NATIONAL TRANSPORTATION SAFETY BOARD

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

August 19, 2022

MATERIALS LABORATORY FACTUAL REPORT Report No. 22-045

A. ACCIDENT INFORMATION

Place	:	Oklaunion, Texas
Date	:	January 8, 2022
Vehicle	:	DOT 117J tank cars
NTSB No.	:	HMD22LR001
Investigator	:	Paul Stancil, RPH-20

B. COMPONENTS EXAMINED

Piece of tank shell, head, front sill pad, head brace, and stub sill from the A end of TILX 731751 and shell piece from TILX 731762.

C. DETAILS OF THE EXAMINATION

1. Piece from A end of TILX731751

Overall views of the submitted piece of tank car TILX 731751 are shown in figures 1 and 2. The piece included the head brace and portions of the stub sill, front sill pad, head, and shell that had been cut by plasma torch from the A end of the tank car. The various components of the assembly are shown labeled in figure 1, and a view of the front sill pad window as viewed from the underside of the tank car piece is shown in figure 2. A computer-generated 3D model of components at the A end of the tank car is shown in figure 3. The model is shown sliced longitudinally through the middle, and individual components are shown labeled.

The submitted piece shown in figures 1 and 2 was generally oxidized and sooty consistent with exposure to heat from a fire. The head and front sill pad were deformed upward and inboard relative to the stub sill, and a contact mark was observed on the front sill pad surface as shown in figure 4. The contact mark had a shape consistent with an opening in the jacket for the stub sill and head brace. The right side of the contact mark aligned with the right side of the head brace, consistent with the jacket being pushed to the left relative to the stub sill before contacting the front sill pad.[1]

The front sill pad and head were fractured at locations shown with red lines in figure 3. A closer view of the fractures in the front sill pad and the head are shown in figure 5. The front sill pad was fractured at the toe of the weld between the head brace and the pad, and the head was fractured near the rectangular window in the front sill pad

[1] References to right and left are as viewed from the B end of the tank car looking toward the A end.

where the pad was welded to the head. The head fracture was approximately 10.25 inches long, and the maximum opening displacement was approximately 2.5 inches.

The vertical plate for the stub sill on the left side was deformed with the lower end bent to the right. A crack was also present at the toe of the weld between the head brace and the stub sill on the left corner. The welds throughout the piece were examined for evidence of preexisting cracks, and no visual evidence of a preexisting crack was observed.

Thicknesses of the shell, head, front sill pad, and head brace were measured using a DeFelsko PosiTector UTG C3 advanced ultrasonic thickness gauge. The shell and front sill pad thicknesses were measured to the left and to the right of the stub sill. The head was also measured to the left and the right of the stub sill and near the centerline within the front sill pad window. The head brace thickness was measured near the centerline. Results of the thickness measurements are listed in table 1. The design nominal thickness values for each component are also included in table 1.

Table 1. Ultrasonic Thickness Measurements

Component	Average Measured Thickness (inch)	Minimum Measured Thickness (inch)	Design Nominal Thickness (inch)
Head	0.623	0.606	0.563
Shell	0.582	0.580	0.563
Front Sill Pad	0.635	0.625	0.625
Head Brace	0.747	0.745	0.75

Additional dimensions were measured using tape measures, calipers, and rulers as appropriate. The length, *l*, from the toe of the head brace-to-pad weld to the front (top) edge of the front sill pad at the centerline was 4.0625 inches. According to the Association of American Railroads (AAR) Manual of Standards and Recommended Practices (MSRP) Section C-III Specifications for Tank Cars,[2] the length, *l*, required for a tank car design is governed by a formula with variables consisting of the thicknesses of the tank wall and front sill pad, tensile strengths of the tank and front sill pad materials, and yield strength of the tank material. Based on these variables for the accident tank car design, the calculated minimum length, *l*, is 2.717 inches, indicating that the measured dimension on the accident tank car conformed to the MSRP requirement.

According to the draft sill and head brace installation drawing provided by the tank car manufacturer, the distance from the top of the head brace to the top edge of the front sill pad should be 4.5 inches minimum. Although the distance from the top corner of the head brace to the top edge of the front sill pad could not be measured directly due to

[2] Manual of Standards and Recommended Practices Section C-III Specifications for Tank Cars, Association of American Railroads, Washington, DC (2014).

deformation, the length of the horizontal leg of the fillet weld between the head brace and the pad (as measured on a metallographic cross-section described below) measured 0.498 inch. Adding the length of the weld leg to the distance from the weld toe, the top edge of the head brace was approximately 4.561 inches from the top edge of the front sill pad, consistent with conforming to the drawing specification.

The length of the head brace to front sill pad weld was measured around the exterior of the head brace, and the total length measured approximately 32.625 inches. The width of the head brace across the inboard faces measured 12.063 inches. The outboard edges of the front sill pad measured approximately 3.875 inches and 3.625 inches from the left and right outboard sides of the head brace, respectively. The window for the front sill pad measured 10.25 inches long and 6.5 inches wide. The distance from the toe of the weld between the interior face of the head brace and the front sill pad to the front edge of the window was 2.563 inches.

Next, cuts were made with a plasma torch and a bandsaw to facilitate further examination of fracture features and to prepare metallographic samples of weld features. First, transverse cuts were made with a plasma torch from the left and right sides of the head inward to the ends of the head and front sill pad fractures to liberate the upper piece of the head and pad from the rest of the piece. Then longitudinal and transverse cuts were made using a bandsaw at locations indicated with dashed lines in figure 6.

A view of the upper portion of the head and front sill pad after the plasma torch cuts and bandsaw cut is shown in figure 7. Closer views of fracture features on the front sill pad fracture are shown in figures 8 and 9. A vertical lip was observed along the front edge (at the toe of the weld), and the fracture extended at a slight angle through the thickness of the front sill pad toward the weld root. The vertical lip had smeared fracture features consistent with shear, and the angled portion had feathery features consistent with limited ductility overstress propagation under tensile stress. The feathery features emanated from an origin area near the right side at the location within the rectangle in figure 7 and shown at higher magnification in figure 8. No evidence of any preexisting cracks or anomalies were observed. At the corners on either side of the fracture, smeared fracture features were observed consistent with direct shear fracture consistent with the outboard portion of the front sill pad moving upward relative to the head brace.

Fracture features for the head are shown in figure 10. The fracture plane was nearly vertical through the thickness of the head. Adjacent to the pad, smooth features were observed consistent with the weld root between the front sill pad window and the head. Just above the weld root, rough matte gray fracture features were observed consistent with ductile overstress fracture propagating upward from the weld toe as indicated with unlabeled arrows in figure 10. At the upper edge of the fracture, smooth features consistent with compression and shear were observed, consistent with an overall upward bending load associated with the fracture. Smeared fracture features were observed on the left and right sides consistent with direct shear fracture as the outboard side of the head moved upward relative to the inboard side at the fracture location. No evidence of preexisting cracks or anomalies were observed.

Overall views of the sectioned pieces from the left side of the submitted piece are shown in figure 11. Metallographic samples were prepared from each of the welds along the centerline cut shown in figure 11. Additionally, a second longitudinal cut was made to the left of the centerline cut as shown in figure 12 where another metallographic sample was prepared. After the longitudinal cuts were made, a transverse cut was made to facilitate preparation of metallographic samples of welds in the transverse plane.

Longitudinal and transverse cross sections cut for metallographic samples are shown in figures 13 through 15. For reference in this report, welds are labeled first by the two components being welded (H = Head, P = front sill Pad, B = head Brace, and S = stub Sill), next by cut plane (L = longitudinal or T = transverse), then by number of the cut plane (1 = 1st centerline or transverse cut, 2 = 2nd longitudinal cut), and finally by relative location of the weld (i = inboard and o = outboard). Metallographic samples of 5 welds were prepared in the plane of the centerline cut as shown in figure 13, and one metallographic sample was prepared at the weld between the head brace and the stub sill in the plane of the second longitudinal cut as shown in figure 14. The locations of 6 welds examined in the transverse cross section are shown in figure 15. Note that the plane shown in figure 15 was angled relative to the head thickness normal direction, but the metallographic samples were prepared in a plane perpendicular to the head thickness to ensure accurate measurements of the weld sizes in the vertical legs.

Metallographic images of each of the examined welds are shown in figures 16 through 25. Each image is a composite of stitched images acquired using a Zeiss Axio Observer Z1m optical metallograph with a 2.5x objective lens. The polished metallographic samples are shown etched with 2% nital, a solution of 2% by volume concentrated nitric acid in alcohol, which reveals microstructural features in steel.

The examined welds consisted of fillet, bevel groove, and U-groove welds. The fillet welds included all welds attaching the front sill pad to the head at the centerline and transverse cut planes (HPL1i, HPL1o, HPT1i, and HPT1o) and welds attaching the head brace to the front sill pad at the centerline cut plane (PBL1i and PBL1o). The transverse plane intersected the tail end of the head brace where welds attaching the head brace to the front sill pad consisted of a bevel groove weld combined with a fillet weld on the inboard side (PBT1i) and a multi-pass weld filling a gouged groove on the outboard side (PBT1o). In welding procedures provided by the tank manufacturer, the cover pass for the weld on the outboard side (PBT1o) is made flush to the surface at the head brace tail end and transitions to blend into the fillet weld around the front of the head brace. The welds attaching the stub sill to the head brace included a multi-pass groove weld around the front of the head brace, including at the two longitudinal cut planes (SBL1 and SBL2). At the tail end of the head brace where the transverse cut plane was located, the inboard weld attaching the stub sill to the head brace (SBT1i) was a multi-pass bevel groove weld on the interior edge of the head brace, and the outboard weld (SBT1o) was a multi-pass weld filling a gouged groove.

Anomalies in the welds were noted as indicated in figures 16 through 25. Cracks were observed at the weld root in welds HPL1o, PBL1i, SBL2, and HPT1i. Inclusions were noted in welds HPL1o and PBL1i. An overlap was observed at the weld toe in weld HPL1o, and incomplete penetration was observed in groove welds attaching the head brace to the front sill pad and the stub sill to the head brace (welds PBT1i, PBT1o, SBT1i, and SBT1o).

The profile of the fracture through the front sill pad is shown in figure 20. The lower end of the fracture intersected the toe of the fillet weld and extended initially through the heat-affected zone of the weld. At the head fracture location shown in figure 17, the fracture initially propagated through resolidified material at the weld root before propagating upward through the head.

Dimensions of fillet welds attaching the front sill pad to the head and the head brace to the front sill pad were measured on the metallographic samples shown in figures 16 through 18, 20, 23, and 24, and results are shown listed in table 2. Nomenclature for measurements listed in table 2 are defined on an idealized fillet weld diagram shown in figure A1 in Appendix A, and an example of measurements defined on an actual weld is shown in figure 26. Measurements for each weld listed in table 2 are shown in Appendix A. The fillet weld size is determined by the length of the vertical and horizontal legs. The theoretical throat is the distance from the weld surface to the theoretical weld root (where the vertical and horizontal legs intersect). The effective throat is the distance from the weld surface to the actual weld root. The gap measures the spacing between the welded components at the weld root. An effective horizontal leg was also measured, which for purposes of this report was defined as the actual welded length in the horizontal plane.

The specified fillet weld sizes derived from tank arrangement drawings and the draft (stub) sill and head brace installation instructions are listed in table 2. For shear strength calculations used to determine the relative strength of welds attaching the pad to the tank relative to the welds attaching the stub sill and head brace to the pad, the shear section of the fillet welds is defined as the length of the weld multiplied by the theoretical throat for the specified weld size. Given the triangular cross-section of the fillet weld, the length of the theoretical throat is 0.707 times the leg length (weld size). The effective throat dimensions as observed on the sampled fillet welds and the measured theoretical throat length for the two groove welds were compared to the specified minimum theoretical throat length (based on specified weld size), and results of the comparison are listed in the last column in table 2. The results in the last column are reported as a percentage calculated as 100 times the difference between the effective throat (or theoretical throat for welds PBT1i and PBT1o) and the specified theoretical throat (specified fillet weld size times 0.707) divided by the specified theoretical throat. For weld PBT1o, the value represents a minimum value using 0.375 inch as the specified fillet weld size. The observed throat dimensions were 5% to 69% larger than the specified theoretical throat length used in the weld strength calculations.

Table 2. Fillet Weld Measurements

Weld‡	Horizontal Leg (inch)	Vertical Leg (inch)	Effective Horizontal Leg (inch)	Theoretical Throat (inch)	Effective Throat (inch)	Gap (inch)	Specified Fillet Weld Size (inch)	Excess throat thickness (%)
HPL1i	0.514	0.617	0.680	0.376	0.453	0.105	0.375	50
HPL1o	0.555	0.454	0.516	0.376	0.350	0.010	0.375	23
HPT1i	0.802	0.574	1.124	0.298	0.332	0.117	0.375	18
HPT1o	0.501	0.543	0.630	0.342	0.395	0.076	0.375	35
PBL1i	0.457	0.437	0.572	0.285	0.348	0.028	0.25	69
PBL1o	0.498	0.470	0.564	0.308	0.341	0.048	0.375	20
PBT1i*	0.294	0.459	+	0.223	+	0.095	0.25	19
PBT1o**	0.447	0.550	+	0.310	+	0.022	Flush to 0.375	5

‡See figures 13 and 15 for weld locations.
+Not measured due to underlying groove weld.
*Fillet weld PBT1i is laid over a bevel weld.
**PBT1o is a gouged groove weld, but the cap weld pass transitions from flush at the surface to a 0.375-inch fillet weld within the region where the metallographic section was prepared.

According to American Welding Society welding specifications for railcars, locomotives, and their components,[3] fillet welds at the edge of a plate thicker than ¼ inch (such as the front sill pad) are generally limited to no more than the thickness of the plate minus 1/16 inch but can be up to the full thickness of the plate provided the weld size can be verified. Welds at the edges of the front sill pad inboard and outboard (HPL1i, HPL1o, HPT1i, and HPT1o) had at least 1/16-inch distance from the lower toe of the weld to the lower edge of the plate.

For the fillet welds attaching the head brace to the front sill pad, the sum of the specified fillet weld sizes on the outboard and inboard sides (3/8 inch and ¼ inch, respectively) equals the nominal thickness of the pad. No specification for an upper limit on the weld size attaching the head brace to the front sill pad was found in the drawings or in welding standards. The ¼-inch fillet weld at the inboard side of the head brace to front sill pad weld had the highest amount of extra material relative to the design specified (minimum) size as shown in the last column in table 2. As a result, the welds attaching the head brace to the front sill pad had a combined effective throat that measured 0.689 inch, which was 0.054 inch greater than the average measured front sill pad thickness of 0.635 inch as listed in table 1.

[3] D15.1/D15.1M:2019 AMD1, Railroad Welding Specification for Cars and Locomotives, American Welding Society, Miami, Florida (2019).

At the inboard weld location for the front sill pad (window weld), the weld at the centerline had an effective throat distance that measured 0.453 inch, which was less than the average measured head thickness of 0.625 inch. However, the fracture appeared to propagate through the weld metal at the toe and into the heat affected zone on the head side of the weld.

Typical microstructural features for the head and the front sill pad in the longitudinal and transverse planes are shown in figures 27 and 28. The images are shown after etching with nital etch. The microstructure showed a mix of ferrite (light gray areas) and pearlite (darker features).

Hardnesses of the head, front sill pad, head brace, and stub sill were measured on the polished cross-sections using a Rockwell indenter. The average hardnesses of head, front sill pad, head brace, and stub sill were 93.1 HRBW, 90.5 HRBW, 80.4 HRBW, and 82.7 HRBW, respectively. According to ASTM Standard A370-21,[4] the measured hardnesses are associated with tensile strengths of approximately 94 ksi, 90 ksi, 72 ksi, and 79 ksi, for the head, front sill pad, head brace, and stub sill, respectively.

In addition to the Rockwell hardness tests, the metallographic specimens for welds in the centerline plane were tested using a Leco LM248AT microhardness tester. Each weld was mapped with a grid of Vicker's indents using a 500-gram load to produce maps of hardness variations across the welds. Resulting hardness maps are shown in figures 29 through 33. In each case, the weld metal and/or the heat-affected zone was harder relative to the adjacent welded components. While isolated areas of relatively high hardness were observed in several welds, areas of relatively higher hardness were also associated with crack locations at the weld root in welds HPL1o and PBL1i. Overall, the highest hardness values were measured in the heat affected zones in welds HPL1o and HPL1i.

2. Shell Piece from TILX 731762

A 3-foot by 3-foot piece of shell from tank car TILX 731762 was submitted for chemistry and mechanical testing. The paint on the shell piece was intact, and the piece had been selected from a tank car that had limited exposure to heat from the pool fire at the accident scene. The shell piece was sent to Lehigh Testing Laboratories in New Castle, Delaware, for chemical analysis including carbon and nitrogen analysis and for tensile testing in the longitudinal and transverse directions. The lab report documenting the results of the testing is included as Appendix B in this report.

The results of the chemical analysis were compared to the product analysis requirements for AAR TC128 Grade B steel as contained in the AAR MSRP Section C-III, Appendix M, and the results for each element or combination of elements conformed to the requirement except for the amount of boron detected in the analysis. The boron

[4] ASTM A370-21, Standard Test Methods and Definitions for Mechanical Testing of Steel Products, ASTM International, West Conshohocken, Pennsylvania (2021).

content measured 0.002% by weight, but the maximum amount allowed by the requirement is 0.0005% by weight.

Yield strength, ultimate tensile strength, elongation in 2 inches, and elongation in 8 inches were determined for 6 full-size plate-type tensile specimens. All specimens had a yield strength that exceeded the minimum yield strength for AAR TC128 Grade B steel, but only one specimen had an ultimate tensile strength that exceeded the minimum strength of 81,000 psi. The remaining specimens had ultimate tensile strengths that were slightly below the specified minimum value, ranging from 79,800 psi to 80,700 psi. The measured elongations in 2 inches and 8 inches exceeded the minimum elongation requirement for AAR TC128 Grade B steel in all 6 test specimens.

