ANDERSON& ASSOCIATES
CONSULTING METALLURGICAL ENGINEERS AND TESTING LABORATORY

PRIVILEGED and CONFIDENTIAL – SUBJECT to ATTORNEY-CLIENT PRIVILEGE

February 7, 2023

TC Energy
450-1 Street S.W.
Calgary, AB, Canada, T2P 5H1
Attn: Brian Yeung
By Email

Re: 220439 TC Energy - Metallurgical Analysis of NPS-36 KS10 MP-14 Pipeline

Dear Mr. Yeung:

Pursuant to your request, this report details the findings of the metallurgical investigation of the Keystone Pipeline rupture near MP-14 in Washington County, Kansas.

GENERAL NOMENCLATURE

The identification and location of specific features of the pipe are made in reference to top dead center (TDC). Clockwise position is established when viewed in the direction of flow. Positions of features are referenced interchangeably using both degrees and inches from TDC, using the conversion 1° = 0.314”.

BACKGROUND INFORMATION

It was reported that on December 7, 2022, TC Energy experienced an in-service failure of the 36” Keystone Pipeline Phase 2 (KS10 segment) near the Mill Creek crossing at MP-14 in Washington County, Kansas. The pipeline was reportedly a 36” nominal diameter with a 0.465” nominal wall thickness, API 5L grade X70 PSL 2 material. The failure was reported at a girth weld joining a 0.515” wall thickness pup to a 30° elbow with a thickness of ~0.80”. The material test reports (MTR) for the pups and elbow are provided in Appendices A and B, respectively. The failed section of pipe was received at Anderson & Associates on December 19, 2022, and the metallurgical investigation began on January 9, 2023. The pipe section is shown after removal from its transport crate below in Figure 1.

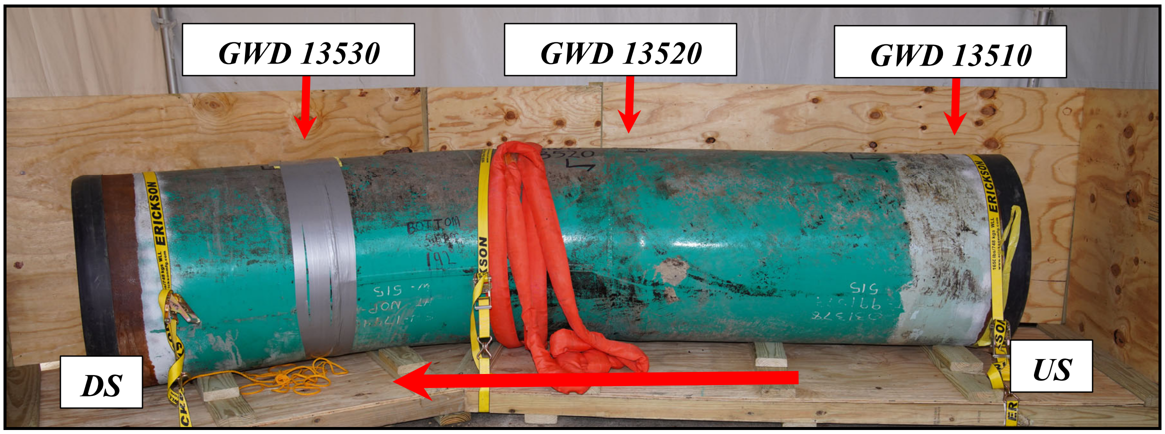


Figure 1 *– Pipe section shown as-received after un-boxing. Girth weld identifications and flow direction (red arrow) were as noted.*

VISUAL EXAMINATION

General Condition

The visual examination was conducted in the as-received condition and after abrasive grit blasting removal of the external coating. The external coating appeared consistent with a green colored fusion bonded epoxy (FBE). The coating appeared to be in good condition, with two isolated instances of "fresh" damage identified. The coating on each end of the pipe sample had been removed, likely during the excavation in preparation to liberate the sample from the line. In order from upstream to downstream, the pipe sample consisted of the following sections:

- A short ligament of spiral welded line pipe joined via girth weld (GWD) 13510 to a longitudinally seam welded pup. An analysis of GWD 13510 was not included in the test protocol.
- The pup section was joined to the upstream side of a 30° elbow via GWD 13520.

- The downstream end of the elbow was joined to a longitudinally seam welded pup section via GWD 13530. The orientation of the seam weld of the pup with respect to TDC was 122° clockwise.

The overall length of the pipe sample was 13', 11.25". The outer diameter (OD) of the pipe was measured in one-foot increments along the length beginning at the upstream side using a pi-tape. The measurements are summarized in Table 1.

Table 1 – Pipe Diameter

Position from US End (ft)	***Diameter (in)***
0	36.050
1	36.025
2	36.059
3	36.078
4	36.075
5	36.125
Wrinkle (5.5)	36.508
6	36.120
7	36.035
8	35.956
9	35.880
10	35.860
11	36.128 (FBE)
12	36.110
13	36.100
13.9375	36.083

Features of Interest

There were two major features of interest that were visually identified – the first being a circumferentially oriented crack located coincidentally with the toe of the girth weld on the pup side of GWD 13530 as shown in Figure 2. There was a protective pad that was duct taped to the pipe covering the crack when it was received. After the protective pad was removed, it was observed that black sharpie marking indicated the visual extent of the crack to span from 333°

to 54°, a total of approximately 81° (~25.43”). The crack appeared to be located entirely on the pipe-side of the girth weld. There were two sections of rubber hosing placed in the crack space, presumably installed in the field to prevent the mating fracture surfaces from contacting each other during transport. The FBE coating on the pipe-side of GWD 13530 exhibited parallel cracking at the terminal ends of the fracture as shown in Figure 3.

The second feature of interest was what initially described as a “bulge”, but upon examination appeared more consistent with a wrinkle (pipe buckle), was located on the intrados (bottom side) of the upstream pup adjacent to GWD 13520 as shown in Figure 4. The wrinkle was approximately centered upon bottom dead center and spanned approximately 180°.

