject criteria for a hard spot. The reject criteria for a hard spot is specified in API Specification 5L, “Specification for Line Pipe”. The 42nd edition of API Specification 5L, dated January 2000, states that any hard spot having a minimum dimension greater than 2 inches in any direction and a hardness *greater than or equal to 35 HRC* (327 HB) shall be rejected. The section of pipe containing the hard spot shall be removed as a cylinder. The more recent editions of the same specification, the 44th edition dated October 2007 and the 46th edition dated April 2018, indicated that a hard spot shall be classified as a defect when the hardness *exceeds 35 HRC* (345HV10, or 327 HBW) based on individual indentations, with the size for rejection remaining the same. The two recent API specifications stated that sections of pipe containing the surface defects shall be cut off within limits on length; or the entire pipe length shall be rejected.

2.2 Hard Spots Identified by ILI Vendor

In 2011, the Tompkinsville to Danville Line 15 was inspected by a hard spot in-line inspection (ILI) tool. The ILI tool vendor was NDT Global. NDT Global reported no evidence of hard spot indications. In 2019, during the on-site investigation, NDT Global was asked by the NTSB Integrity Group to re-evaluate the accident pipe joint for hard spots. NDT Global reviewed the 2011 hard spot ILI data and on August 8, 2019 reported 10 hard spot indications that were not previously reported. Appendix 2 shows the NDT Global 2011 hard spot ILI screen shot with the 10 reported hard spot indications (identified as #1 through #10). The origin of the fracture was identified by NTSB and it was located approximately 7.6 feet north of from girth weld number 115430 and approximately at the 4:00 clock position, coinciding with the general location of hard spot indications #2 and #3 shown on the Global NDT ILI screen shot dated August 8, 2019.

2.3 Selected Pipe Pieces Shipped to NTSB

The ejected pipe segment was cut into three pieces, referred to as segments “A”, “B”, and “C”, in figure 5 and Appendix 3A, to facilitate shipping and handling. The exposed fractured ends of the pipe that were located within the crater were cut in areas that coincided with the border of the crater, see Appendix 3B. The fractured ends of all the pipe pieces were sprayed with WD-40 lubricant to preserve the fracture features. The origin of the fracture was covered with rubber hose that was split longitudinally. Two ring pieces of the pipe, each approximately 4-feet long, were cut from areas where the coating on the outer diameter showed no visual evidence of heat damage (no evidence of solidification) and they were reserved for mechanical testing and chemical analysis, see Appendix 3C. The two ring pieces were referred to as the north and south ring pieces. The south end of the north ring piece was cut at a location approximately 50 feet north from the fractured north end of the pipe. The north end of the south ring piece was cut at a location approximately 42.8 feet south from the fractured south end of

[6] According to Glossary of Oilfield Production Terminology (GOT), Definitions and Abbreviations, 1988 edition, issued by American Petroleum Institute (API). The same definition is found in API Standard 5T1, “Standard on Imperfection Terminology”, 10th Edition, November 1996.

the pipe. Appendix 4 shows the typical bedding at the bottom of the pipe. The cut pipe segments were crated and shipped by truck to the NTSB Training Academy, Ashburn, Virginia.

3. NTSB Materials Laboratory Group Examination

Metallurgical group examination of the pipe was performed between September 16 and 20, 2019 at the NTSB Training Academy, Ashburn, Virginia, and at the Safety Board's Materials Laboratory, Washington, D.C. The following personnel participated in the examinations:

Frank Zakar	NTSB	Senior Metallurgist
Ed Komarnicki	NTSB	Technician
Sean Lynum	NTSB	Chief, Pipeline Division
Sara Lyons	NTSB	Pipeline Investigator
Gary Vervake	Enbridge	Metallurgical Engineer Specialist
Stephen Rapp	Enbridge	Manager, Metallurgy and Quality Assurance

Examination of the pipe pieces continued after the group examination.

3.1 Examination of the Ejected Pipe Segment at the NTSB Ashburn Facility

A straight edge, plastic ruler, was placed on the outer surface of the ejected pipe segment to check for evidence of flat spots (isolated flat areas). Inspection of the outer surface was made with the straight edge aligned parallel to the length of the pipe and with the straight edge aligned perpendicular to the length of the pipe. Isolated flat areas were found on the outer surface on both sides of the fracture face, in areas adjacent to the origin of the fracture, only for conditions where the ruler was oriented in the longitudinal or circumferential orientation and not in both orientations, see figures 6 and 7.

The NTSB Materials Laboratory contracted Mears Group Inc (Mears), Rosebush, Michigan, to perform hardness testing on the outer surface of the pipe in the general area of the fracture origin area with a portable hardness tester using the Leeb Rebound Probe test method to determine the presence of hard spots (elevated hardness relative to the base metal). Portable hardness testing was performed on the outer surface of the pipe at each side of the fracture corresponding to the origin of the fracture, with the exception of a 1-inch wide portion of the outer surface that ran along the length of each fracture face that was masked with duct tape. The masked areas were preserved for detailed fracture examination of the origin area (fracture examination is discussed in section 3.2 titled "Examination of the Fracture Origin Area at the NTSB Materials Laboratory, Washington, DC"). The outer surface was ground and polished prior to measuring the hardness with a portable hardness tester. The portable hardness testing showed evidence of elevated hardness relative to the surrounding areas in the general area of the fracture origin area (see Mears report in Appendix 5). The greatest measured hardness value was 336 Brinell Hardness Number (BHN). The areas of elevated hardness on the outer surface of the pipe corresponded to the general area of hard spot indications "2" and "3" reported by Global NDT, see Appendix 2. The outer surface at the areas of elevated hardness were etched with 10% Nital reagent. The etching procedure revealed a darker etching region compared to the surrounding area that was consistent with a hard spot in the general area of the fracture origin area, see Mears report in Appendix 5 and figure 10 in this report. Corrosion pitting with a maximum depth of 0.013 inch, which is approximately 3.5% of the nominal wall thickness, was noted in the general area of the fracture origin.

Mears inspected the general area of the fracture origin by the wet magnetic particle (MT) method and by the straight beam ultrasonic (UT) method, prior to masking the origin of the fracture with masking tape. MT inspections showed no evidence of linear crack indications or colonies of linear crack indications. UT inspection showed no evidence of mid-wall lamination.

Portable hardness testing was also performed in the general area of indication “4” an area identified by ILI as having a hard spot. Portable hardness testing showed no evidence of an elevated hardness reading in the general area of indication “4” and etching the outer surface in this area showed no evidence of color (tint) variation with respect to the surrounding area. MT inspection of the outer surface in the general area of ILI indication “4” showed no evidence of linear crack indications or colonies of linear crack indications. UT inspection of the same area showed no evidence of mid-wall lamination.

An approximately 2-feet by 1-foot coupon was torch cut from the east face of the fracture that incorporated the origin of the fracture and another similar size coupon was torch cut from the mating fracture face (resulting in two cut coupons). The approximate torch cut locations are indicated by blue lines in figures 8 and 9. These two torch cut coupons were transported to the NTSB Materials Laboratory, Washington, D.C.

3.1.1 Examination of the North Ring Segment at the NTSB Ashburn Facility

Visual examination of the north ring segment revealed the outer surface was covered with coal tar enamel coating. The coating contained wrinkles along the length of the pipe segment at approximately the 3 and 9 o’clock positions. An isolated area of the wrinkled coating at approximately 3 o’clock was fractured that exposed the outer surface of the pipe. At the fractured coating location, the exposed outer surface of the pipe was covered with a smooth layer of coal tar coating with no evidence of exposed bare metal.

3.1.2 Pipe Dimensions

The wall thickness of the north ring segment, south ring segment, and cut wall pieces near the general area of the fracture was measured with a point micrometer. For pipe diameter sizes 20 inches and greater, the wall thickness tolerance is +15.0% and -10.0%. The thickness of the wall measured approximately 0.383 inch, which was within the specified tolerances for 0.375-inch nominal thickness pipe (0.338 inch to 0.431 inch). The outside diameter tolerance for a 30-inch outside diameter pipe is +1% and -1%. Using a pi tape, the circumference of the north ring segment at the outside diameter measured approximately 94.25 inches. This calculates to an outside diameter of 30.01 inches, which was within the API 5LX specified range (between 20.7 and 30.3 inches).

3.2 Examination of the Fracture Origin Area at the NTSB Materials Laboratory, Washington, DC

A 6-inch long by 1.5-inch wide portion of the pipe that incorporated the east face of the fracture face and the origin was cut by water-cooled abrasive cut-off wheel to facilitate cleaning and handling of the fracture origin. A similar size portion of the pipe was cut from the mating fracture face. Figure 11 shows a photograph of the mating fracture faces after the cut made by the abrasive cut-off wheel.

3.2.1 Bench Binocular Microscope Examination

Bench binocular microscope examination of the 6-inch long portion of the east face of the fracture revealed the fracture emanated from the outer surface of the pipe in the area indicated by bracket “O” in figures 11 and 12. The face of the fracture was covered with brown oxide. Portions of the origin contained evidence of minor scratches. No evidence of a gouge or dent was found at the origin. The origin of the fracture was on a linear plane, did not emanate from multiple points, and showed no evidence of ratchet marks. The outer surface in many areas exhibited evidence of corrosion pitting. The corrosion pitting areas were clearly visible in areas that were polished prior to portable hardness testing (see figures 10 and 11 and Appendix 5). The length of the origin at the outer surface measured approximately 0.8 inch and shear lips extended from both ends of the origin. The fracture face at the inner surface (opposite of the origin) contained a minor shear lip. The thickness of the shear lip at the inner surface measured approximately 0.04 inch. An isolated area of the fracture face that extended below the origin was on a flat plane and exhibited a rough texture, area enclosed by a yellow line in figure 12. The flat fracture area was bound by the shear lip regions at the outer and inner surfaces of the pipe. The length of the flat fracture in the area between the inner and outer surface measured approximately 5 inches. The flat fracture region in the area that coincides with the origin of the fracture extended through the majority of the wall cross section. The fracture areas located outside of the north and south ends of the flat fracture region were on a slant plane and contained a river pattern.

The outer surface near the fracture face contained an isolated, smooth, globule-like, irregular feature consistent with solidified metal when compared to the surrounding surface, consistent with an arc burn (arc strike).[7] Figures 11 and 19 show the arc strike on the outer surface of the pipe.

3.2.2 Scanning Electron Microscope (SEM) Examination

SEM examination of the east face of the fracture revealed evidence of iron oxide that covered the fine fracture features. The fracture face was ultrasonic cleaned with Alconox®, a detergent for removing oxide from ferrous metals, for a total of 45 minutes, followed by immersing the fracture face in Evaporust®, another rust remover, for approximately 1.5 hours.

SEM examination of the east face of the fracture revealed the cleaning procedure exposed the fine fracture features. Detailed SEM examination of the fracture face revealed the origin exhibited intergranular fracture features, see figures 13 through 15. Shear lips extended from both ends of the origin. Within the flat fracture region described earlier, the intergranular fracture features extended between the outer surface and approximately 0.1 inch below the outer surface to the areas indicated by a red dashed line in figure 13, which calculates to a depth of approximately 30% of the nominal wall thickness. The flat fracture region in the area

[7] Arc burns is defined as localized points of surface melting caused by arcing between electrode or ground and pipe surface, according to API Standard 5T1.

that extended between 0.1 inch from the outer surface and the shear lip region at the inner surface exhibited a mixed fracture, consisting of intergranular and woody fracture features.[8] Figure 14 shows a close-up composite photograph of the mixed fracture region. The amount of intergranular fracture features decreased toward the inner surface. Within the mixed fracture region, the areas closer to the outer surface exhibited a greater amount of intergranular fracture features compared to the woody fracture features (see figure 16). The mixed fracture region at the mid wall location and at many areas closer to the inner surface exhibited a greater amount of woody fracture (see figure 17) compared to other fracture areas. The shear lip at the inner surface exhibited micro-void coalescence fracture features typical of ductile overstress separation (see figure 18).

3.2.3 Hardness Testing at the Outer Surface

The pipe was specified as API Standard 5LX, grade X52, minimum tensile strength of 66,000 pounds per square inch (psi). This minimum tensile strength converts to a hardness value of approximately 75 HRB, among other converted hardness values shown in table 1. The lowest hardness value measured by the portable hardness tester (Leeb Rebound Probe) was approximately 77 HRB, as summarized in table 2, and reported in Appendix 5.

Rockwell hardness testing was performed by the NTSB Materials Laboratory at the outer surface of the 6-inch length cut out segments that incorporated the mating fracture faces. The measured Rockwell hardness values and their location are shown in figure 19. The outer surface of the pipe in the general area of the fracture origin showed evidence of elevated hardness values relative to the surrounding areas of the pipe, consistent with a hard spot.

3.2.4 Microhardness Testing of the Wall Cross Section

A longitudinal-radial cross section was made through the wall of the pipe at an area located approximately 0.8-inch east of the origin, represented by section line “A-A” in figure 19. Microhardness testing was performed on cross section “A-A” with a Leco model LM248AT microhardness tester using a Vicker’s indenter and a 500-gram load. Hardness measurements were made throughout the section (both longitudinally and radially) at 0.05-inch intervals. Figure 20 shows the measured hardness profile for cross section “A-A” using a color pattern representation, and table 3 shows the measured hardness values that corresponded to those color patterns. The measured Vicker’s hardness values were converted to Rockwell “C” (HRC) and Brinell (HBW) hardness values. Traverse microhardness testing of section “A-A” in areas located adjacent to the outer surface, approximately 0.01 inch below the surface, produced continuous hardness values in the range between 39 HRC and 41 HRC for a length of approximately 5.85 inches, consistent with a hard spot. Hardness values within this range extended to a depth of approximately 0.1 inch below the outer surface, which corresponds to a depth of approximately 30% of the specified nominal wall thickness. Elevated hardness readings consistent with a hard spot extended through the wall. The areas adjacent to the inner surface corresponding to the hard spot exhibited non-continuous hardness values in the same hardness range (between 39 HRC and 41 HRC). The remaining areas adjacent to the inner surface and the mid-wall area corresponding to the hard sport showed hardness values ranging

[8] Woody fracture refers to a fracture face that appears similar to coarse grains found on the fracture surface of a wood board that was split (fractured) in the longitudinal orientation.

between 36 HRC and 38 HRC with isolated spots having a hardness in the range between 32 HRC and 35 HRC.

Section “A-A” also intersected the arc strike area shown in figure 19. The length and width of the arc strike measured approximately 0.6 inch and 0.3 inch, respectively. Although not shown in the section “A-A” hardness profile, isolated areas within the arc strike exhibited hardness values as great as 51 HRC. The heat affected zone (HAZ) of the arc strike extended approximately 0.06 inches beyond the edges of the arc strike area and below the outer surface, when measured on a prepared cross section that was etched with 2% Nital reagent.

A circumferential-radial section was made through the wall that intersected the origin of the fracture, represented by section line “B-B” in figure 19. Microhardness testing of section “B-B” in areas located approximately 0.01 inch below the outer surface produced continuous hardness values in the range between 39 HRC and 41 HRC for a width of approximately 3 inches, consistent with a hard spot. The measured hardness profile through the thickness of the wall was similar to those in section “A-A”. Diagram of the hardness profile for section “B-B” is not displayed. Based on the microhardness measurements, the origin of the fracture intersected a hard spot area whose hardness adjacent to the outer surface was between 39 HRC and 41 HRC (362 and 381.Brinnel) and for this hardness range measured approximately 5.85 inches by approximately 3 inches. According to recent versions of API 5L Specifications this hard spot is classified as a defect because the dimension of the hard spot exceeded 2 inches in either direction and the hardness was greater than or equal to 35 HRC (327 HB).

3.2.5 Microstructure

Sections “A-A” and “B-B” were polished and etched with 2% Nital reagent. Examination of sections “A-A” and “B-B” revealed the wall of the pipe in an area with elevated hardness values contained a microstructure of martensite. The wall of the pipe in the area that extended between the outer surface and approximately 0.1 inch below the outer surface contained a microstructure of martensite, see figure 21, whereas, the remaining wall portion showed a microstructure of martensite with a precipitating second phase at the grain boundaries, see figure 22. In section “B-B”, the origin of the fracture showed evidence of intergranular fracture features, see figure 23. The origin of the fracture showed no evidence of branching cracks.