Matthew R. Fox, Ph.D.
National Resource Specialist - Materials

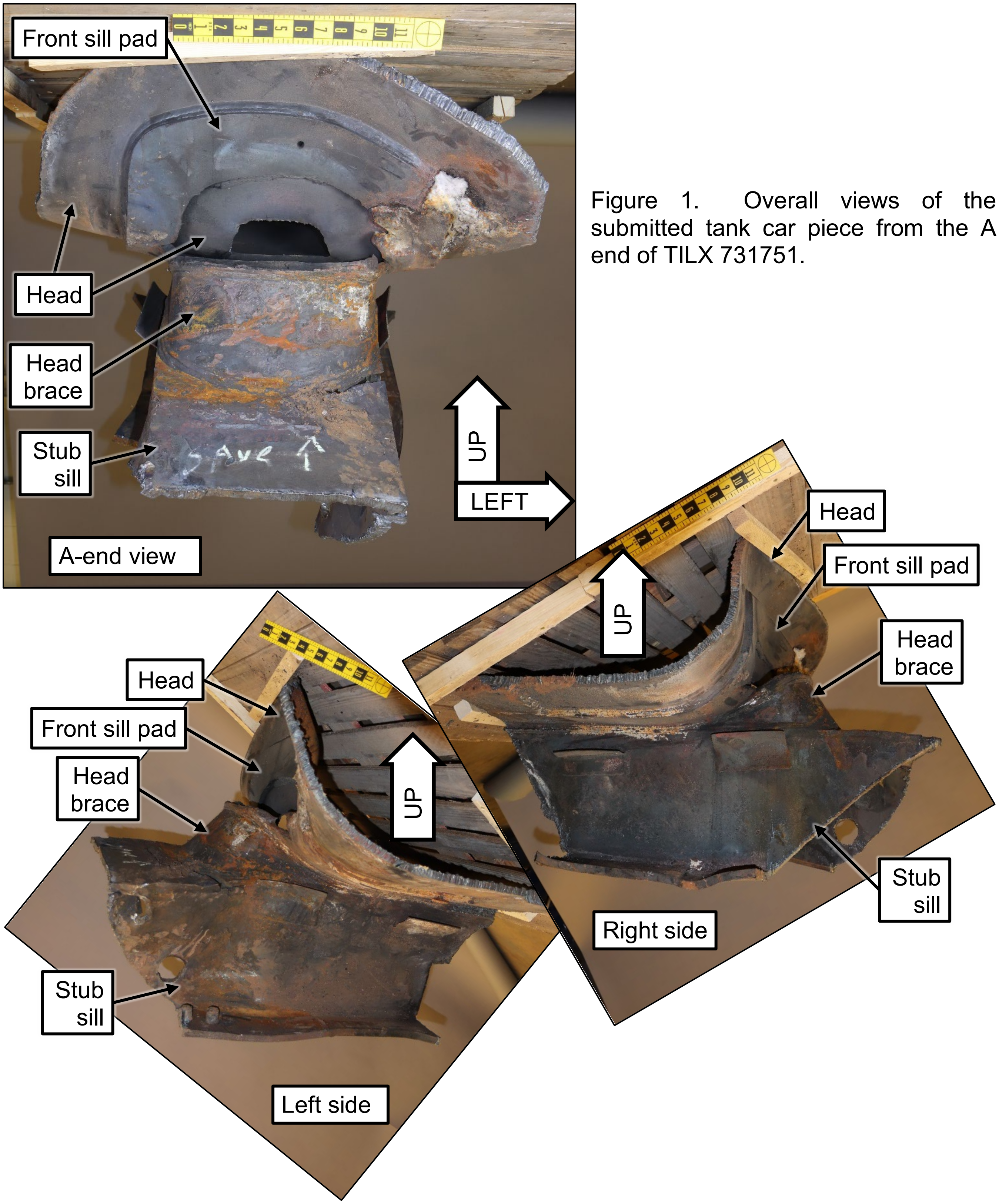


Figure 1. Overall views of the submitted tank car piece from the A end of TILX 731751.

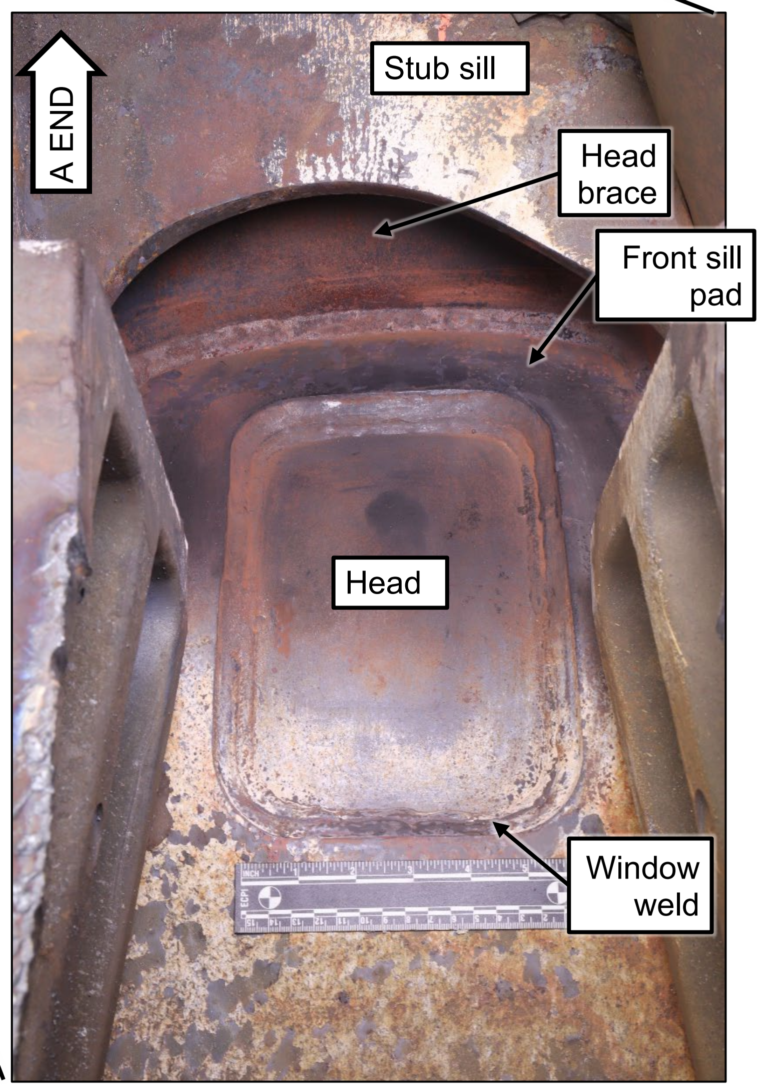
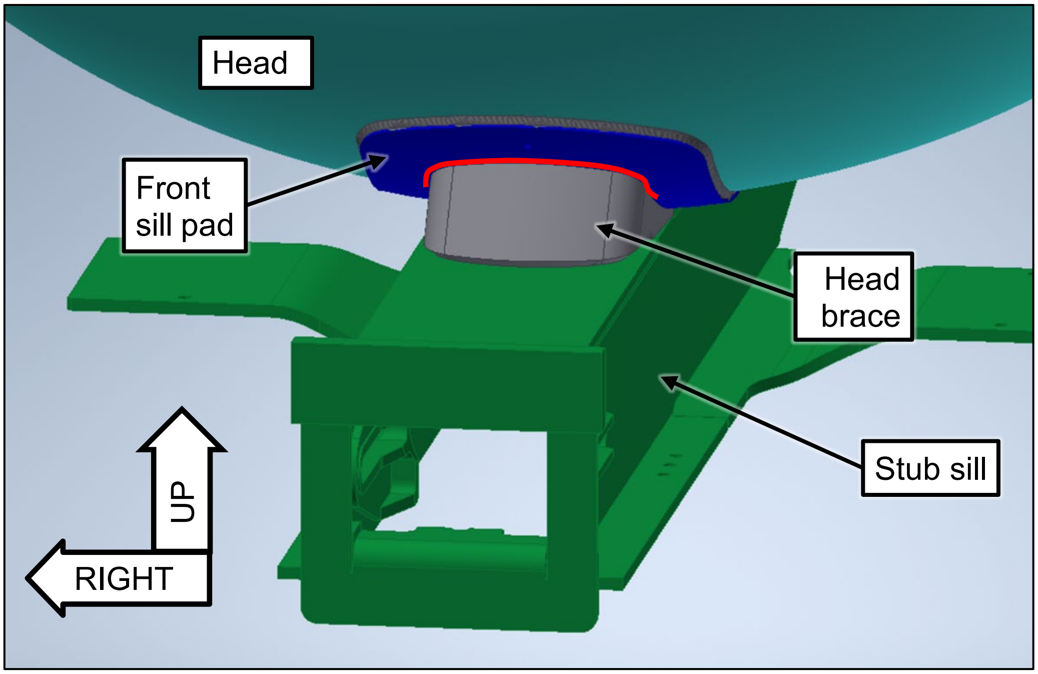


Figure 2. Lower side of the submitted tank car piece including a closer view of head brace-to-pad welds and pad-to-head welds at the front sill pad window (area where head is visible).



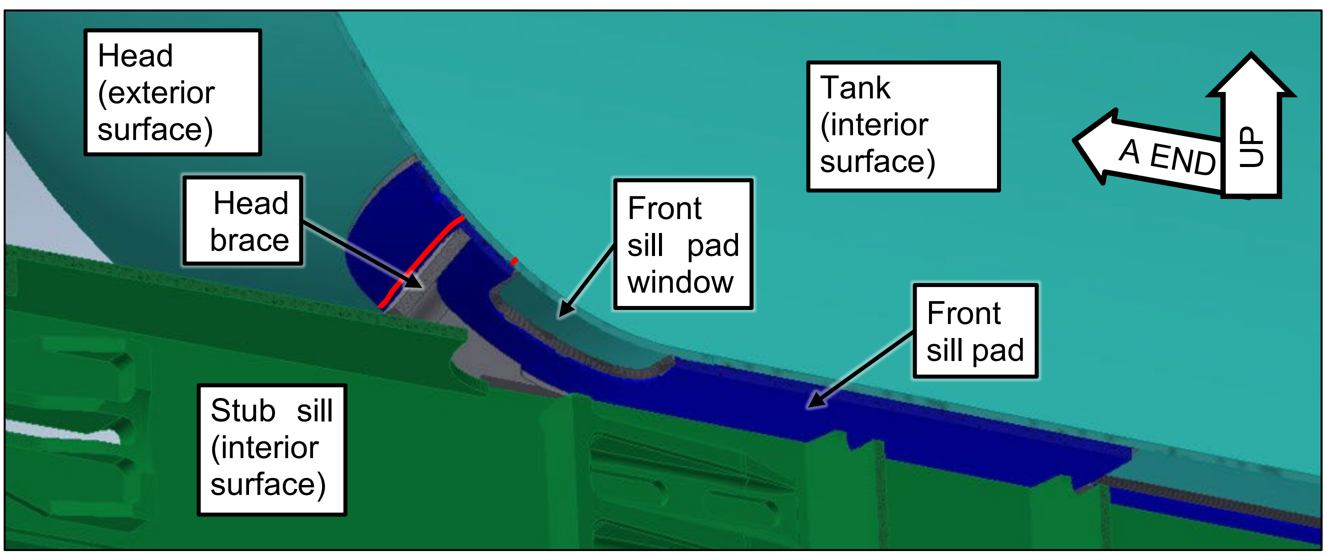


Figure 3. A-end view (upper image) and longitudinal cross-section (lower image) from a 3D computer model showing various components of the tank car construction. Fracture locations are indicated in red. (Adapted from images provided courtesy of TrinityRail).

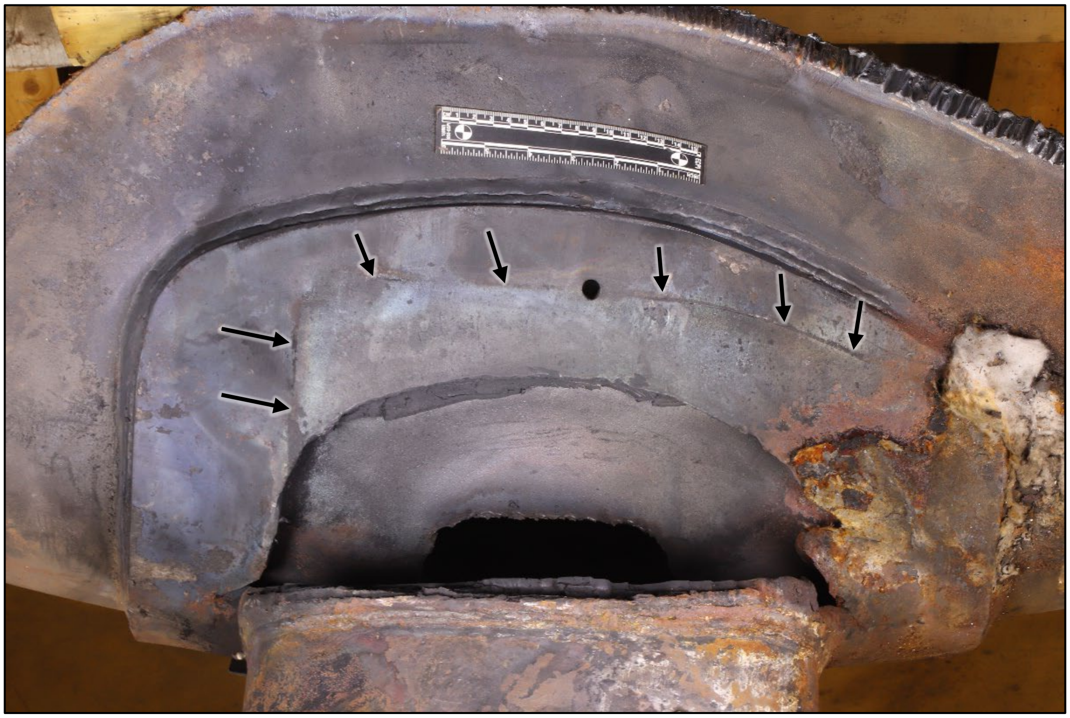


Figure 4. Contact mark on the front sill pad (unlabeled arrows) corresponding to contact with the jacket opening for the stub sill.

Figure 5. Closer view of fractures through the front sill pad and the head.

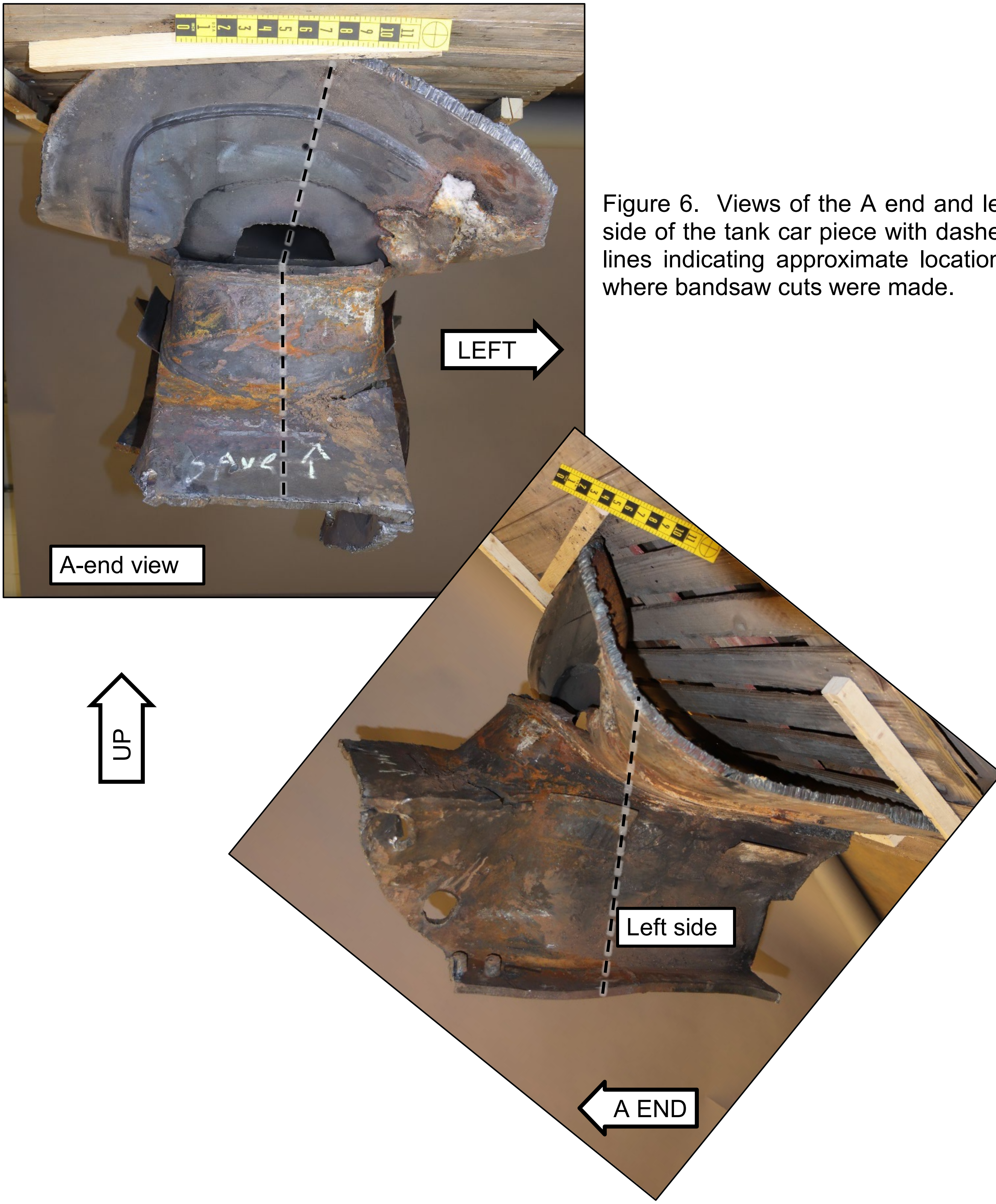


Figure 6. Views of the A end and left side of the tank car piece with dashed lines indicating approximate locations where bandsaw cuts were made.

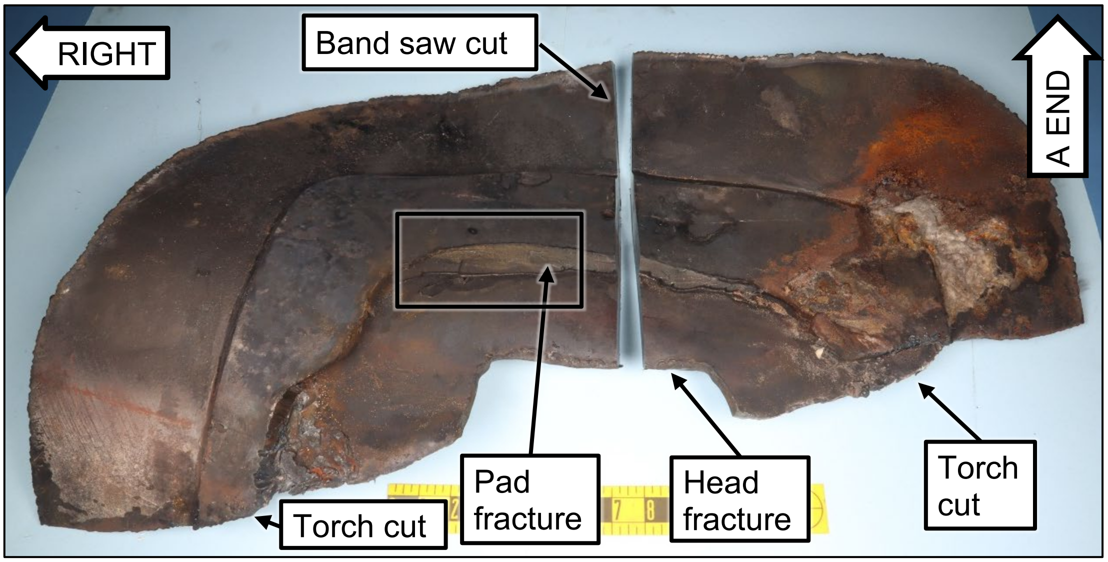


Figure 7. Head and front sill pad pieces with fracture surfaces after transverse plasma torch cuts and a longitudinal band saw cut were made to separate the pieces for closer views of the fracture surfaces and for the preparation of metallographic samples. The area in the rectangle is shown in figure 8.