(a)

(b)

Figure 2 *– (a) Photograph showing the condition of GWD 13530 as it was received. The leak location was protected with a yellow pad and secured in place with duct tape. (b) Photograph showing rupture in the pipe at GWD 13530 after removing the protective covering. There were sections of rubber hosing installed in the rupture location, presumably to protect the fracture faces from mechanical contact.*

Figure 3 *– View of parallel cracking in the FBE coating on the pipe-side of GWD 13530 at the counter-clockwise terminal end of the crack. Protective rubber hosing installed in the crack surfaces to prevent contact.*

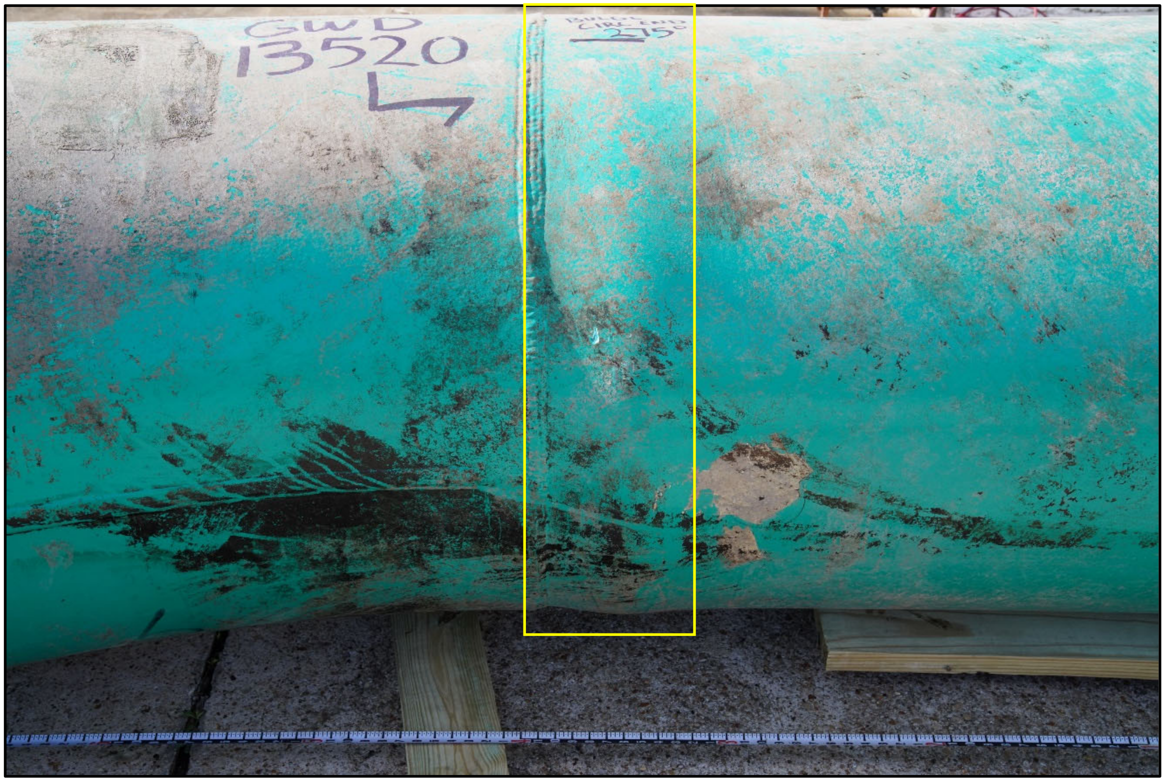


Figure 4 *– View of the bulge (wrinkle) on the intrados side of the US pup adjacent to GWD 13520.*

Following the initial visual inspection, the pipe was transported to AAA Blastcoat in Houston, Texas for the purposes of removing the FBE coating via abrasive grit blasting. Approximately 9" either side of GWD 13530 and approximately 180° around the circumference were masked off to prevent contamination of the fracture with the abrasive media. Removal of the FBE coating was necessary for subsequent non-destructive analyses that were to be performed by Applus RTD. A photograph showing the freshly grit blasted pipe is shown in Figure 5.

With the FBE coating removed, stamped identification was located on the intrados side of the elbow fitting. The identification on the elbow fitting was as follows:

Redacted by TC Energy

[redacted]

***Figure 5** – View of the pipe after grit blasting to remove the FBE coating in preparation for NDT.*

NON-DESTRUCTIVE TESTING

Applus RTD was contracted to perform a series of non-destructive testing (NDT). Included in the scope of work was the following examinations on the girth welds: radiographic testing (RT), phased array ultrasonic testing (PAUT), ultrasonic wall thickness testing, magnetic particle inspection (MPI) on both OD and inner diameter (ID) of the girth welds, time of flight diffraction (TOFD), and inverse wave field extrapolation (IWEX). The entirety of the OD and ID surfaces were also mapped via laser scanning and wall thickness measurements were taken ultrasonically.

Of particular importance for the metallurgical failure investigation were the results of the radiographic testing, PAUT and MPI, which would help guide the sectioning plan to extract the crack and subsequent metallographic sections from the pipe. The radiographic report for GWD 13530 indicated the presence of a "rejectable crack" spanning a total of approximately 47.73" (152°) of the circumference. Radiographic examination of GWD 13520 showed several instances of porosity and slag inclusions, none of which were identified as rejectable per the Applus RTD radiography report. There were numerous MPI indications identified around the circumference, both OD and ID on both GWD 13520 and 13530, most if not all were associated with the toe of the girth welds. PAUT identified numerous toe lack-of-fusion and toe cracks on both GWD 13520 and 13530, most if not all were coincident with MPI indications. Radiography, PAUT, UT wall thickness, TOFD, and IWEX reports have been delivered to TC Energy by Applus RTD, the NDT report is provided in Appendix C.

Crack Measurement

The physical dimensions of the crack were documented prior to extraction from the pipe. The dimensions were measured by first tracing the crack on to sheets of white tracing paper, then measuring the width of the transcribed crack using calipers in half-inch increments as shown in Figure 6. Using this technique, the overall length of the crack on the OD was determined to be 26.50", and the maximum displacement (width) was measured to be 0.638". From these measurements it was found that the crack was not symmetric about TDC.