A longitudinal-radial section was made through the wall in an area located approximately 10 inches north of the fracture origin, indicated by section line “C-C” in figure 9. Section “C-C” was polished and etched with 2% Nital reagent. Examination of etched section “C-C” revealed the wall contained a microstructure of ferrite and banded pearlite typical of a hot rolled steel, see figure 24.

Report prepared by:

Frank Zakar
Senior Metallurgist

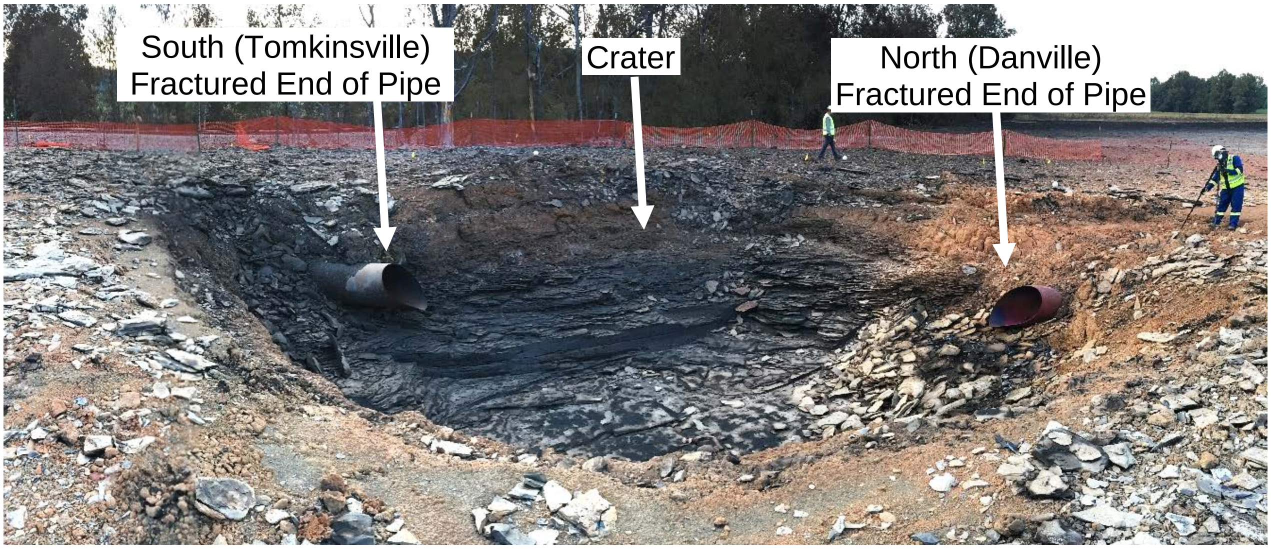


Figure 1. Photograph of the two fractured ends of the ruptured gas transmission pipe within the crater. The fractured end of the pipe extending from the Danville pumping station is referred to as the north end.

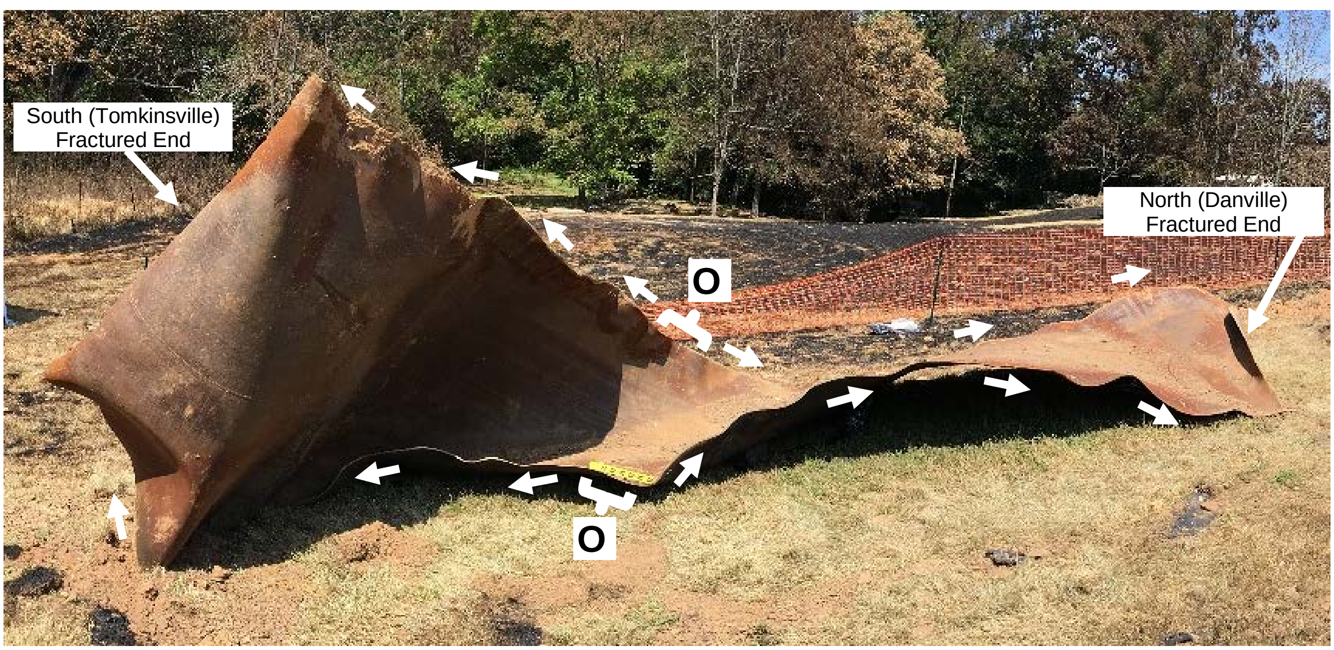


Figure 2. Photographs of the ejected segment of pipe that was fond 481 feet from the crater showing the inner surface. The origin of the fracture is located in the area indicated by brackets “O” (mating fractures), and the general direction of fracture propagation is indicated by white unmarked arrows. The origin of the fracture is located approximately at the 4 o’clock position looking north.

Figure 3. Photographs of the ejected segment of pipe that was found 481 feet from the crater showing the inner surface on the upper left side of photograph and for the most part the outer surface on the right side of the photograph. The origin of the fracture was located in the area indicated by brackets “O” (they are mating fractures).

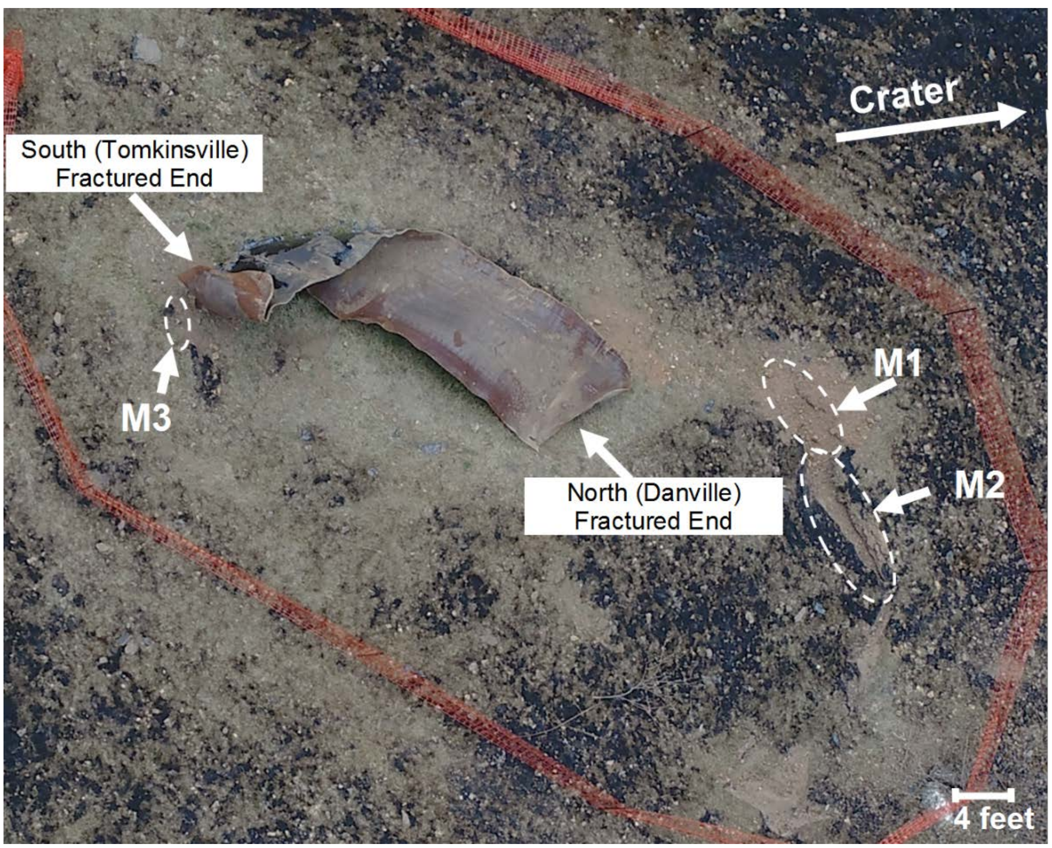


Figure 4. Aerial photograph by NTSB drone of the ejected piece of pipe that was discovered approximately 481 feet from the rupture location (crater). Ground impact marks were found on the ground near the pipe in the areas indicated by arrows “M1” through “M3”. Each ground impact mark exhibited a linear-like impression.

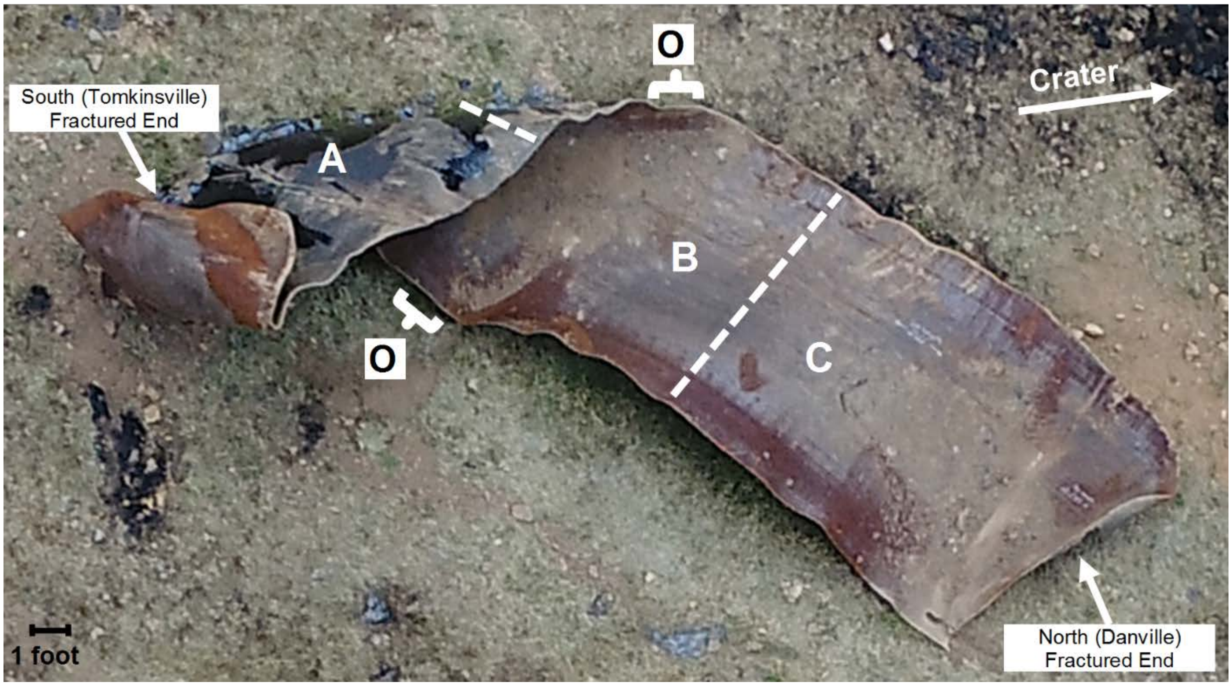


Figure 5. Aerial photograph by NTSB drone of the ejected piece of pipe that was discovered approximately 481 feet from the rupture location showing predominantly the inner surface (light brown areas) and the outer surface (black area). The fracture origin area indicated by brackets “O”.

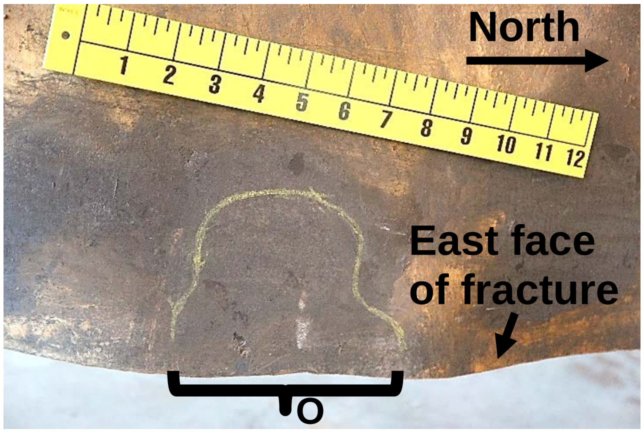


Figure 6. Photograph of the outer surface of the pipe at the east face of the fracture (fracture face is facing down) showing the fracture origin area, indicated by bracket "O". The outer surface adjacent to the fracture origin contained an isolated area that was flat when a straight edge was placed parallel to the length of the pipe, restricted to the area bound by the yellow line. The outer surface at the same isolated area exhibited a deformed curvature when a straight edge was placed perpendicular to the length of the pipe. The area marked in yellow measured as great as approximately 5 inches along the length of the pipe and it extended approximately 4 inches along the circumference.

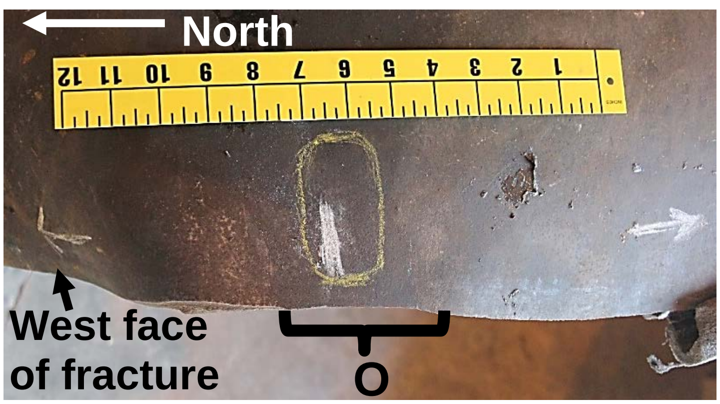


Figure 7. Photograph of the outer surface of the pipe at the west face of the fracture (fracture face is facing down) showing the fracture origin area, indicated by bracket "O". The outer surface adjacent to the fracture origin exhibited an isolated area that was flat when a straight edge was placed perpendicular to the length of the pipe for the area enclosed by the yellow line, but the outer surface on the same area exhibited evidence outward bending deformation when a straight edge was placed parallel to the length of the pipe. The area marked in yellow measured approximately 2 inches along the length of the pipe and approximately 3 inches along the circumference.