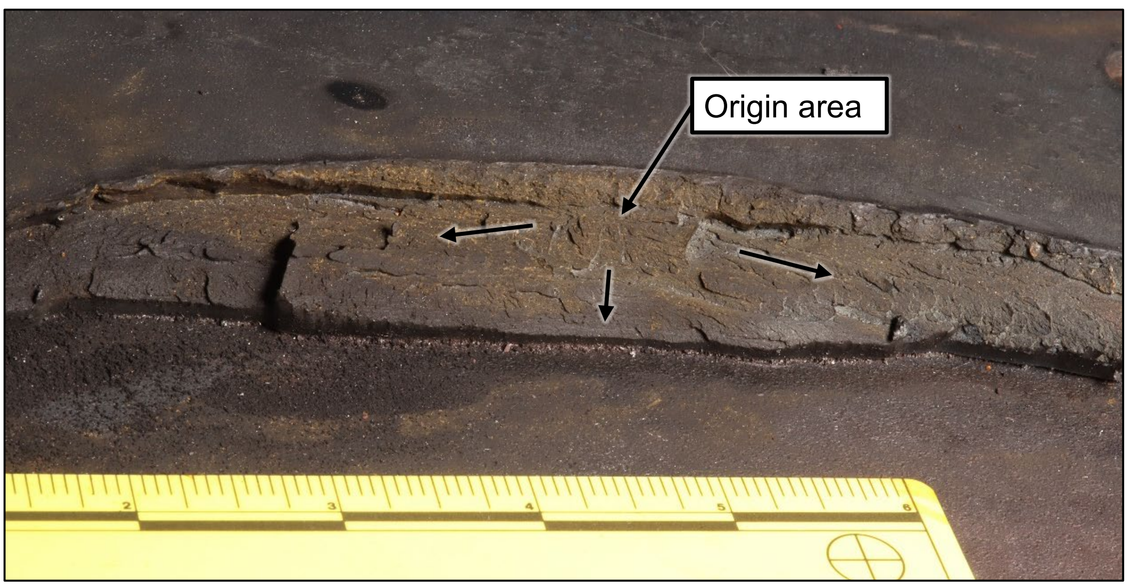


Figure 8. Close view of the pad fracture in the area highlighted with a rectangle in figure 7. Fracture features generally emanated from an origin area at the toe of the weld between the head brace and the front sill pad at the location indicated.

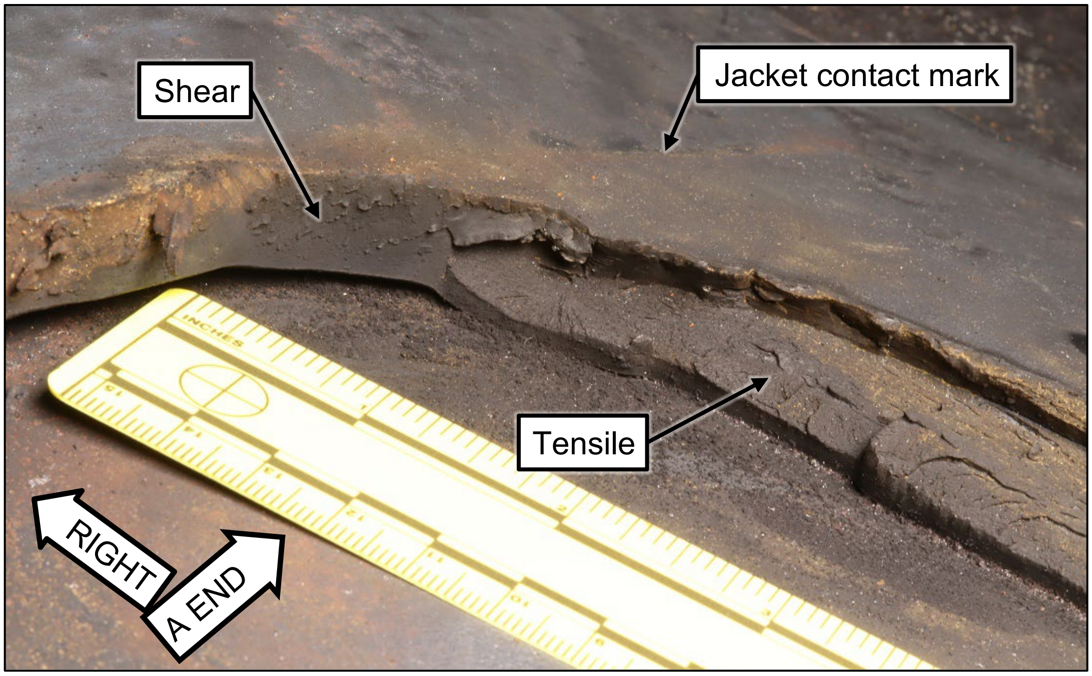


Figure 9. Right side of the front sill pad fracture showing transition from tensile fracture features to direct shear features consistent with the head brace moving downward relative to the front sill pad.

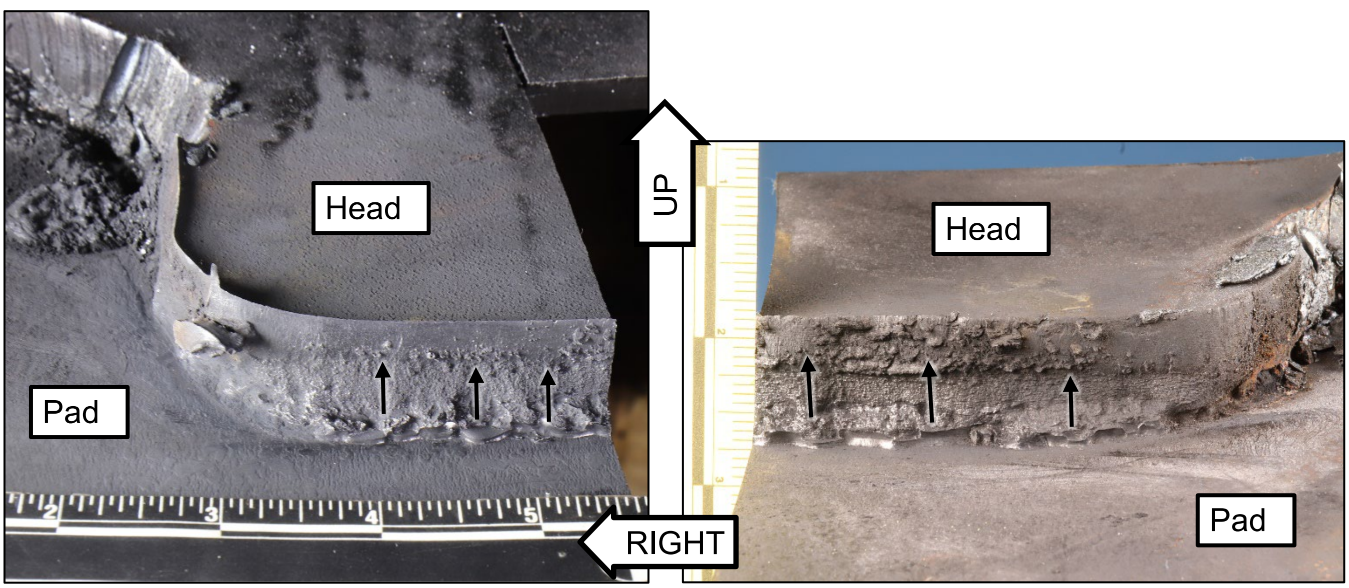


Figure 10. Close view of the head fracture after longitudinal and transverse cuts were made using a bandsaw. Fracture initiated at the weld root between the pad window and the head then propagated upward as indicated by unlabeled arrows. The upper side of the fracture was smeared consistent with a bending load at the fracture location.

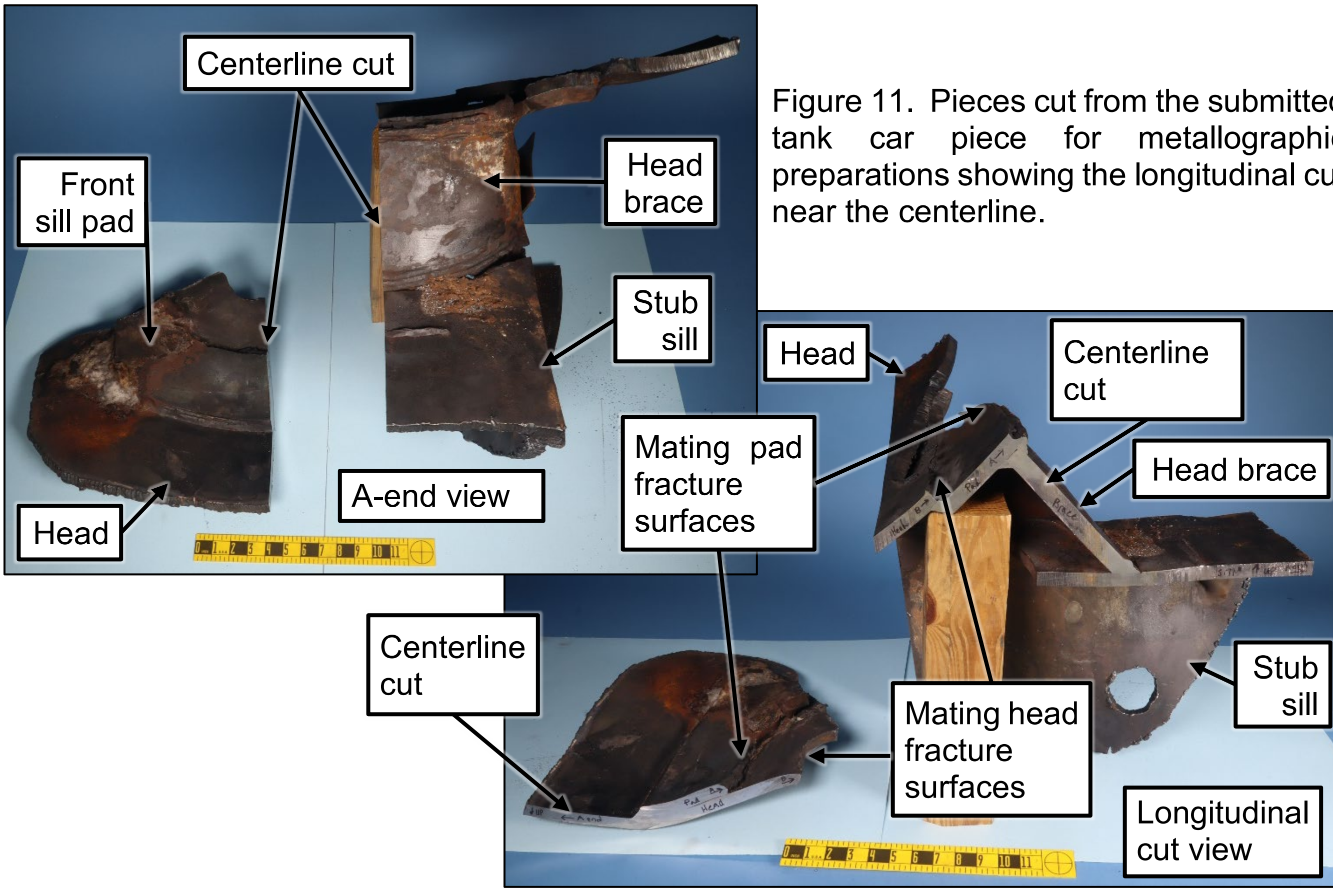


Figure 11. Pieces cut from the submitted tank car piece for metallographic preparations showing the longitudinal cut near the centerline.

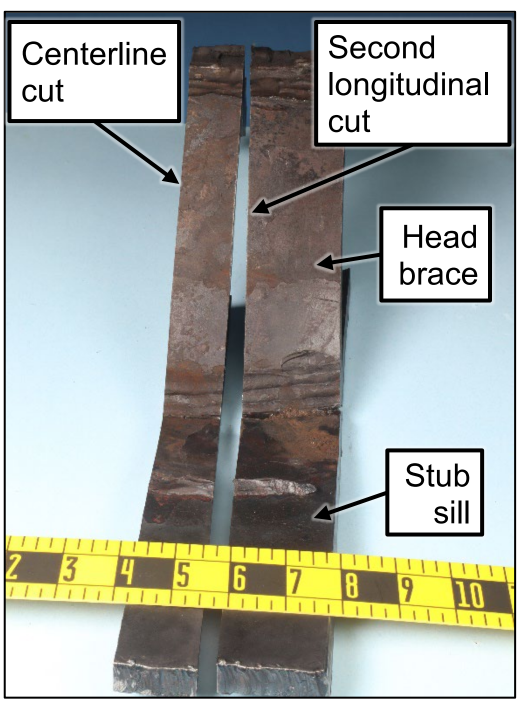


Figure 12. Pieces sectioned from the stub sill piece shown in figure 11 showing locations of additional longitudinal cuts to the left of the centerline cut. Metallographic sample SBL2 was prepared on the face of the second longitudinal cut indicated.

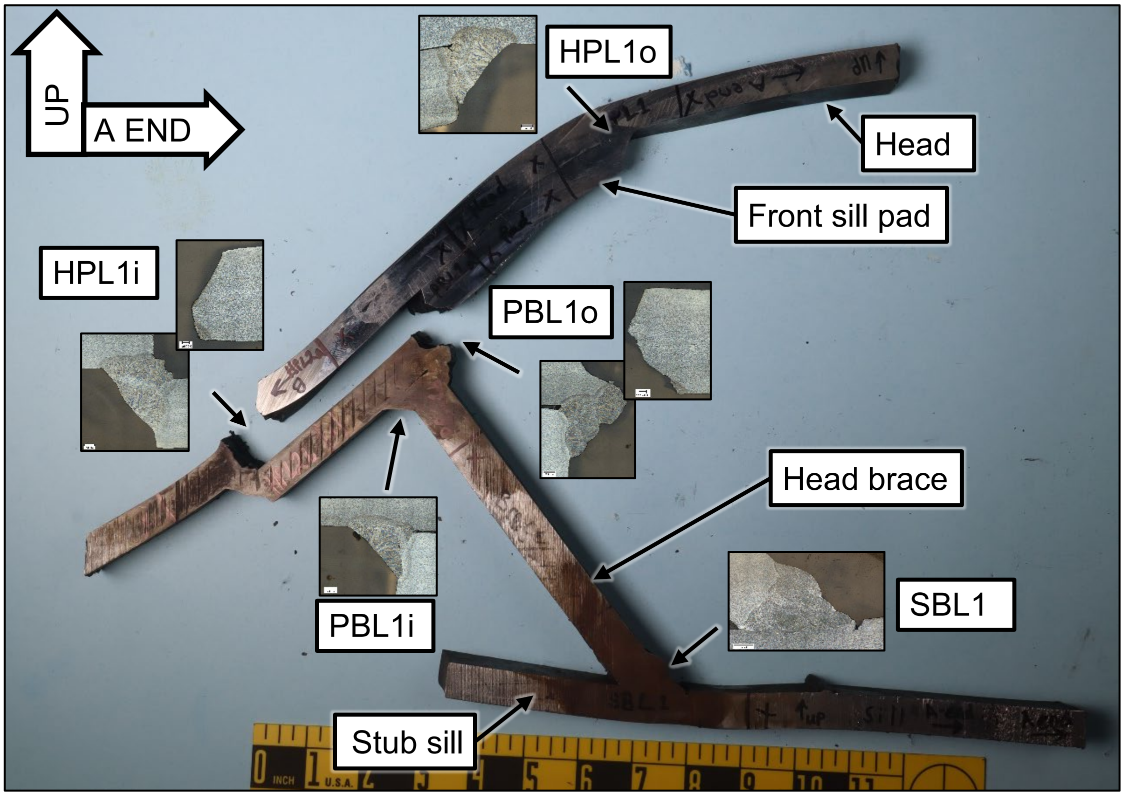


Figure 13. Centerline longitudinal cross-section with labeled metallographic images of each weld area shown in subsequent figures.

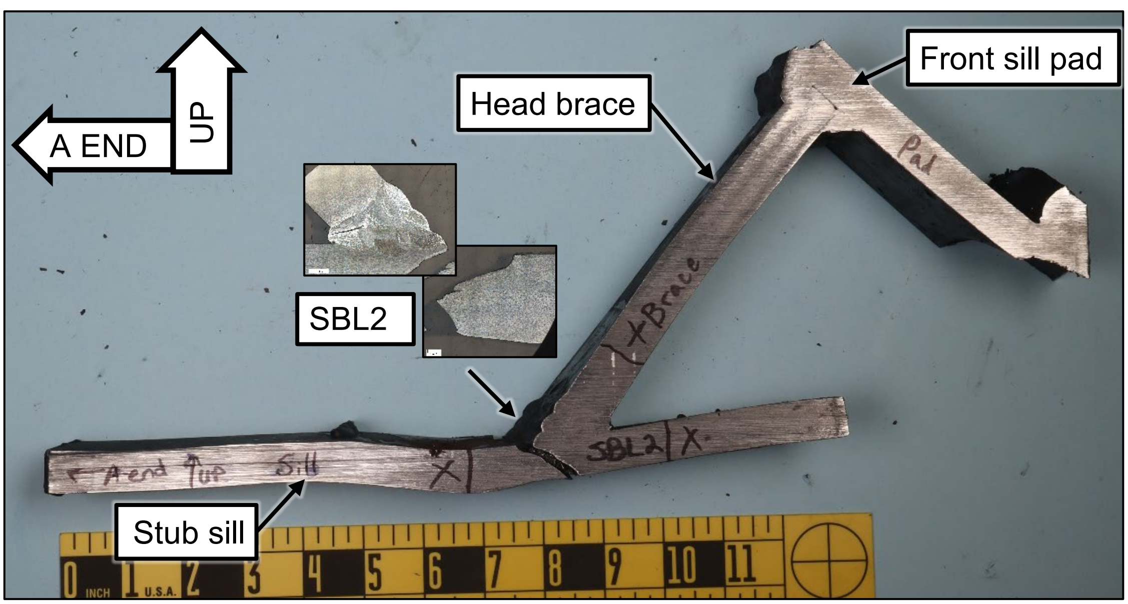


Figure 14. Second longitudinal cross-section with a labeled image of the metallographic sample prepared from this section (prepared on the face resting on the table).