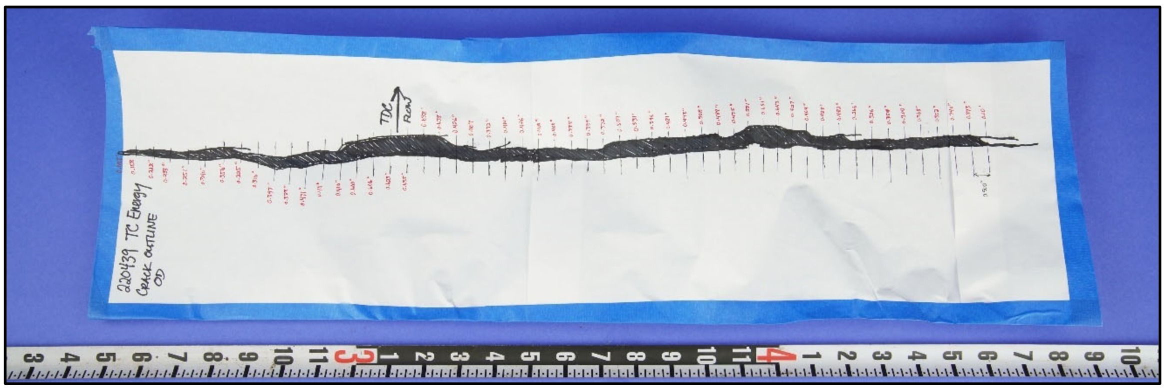


***Figure 6** – Traced image of the crack on the OD of GWD 13530 with width measurements acquired every 0.50".*

Crack Length (in)	*Crack Width (in)*
0	0.097
0.50	0.158
1.00	0.222
1.50	0.233
2.00	0.251
2.50	0.340
3.00	0.356
3.50	0.225
4.00	0.310
4.50	0.397
5.00	0.383
5.50	0.471
6.00	0.411
6.50	0.410
7.00	0.600
7.50	0.606
8.00	0.623
TDC	
8.50	0.635
9.00	0.638
9.50	0.638
10.00	0.426
10.50	0.407
11.00	0.372
11.50	0.414
12.00	0.426
12.50	0.408
13.00	0.400
13.50	0.335
14.00	0.339
14.50	0.372
15.00	0.507
15.50	0.531
16.00	0.596
16.50	0.481
17.00	0.473
17.50	0.508
18.00	0.489
18.50	0.455
19.00	0.551
19.50	0.651
20.00	0.643
20.50	0.527
21.00	0.464
21.50	0.428
22.00	0.482
22.50	0.266
23.00	0.326
23.50	0.359
24.00	0.300
24.50	0.368
25.00	0.352
25.50	0.340
26.00	0.373
26.50	0.100

Following the completion of NDT inspections, the fracture on both the OD and ID was masked and a panel encompassing the fracture in GWD 13530 was removed using a plasma cutter. The extracted panel is shown in Figure 7. To facilitate trimming, the weld on the ID was examined using wet fluorescent magnetic particle inspection to assess the extent of ID crack extension. As shown in Figures 8 and 9, there were linear indications on the pipe-side weld toe spanning nearly the entire length of the panel. Consequently, initial trim cuts were conservative e.g., removing minimal material from the edges so to as inspect for any evidence of depth of the indications. Following several initial trim cuts with no evidence of visible extension of the indications through the thickness of the material, the decision was made to trim at the visible extent of the opened crack region. The panel was then submerged in liquid nitrogen to facilitate freeze breaking the remaining ligaments. The reassembled panel after breaking is shown in Figure 10.

***Figure** 7 – View of the panel containing the ruptured section of GWD 13530 after removal from the pipe.*

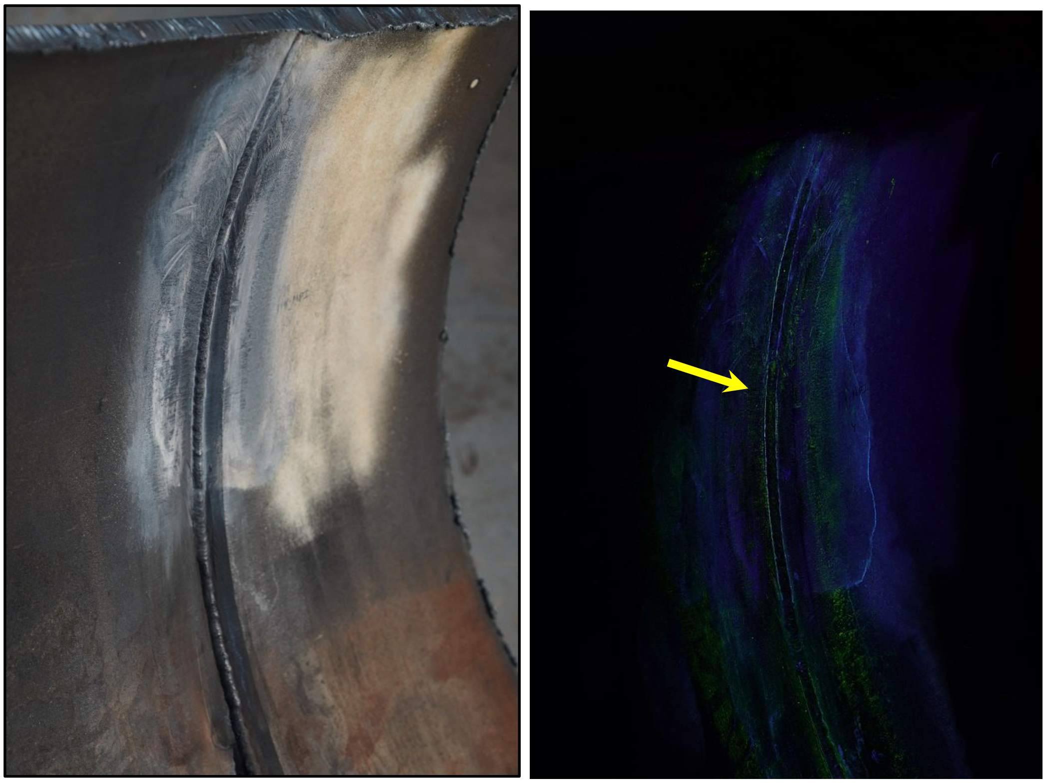


Figure 8 *– (L) photograph showing the ID of GWD 13530 clockwise to the rupture (R) same portion of the weld using ultra-violet light after WFMP showing a crack-like indication at the toe (yellow arrow).*

***Figure 9** – (L) photograph showing the ID of the GWD 13530 counter-clockwise to the rupture (R) same portion of the weld using ultra-violet light after WFMP showing a crack-like indication at the toe (yellow arrow).*