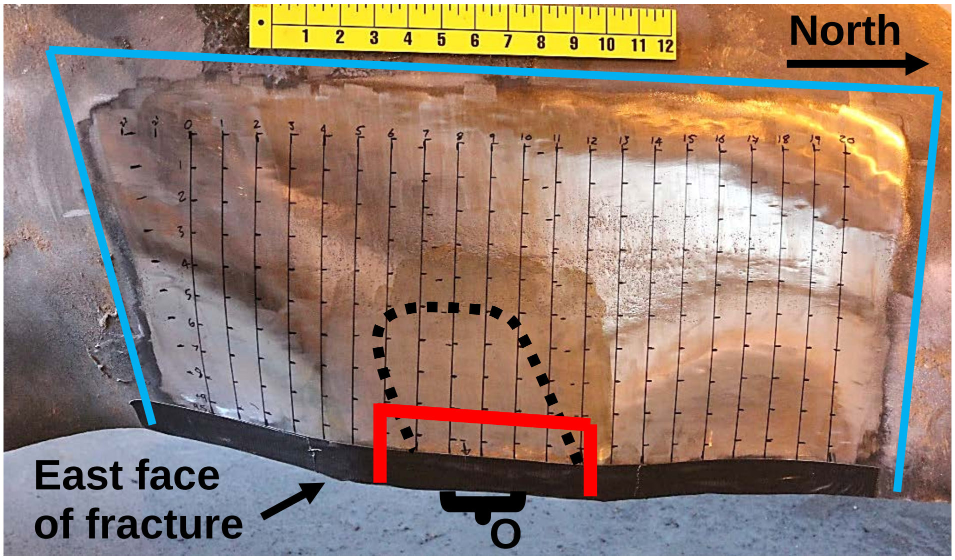


Figure 8. Photograph of the outer surface of the pipe at the east face of the fracture after polishing and etching followed by surface hardness testing. Origin of the fracture is indicated by bracket "O". Grid patterns are at one-inch interval. A darker etching region was located between the fracture face and area indicated by the black dashed line. A one-inch wide portion along the fracture was masked with black tape and was not polished/etched. The 6-inch segment indicated by red lines was cut from the pipe for fracture examination.

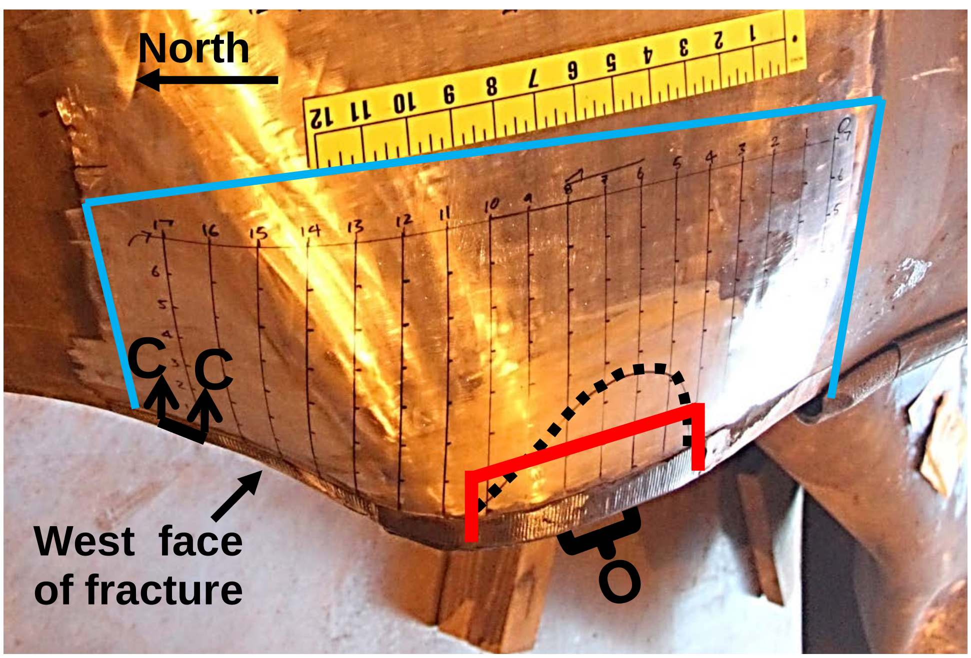


Figure 9. Photograph of the outer surface of the pipe at the west face of the fracture after polishing and etching followed by surface hardness testing. The origin of fracture is indicated by bracket "O". A darker etching region is located between the fracture face and the area indicated by a black dashed line. A one-inch wide portion along the fracture face was masked with tape and was not polished/etched. The 6-inch segment indicated by red lines was cut from the pipe for fracture examination.

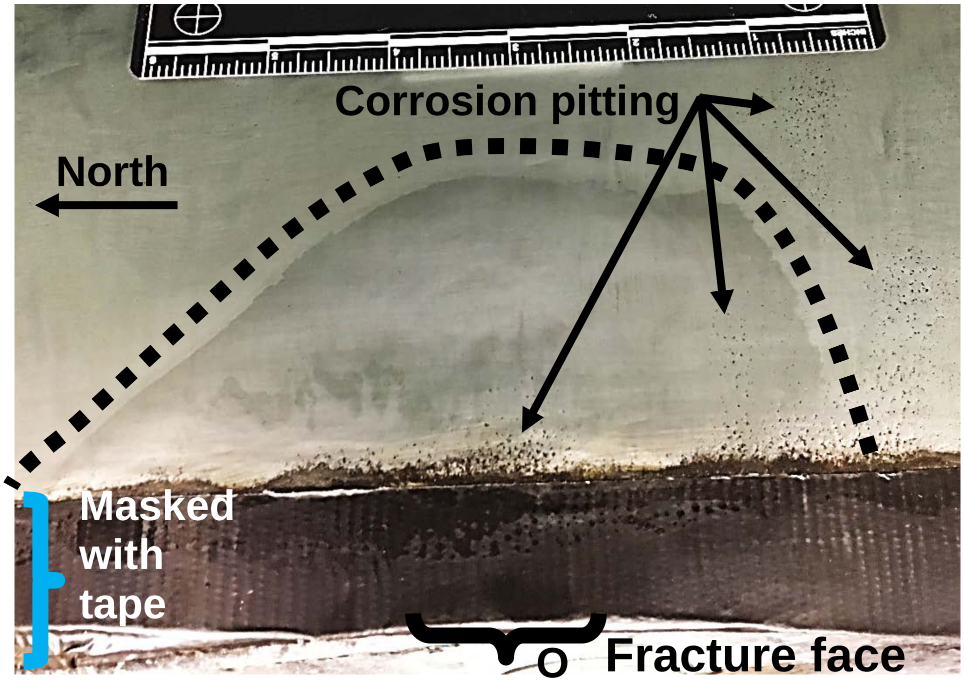


Figure 10. Photograph of the outer surface of the pipe at the west face of the fracture showing the origin area, indicated by bracket “O”, and a darker etching region (border is indicated by a dashed line), same area as indicated by dashed line in figure 9. A one-inch wide portion along the fracture face was masked with tape (protected the fracture face from polishing and etching procedure). Evidence of corrosion pitting was clearly visible in polished areas. Polished and re-etched by NTSB.

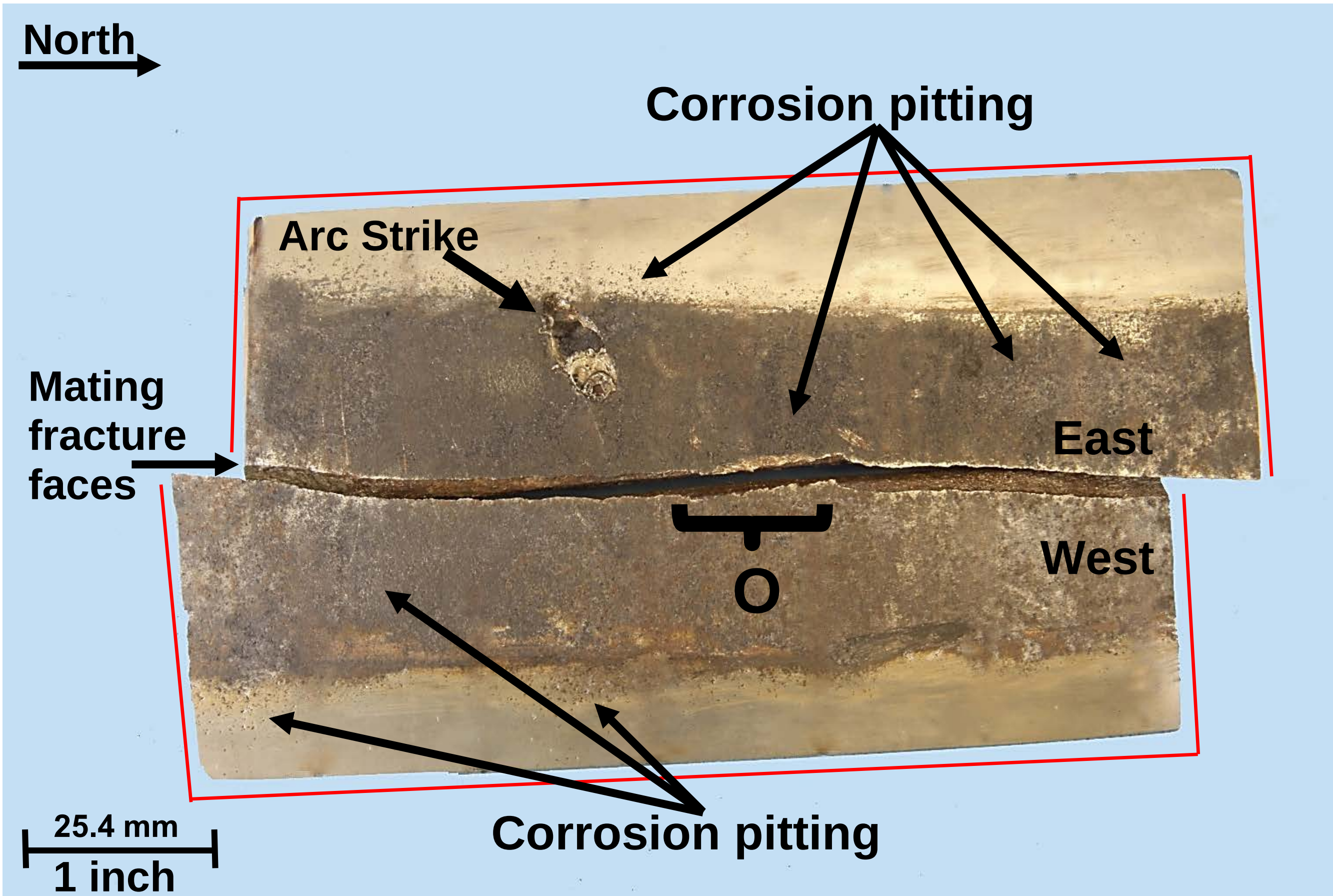


Figure 11. Photograph of the 6-inch long cut-out portion of the east fracture face and similar cut-out from the mating fracture face positioned next to each other as if intact showing the outer face of the pipe and the fracture origin area indicated by bracket “O”. The cut-out portions outlined by red lines in this photograph correspond to the same areas indicated by red lines in figures 8 and 9. Corrosion pitting was noted in the general area of the fracture origin and surrounding areas on both sides of the fracture, such as in the areas indicated by arrows. The corrosion pitting areas are clearly visible in areas that were polished prior to hardness testing. An arc strike was located near the fracture.

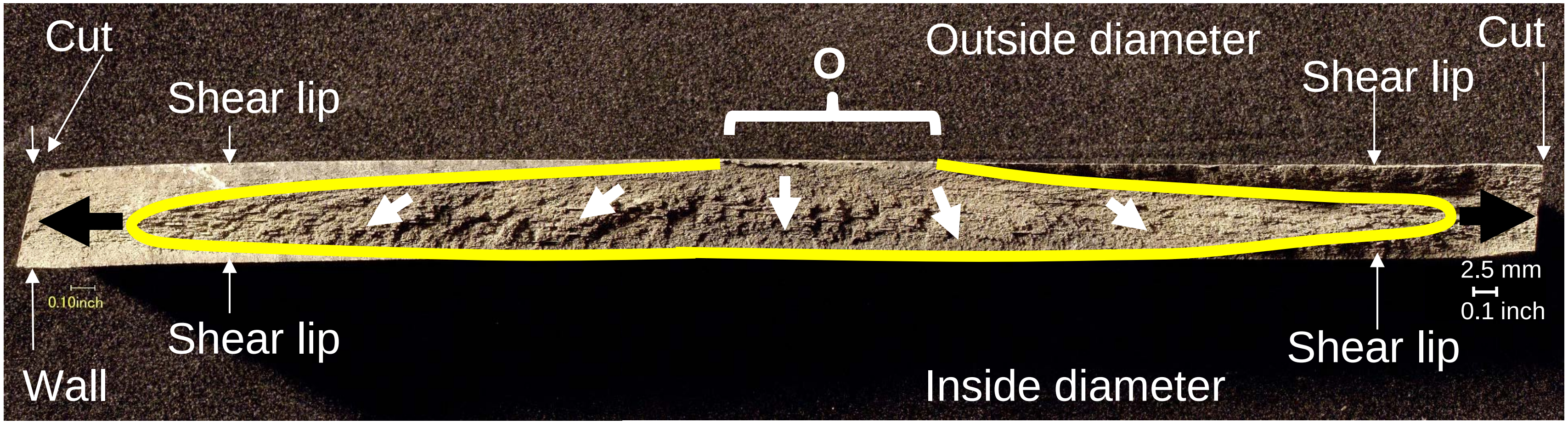


Figure 12. Optical composite photograph of the east face of the fracture showing the origin at the outer surface in the area indicated by bracket “O”, between two shear lips. The origin of the fracture and an area extending below the origin contained a flat region with a rough texture, indicated by a yellow line. Fracture propagation was in the general direction indicated by arrowheads.

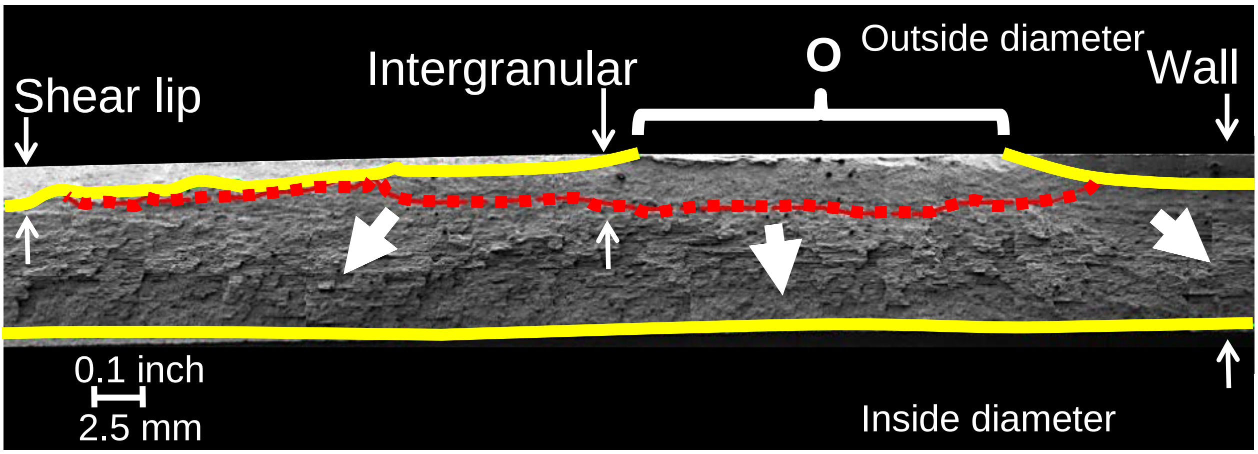


Figure 13. SEM composite photograph of the east face of the fracture showing the origin at the outer surface of the pipe in the area indicated by bracket “O”. Fracture propagation was in the general direction indicated by arrowheads. The intergranular region extended from the outer surface to the area indicated by a red dashed line. Portion of the flat region is outlined by yellow lines.