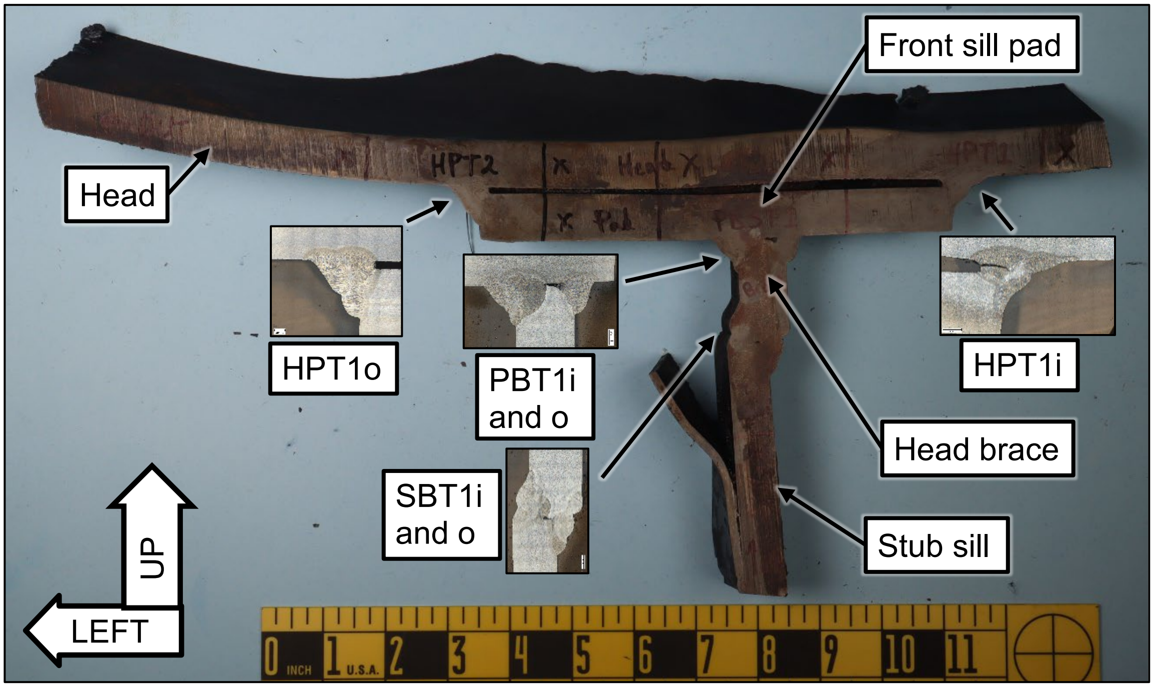


Figure 15. Transverse cross-section with labeled metallographic images of each weld area shown in subsequent figures.

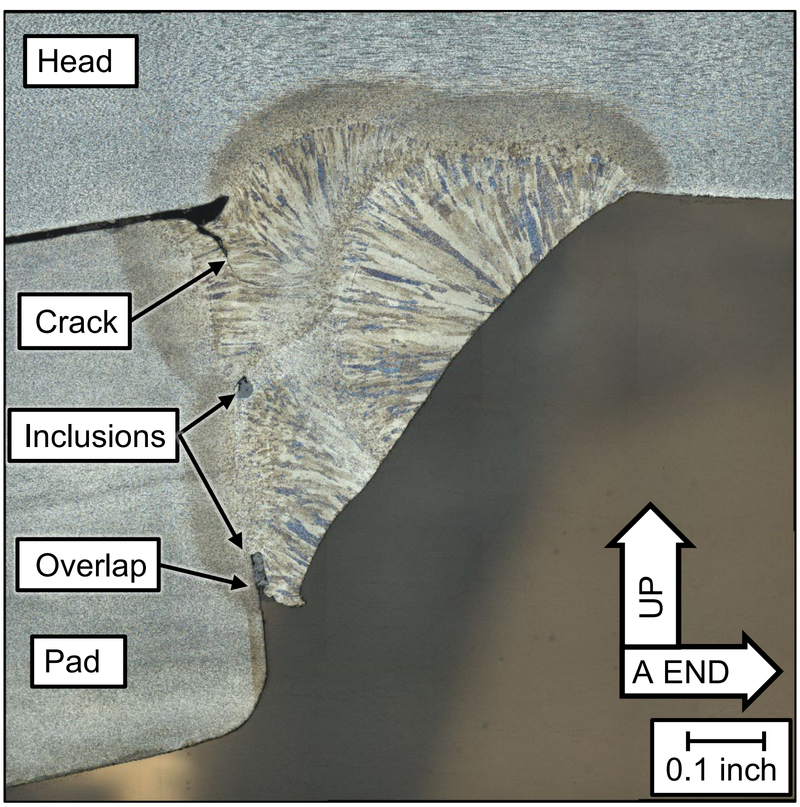


Figure 16. Fillet weld between the head and the front sill pad outboard edge in the centerline longitudinal cut plane (weld HPL1o). Image is a stitched montage using a 2.5x objective lens and is etched with 2% nital.

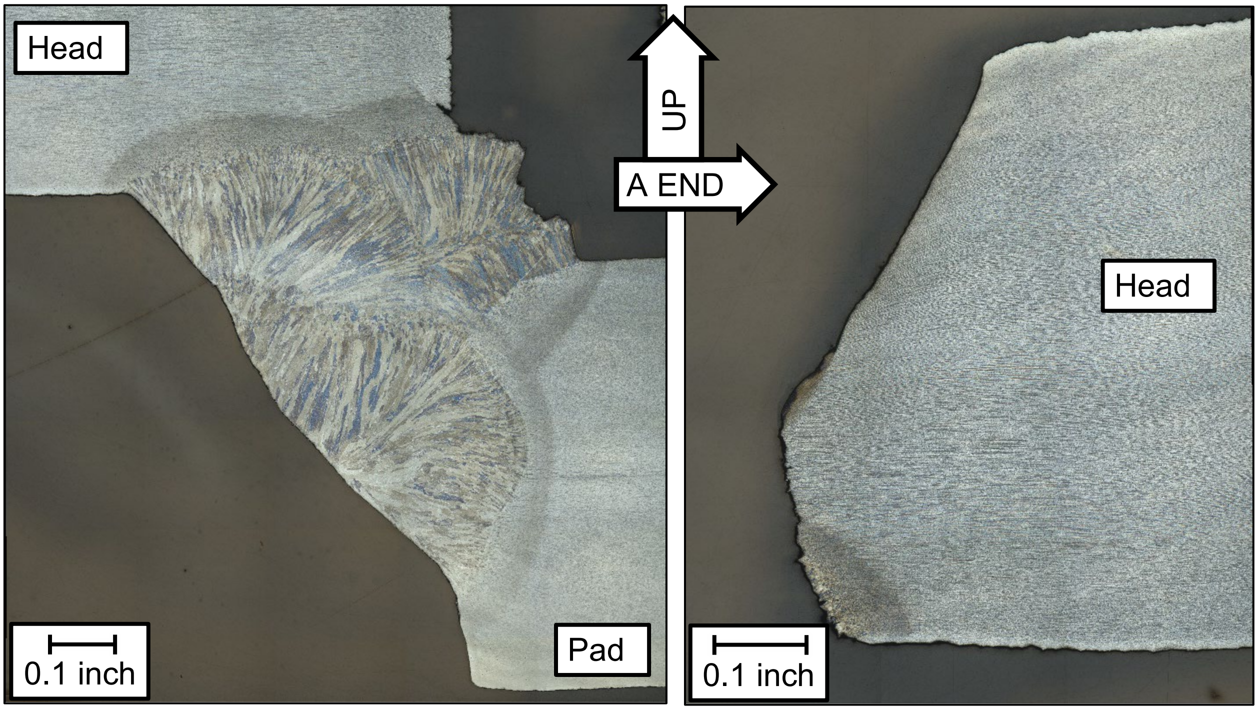


Figure 17. Fillet weld between the head and the front sill pad window in the centerline longitudinal cut plane (weld HPL1i). Images are stitched montages using a 2.5x objective lens and are etched with 2% nital.

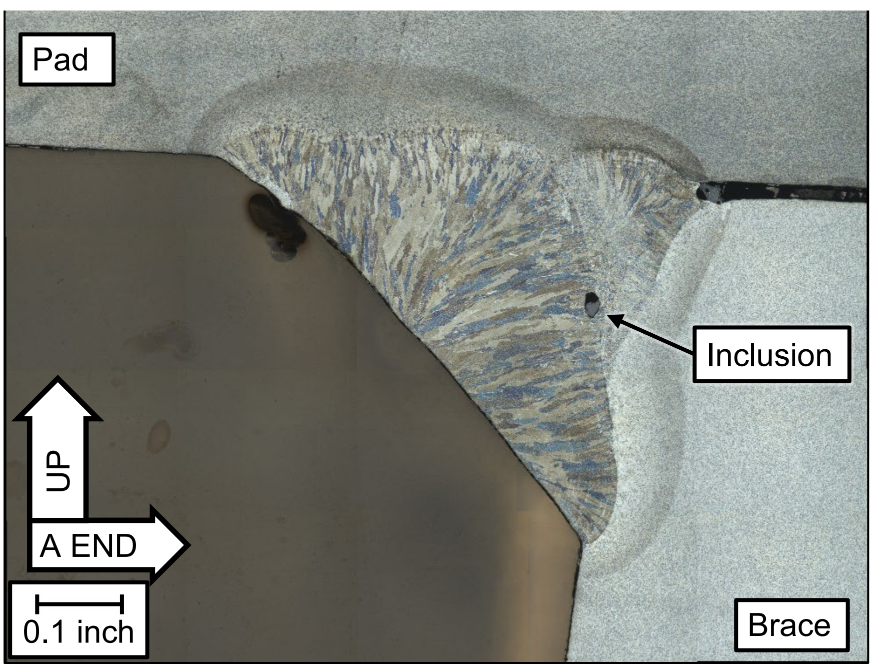


Figure 18. Fillet weld between the head brace and the front sill pad on the inboard side of the brace in the centerline longitudinal cut plane (weld PBL1i). Image is a stitched montage using a 2.5x objective lens and is etched with 2% nital.

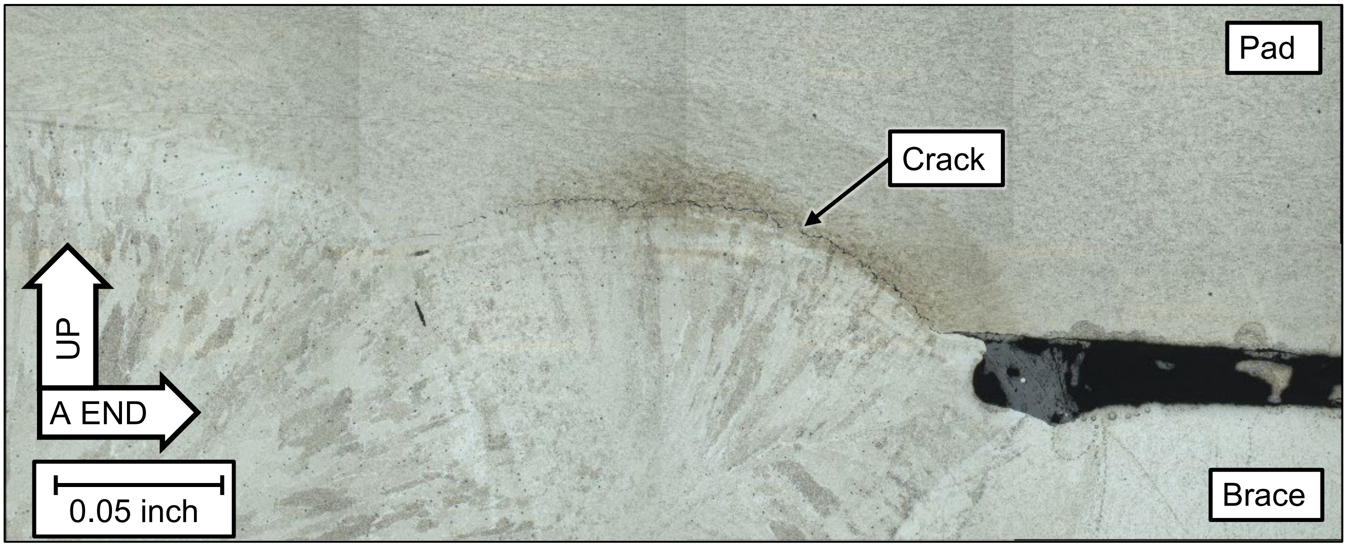


Figure 19. Closer view of a crack emanating from the weld root in the heat affected zone in weld PBL1i. Image is a stitched montage using a 2.5x objective lens and is etched with 2% nital.

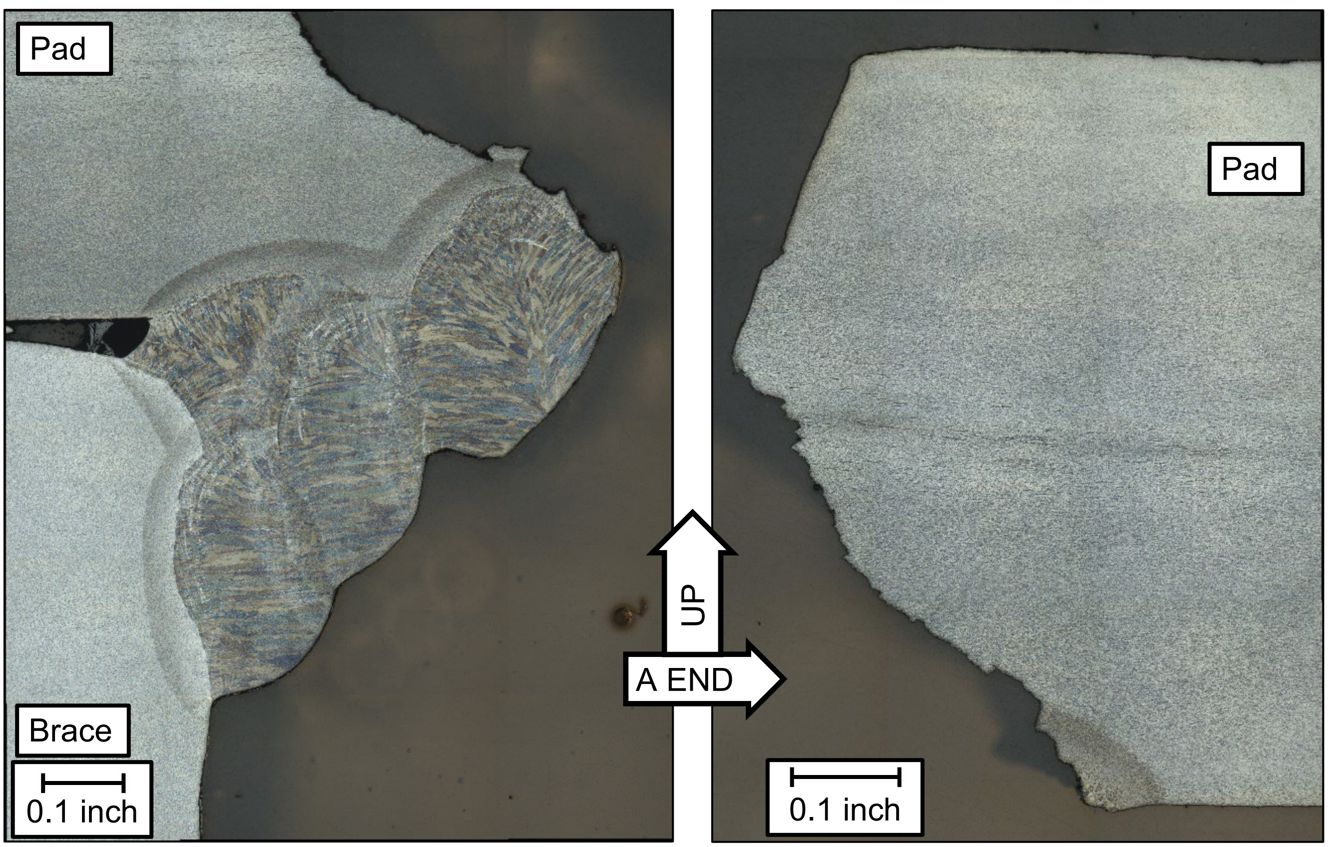


Figure 20. Outboard fillet weld between the front sill pad and the head brace in the centerline longitudinal cut plane (weld PBL1o). Images are stitched montages using a 2.5x objective lens and are etched with 2% nital.

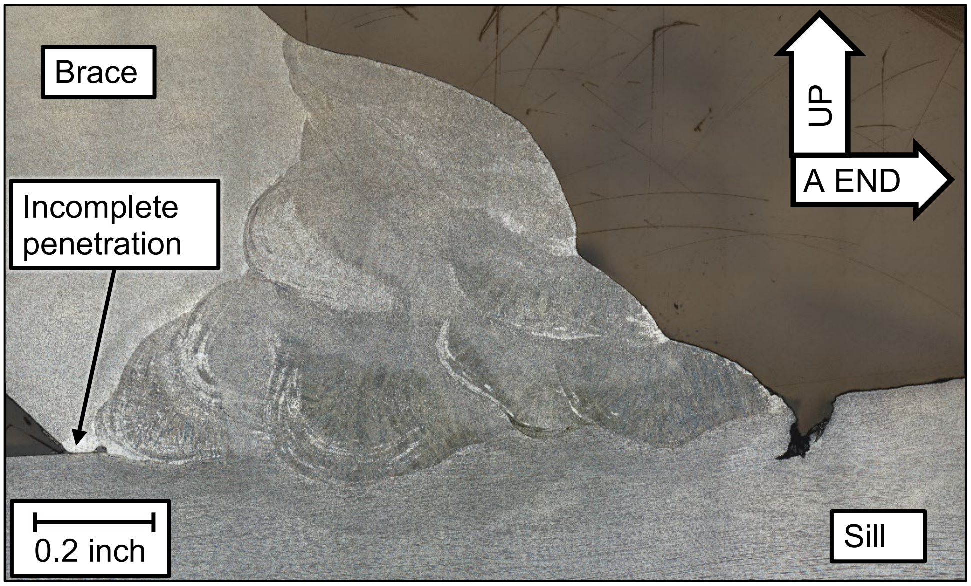
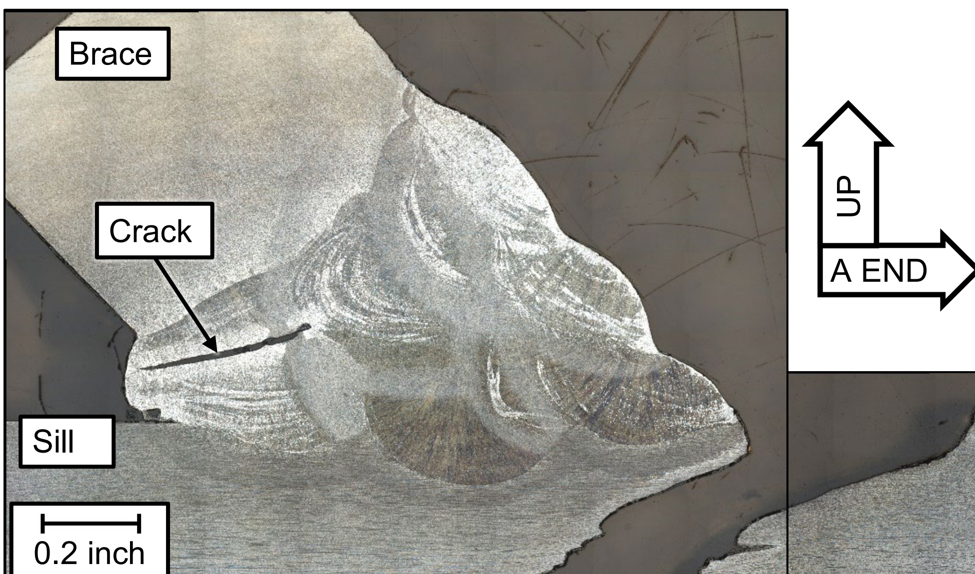


Figure 21. Multi-pass groove weld between the head brace and the stub sill in the centerline longitudinal cut plane (weld SBL1). The image is a stitched montage using a 2.5x objective lens and is etched with 2% nital.