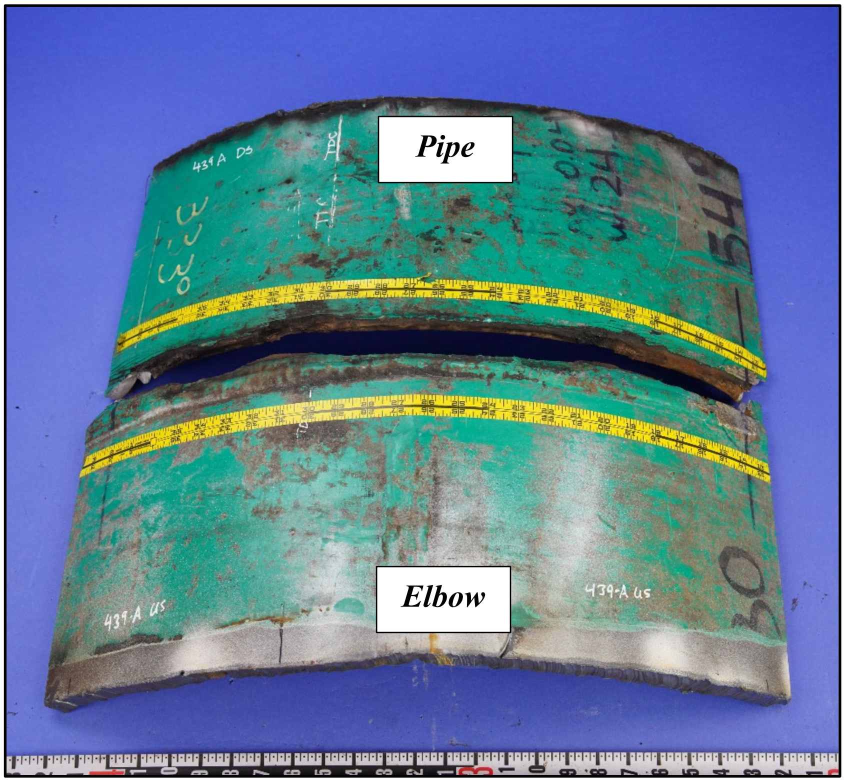


Figure 10 *– View of the re-assembled freeze fractured panel from GWD 13530. Yellow scales are in inches.*

FRACTOGRAPHIC EXAMINATION

Visual and Stereoscopic Examination

After freeze breaking the fractured region to expose the surfaces for detailed examination it was observed that there were three prominent elliptical or bow shaped crack features present on the fractured surface as shown on the DS side (pipe side) panel in Figure 11. All the elliptical crack shaped features appeared flat, coincident with the weld toe, and appeared to originate at or near the ID surface. The largest, shown in Figure 12 was symmetrical in profile and spanned approximately 8.70” and was centered approximately 4.5” (14.3°) clockwise from TDC. The second largest elliptical crack feature shown in Figure 13 measured approximately 4” in length and was asymmetrical in the depth profile (tear drop shaped) and the deepest portion was located approximately 4.25” (13.5°) counterclockwise from TDC. The elliptical crack feature with the smallest profile shown in Figure 14 also had an asymmetric depth profile and the deepest portion was located approximately 13" (41.4°) clockwise from TDC.

Separating Cracks 2 and 3 from Crack 1 were two regions exhibiting a shear morphology (fracture surfaces oriented at ~45°). Examination of the Upstream fracture side (weld side) showed that these two shear regions appeared coincident with discontinuities in the continuous root pass that appeared consistent with weld repairs. Further evidence observed indicating these two regions were coincident with weld repairs were grind marks observed as shown in Figures 15 and 16. It was further observed that the weld bead in these two shear regions was thicker in comparison to the original root pass.

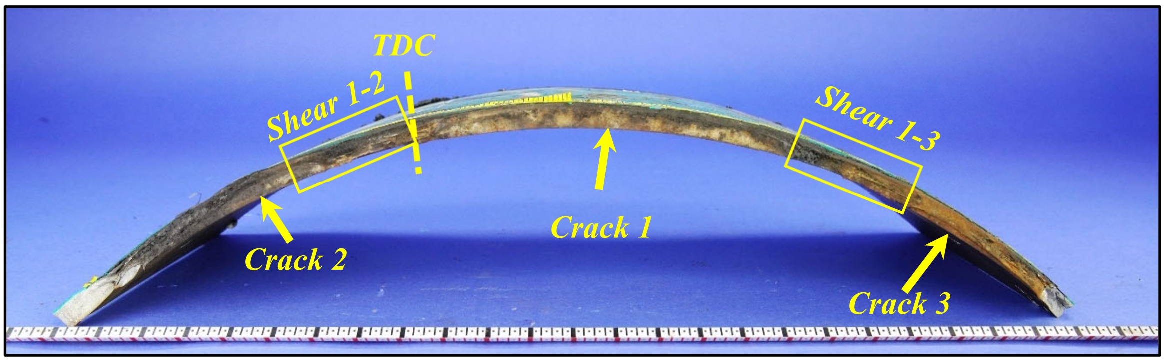
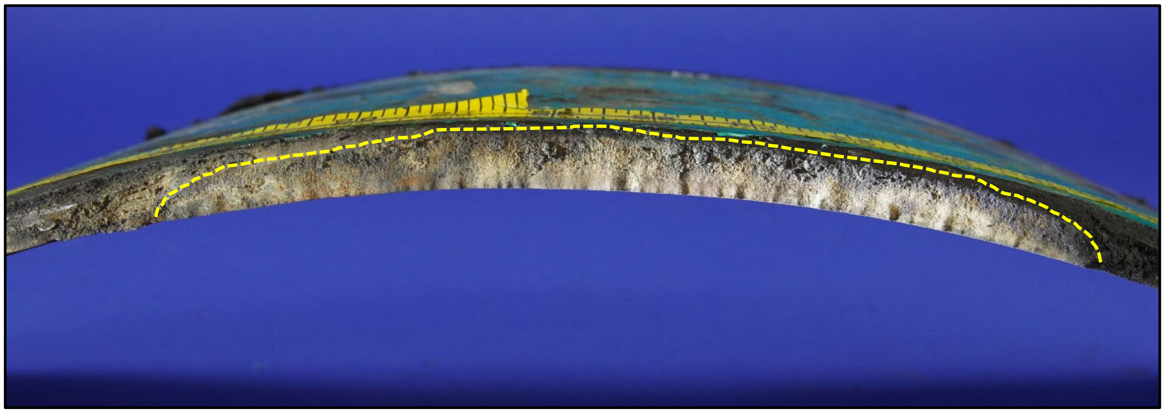
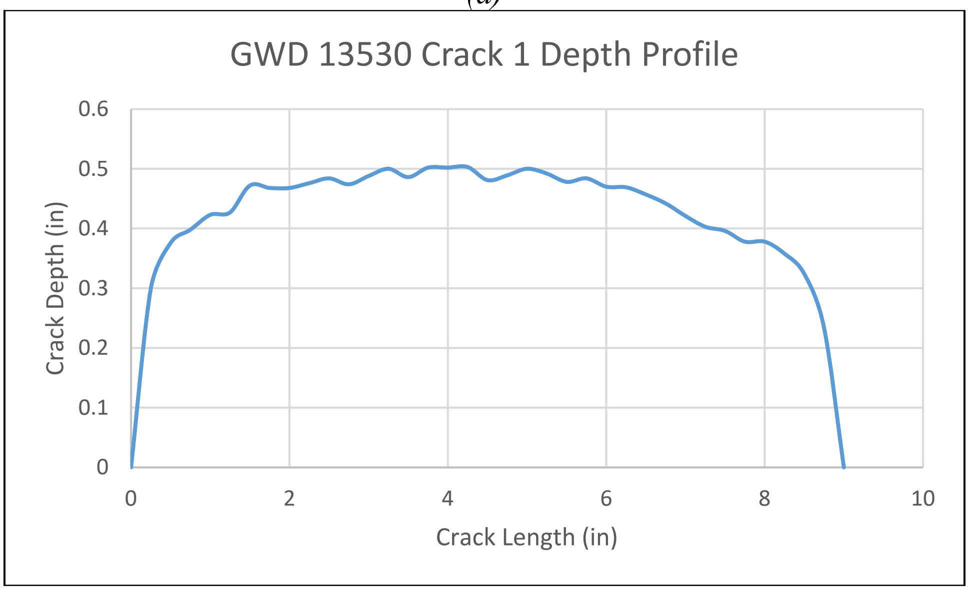