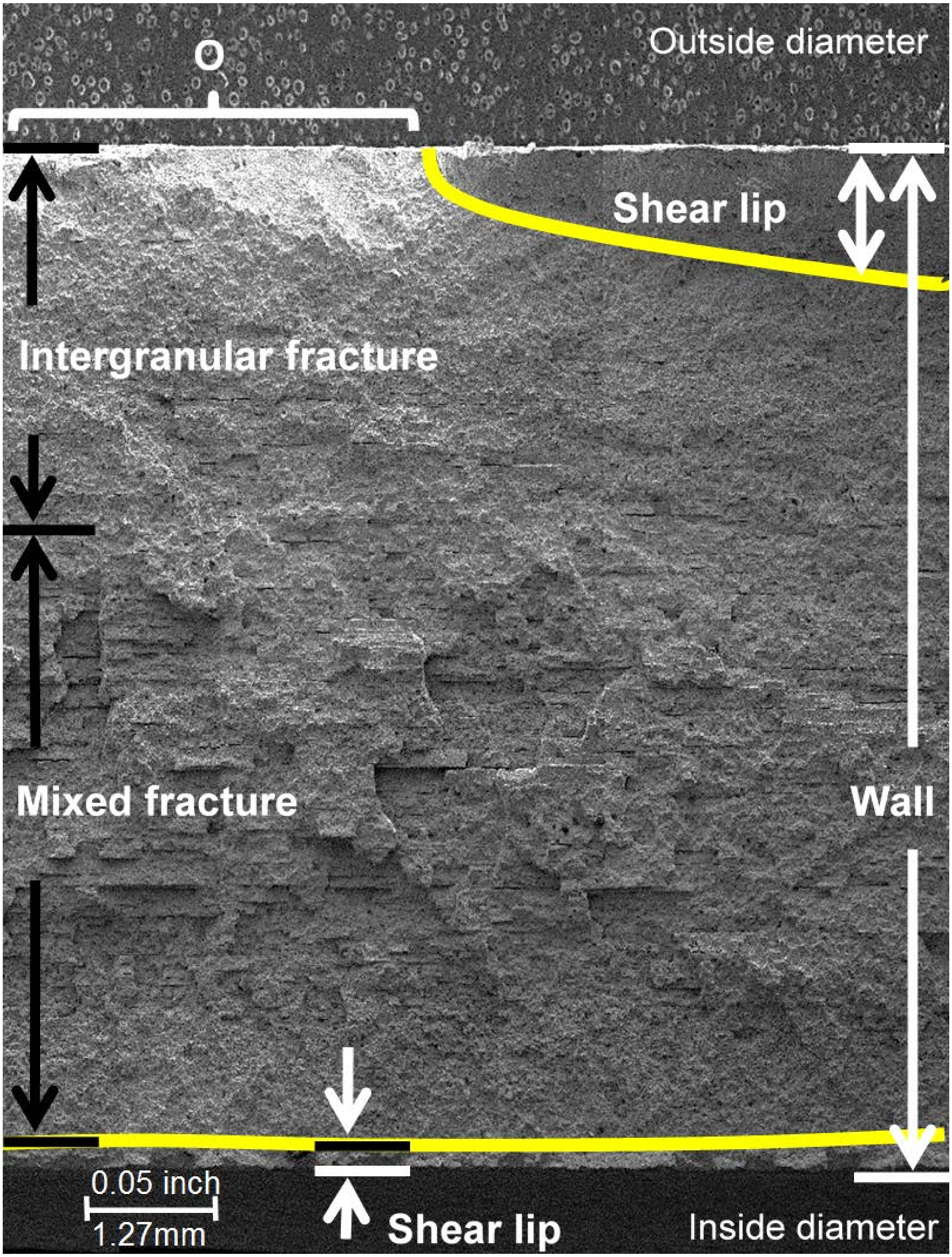


Figure 14. SEM composite photograph of the east face of the fracture and a portion of the fracture origin area at the outer surface next to the start of a shear lip. The flat region is located between the yellow lines.

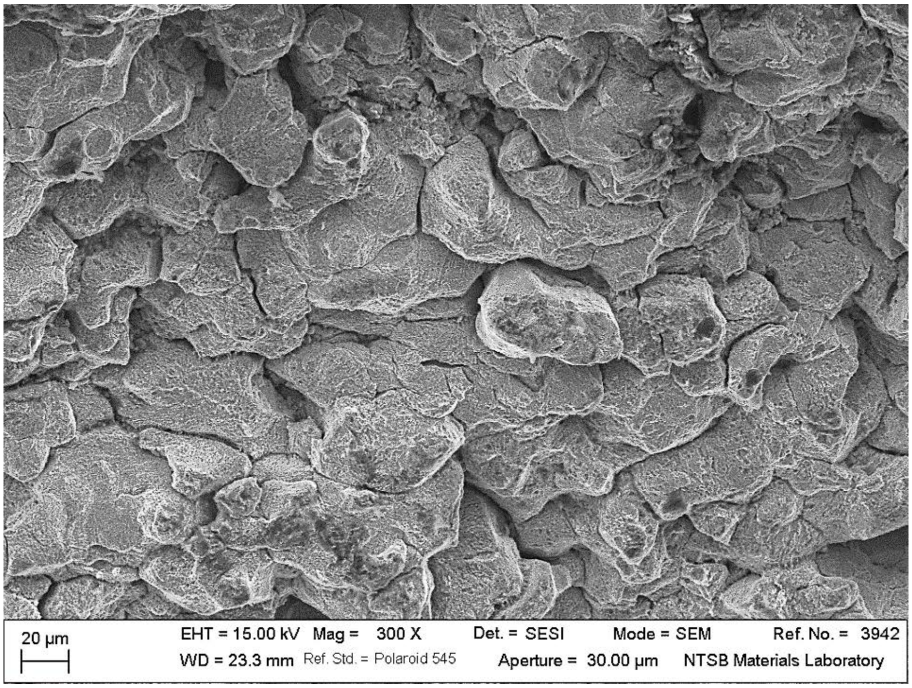


Figure 15. SEM photograph of the east fracture face at the origin of the fracture showing intergranular fracture features.

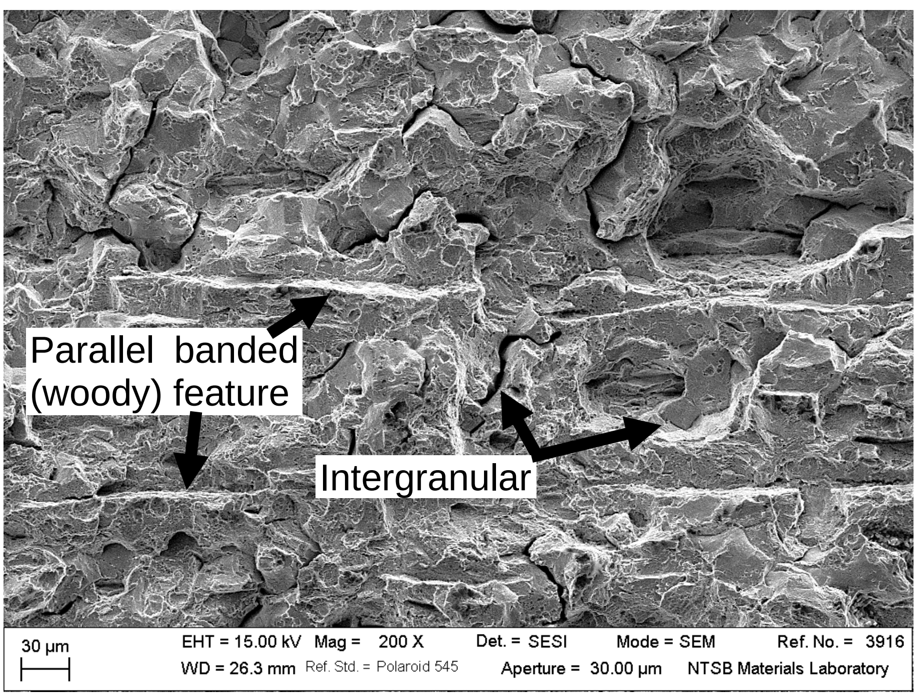


Figure 16. SEM photograph of the east fracture face at the mixed fracture region in an area near the intergranular region showing intergranular fracture features and includes a parallel banded (woody) feature that is associated with vintage hot rolled steel having a banded ferrite-pearlite microstructure.

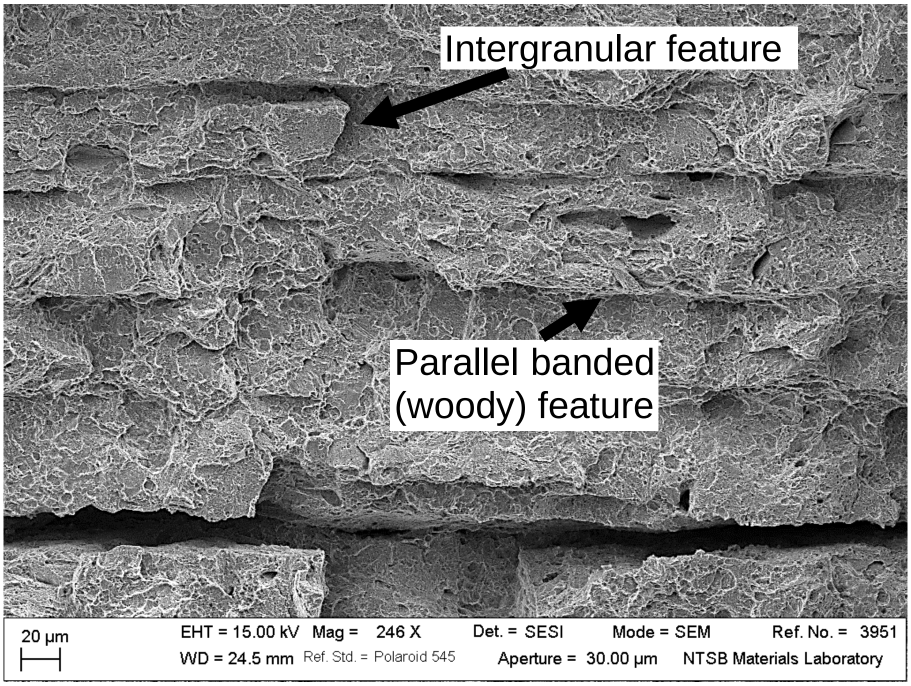


Figure 17. SEM photograph of the east fracture face at the mixed fracture region in an area located midway between the outer and inner wall surfaces showing intergranular and micro-void coalescence features and includes a parallel banded (woody) feature that is associated with vintage hot rolled steel having a banded ferrite-pearlite microstructure.

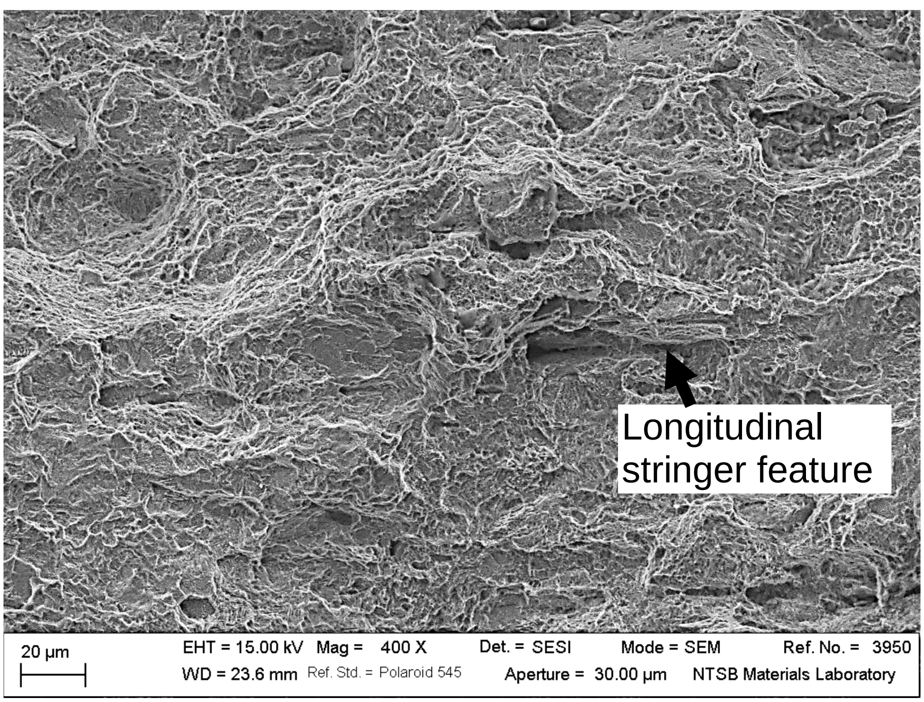


Figure 18. SEM photograph of the east fracture face at the mixed fracture region in an area near the shear lip at the inner surface showing micro-void coalescence features with several longitudinal stringer features.

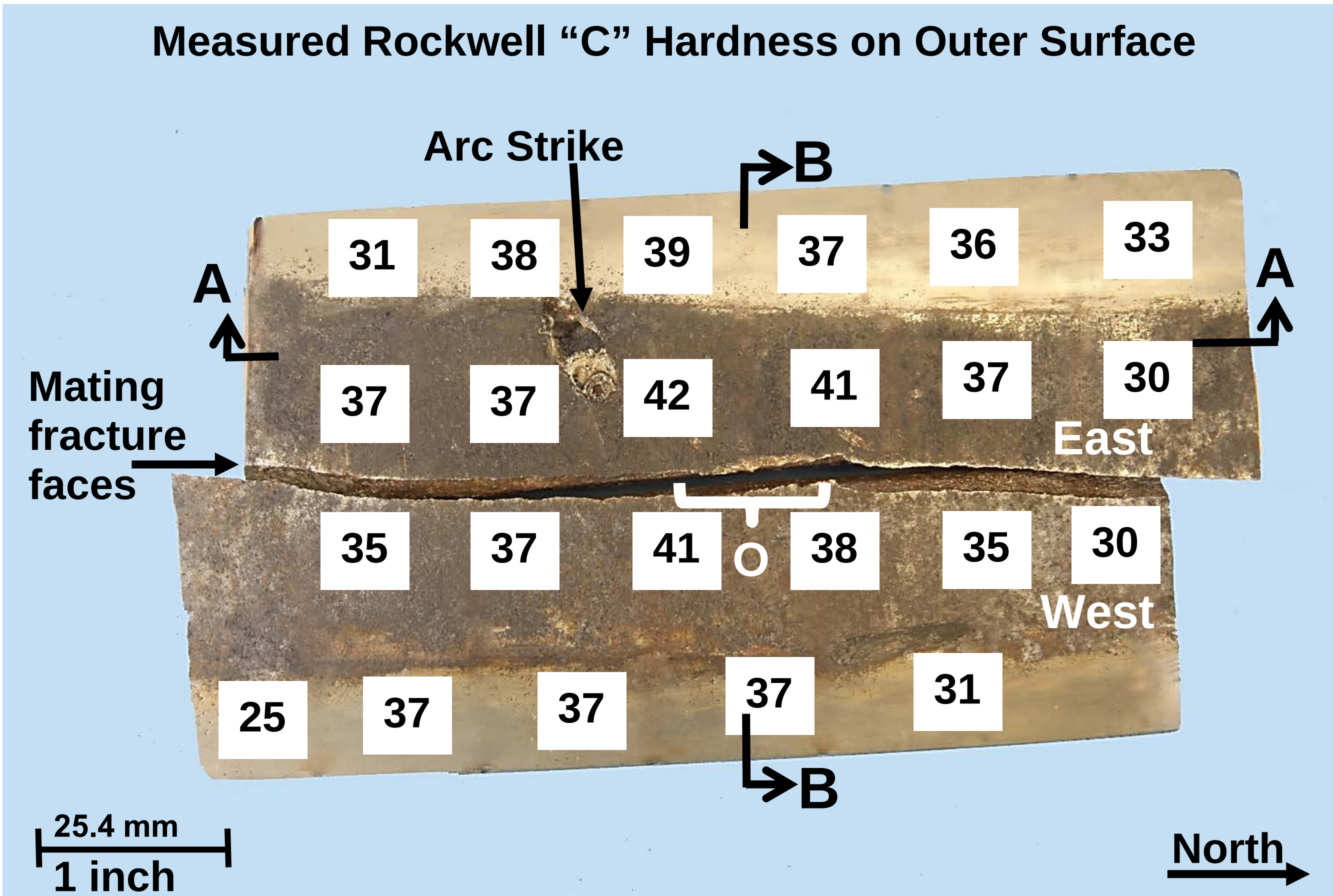


Figure 19. Photograph of the 6-inch long cut-out portion of the east fracture face and similar cut-out from the mating fracture face positioned next to each other as if intact showing the outer face of the pipe and the origin area indicated by bracket "O". Rockwell hardness testing was performed on the outer surface by the NTSB Materials Laboratory. Results are reported in Rockwell "C" hardness values (HRC). The position of each hardness reading reflects the approximate position of the measured hardness. A longitudinal-radial section was made in the area indicated by section line "A-A", and a circumferential-radial section was made in the area indicated by section line "B-B".