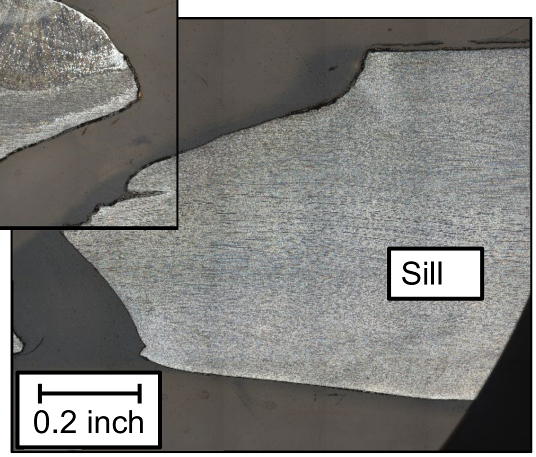


Figure 22. Multi-pass groove weld between the head brace and the stub sill in the second longitudinal cut plane (weld SBL2). Images are stitched montages using a 2.5x objective lens and are etched with 2% nital.

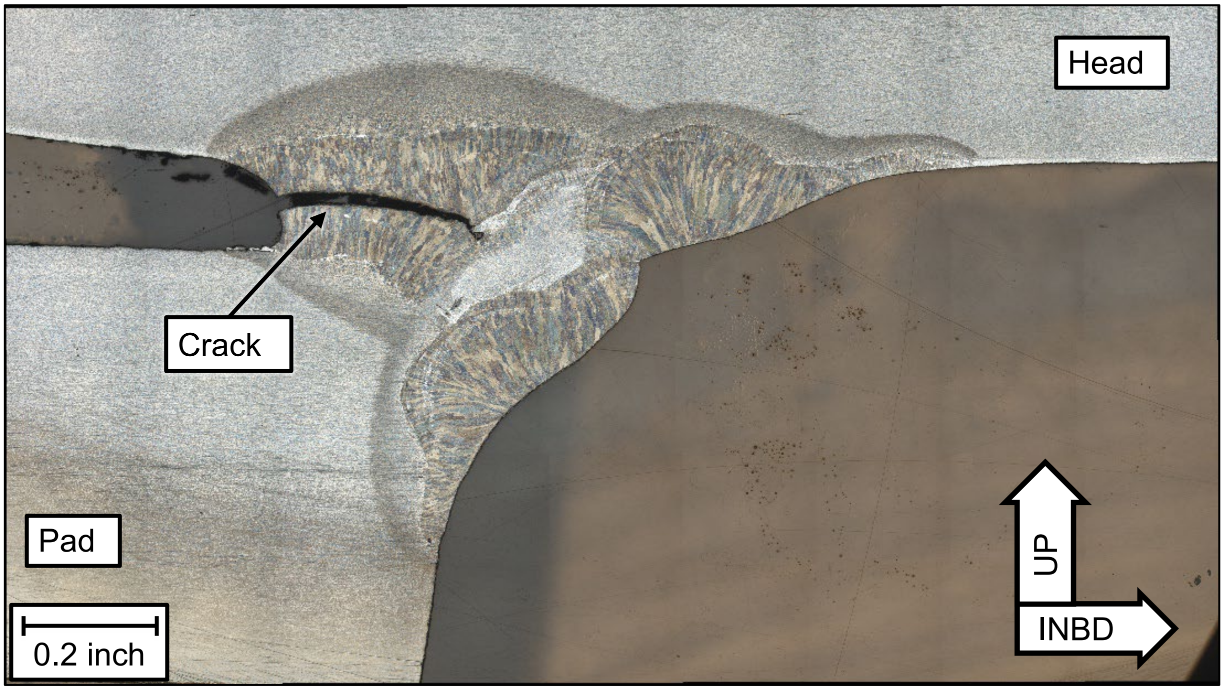


Figure 23. Fillet weld between the head and the front sill pad window in the transverse cut plane (weld HPT1i). Image is a stitched montage using a 2.5x objective lens and is etched with 2% nital.

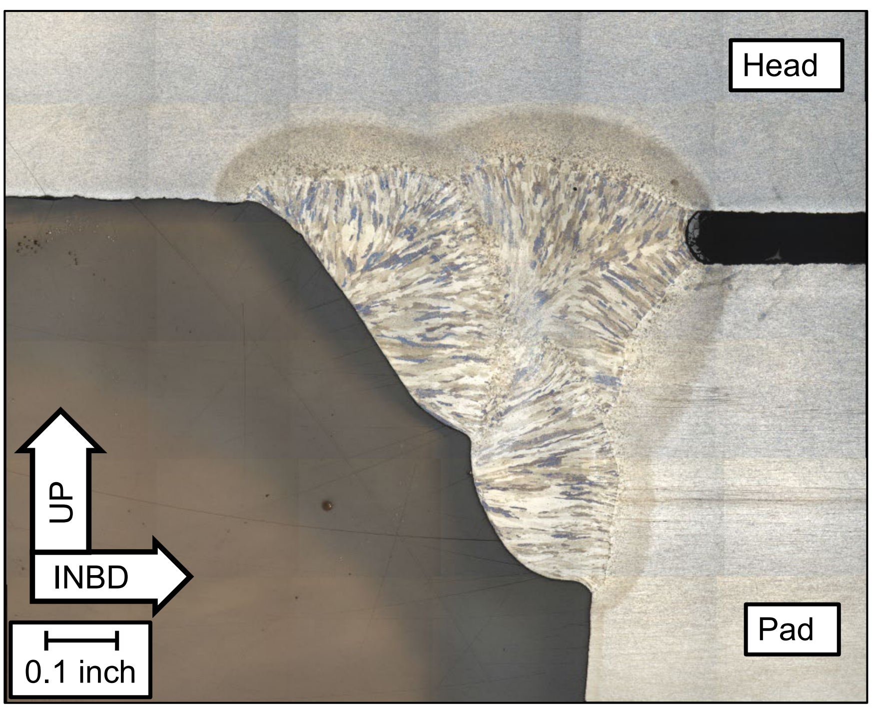


Figure 24. Fillet weld between the head and the front sill pad outboard edge in the transverse cut plane (weld HPT1o). Image is a stitched montage using a 2.5x objective lens and is etched with 2% nital.

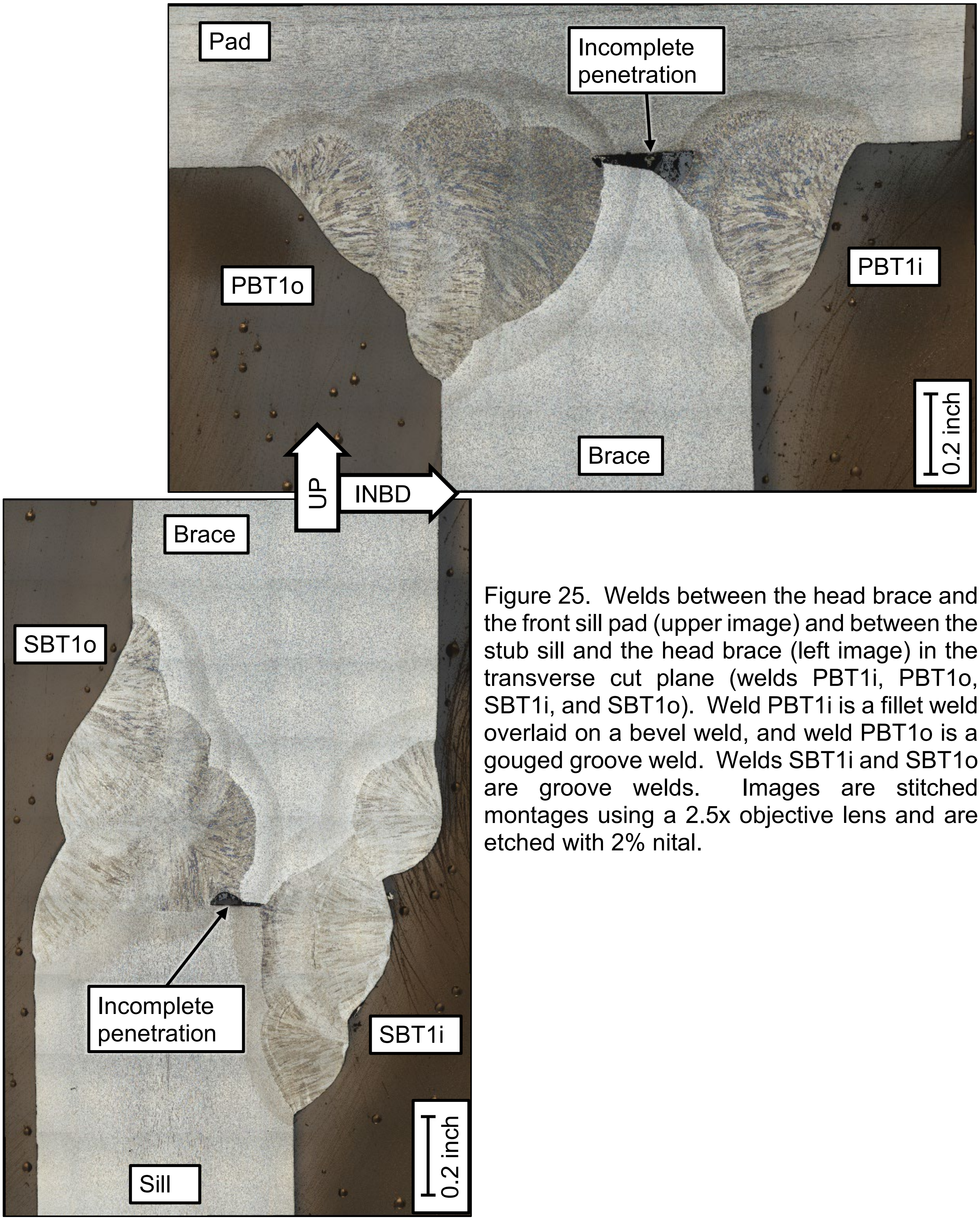


Figure 25. Welds between the head brace and the front sill pad (upper image) and between the stub sill and the head brace (left image) in the transverse cut plane (welds PBT1i, PBT1o, SBT1i, and SBT1o). Weld PBT1i is a fillet weld overlaid on a bevel weld, and weld PBT1o is a gouged groove weld. Welds SBT1i and SBT1o are groove welds. Images are stitched montages using a 2.5x objective lens and are etched with 2% nital.

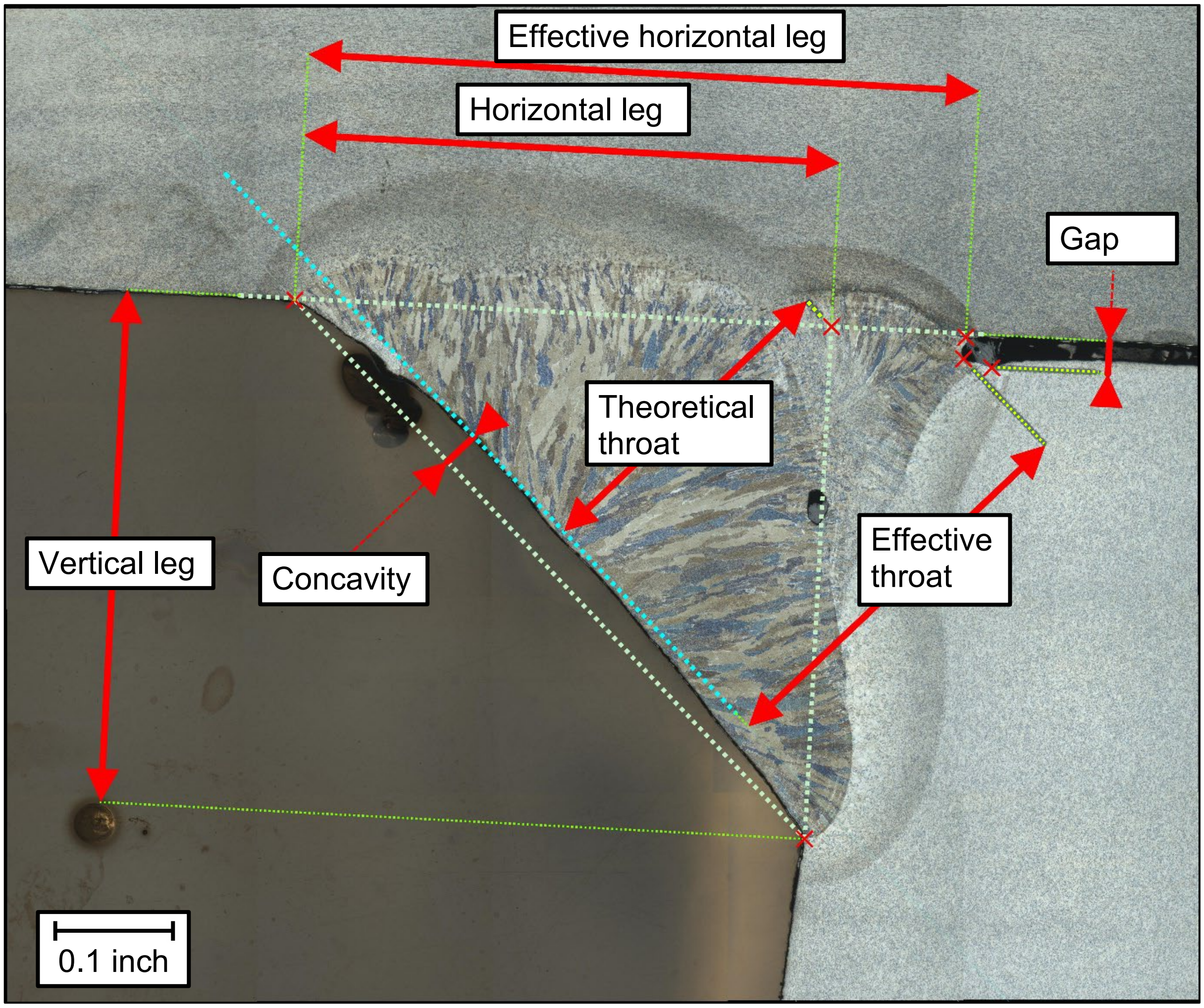


Figure 26. Example of fillet weld measurement features.

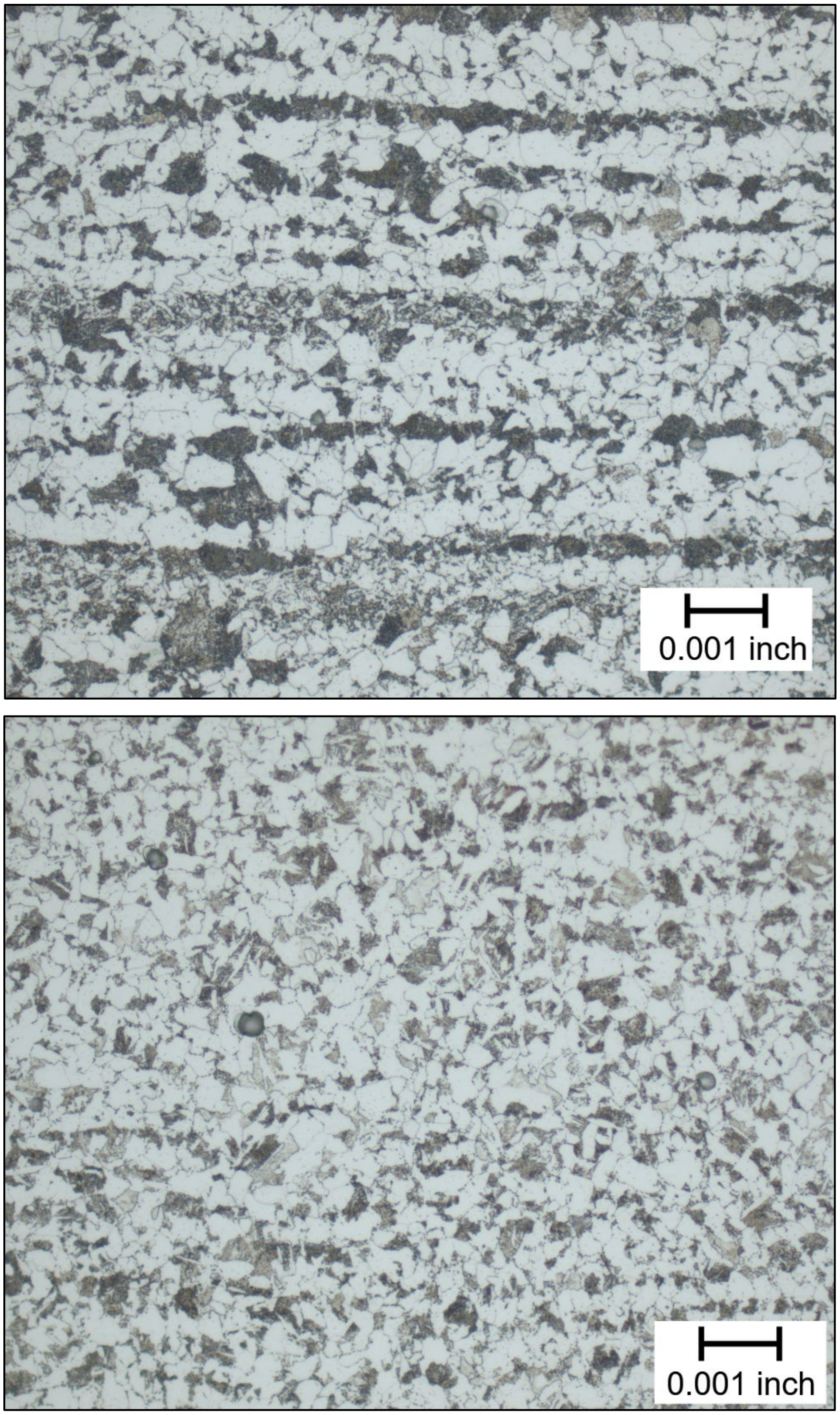
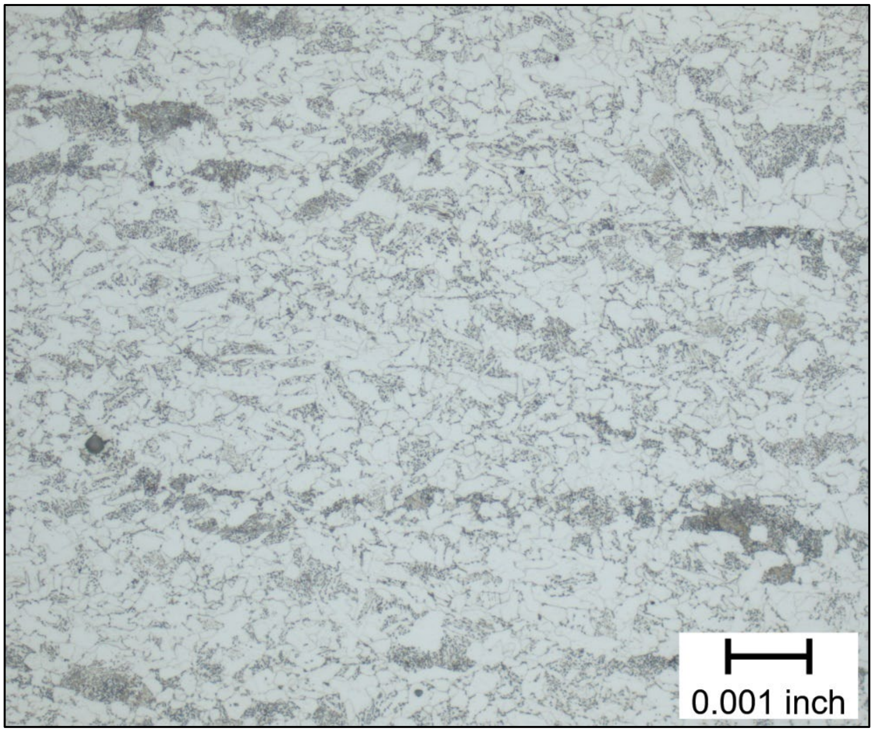


Figure 27. Typical microstructural features of the head in the longitudinal (upper image) and transverse (lower image) planes. Etched with 2% nital.