Figure 11 *– View of the GWD 13530 downstream (pipe side) of the exposed fracture. The yellow arrows identify the three elliptical crack features, TDC is marked with the dashed yellow line.*

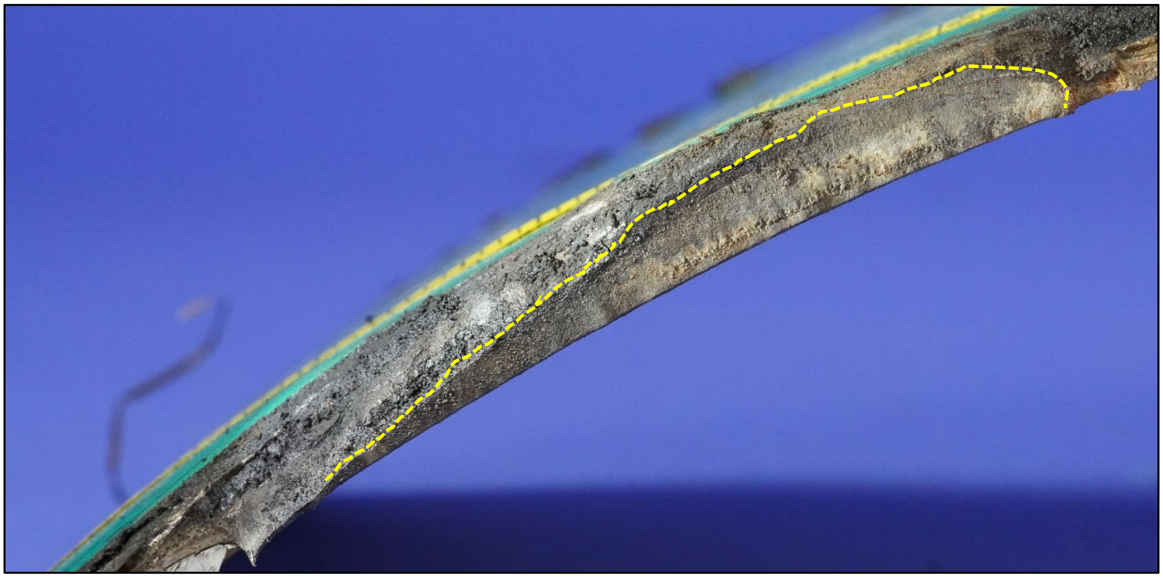


(a)

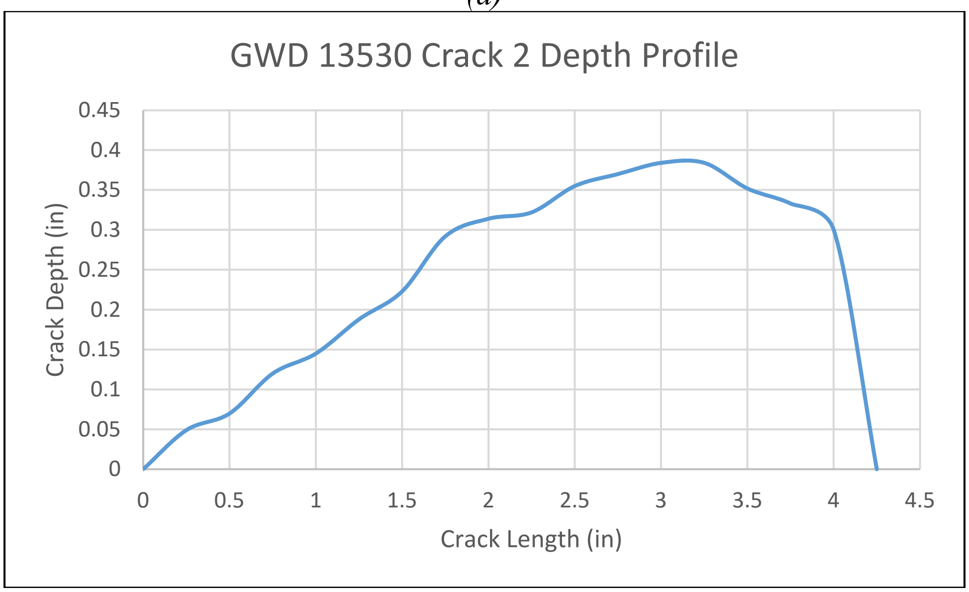


(b)

***Figure 12** – (a) Magnified view of Crack 1 (b) Crack 1 depth profile measured with calipers.*

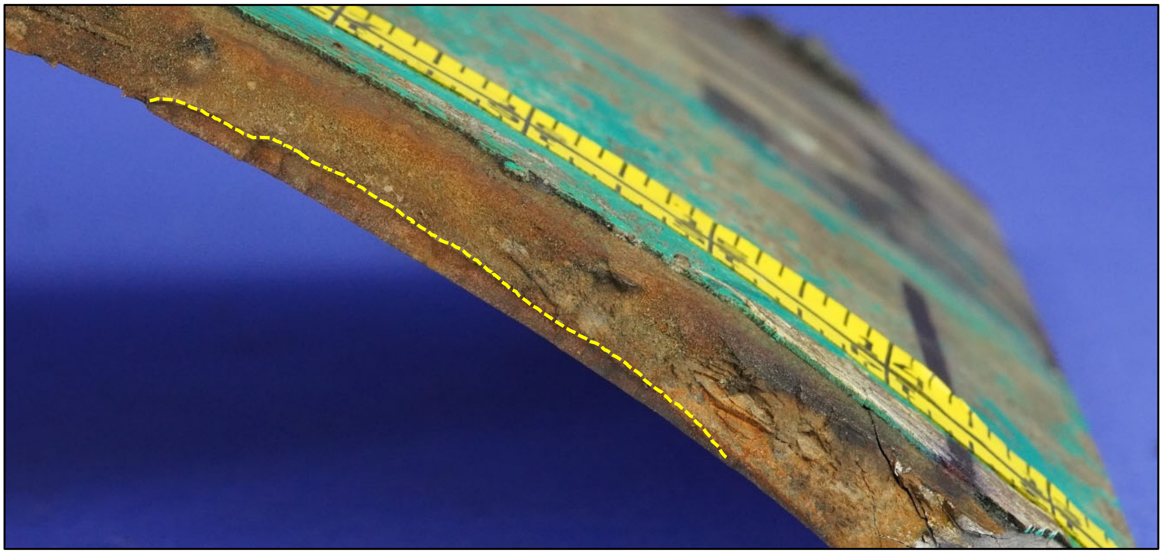


(a)