Table 1. Minimum Specified Tensile Strength for API 5L Grade X52 Pipe and Converted Hardness			
Specified Tensile Strength, Minimum (psi)	Converted Hardness		
	Vicker's (HV)	Rockwell B (HRB)	Brinell (HBW)
66,000	137	75	137

Note: (***) Rockwell hardness values that are less than those found on the "HRC" scale are reported as hardness values in the "HRB" scale. Conversion per ASTM A370.

Table 2. Least Hardness Value on the Outer Surface (Measured by Leeb Rebound Probe Test Method)		
Measured	Converted	
Vicker's (HV)	Rockwell B (HRB)	Brinell (HBW)
140	77	140

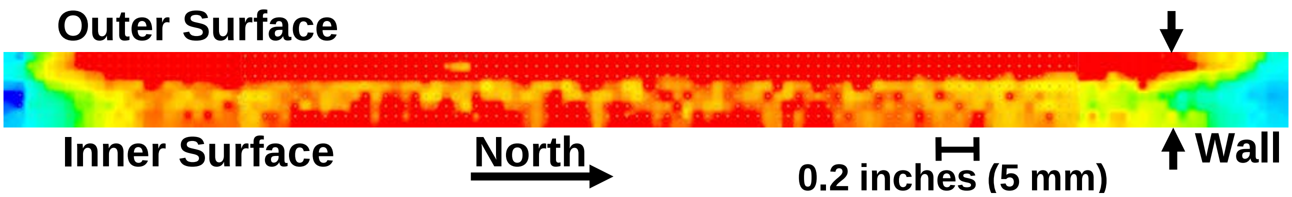


Figure 20. Diagram of longitudinal-radial cross section “A-A” showing the measured traverse hardness profile of the hard spot using color pattern to represent various ranges of hardness. The measured hardness is represented by the colors red, dark yellow, light yellow, green, light blue, and dark blue (greatest to least hardness, respectively). The measured hardness and colors that correspond to the measured hardness is shown in table 3. This section was made parallel and approximately 0.8 inch away from the origin of the fracture. The center of the section is aligned with the origin of the fracture.

Table 3.
Microhardness Profile for Section “A-A”
Color Pattern Interpretation

Color	Hardness Range		
	Measured	Converted	
	Vicker’s (HV_{500})	Rockwell “C” (HRC)	Brinell (HBW)
Red	382-402	39-41	362-381
Dark Yellow	354-372	36-38	336-353
Light Yellow	318-345	32-35	301-327
Green	266-310	25-31	253-294
Light Blue	254-302	23-30	243-286
Dark Blue	238-243	20-21	226-231

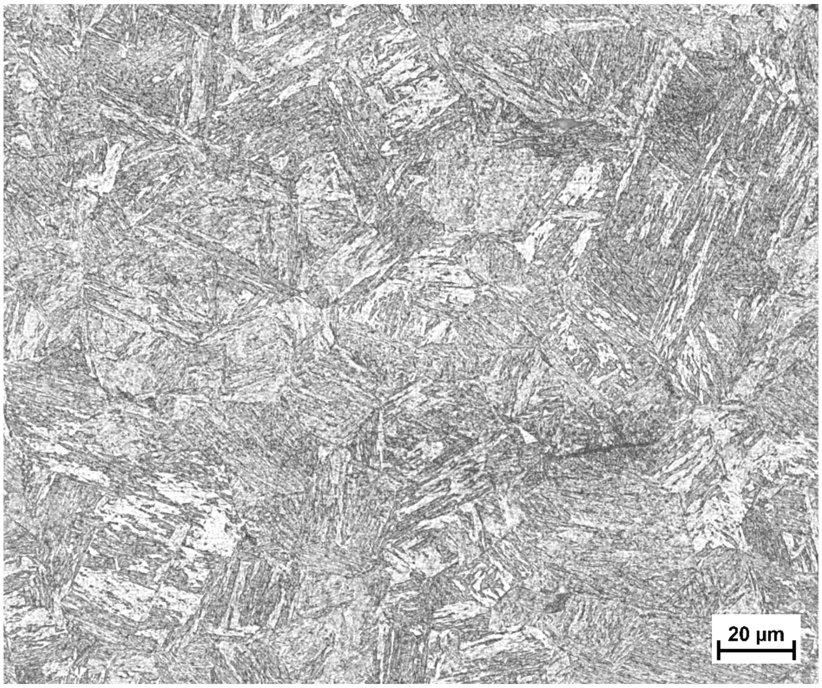


Figure 21. Typical microstructure of the hard spot in the area adjacent to the outer surface showing martensite. (2% Nital etch)

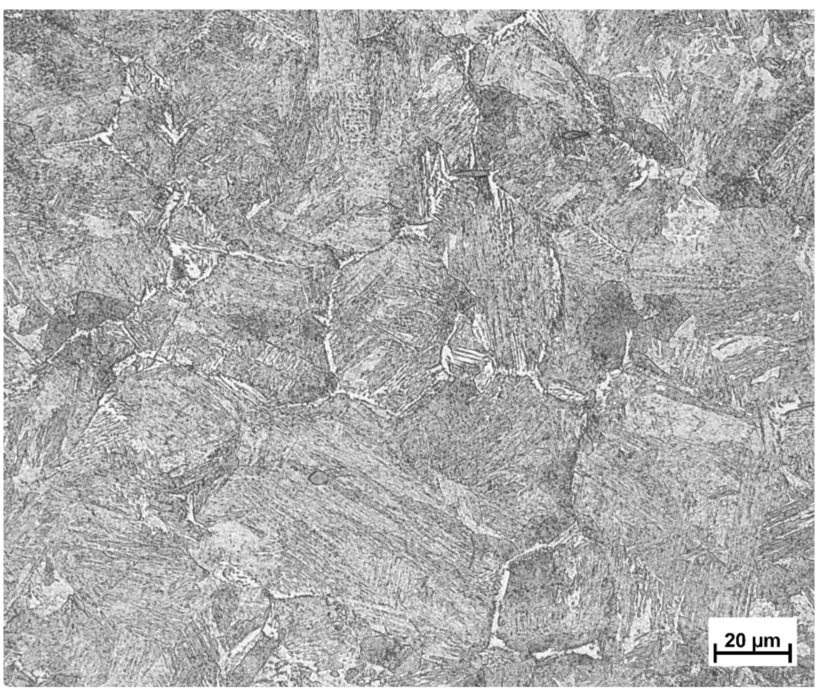
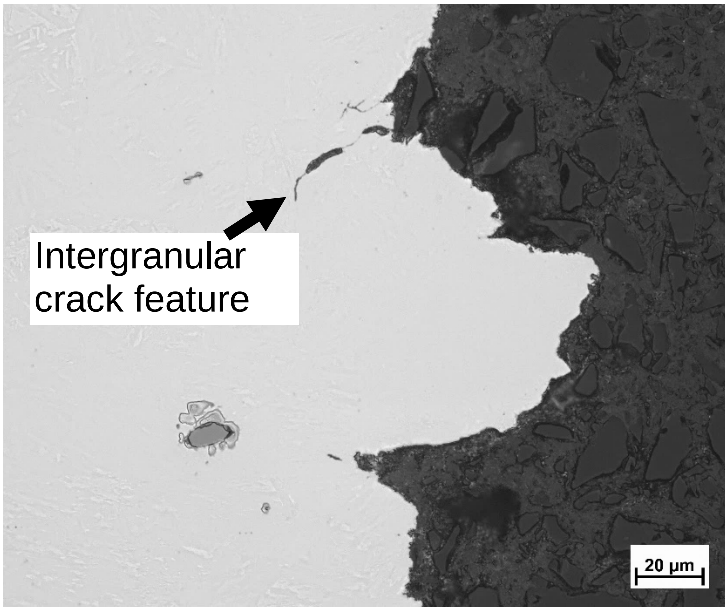


Figure 22. Typical microstructure of the hard spot in the area between the outer and inner surface showing martensite with second phase at the grain boundaries. (2% Nital etch)



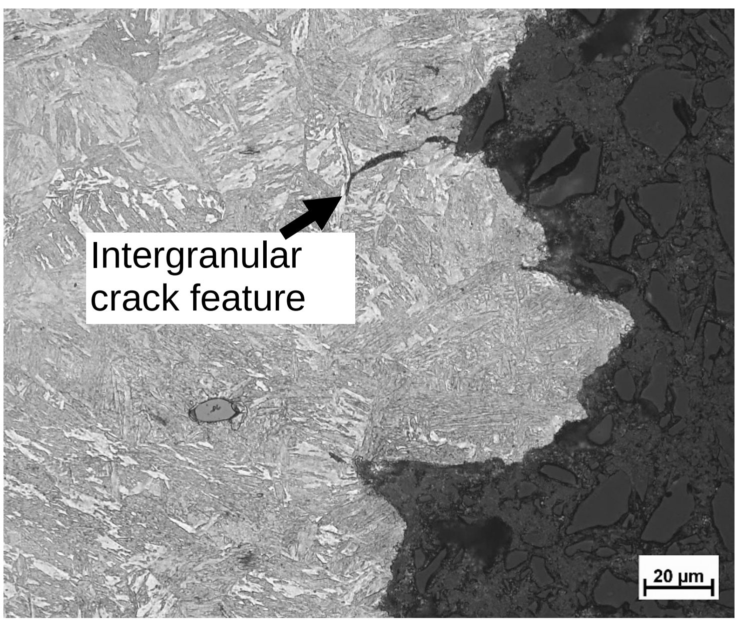


Figure 23. Cross section through the origin of the fracture showing intergranular fracture features before etching (upper side of page) and after 2% Nital etch (lower side page).

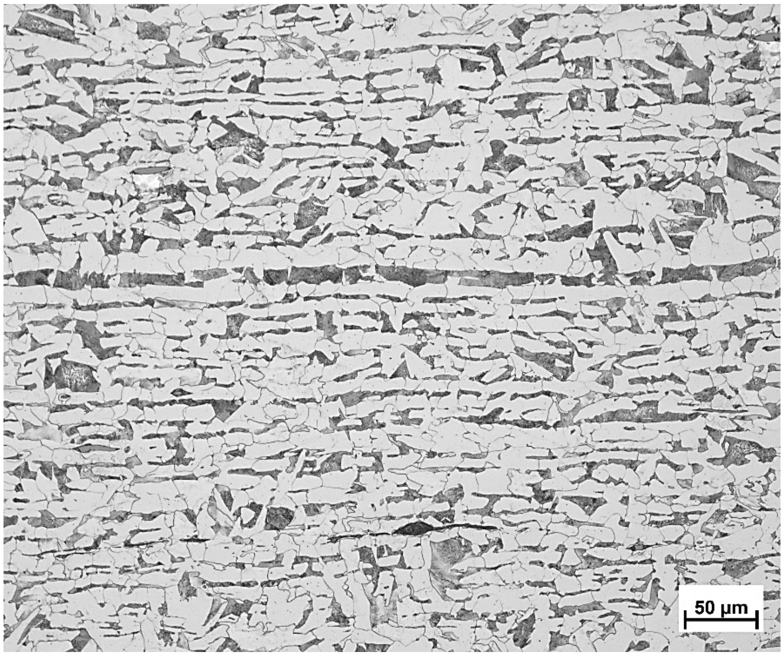
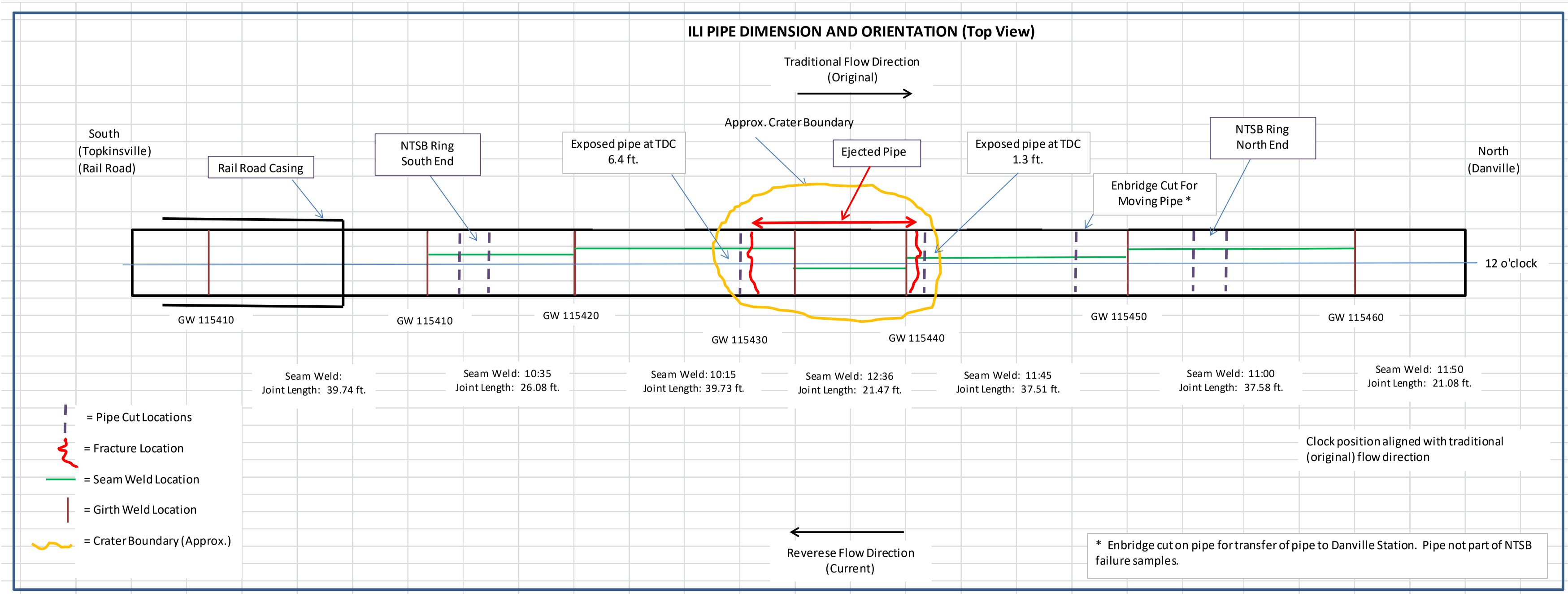


Figure 24. Typical microstructure of the pipe wall in metallurgical section “C-C” showing ferrite and banded pearlite grains with longitudinal manganese sulfide stringers. (2% Nital etch)