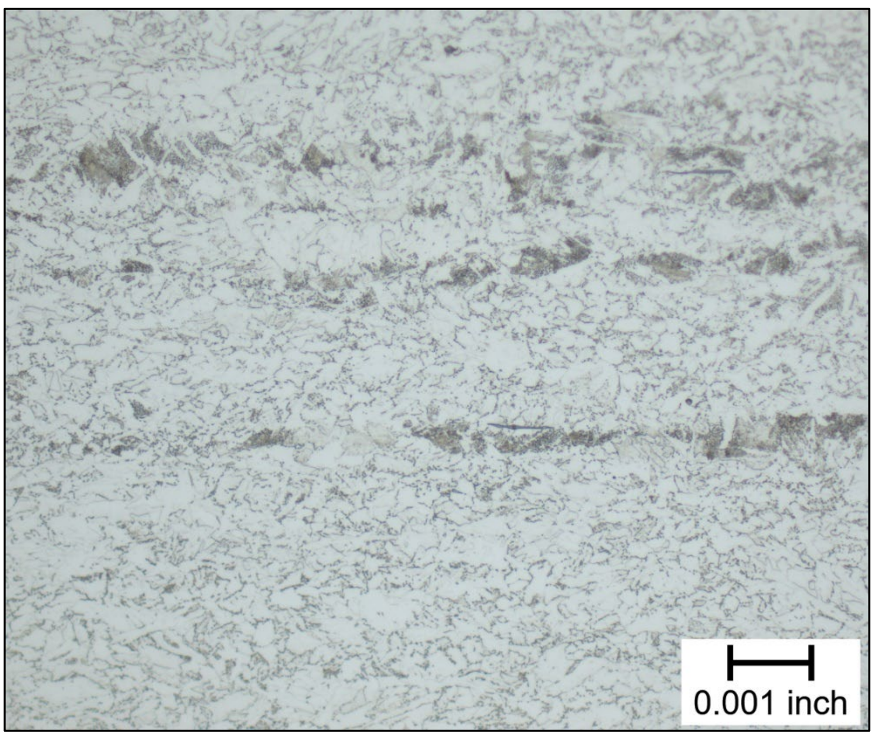


Figure 28. Typical microstructural features of the pad in the longitudinal (upper image) and transverse (lower image) planes. Etched with 2% nital.

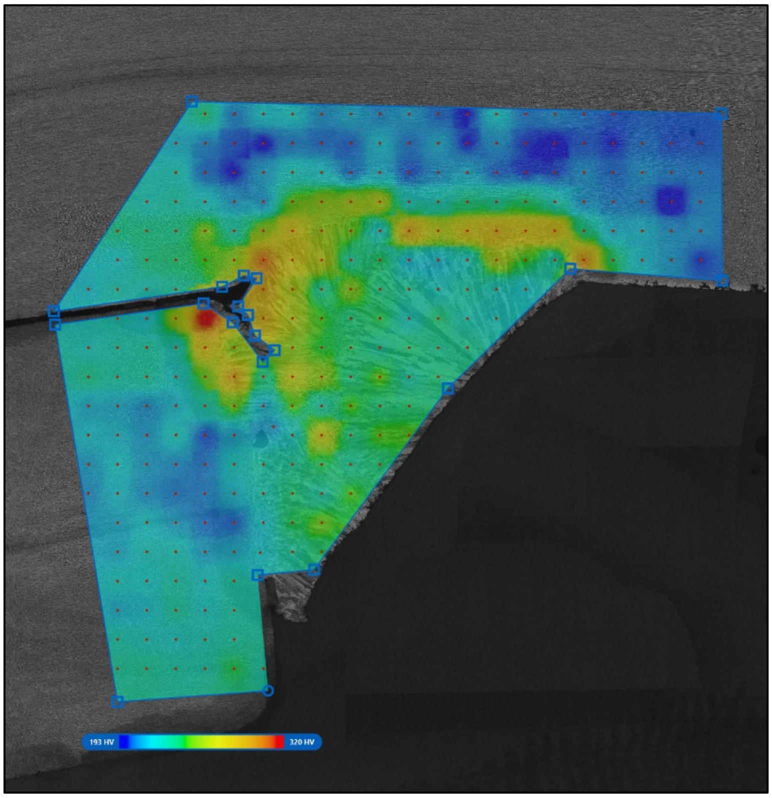


Figure 29. Hardness map for the fillet weld between the head and the front sill pad at the outboard edge of the pad in the centerline longitudinal cut plane (weld HPL1o). Hardness ranged from 193 HV (blue) to 320 HV (red). On the Rockwell scale, hardness ranged from 91.5 HRB to 32.3 HRC.

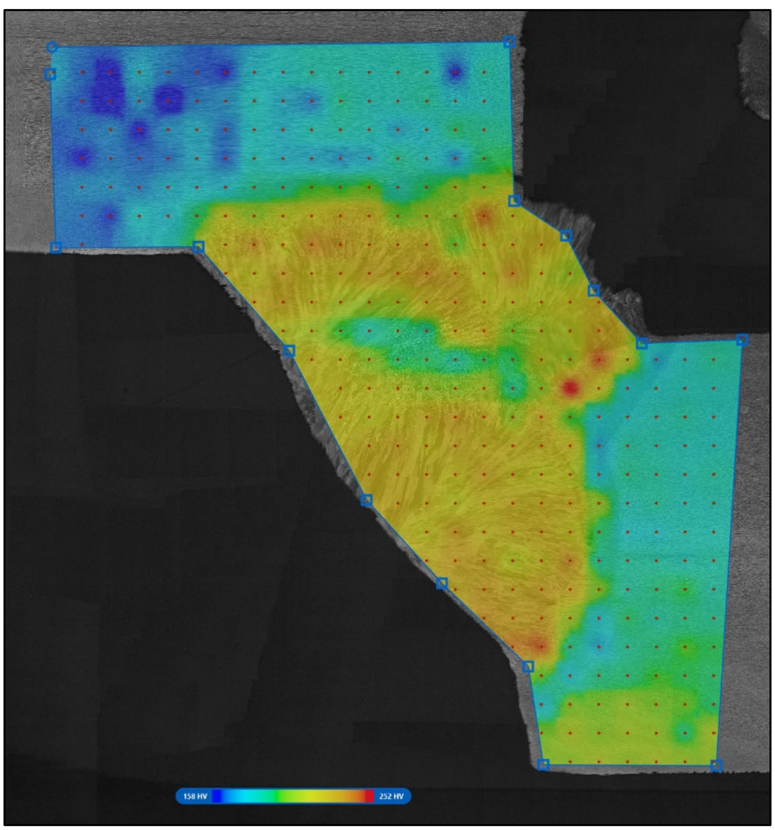


Figure 30. Hardness map for the fillet weld between the head and the front sill pad at the pad window in the centerline longitudinal cut plane (weld HPL1i). Hardness ranged from 158 HV (blue) to 252 HV (red). On the Rockwell scale, hardness ranged from 82.6 HRB to 22.6 HRC.

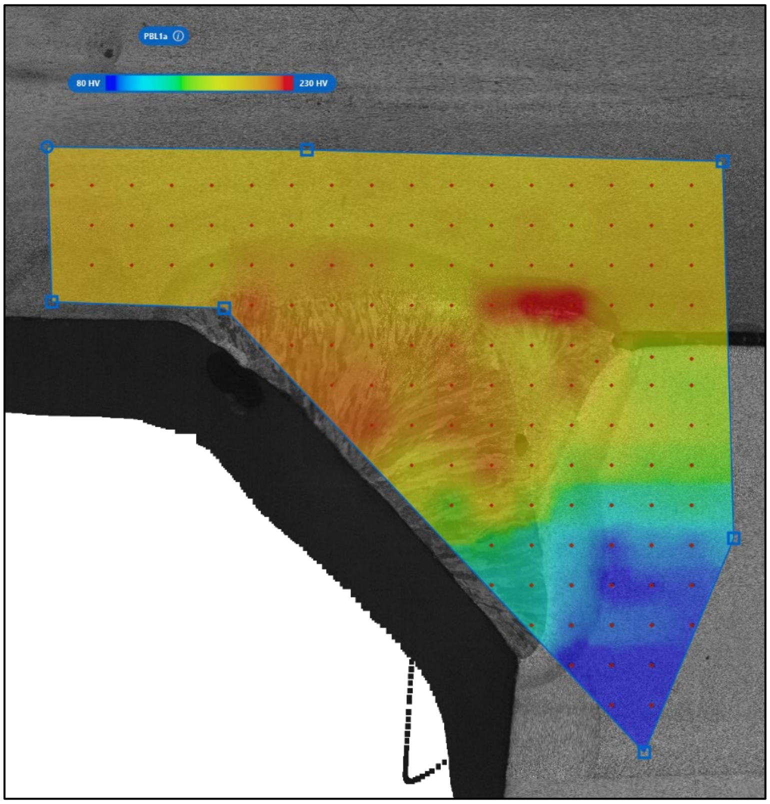


Figure 31. Hardness map for the fillet weld between the front sill pad and the head brace at the inboard side of the brace in the centerline longitudinal cut plane (weld PBL1i). Hardness ranged from 80 HV (blue) to 230 HV (red). On the Rockwell scale, hardness ranged from less than 55 HRB to 98.3 HRB.

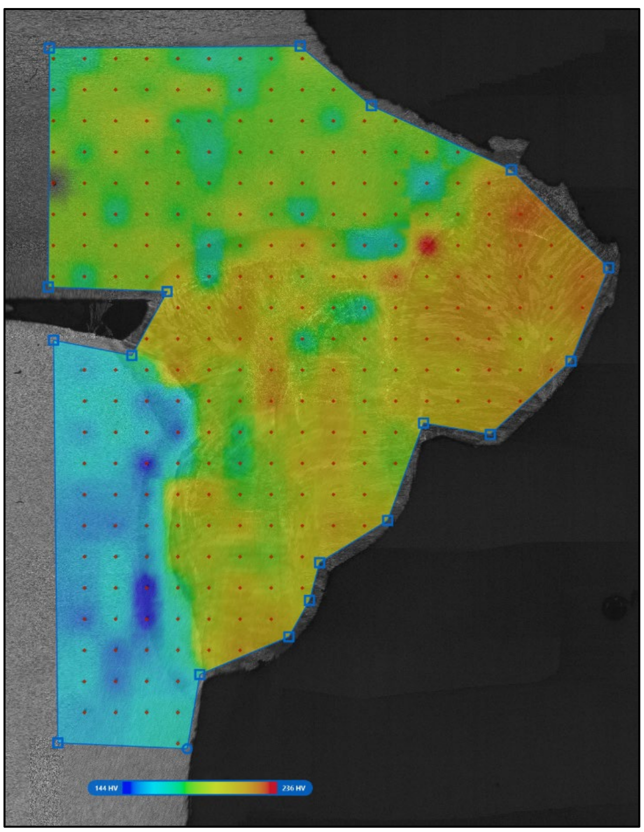


Figure 32. Hardness map for the outboard weld between the front sill pad and the head brace in the centerline longitudinal cut plane (weld PBL1o). Hardness ranged from 144 HV (blue) to 236 HV (red). On the Rockwell scale, hardness ranged from 78.0 HRB to 99.3 HRB.

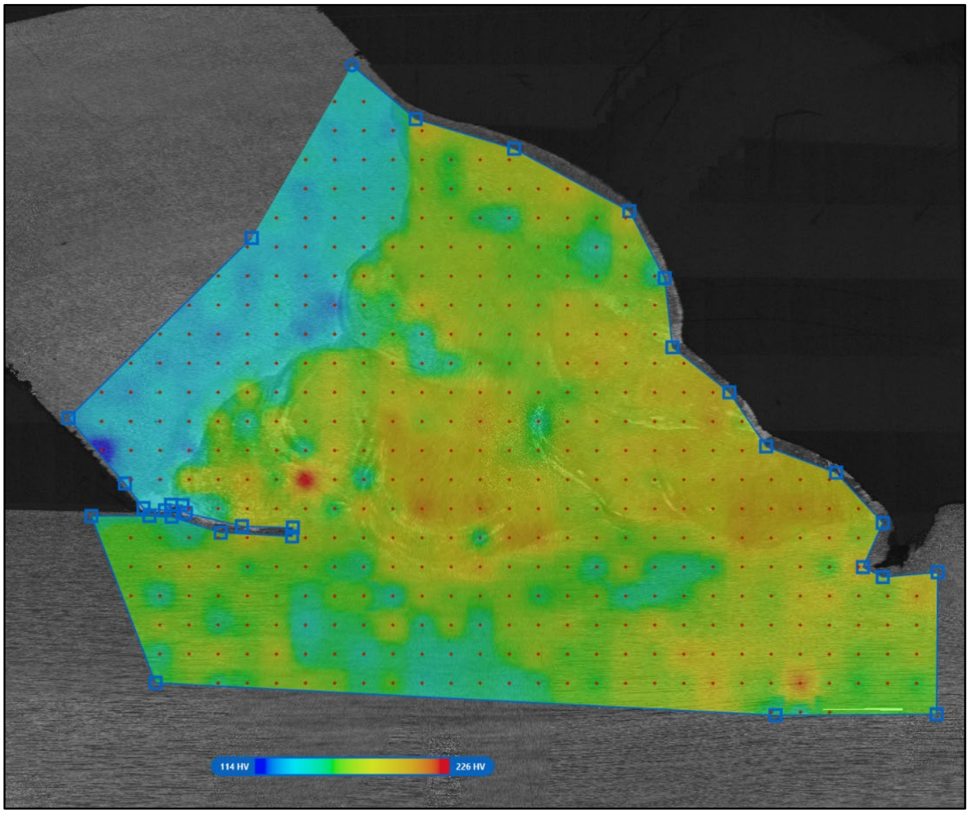


Figure 33. Hardness map for the weld between the head brace and the stub sill in the centerline longitudinal cut plane (weld SBL1). Hardness ranged from 114 HV (blue) to 226 HV (red). On the Rockwell scale, hardness ranged from 64.0 HRB to 97.6 HRB.

D. APPENDIX A: IMAGES USED FOR FILLET WELD MEASUREMENTS IN TABLE 2[5]

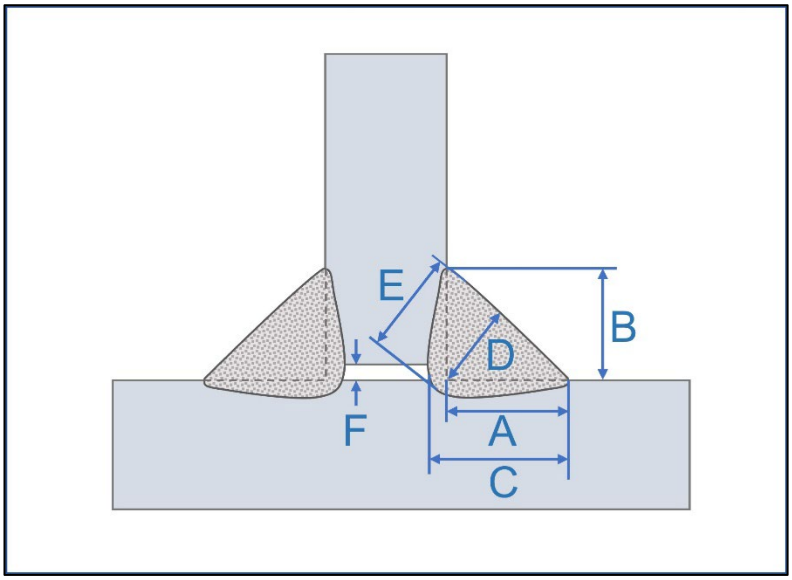


Figure A1. Fillet weld measurement diagram. A=horizontal leg, B=vertical leg, C=effective horizontal leg, D=theoretical throat, E=effective throat, and F=gap.

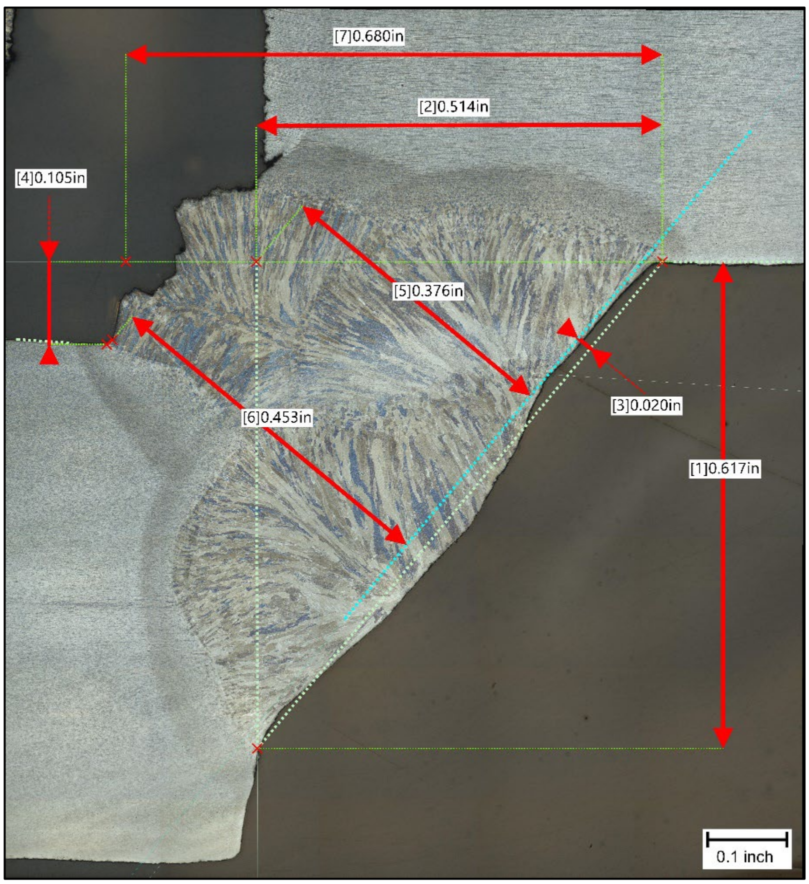


Figure A2. Measurements for weld HPL1i.