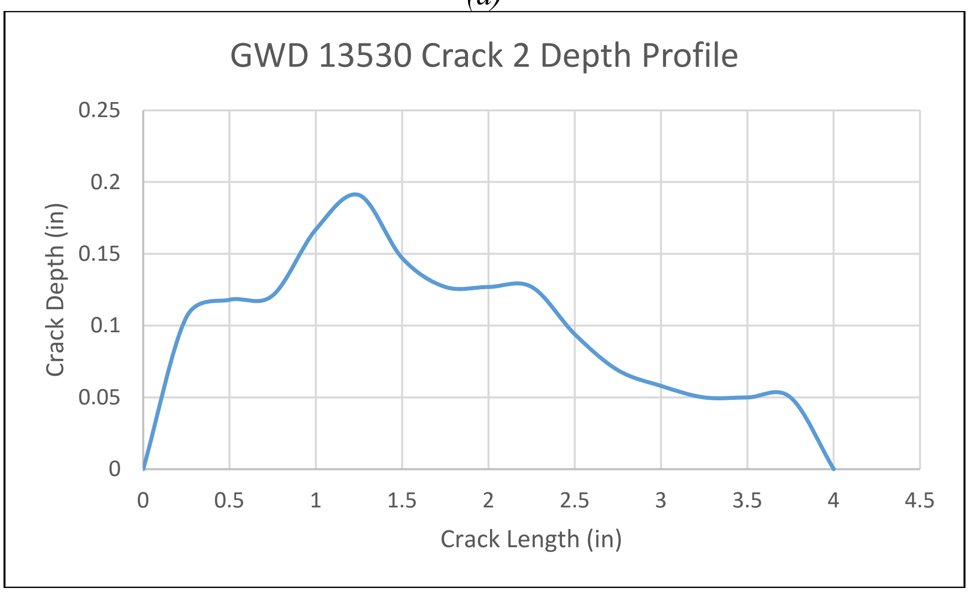


(b)

***Figure 13** – (a) Magnified view of Crack 2 (b) Crack 2 depth profile measured with calipers.*



(a)



(b)

***Figure 14** – (a) Magnified view of Crack 3 (b) Crack 3 depth profile measured with calipers.*

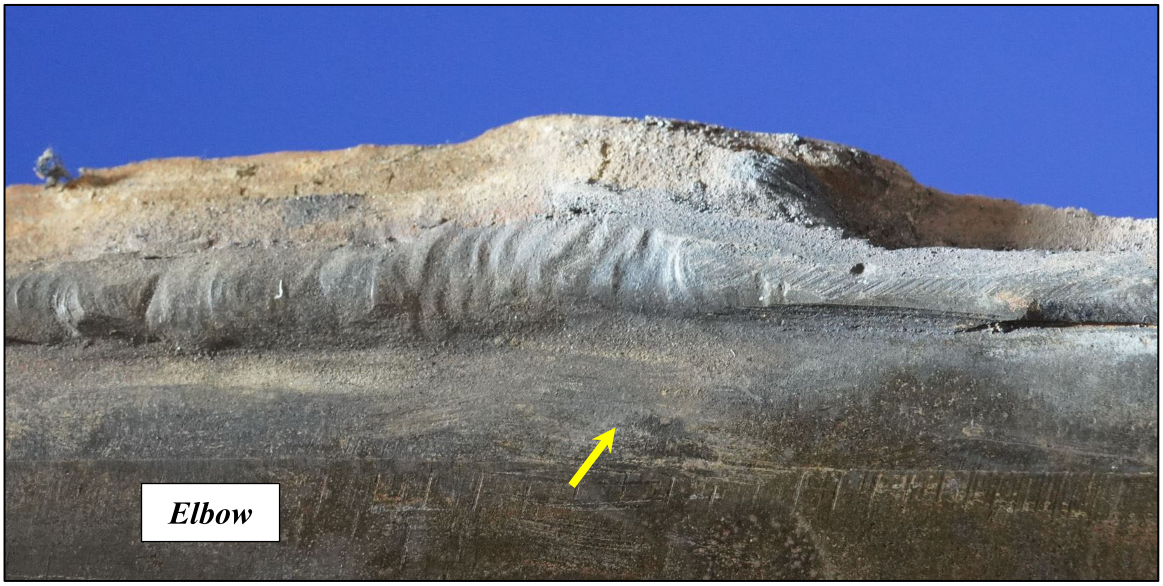


***Figure 15** – Photograph showing the ID region of the rupture coincident with the shear lip separating GWD 13530 Cracks 1 and 2. The arrow identifies grind marks identified on the bevel of the elbow.*