APPENDIX 1

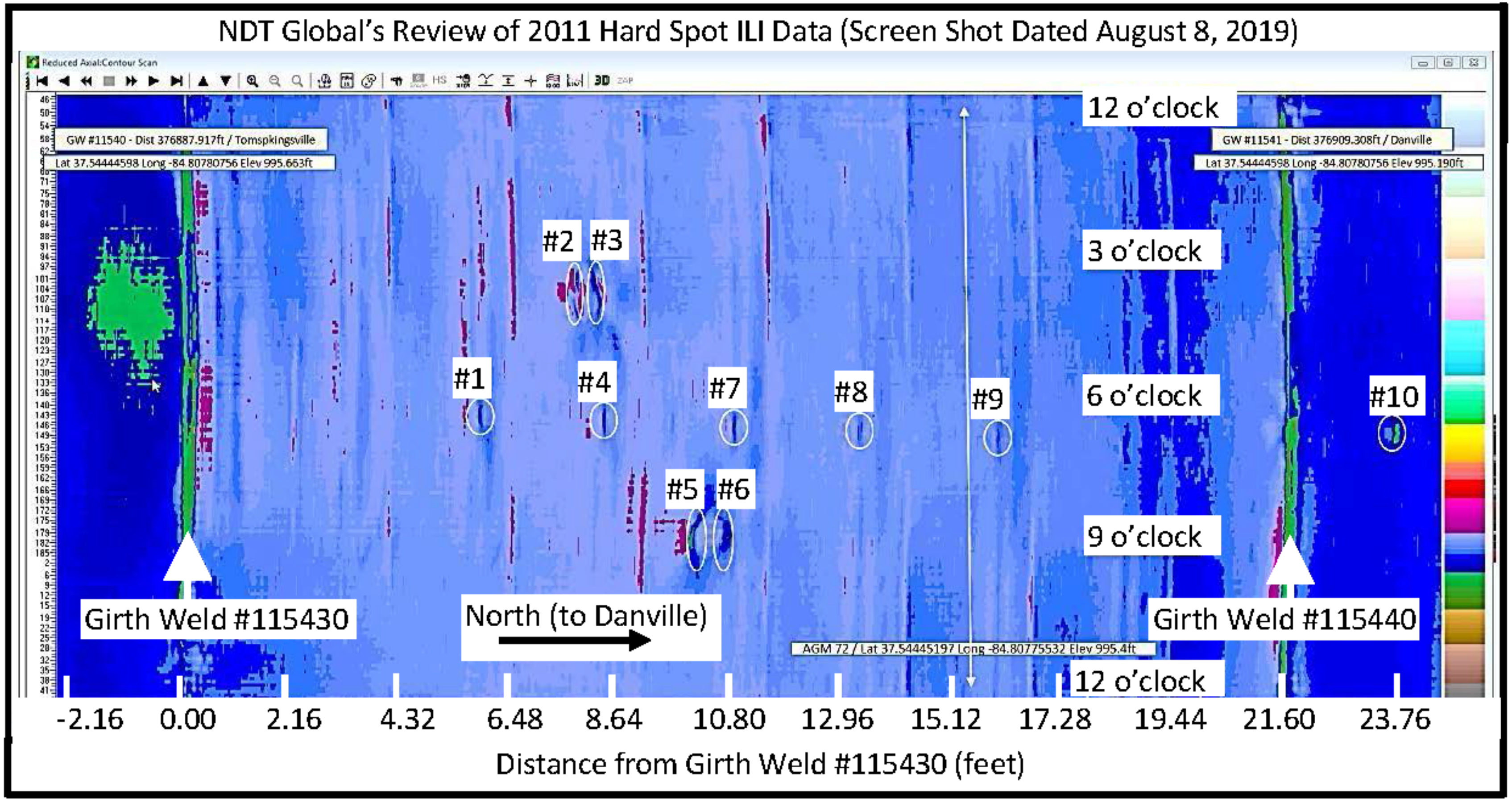
Diagram the Pipe Fracture
and
Weld Locations



Appendix 1. Diagram of the pipe showing the location of the welds and fracture locations.

APPENDIX 2

NDT Global's
Screen Shot Dated August 8, 2019
Showing 10 Hard Spot Indications
(from Review of the 2011 Hard Spot ILI Data)



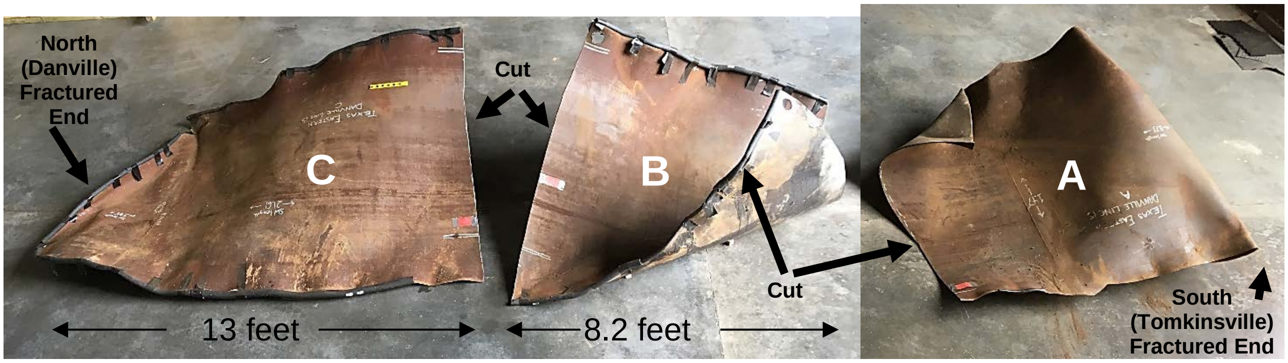
Appendix 2. Diagram of NDT Global's screen shot dated August 8, 2019 showing 10 hard spot indications (from review of the 2011 hard spot inline inspection [ILI] data). Hard spot indications are enclosed by a circle and they are numbered #1 through #10. The length between girth welds 115430 and 115440 measured approximately 21.6 feet.

Note: The ILI screen shot shows in small characters the girth weld (GW) numbers 11540 and 11541 that is from the NDT 2011 Hard Spot Tool run. The GW numbers [GW 115430 and 115440] and in the table associated with this screen shot are from a more recent GW numbering system associated with recent HRMFL ILI runs. The recent GW numbering system [GW 115430 and 115440] was used for pipe identification and numbering purposes during the investigation.

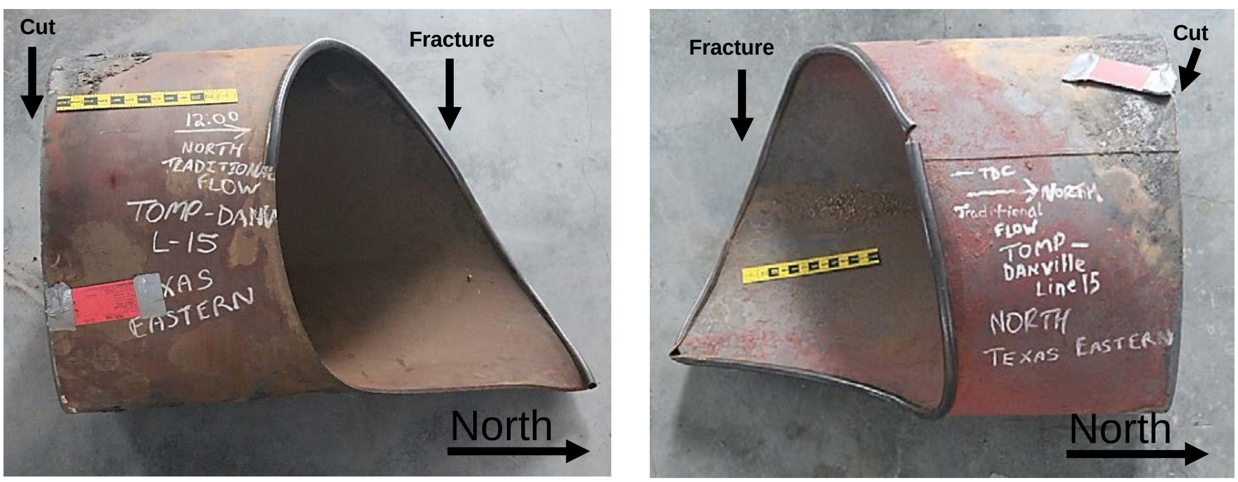
Positions and Estimated Hardness by NDT Global of the ILI Indications shown in Appendix 2 NDT Global's Review of 2011 Hard Spot ILI Data (Screen Shot Dated August 8, 2019)							
Indication	Event Distance (feet)	Clock Position Looking North	Orientation (degrees)	Distance from TDC Clockwise (inches)	Distance from Seam Weld Clockwise (inches)	Distance from Upstream GW115430 (feet)	Estimated Hardness by NDT Global (Brinell)
GW115430	376887.917	-	-	-	-	0.000	-
#1	376893.500	6:40	199	52.36	47.65	5.583	236
#2	376895.508	4:30	134	35.34	30.63	7.592	245
#3	376895.842	4:30	134	35.34	30.63	7.925	241
#4	376895.967	7:00	210	54.98	50.27	8.050	236
#5	376897.750	9:15	277	72.65	67.94	9.833	243
#6	376898.375	9:00	271	70.69	65.97	10.458	236
#7	376898.500	7:00	209	54.98	50.27	10.583	236
#8	376901.042	6:50	205	53.67	48.96	13.125	236
#9	376903.633	6:50	205	53.67	48.96	15.717	236
GW115440	376909.308	-	-	-	-	21.392	-
#10	376911.425	6:20	189	49.74	51.71	23.507	238

APPENDIX 3

Photographs of Parts Shipped to NTSB



Appendix 3A. As-received cut pipe pieces “A”, “B”, and “C” showing the inner faces.

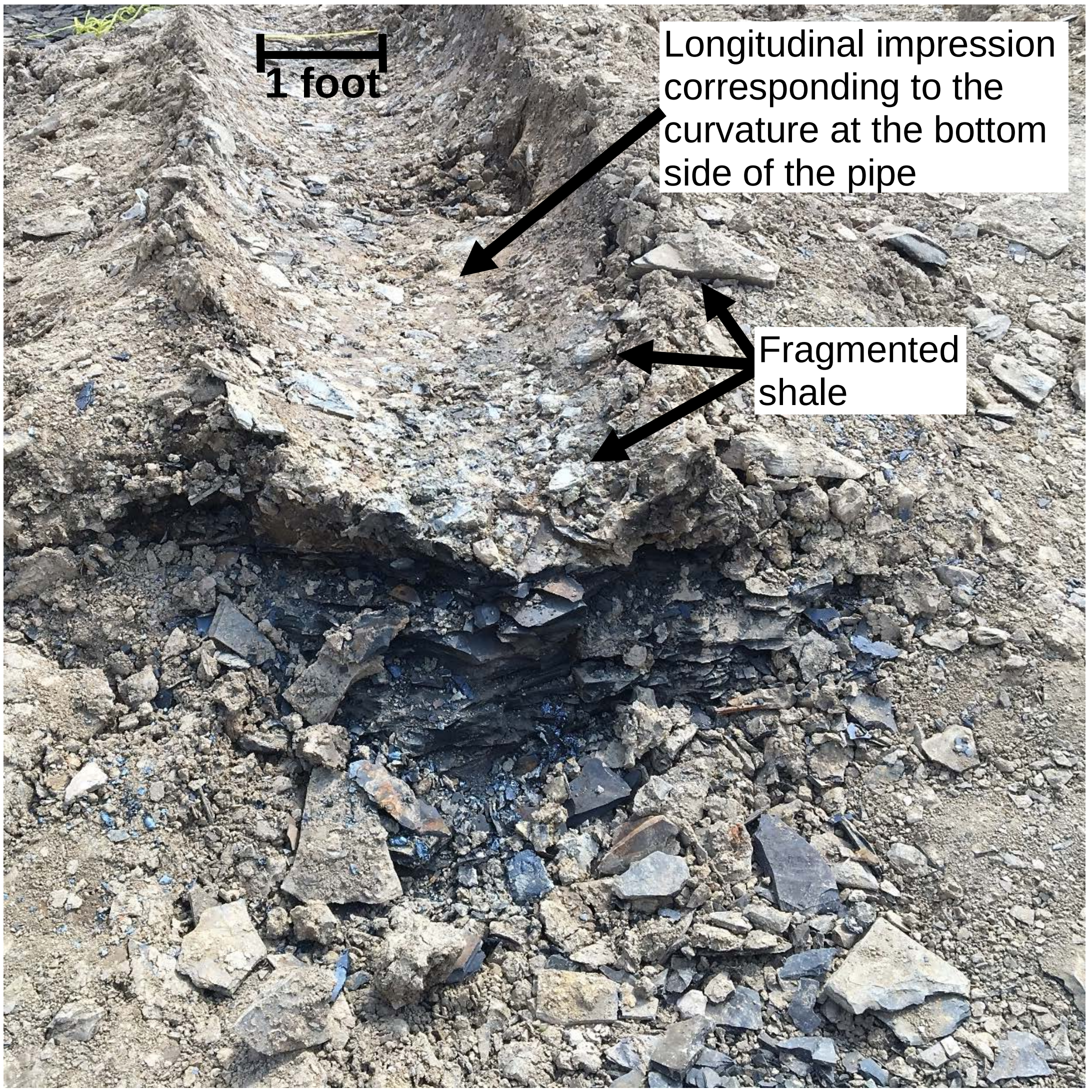


Appendix 3B. As-received fractured ends of the pipe that extended into crater.

Appendix 3C. As-received 4-foot long ring segments of the pipe that were cut from the pipeline. North sample is shown on the top side of the page and the south sample is shown at the bottom of the page.

APPENDIX 4

Photograph of Typical Ground Bedding Bottom of Installed Pipe



Appendix 4. Typical ground bedding found at the bottom of the installed pipe.

APPENDIX 5

Mears Group Inc
Portable Hardness Testing Report
Mears Job # 9131900304
(total of 24 pages)

Portable Hardness Testing
NTSB Accident Investigation PLD19FR002

Prepared Date: 11/19/2019

Mears Job # 9131900304

Prepared for:

The National Transportation Safety Board

Prepared by:

Mears Group, Inc.

SIGNATURE FORM

This Signature Form shall be signed by the appropriate personnel. By signing this page, representatives acknowledge and agree that they are approving the statements and documentation presented in the individual forms contained within this report titled:

Portable Hardness Testing
NTSB Accident Investigation PLD19FR002
Prepared Date: November 18, 2019

Furthermore, by providing approval with their signature below, each representative agrees with and approves the content, results, conclusions and recommendations contained within the forms and documents included with this report.

Company Representative(s) responsible for preparing the report:

[redacted] Date: 11/19/19

Sam Fryett, Senior Engineer, Mears Group, Inc.

Date:

Date:

Executive Summary

Mears Group, Inc. (Mears) was retained by the National Transportation Safety Board (NTSB) to conduct testing on a pipe segment related to an NTSB accident investigation (accident number PLD19FR002). This investigation follows a pipeline rupture located on the Enbridge 30-inch diameter, 0.375-inch nominal wall thickness TOMP-DANV Line 15 near Danville, KY. The test methods performed on the outer surface of the pipe by Mears included magnetic particle inspection, straight beam ultrasonic testing, acid etching, and portable hardness testing. The three inspection areas were referred to as East, West, and Feature 4.

Visual inspection noted surface corrosion pitting within the East sample inspection area. The surface corrosion pitting was considered interacting and covered an area 25-inches long, by 4.75-inches wide. The maximum depth of corrosion pitting was measured using a manual pit gauge and was measured at 0.013-inches. No visible mechanical damage wall loss was identified on the pipe surface in all three inspection areas.

White contrast magnetic particle inspection was performed over each inspection area. No magnetic particle linear indications were identified.

Ultrasonic scanning of each inspection area did not identify any mid-wall laminations. The minimum wall thickness was found to be 0.375-inches and the maximum wall thickness was found to be 0.386-inches.

Acid etching identified darker areas at the pipe outer surface within the East and West Inspection areas. No color variation was identified on the Feature 4 inspection area. The darker areas were found to correspond with elevated hardness values.

Hardness testing was performed using a Leeb Rebound Probe test method, and results were recorded in Brinell Harness Numbers. The hardness values were found to be higher over the darker areas identified with acid etching, which also corresponded with the fracture origin area. The maximum hardness value was found to be 336 BHN, on the East inspection area. This location was aligned with the fracture origin identified by the NTSB. The maximum hardness value found within the West inspection area was 287 BHN, and the maximum on the Feature 4 inspection area was found to be 169 BHN. The minimum hardness value was found to be 140 BHN on the West inspection area.

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Acronyms and Abbreviations

BHN	Brinell Hardness Number
ILI	In-Line Inspection
MPI	Magnetic Particle Inspection
NWT	Nominal Wall Thickness
NTSB	National Transportation Safety Board
TOMP-DANV	Tompkinsville - Danville
U/S	Upstream

1.0 INTRODUCTION

Mears Group, Inc. (Mears) was retained by the National Transportation Safety Board (NTSB) to conduct testing on a pipe segment related to an NTSB accident investigation (accident number PLD19FR002). This investigation follows a pipeline rupture located on the Enbridge 30-inch diameter, 0.375-inch nominal wall thickness TOMP-DANV Line 15 near Danville, KY. All testing completed by Mears was performed at the NTSB Training Academy in Ashburn, Virginia, on September 16th, 2019. The test methods performed on the outer surface of the pipe included magnetic particle inspection, straight beam ultrasonic testing, acid etching, and portable hardness testing. Testing methodology followed field testing procedures before samples were cut for further laboratory analysis.