[5] Images used in measurements are mirror images to the metallographic images shown in the main body of the report.

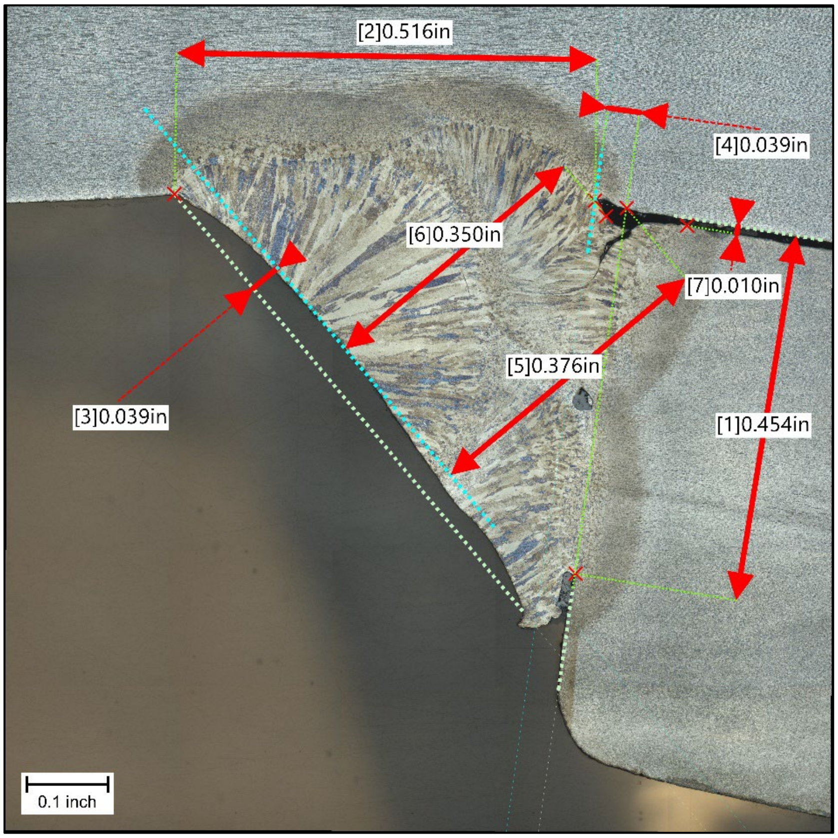


Figure A3. Measurements for weld HPL1o.

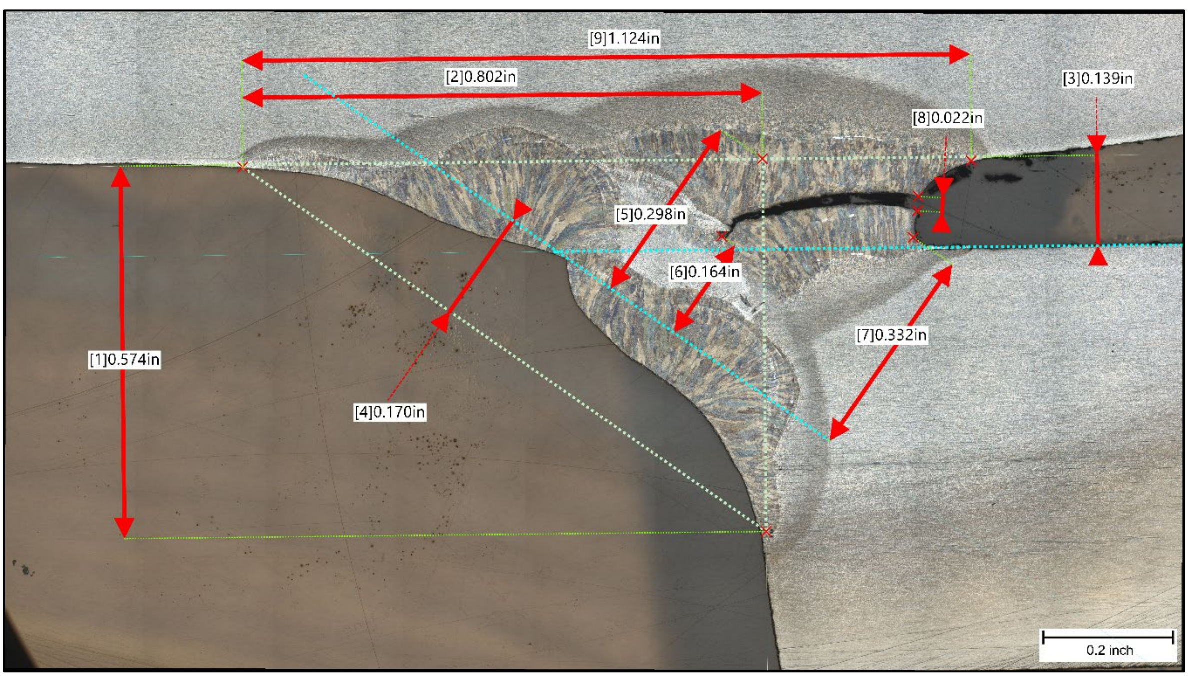


Figure A4. Measurements for weld HPT1i.

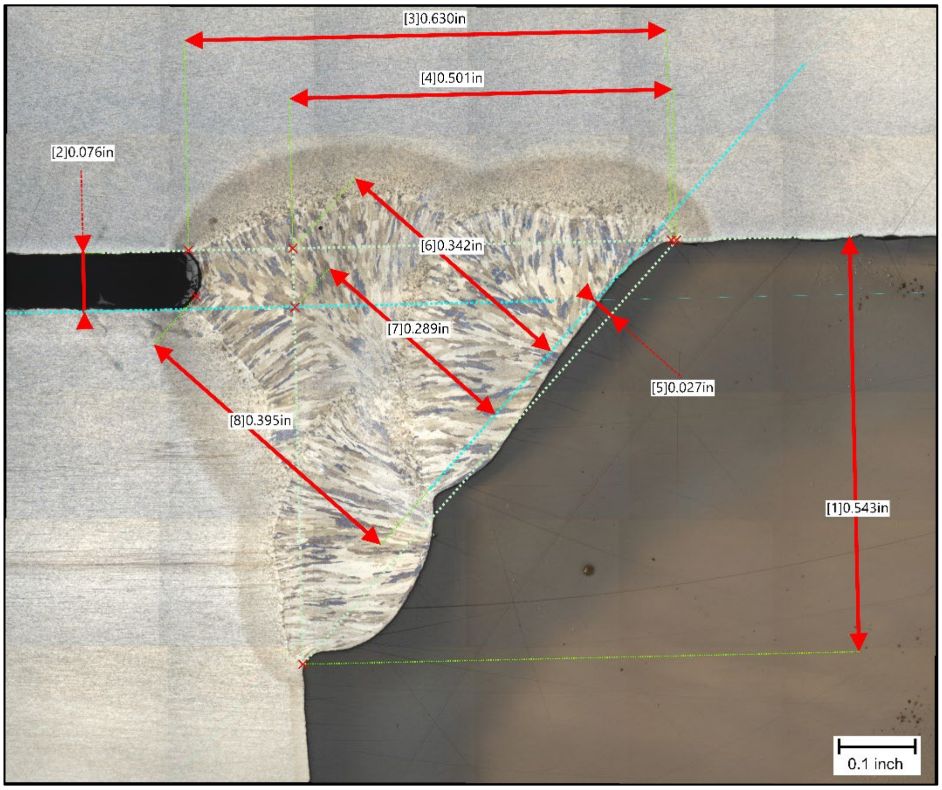


Figure A5. Measurements for weld HPT1o.

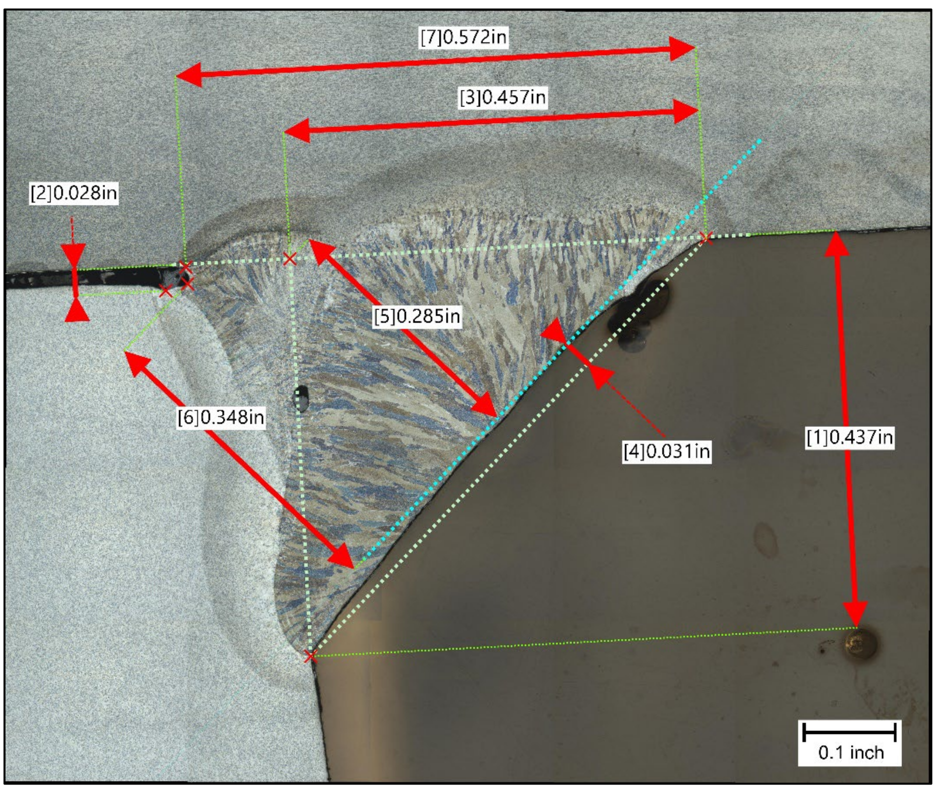


Figure A6. Measurements for weld PBL1i.

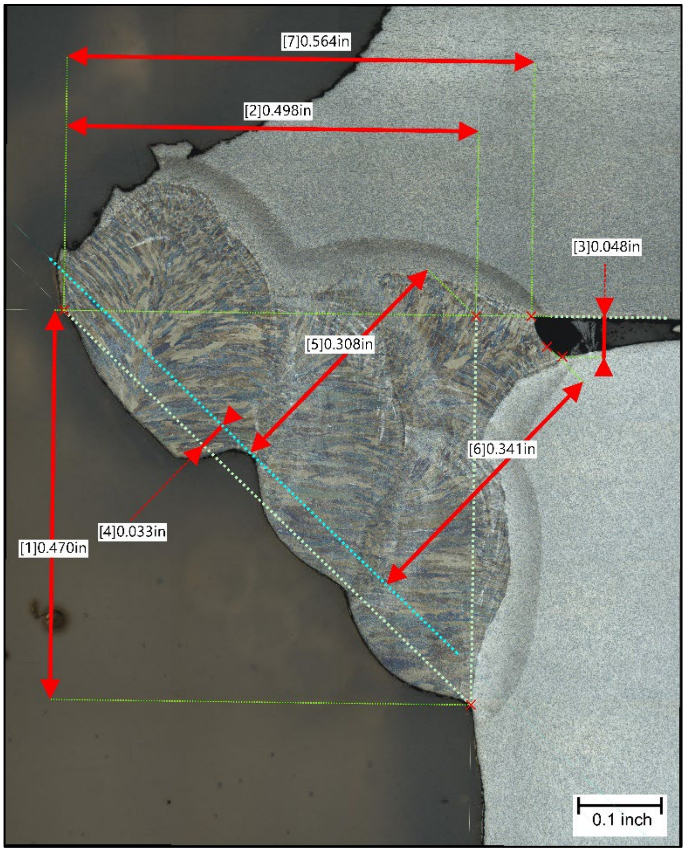


Figure A7. Measurements for weld PBL1o.

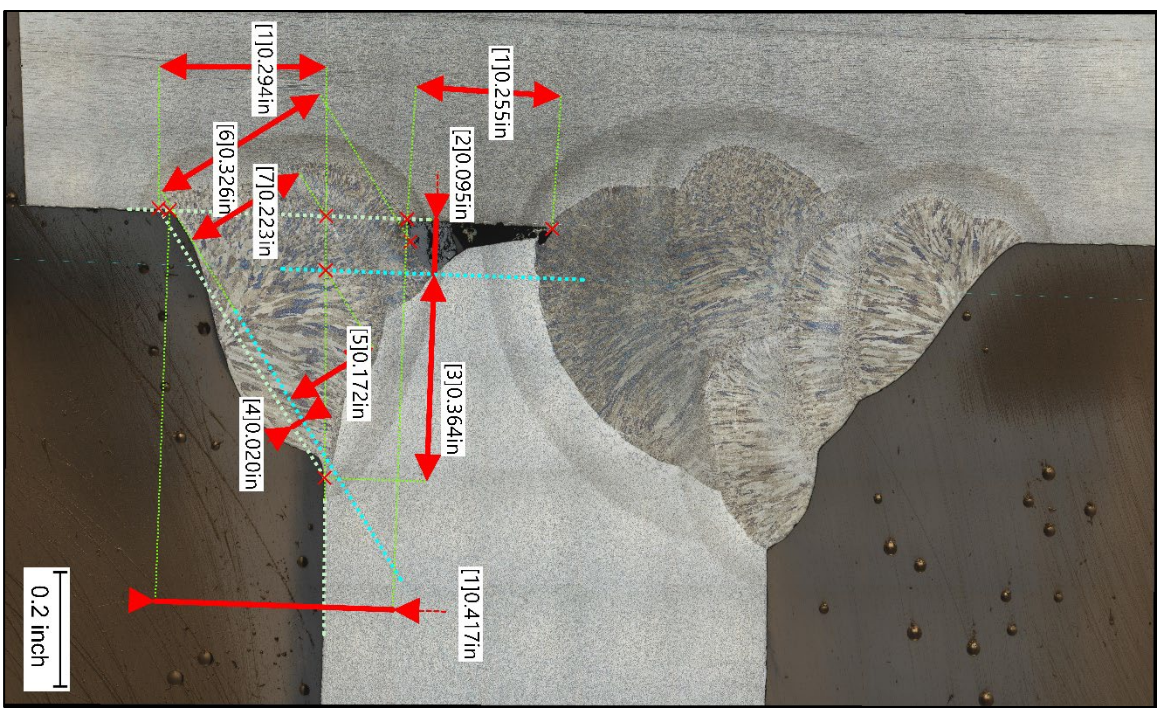


Figure A8. Measurements for weld PBT1i.

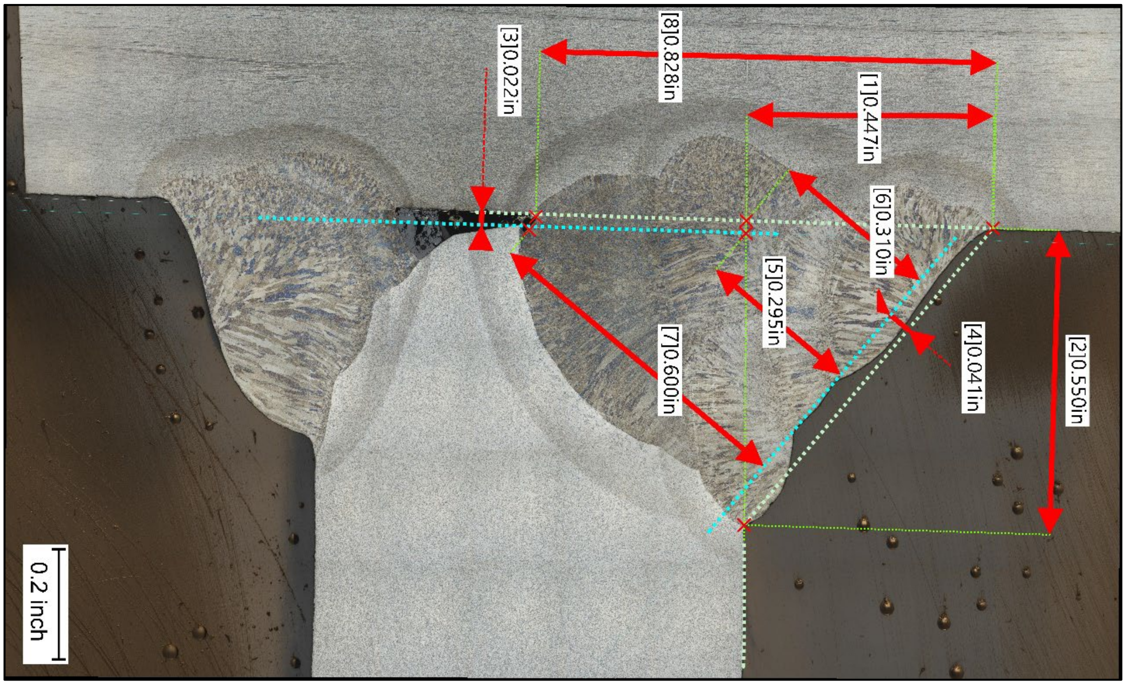


Figure A9. Measurements for weld PBT1o.

E. APPENDIX B: CHEMISTRY AND TENSILE TESTS LAB REPORT

Lehigh Testing Laboratories
308 WEST BASIN ROAD • P.O. BOX 903 • NEW CASTLE, DELAWARE 19720
(302) 328-0500 • FAX (302) 328-0417

TEST REPORT

NATIONAL TRANSPORTATION
ATTENTION: MATTHEW FOX
490 L'ENFANT PLAZA EAST SW
WASHINGTON, DC 20594

DATE: June 21, 2022

PO NO: **Verbal Credit Card**

LEHIGH NO: **J-74-5**

MATERIAL: NORMALIZED TC-128 STEEL
SAMPLE DESIGNATION: (1) SAMPLE: ~3' X ~3' X 9/16" RAIL TANK CAR SHELL WALL
REFERENCE: HMD22LR001

CHEMICAL ANALYSIS (%)

Carbon	0.12
Sulfur	<0.005
Manganese	1.51
Phosphorus	0.014
Silicon	0.34
Vanadium	<0.001
Copper	0.15
Nickel	0.16
Chromium	0.15
Molybdenum	0.02
Aluminum	0.03
Niobium	0.010
Titanium	0.003
Boron	0.002
Tin	<0.01
Nitrogen	<0.005

Results are for information only.