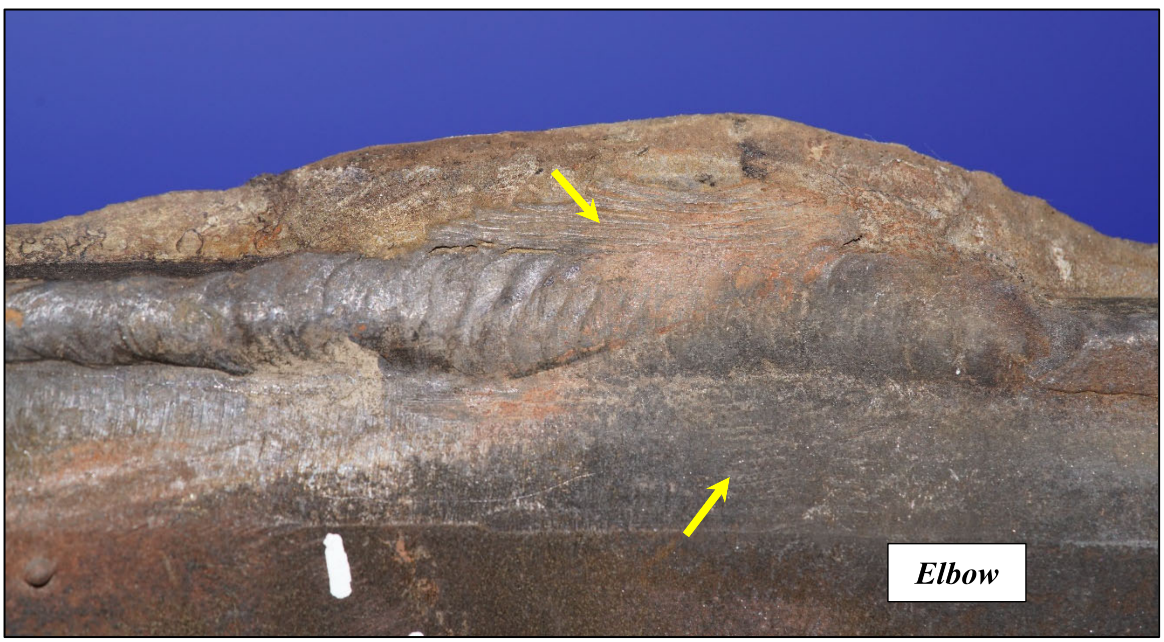


***Figure 16** – Photograph showing the ID region of the crack coincident with the shear lip separating GWD 13530 Cracks 1 and 3. The arrows identify grind marks on the remnant pipe ligament (top) and elbow bevel (bottom).*

The elliptical crack regions were sectioned out using dry saw cuts and cleaned using a combination of a dilute Citrinox solution (2%) and an ultrasonic bath. One elliptical crack section (Sample 1-1) was not initially cleaned so that the chemical composition of the surface scale could be examined in the SEM. The remaining sections were initially examined using a low magnification digital microscope (Keyence VHX-6000). The general features common to the three elliptical cracks were as follows:

- Each appeared to initiate at or near the ID surface and had multiple, radially oriented crack initiation features (ratchet marks).
- Each showed evidence of progressive cracking in the form of multiple crack arrest features; 10 - 15 clearly distinguishable arrest lines were identified on Cracks 1 and 2. There was evidence observed that the crack arrest features were coincident with individual weld passes as shown in Figure 18.

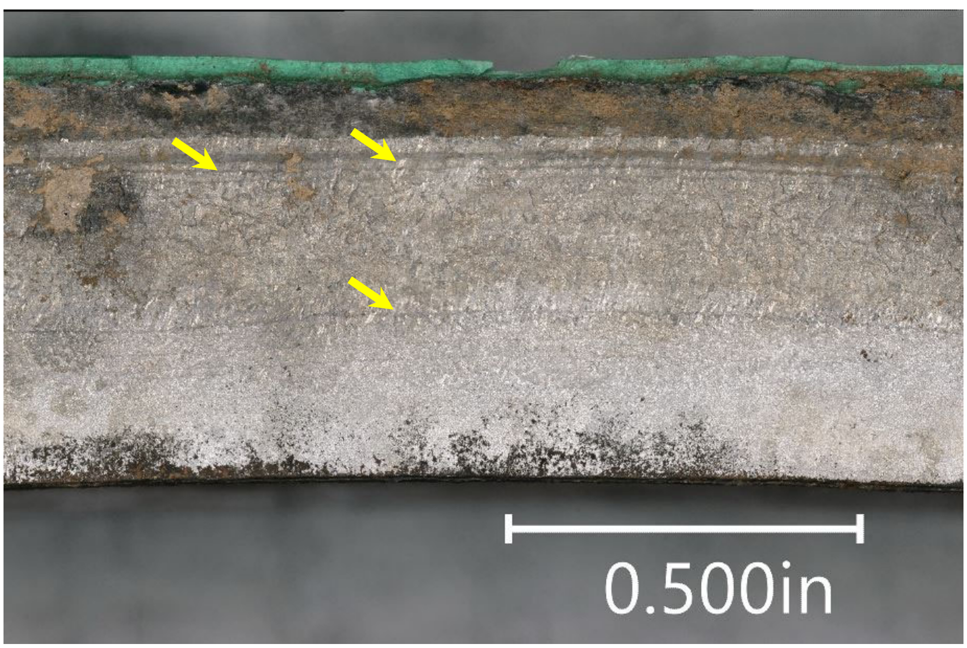


Figure 17 *– Low magnification view of the center region of GWD13530 Crack 1 showing multiple crack arrest lines throughout the elliptical crack feature. Several of the most clearly defined arrest lines are identified with yellow arrows.*