2.0 SCOPE OF WORK

Three areas of interest on the outer surface of the pipe were identified by the NTSB to be inspected by Mears. The three areas of interest were located in the same general areas identified by the hard spot in-line inspection (ILI) tool vendor (NDT Global) as having hard spot indications. Table 1 shows the location of the three hard spots identified by NDT Global ILI data (screen shot dated August 8, 2019). ILI Clock positions are read looking North (towards Danville). The areas of interest were located on a fractured pipe segment that was removed from the accident site and located at the NTSB Training Academy in Ashburn, Virginia. Two hard spot indications (referred to as features “2” and “3”) were located in the general area of the facture origin identified by the NTSB, and another hard spot indication (referred to as feature “4”) was located near features “2” and “3”. This report refers to the three inspection areas as the East, West, and Feature 4. The inspection area East of the fracture origin area was referred to as “East”, the inspection area West of the fracture origin was referred to as “West”, and the inspection area slightly West of the fracture origin was referred to as “Feature 4”. The East and West sample post inspection are shown in Figure 1.

Table 1: As-Called ILI features

Event Distance (ft.)	Clock Position	Feature #
376,895.508	4:30	Feature 2
376,895.842	4:30	Feature 3
376,895.967	7:00	Feature 4

The inspection areas were sized as shown in Table 2 below. Inspection areas were sized larger than the callout area to ensure any potential hard spots were covered. Inspection areas were located by measuring from the U/S girth weld number 115430 and the long seam weld. The event distances reference back to the ILI data collected by NDT Global for line 15.

Table 2: Inspection Area Sizes

Inspection Area	Length (in.)	Width (in.)
East	20	9.5
West	17	7
Feature 4	12	12

The edge along the fracture was covered with approximately 1-inch of tape along the edge of the East and West inspection areas to preserve the fracture initiation area. This is shown in Figure 1 where the tape has been removed and mating fractures were placed next to each other.

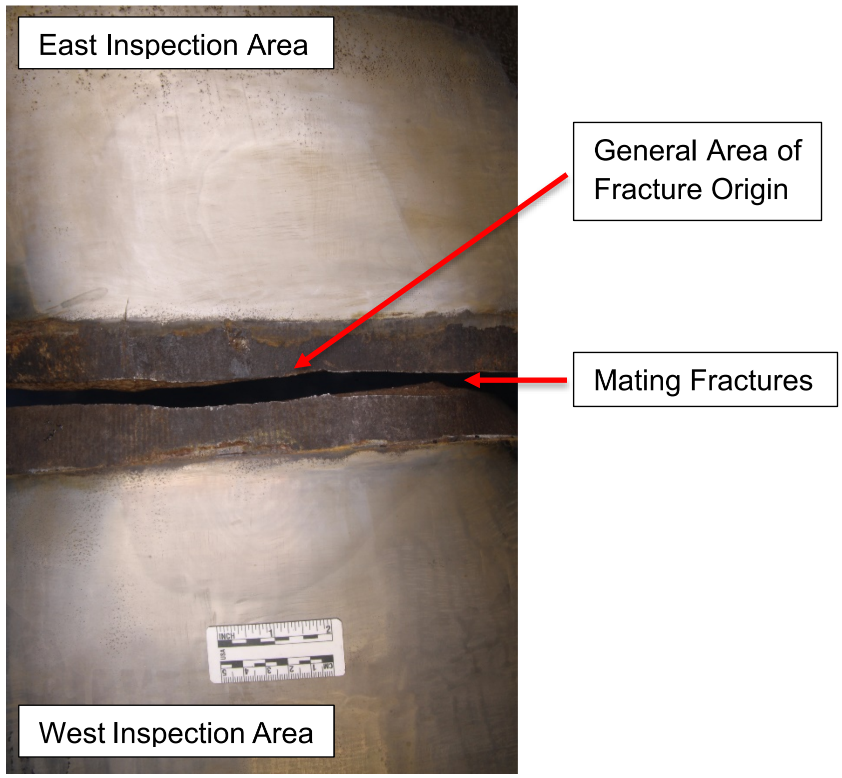

Figure 1: East and West Inspection Area on the Outer Surface of the Pipe After Etching. Photo by NTSB

The scope of work was to perform field testing to identify potential hard spots within the three inspection areas. The process to complete the field testing is outlined below and described in the following sections.

1. Surface preparation,
2. Magnetic particle inspection,
3. Ultrasonic wall thickness measurements,
4. Surface preparation (grinding/buffing),
5. Acid etching, and
6. Portable hardness testing.

3.0 RESULTS AND EVALUATION

The following sections outline the testing procedures performed and the findings.

3.1 Surface Preparation

Surface preparation was performed to remove existing remaining coating and debris from the pipe surface over the inspection areas. This was performed using a wire brush/wheel attachment on a 4-inch angle grinder. The inspection areas were prepared to a clean surface of bare metal to allow for magnetic particle inspection and ultrasonic thickness measurements.

After the surface was prepared, visual inspection noted surface corrosion pitting within the East sample inspection area. This is shown in Figure 2 and Figure 3. The surface corrosion pitting was considered interacting and covered an area 25-inches long, by 4.75-inches wide. It was noted that the surface pitting continued both upstream and downstream of the East inspection area. The maximum depth of corrosion pitting was measured using a manual pit gauge and was measured at 0.013-inches. No visible mechanical damage wall loss was identified on the pipe surface in all three inspection areas.

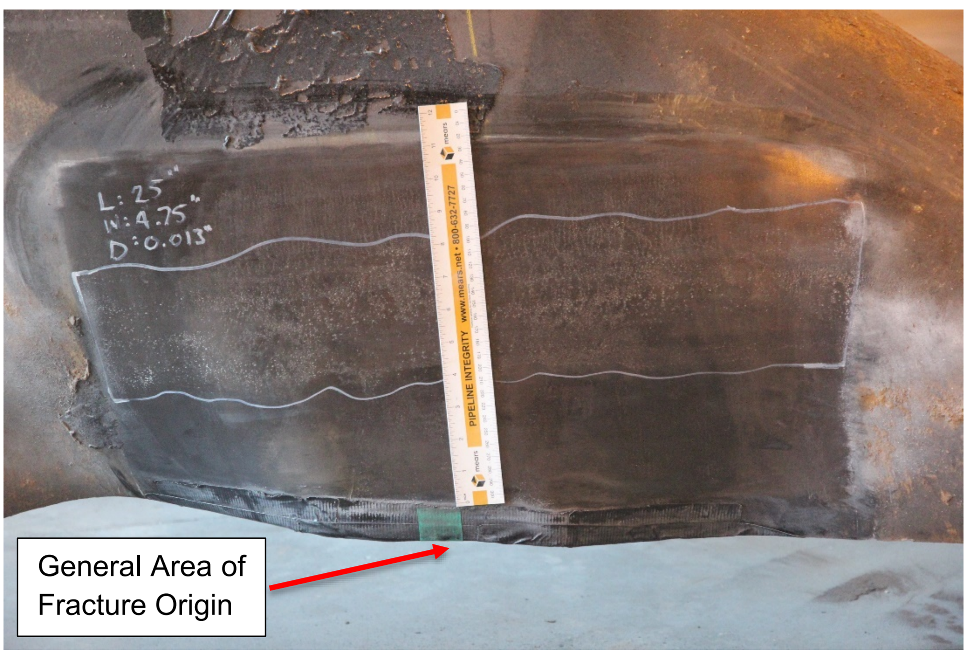

Figure 2: Surface Corrosion Pitting on East Inspection Area. Photo by NTSB

Figure 3: Zoomed View of Surface corrosion Pitting within East Inspection Area. Photo by NTSB

3.2 Magnetic Particle Inspection

White contrast magnetic particle inspection was performed bi-directional over the complete surface of each inspection area. The inspection included looking for individual or colonies of crack indications. Magnetic particle inspection did not identify any MPI linear indications on all three inspection areas.

3.3 Ultrasonic Wall Thickness Measurements

Ultrasonic wall thickness measurements were performed to scan for mid wall laminations, along with recording the wall thickness of the pipe at representative locations over each pipe sample. Scanning over each inspection area did not identify any mid-wall laminations.

Wall thickness measurements were recorded at representative locations to allow for surface grinding/buffing for acid etching and hardness testing. The minimum and maximum wall thickness before surface preparation over each inspection area is shown in Table 3. Nominal Specified Wall Thickness was 0.375-inch.

Table 3: Wall Thickness Measurements Before Surface Preparation

Inspection Area	Min (in.)	Max (in.)
East	0.382	0.386
West	0.375	0.386
Feature 4	0.380	0.385

All wall thickness measurements recorded for each inspection area are shown in Appendix A through C.

3.4 Surface Preparation (Grinding/Buffing)

Surface grinding and buffing was performed to remove any surface imperfections and provide a surface finish adequate for acid etching. This was performed by using soft pad buffing wheels on a 4-inch angle grinder, followed by buffing using flapper wheels on a die grinder. Surface preparation was performed in multiple stages utilizing various sanding grits. Initial grinding was performed using an 80-grit flapper wheel, and final surface polishing was performed using a 320-grit flapper wheel on a die grinder.

3.5 Acid Etching

Acid etching was performed over each inspection area post surface preparation. This utilized a 10% Nital acid solution that was applied over the inspection areas. Results of the etching identified darker areas on both the East and West sample, however no darker areas were identified with etching within the Feature 4 inspection area.

Darker areas on both the East and West sample that correlated with elevated hardness values were identified. These darker areas were more prominent when the etchant was applied and still wet. This is shown in Figure 4 and Figure 5. In Figure 4, the etchant had been applied and the surface was still wet which showed the darker areas of the pipe surface. After the surface was etched multiple times and wiped clean with a dry cloth the darker area was still present (Figure 5), however it was not as prominent. This was also the case for the East Inspection area; however, the darker area was not as prominent as the West sample for both cases (wet/dry).

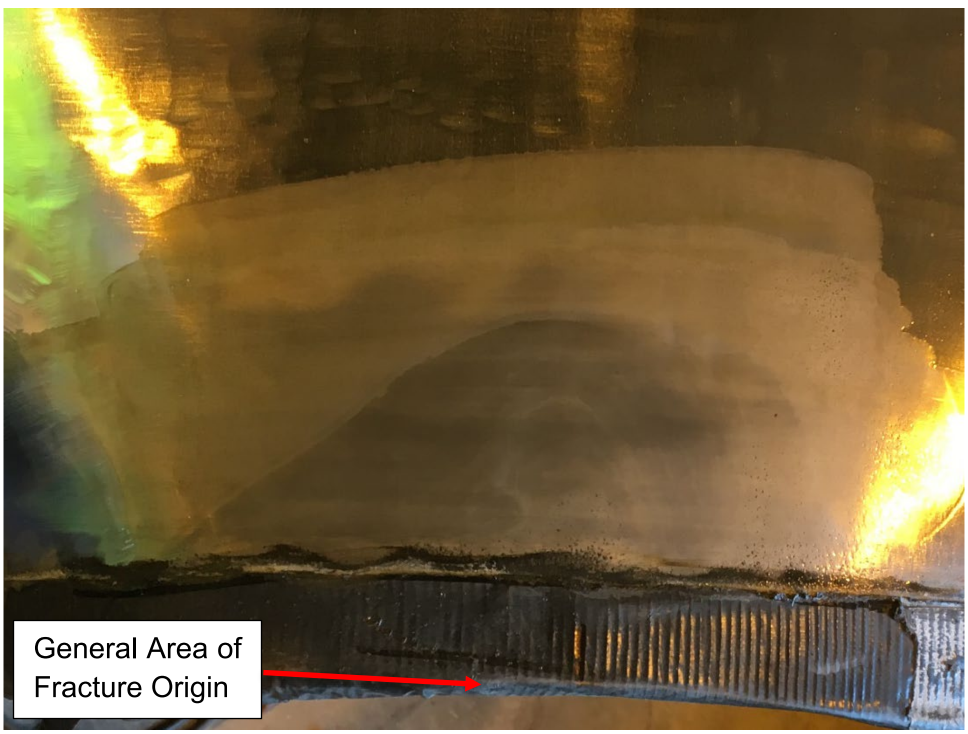

Figure 4: West Area with Etchant Applied. Photo by NTSB

Figure 5: West Area After Etchant was Removed and Surface Clean/Dry. Photo by NTSB

3.6 Hardness Testing

Each inspection area was marked out in 1-inch grids to allow for a hardness measurement to be recorded within each 1-inch area. Grids were numbered using the leading-edge method with the zero reference being the upstream edge of the grid. Marked up grids for each inspection area are shown in Figure 6 and Figure 7. A Leeb Rebound Probe portable hardness tester was used, and results were recorded in Brinell hardness numbers (BHN). All hardness values are included within Appendix A through C inspection reports and have been color formatted with a scale from green to red, where green is the lowest recorded number and red is the highest recorded number.

Information provided by the NTSB correlated the origin of the fracture with line 9 on the East inspection area and line 8 on the West inspection area. These are marked in Figure 6 through Figure 9. Elevated hardness values within the East and West inspection areas were identified and found to correlate with the darker areas identified during acid etching.

The maximum hardness value of 336 BHN was identified on the East inspection area within the 8-inch increment shown in Figure 8. This correlates with the information provided by the NTSB that identified the fracture origin aligning with the 9-inch line on the East grid.

The maximum and minimum hardness values for each inspection area are summarized in Table 4.

Table 4: Summary of Hardness Values (BHN)