Procedure: *QA-CH-P-018 Rev 5 (OES)*
QA-CH-P-122 Rev 1 (Leco N)

Lehigh Testing Laboratories

Peter M. Engelgau

Peter M. Engelgau, Principal Chemist

Lehigh Testing Laboratories
308 WEST BASIN ROAD • P.O. BOX 903 • NEW CASTLE, DELAWARE 19720
(302) 328-0500 • FAX (302) 328-0417

TEST REPORT

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MATERIAL: NORMALIZED TC-128 STEEL
SAMPLE DESIGNATION: (1) SAMPLE: ~3' X ~3' X 9/16" RAIL TANK CAR SHELL WALL
REFERENCE: HMD22LR001

MECHANICAL PROPERTIES (Per ASTM A370-21)

	LONGITUDINAL TENSILES			TRANSVERSE TENSILES		
	L-1	**L-2**	**L-3**	**T-1**	**T-2**	**T-3**
Width (inches):	1.503	1.505	1.505	1.505	1.503	1.503
Thickness (inches):	0.582	0.584	0.584	0.583	0.584	0.586
Area (square inches):	0.8747	0.8789	0.8789	0.8774	0.8778	0.8808
Yield Strength (psi): 0.2% offset:	56,500	56,200	56,600	59,900	58,500	58,700
Yield Strength (psi): 0.5% EUL:	57,300	56,400	57,100	59,700	58,500	58,400
Ultimate Tensile Strength (psi):	80,100	79,900	81,500	80,700	79,800	79,800
Elongation (%) in 2":	50	45	45	48	50	45
Elongation (%) in 8":	26	26	26	27	25	25
Reduction of Area (%):	65	63	64	59	63	58

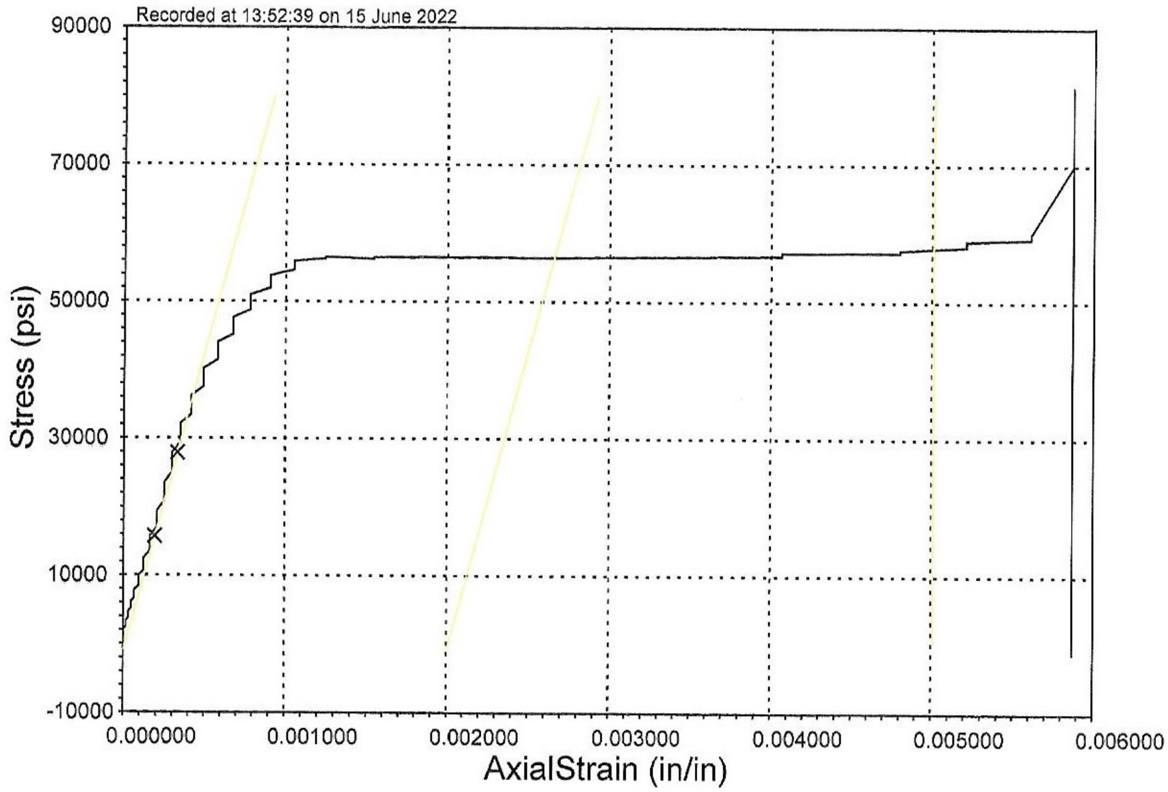
Results are for information only.

Stress Strain Charts Attached.

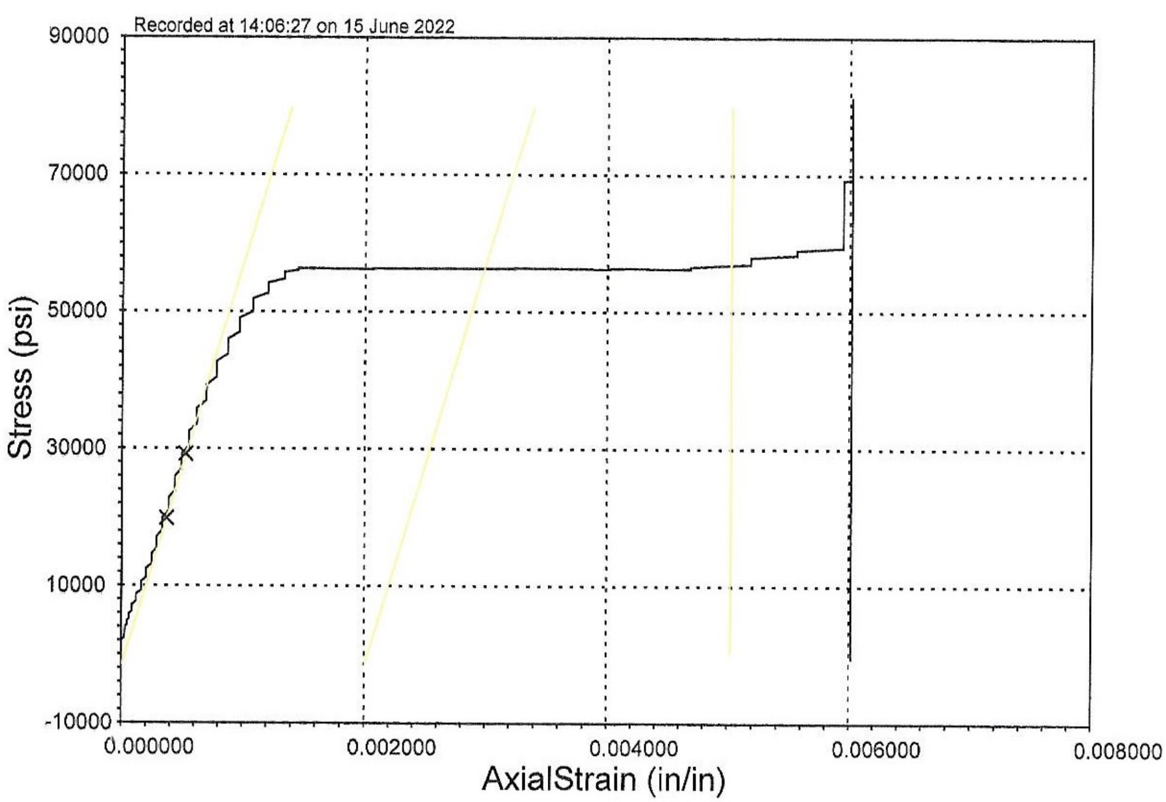
Lehigh Testing Laboratories

Kevin M. Sexton

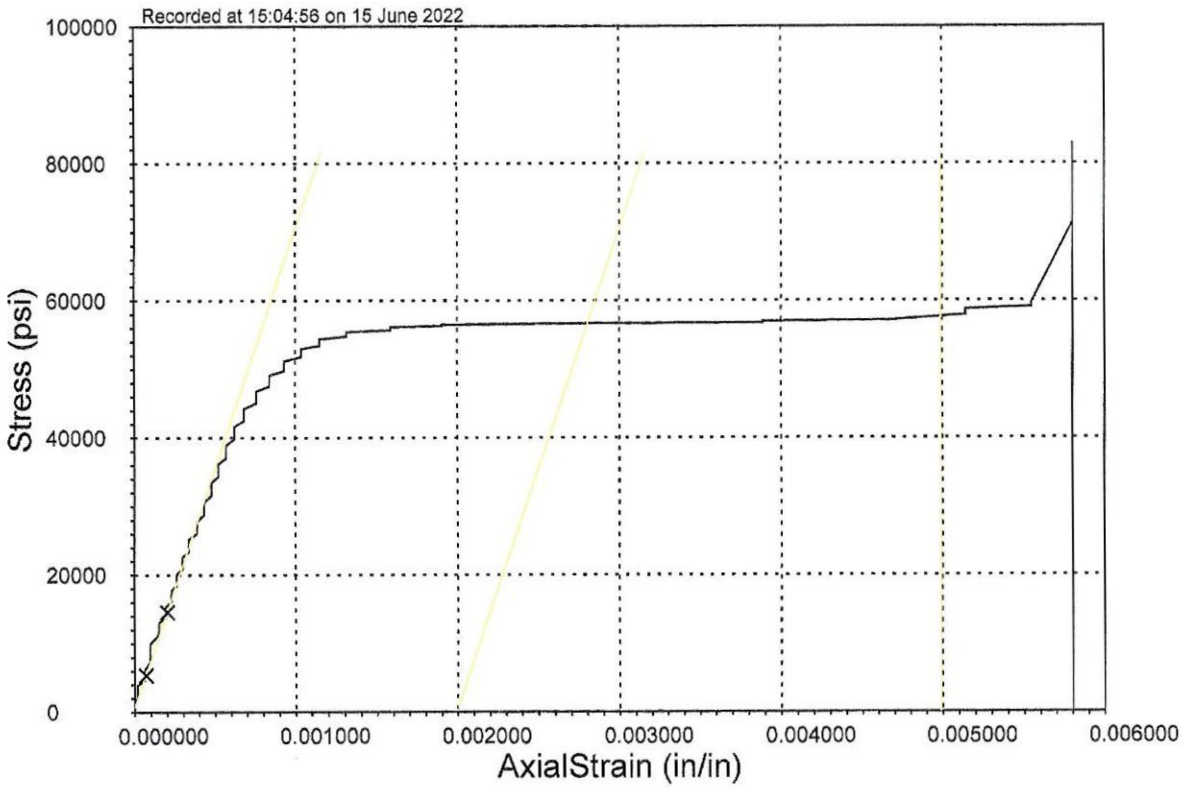
Kevin M. Sexton, Mechanical Testing & Metallography Supvr.



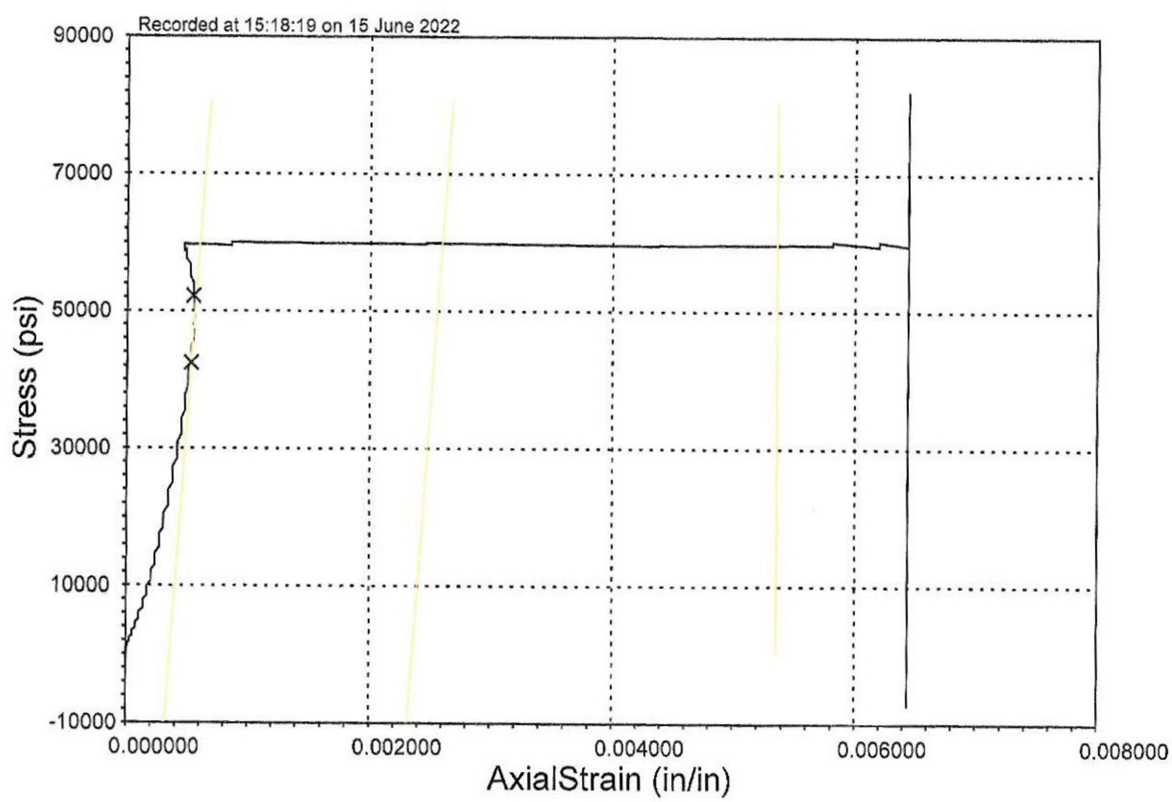
Longitudinal Tensile – “L-1”



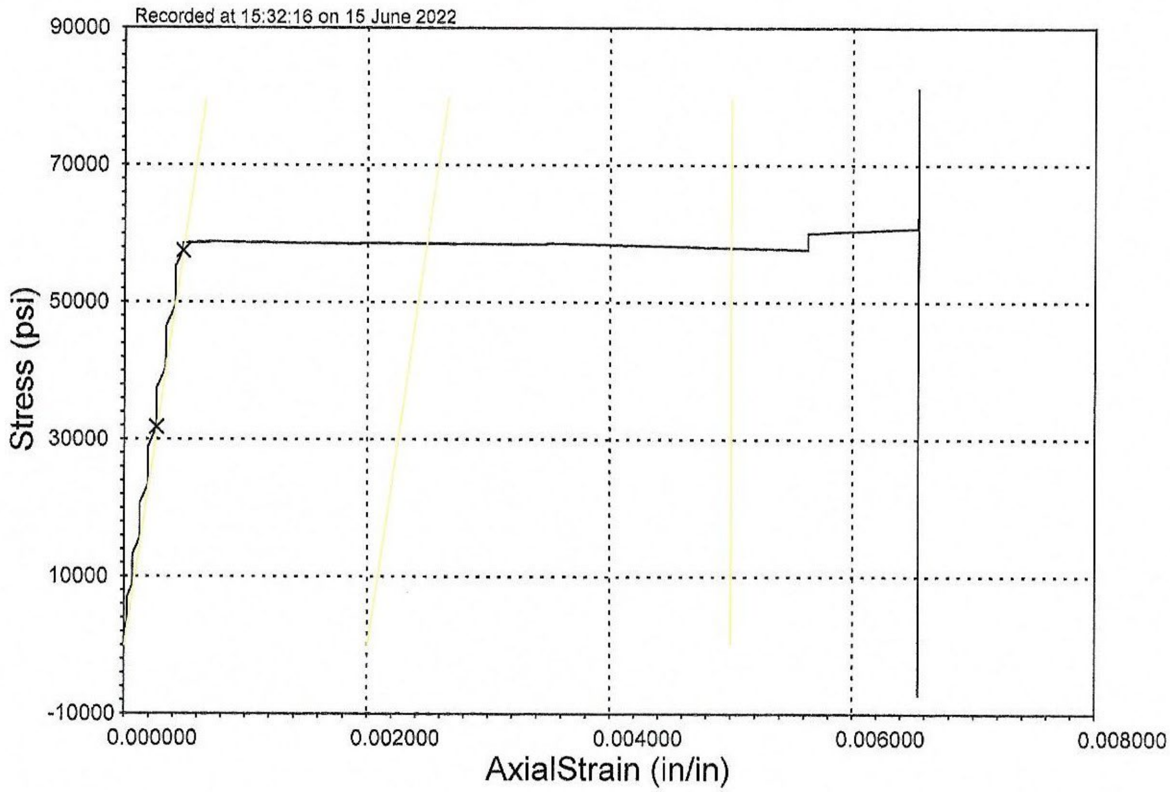
Longitudinal Tensile “L-2”



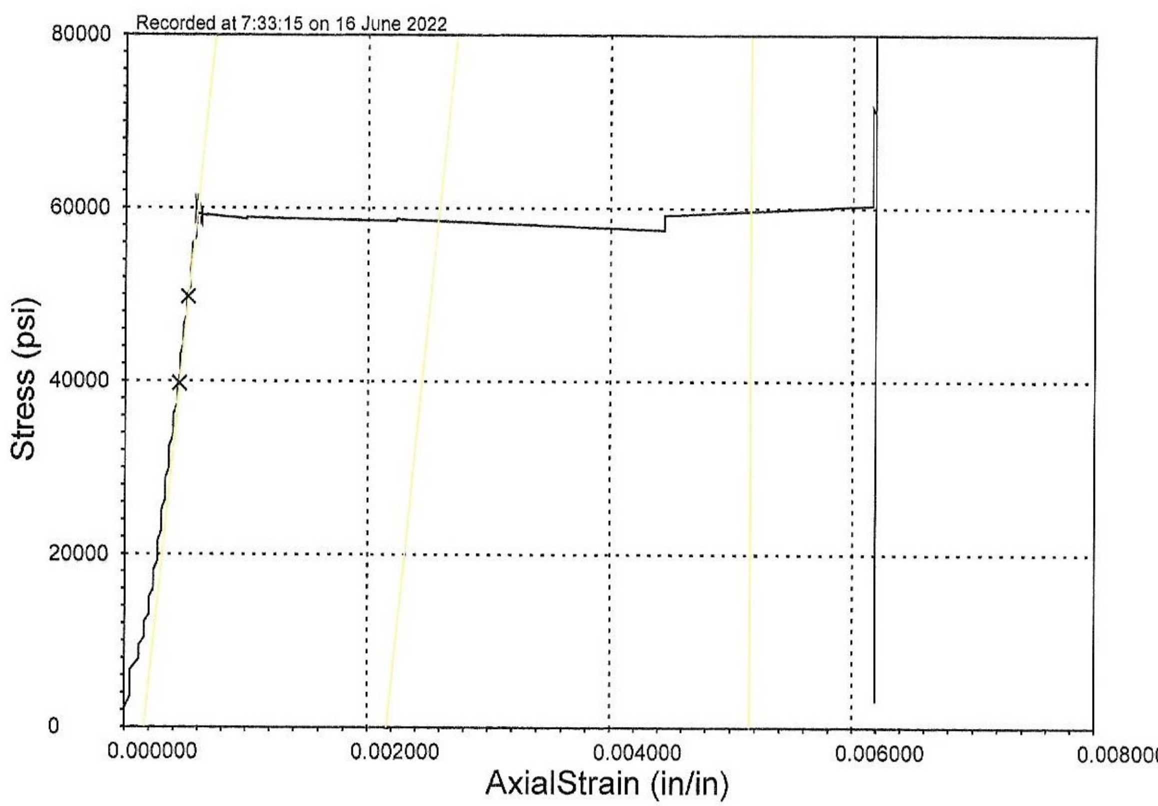
Longitudinal Tensile “L-3”



Transverse Tensile “T-1”



Transverse Tensile “T-2”



Transverse Tensile “T-3”