Inspection Area	Min	Max
East	146	336
West	140	287
Feature 4	143	169

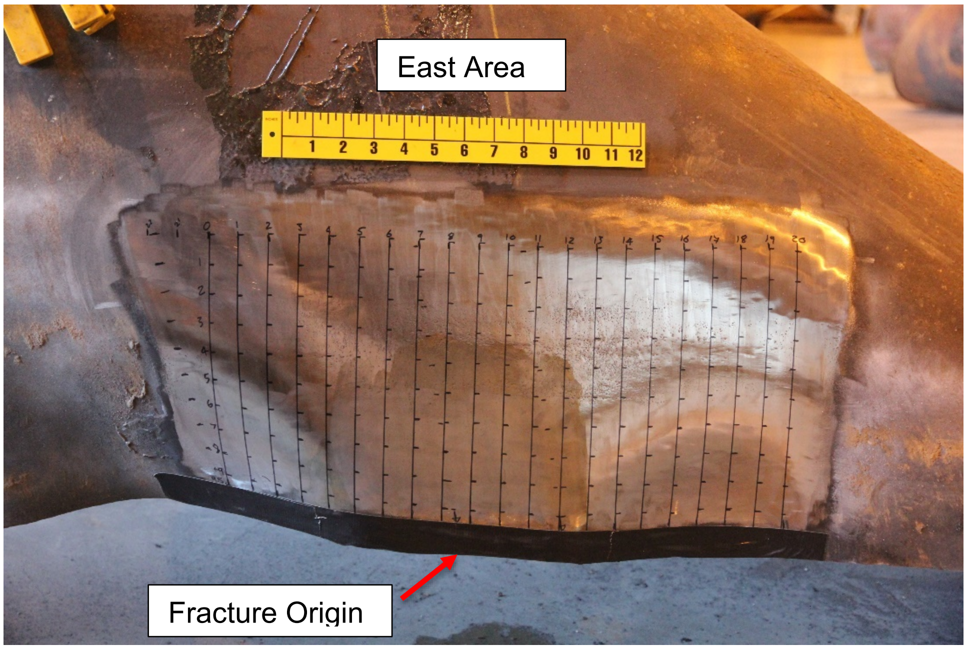

Figure 6: East Sample Grid for Hardness Testing. Photo by NTSB

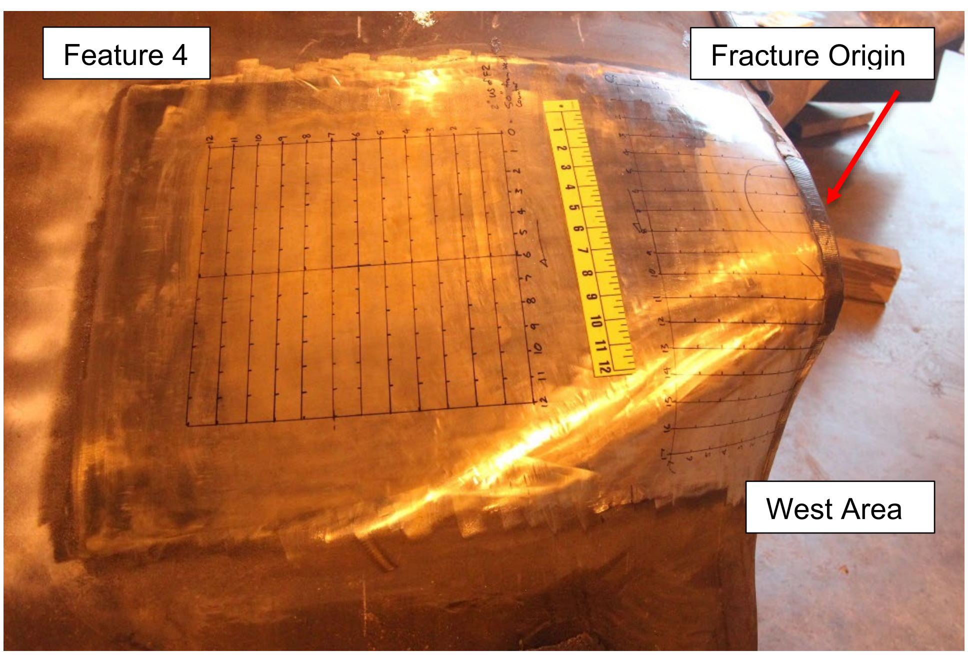

Figure 7: Feature 4 Grid and West Grid for Hardness Testing. Photo by NTSB

East Grid

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	169	164	169	165	166	168	169	170	166	179	169	165	161	165	159	161	169	160	168	156
2	161	163	168	166	165	162	173	170	161	167	167	166	167	165	165	161	163	162	160	163
3	167	169	169	164	169	160	176	169	159	172	168	170	164	163	161	171	164	164	160	170
4	168	167	165	165	163	167	168	169	170	173	170	167	171	173	168	162	167	170	163	174
5	167	162	170	170	169	171	177	177	190	174	166	171	154	162	161	162	157	162	164	167
6	164	168	165	164	169	178	186	255	245	181	179	178	165	166	173	167	163	161	172	171
7	166	163	166	164	168	176	251	301	295	283	232	164	163	164	162	164	160	163	157	171
8	162	161	164	203	186	208	289	293	309	305	282	169	154	162	167	164	158	160	155	173
9	150	158	166	194	202	210	291	310	319	313	303	173	165	162	158	162	161	157	159	160
9.5	161	146	164	195	202	211	280	336	326	304	303	245	155	163	155	157	163	167	159	163

Fracture Origin

West Grid

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	163	196	190	167	231	280	287	285	276	236	151	156	159	153	151	149	149
2	151	158	170	162	170	248	250	257	245	149	144	158	160	166	154	149	150
3	164	150	160	162	159	175	174	162	146	153	148	156	160	164	157	156	150
4	159	159	156	157	155	153	149	146	144	148	148	144	152	156	158	149	147
5	153	161	156	152	154	147	148	151	147	147	146	146	154	153	157	153	150
6	153	153	158	153	152	149	156	151	140	149	146	149	149	159	157	155	147
7	156	155	155	152	157	151	153	148	152	151	150	152	153	153	159	152	149

Figure 8: East and West Grid Hardness Values

Feature 4

0	1	2	3	4	5	6	7	8	9	10	11	12
1	159	166	162	164	159	169	164	159	154	159	151	147
2	154	152	158	158	160	161	165	158	151	156	165	158
3	150	151	153	150	155	149	149	158	153	153	151	154
4	151	147	144	146	150	144	146	153	150	157	149	153
5	154	147	147	147	151	150	146	151	150	149	153	159
6	147	143	146	148	144	145	146	147	151	150	152	153
7	150	151	155	149	150	151	151	145	149	152	149	144
8	152	149	150	146	155	145	150	152	152	153	155	148
9	154	161	154	147	145	154	146	147	153	157	151	152
10	151	149	154	151	159	159	148	154	152	155	151	154
11	157	158	159	155	151	157	148	144	152	155	158	153
12	156	153	156	155	153	153	145	149	155	151	150	158

Figure 9: Feature 4 Grid Hardness Values

4.0 CONCLUSIONS

Inspection of a pipe segment using field testing methodologies was performed on September 16th, 2019 at the NTSB Training Academy. Inspection for each area of interest included visual inspection, magnetic particle inspection, ultrasonic thickness testing for laminations and wall thickness, acid etching, and portable hardness testing. The three inspection areas were referenced as East, West, and Feature 4.

Visual inspection noted surface corrosion pitting within the East sample inspection area. The surface corrosion pitting was considered interacting and covered an area 25-inches long, by 4.75-inches wide. The maximum depth of corrosion pitting was measured using a manual pit gauge and was measured at 0.013-inches. No visible mechanical damage wall loss was identified on the pipe surface in all three inspection areas.

White contrast magnetic particle was performed over each inspection area. No magnetic particle linear indications were identified.

Ultrasonic scanning of each inspection area did not identify any mid-wall laminations. The minimum wall thickness was found to be 0.375-inches on the West inspection area, and the maximum wall thickness was found to be 0.386-inches on both the East and West inspection areas.

Acid etching identified darker areas of the pipe surface within the East and West Inspection areas. No color variation was identified on the Feature 4 inspection area. The darker areas were found to correspond with elevated hardness values.

Hardness testing was performed using a Leeb Rebound Probe test method, and results were recorded in Brinell Harness Numbers. The hardness values were found to be higher over the darker areas identified with acid etching, which also corresponded with the fracture origin area. The maximum hardness value was found to be 336 BHN, on the East inspection area. This location was aligned with the fracture origin identified by the NTSB. The maximum hardness value found within the West inspection area was 287 BHN, and the maximum on the Feature 4 inspection area was found to be 169 BHN. The minimum hardness value was found to be 140 BHN on the West inspection area.

5.0 APPENDICES

Appendix A – East Inspection Area Hardness Testing Report
Appendix B – West Inspection Area Hardness Testing Report
Appendix C – Feature 4 Inspection Area Hardness Testing Report

Appendix A

Appendix A – East Inspection Area Hardness Testing Report

Work Location and Details	EAST Inspection Area		
DE Technician	Beau Spaulding	Date	9/16/2019
Engineer/Inspector	Sam Fryett	Nominal OD (in)	30
Segment/Route	TOMP-DANV	Nominal WT (in)	0.375
Line Number	15	Pipe Grade	X-52
Target Feature	Feature 2 & 3	Seam Type	AO Smith AFW
Target Wheel Count	376,895.508 & 376,895.842	Seam Clock Position	12:36

Hardness Equipment Details

Hardness Technique	BHN (Brinell Hardness No.)	Test Unit Model No.	THX281 Plus
Test Unit Manufacturer	Cimetrix	Test Unit S/N	TMO170900049
Calibration Date	8/22/2019		

Probe Manufacturer	Cimetrix	Probe Model No.	Type D
Calibration Date	8/22/2019	Probe S/N	317-565

Calibration Details

Qty. of Cal. Blocks Used	1	
Calibration Block 1		
Block Manufacturer	Cimetrix	
Cal. Block S/N	L7101200	
Cal. Block Actual Hardness	775	
Cal. Block Hardness Scale	HLD	
Cal Block Tolerance (%)/No.	2%	15.5

Calibration Results

	Cal Block	1	2	3	4	5	Avg.	Std. Dev	Time	Date
Pre-Test	1	769.00	774.00	764.00	768.00	764.00	767.80	3.71	2:30	9/16/19
Post Test	1	774.00	773.00	774.00	775.00	767.00	772.60	2.87	4:30	9/16/19

Hardness Test Location Details

Wheel Count	376,895.508 & 376,895.842
Clock Position	4:30, 4:30
Length (in)	20
Width (in)	9.5

Ultrasonic Thickness Measurements

Pre-Surface Prep (in)

0.386			0.383
0.382	0.384	0.383	0.383

Post-Surface Prep (in)

0.371			0.365
0.369	0.370	0.362	0.368

Hardness Testing Results

Hardness Readings Per Increment - Full Area

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	169	164	169	165	166	168	169	170	166	179	169	165	161	165	159	161	169	160	168	156
2	161	163	168	166	165	162	173	170	161	167	167	166	167	165	165	161	163	162	160	163
3	167	169	169	164	169	160	176	169	159	172	168	170	164	163	161	171	164	164	160	170
4	168	167	165	165	163	167	168	169	170	173	170	167	171	173	168	162	167	170	163	174
5	167	162	170	170	169	171	177	177	190	174	166	171	154	162	161	162	157	162	164	167
6	164	168	165	164	169	178	186	255	245	181	179	178	165	166	173	167	163	161	172	171
7	166	163	166	164	168	176	251	301	295	283	232	164	163	164	162	164	160	163	157	171
8	162	161	164	203	186	208	289	293	309	305	282	169	154	162	167	164	158	160	155	173
9	150	158	166	194	202	210	291	310	319	313	303	173	165	162	158	162	161	157	159	160
9.5	161	146	164	195	202	211	280	336	326	304	303	245	155	163	155	157	163	167	159	163
	1-inch area covered by Tape																			

Max
336.00
Min
146.00
Avg.
181.55
Range
190.00
Std Dev
41.24

Comments:

- Hardness readings were recorded in Brinell Hardness scale.
- Mag particle was performed over the inspection area. No MP indications were identified.
- UT was performed over the inspection area scanning for internal laminations. No laminations were identified.
- Minor external corrosion pitting was present for the full length of the inspection area. Max depth was measured at 0.013" with a manual pit guage.

- NTSB confirmed the fracture origin aligns with the 9" line in the photos.

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Appendix B
Appendix B – West Inspection Area Hardness Testing Report

Work Location and Details	WEST Inspection Area		
DE Technician	Beau Spaulding	Date	9/16/2019
Engineer/Inspector	Sam Fryett	Nominal OD (in)	30
Segment/Route	TOMP-DANV	Nominal WT (in)	0.375
Line Number	15	Pipe Grade	X-52
Target Feature	Feature 2 & 3	Seam Type	AO Smith AFW
Target Wheel Count	376,895.508 & 376,895.842	Seam Clock Position	12:36

Hardness Equipment Details

Hardness Technique	BHN (Brinell Hardness No.)	Test Unit Model No.	THX281 Plus
Test Unit Manufacturer	Cimetrix	Test Unit S/N	TMO170900049
Calibration Date	8/22/2019		

Probe Manufacturer	Cimetrix	Probe Model No.	Type D
Calibration Date	8/22/2019	Probe S/N	317-565

Calibration Details

Qty. of Cal. Blocks Used	1	
Calibration Block 1		
Block Manufacturer	Cimetrix	
Cal. Block S/N	L7101200	
Cal. Block Actual Hardness	775	
Cal. Block Hardness Scale	HLD	
Cal Block Tolerance (%)/No.	2%	15.5

Calibration Results

	Cal Block	1	2	3	4	5	Avg.	Std. Dev	Time	Date
Pre-Test	1	769.00	774.00	764.00	768.00	764.00	767.80	3.71	2:30	9/16/19
Post Test	1	774.00	773.00	774.00	775.00	767.00	772.60	2.87	4:30	9/16/19

Hardness Test Location Details

Wheel Count	376,895.508 & 376,895.842
Clock Position	4:30, 4:30
Length (in)	17
Width (in)	7

Ultrasonic Thickness Measurements

Pre-Surface Prep (in)

0.386			0.386
0.380	0.375	0.380	0.383

Post-Surface Prep (in)

0.372			0.372
0.369	0.362	0.369	0.371

Hardness Testing Results

Hardness Readings Per Increment - Full Area

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
	1-inch area covered by Tape																
1	163	196	190	167	231	280	287	285	276	236	151	156	159	153	151	149	149
2	151	158	170	162	170	248	250	257	245	149	144	158	160	166	154	149	150
3	164	150	160	162	159	175	174	162	146	153	148	156	160	164	157	156	150
4	159	159	156	157	155	153	149	146	144	148	148	144	152	156	158	149	147
5	153	161	156	152	154	147	148	151	147	147	146	146	154	153	157	153	150
6	153	153	158	153	152	149	156	151	140	149	146	149	149	159	157	155	147
7	156	155	155	152	157	151	153	148	152	151	150	152	153	153	159	152	149

Max
287.00
Min
140.00
Avg.
163.40
Range
147.00
Std Dev
30.68

Comments:

- Hardness readings were recorded in Brinell Hardness scale.
- Mag particle was performed over the inspection area. No MP indications were identified.
- UT was performed over the inspection area scanning for internal laminations. No laminations were identified.

- NTSB confirmed the fracture origin aligns with the 8" line in the photos.

Appendix C
Appendix C – Feature 4 Inspection Area Hardness Testing Report

Work Location and Details	Feature 4 Inspection Area		Page 1 of 2
DE Technician	Beau Spaulding	Date	9/16/2019
Engineer/Inspector	Sam Fryett	Nominal OD (in)	30
Segment/Route	TOMP-DANV	Nominal WT (in)	0.375
Line Number	15	Pipe Grade	X-52
Target Feature	Feature 4 Inspection Area	Seam Type	AO Smith AFW
Target Wheel Count	376,895.97	Seam Clock Position	12:36

Hardness Equipment Details

Hardness Technique	BHN (Brinell Hardness No.)	Test Unit Model No.	THX281 Plus
Test Unit Manufacturer	Cimetrix	Test Unit S/N	TMO170900049
Calibration Date	8/22/2019		

Probe Manufacturer	Cimetrix	Probe Model No.	Type D
Calibration Date	8/22/2019	Probe S/N	317-565

Calibration Details

Qty. of Cal. Blocks Used	1	
Calibration Block 1		
Block Manufacturer	Cimetrix	
Cal. Block S/N	L7101200	
Cal. Block Actual Hardness	775	
Cal. Block Hardness Scale	HLD	
Cal Block Tolerance (%)/No.	2%	15.5

Calibration Results

	Cal Block	1	2	3	4	5	Avg.	Std. Dev	Time	Date
Pre-Test	1	774.00	773.00	774.00	775.00	767.00	772.60	2.87	4:30	9/16/19
Post Test	1	763.00	762.00	772.00	767.00	766.00	766.00	3.52	6:12	9/16/19

Hardness Test Location Details

Wheel Count	376,895.97
Clock Position	7:00
Length (in)	12
Width (in)	12

Ultrasonic Thickness Measurements

Pre-Surface Prep (in)

0.380		0.385
	0.383	
0.382		0.384

Post-Surface Prep (in)

0.369		0.368
	0.37	
0.372		0.370

Hardness Testing Results

Hardness Readings Per Increment - Full Area

0	1	2	3	4	5	6	7	8	9	10	11	12
1	159	166	162	164	159	169	164	159	154	159	151	147
2	154	152	158	158	160	161	165	158	151	156	165	158
3	150	151	153	150	155	149	149	158	153	153	151	154
4	151	147	144	146	150	144	146	153	150	157	149	153
5	154	147	147	147	151	150	146	151	150	149	153	159
6	147	143	146	148	144	145	146	147	151	150	152	153
7	150	151	155	149	150	151	151	145	149	152	149	144
8	152	149	150	146	155	145	150	152	152	153	155	148
9	154	161	154	147	145	154	146	147	153	157	151	152
10	151	149	154	151	159	159	148	154	152	155	151	154
11	157	158	159	155	151	157	148	144	152	155	158	153
12	156	153	156	155	153	153	145	149	155	151	150	158

Max
169.00
Min
143.00
Avg.
152.38
Range
26.00
Std Dev
5.08

Comments:

- Hardness readings were recorded in Brinell Hardness scale.
- Mag particle was performed over the inspection area. No MP indications were identified.
- UT was performed over the inspection area scanning for internal laminations. No laminations were identified.
- All hardness readings were consistent and did not identify the as-called feature 4 hard spot by the ILI report.