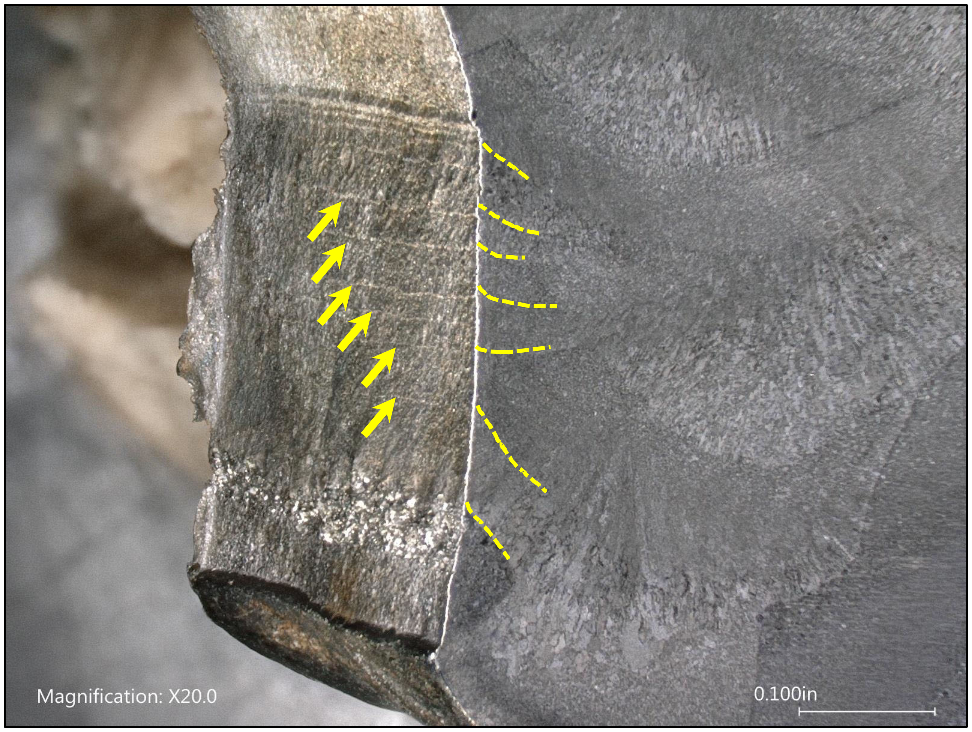


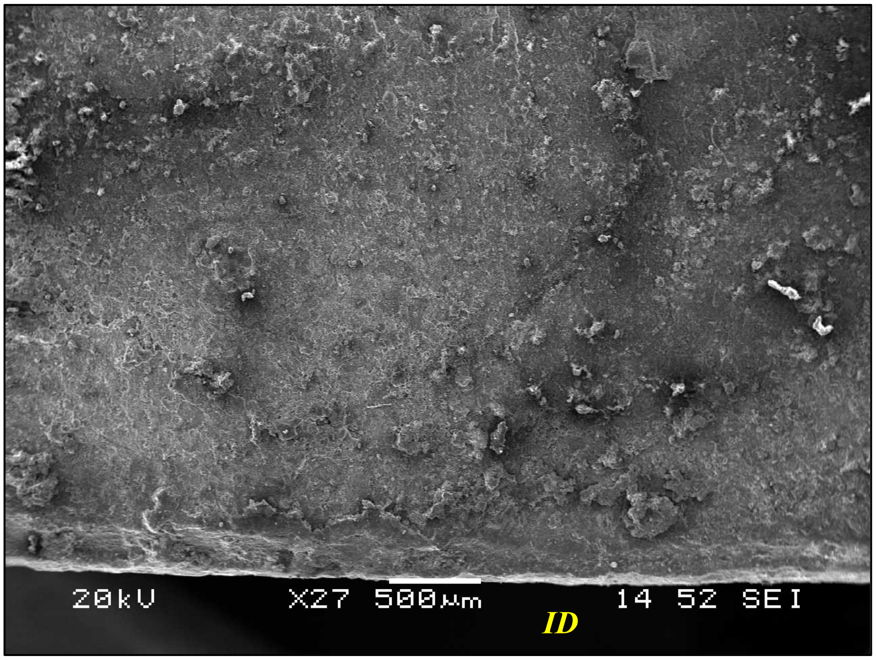
***Figure 18** – Oblique view of the weld-side metallographic section prepared through GWD 13530 Crack 2 showing coincidence between crack arrest lines (yellow arrows) and individual weld passes (highlighted with yellow dashed lines).*

***Figure 19** – Low magnification view of GWD 13530 Crack 3. This crack was unique amongst the fatigue cracks as it exhibited multiple advancing crack fronts, the peaks of the two advancing fronts are identified with yellow arrows.*

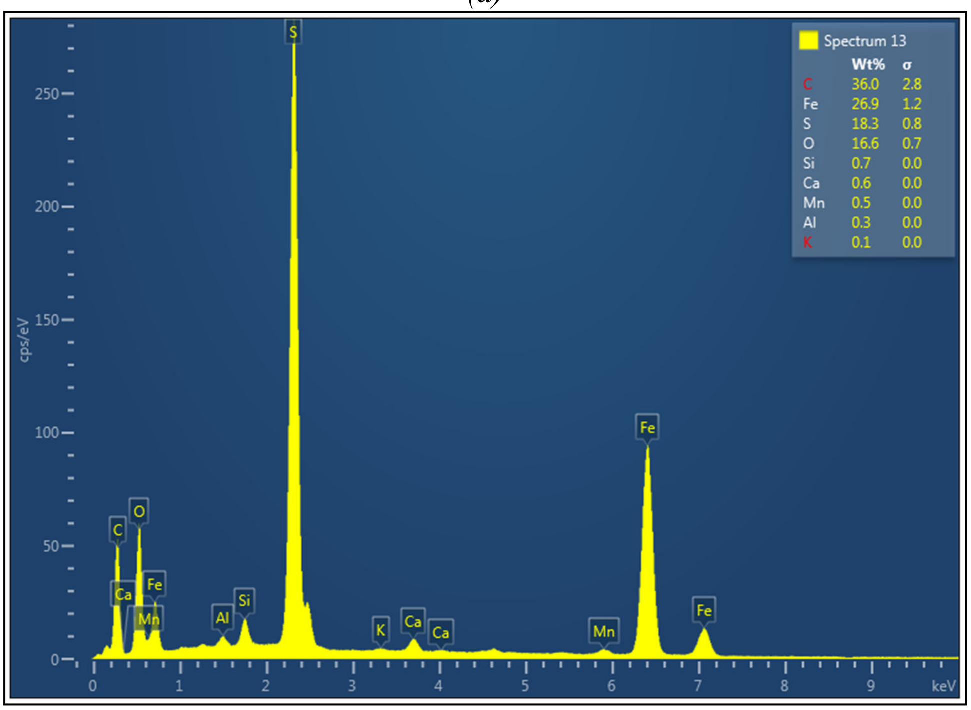
SEM/EDS Examination

The sectioned portions of each elliptical crack features on the DS (pipe side) were examined in the scanning electron microscope (SEM) using both backscatter electron contrast (BES) and secondary electron imaging (SEI), the latter being more sensitive to surface topography. The DS fracture surfaces were selected for examination to mitigate the need to trim potentially salient weld features on the US (elbow side). All samples except for Sample 1-1 were cleaned using a combination of a 2% Citrinox solution and an ultrasonic bath. Sample 1-1 was examined "as-is" so that the chemistry of the scale product on the surface could be examined using energy dispersive x-ray spectroscopy (EDS). EDS is a qualitative chemical analysis technique that can accurately identify elements present on a surface but cannot identify compounds and only provides a semi-quantitative chemical composition. The results of the EDS analysis, shown in Figure 21 showed primarily carbon, sulfur, silicon, aluminum, calcium, and oxygen; elements typically found in both crude oil and soil.

***Figure 20** – Low magnification digital photograph showing GWD 13530 Sample 1-1 before cleaning. EDS examination shown in Figure 21 was taken from the region encompassed by the yellow box.*



(a)



(b)

Figure 21 *– (a) Low magnification view of GWD 13530 Sample 1-1 before cleaning with the area examined with EDS encompassed within the yellow box (b) Corresponding EDS spectrum showing high concentrations of non-native elements (sulfur, calcium, and oxygen). The non-native elements identified via EDS appeared consistent with exposure to crude oil and soil.*

GWD 13530 Crack 1 - Sample 1-2

The central region of Crack 1 identified as "Sample 1-2" is shown after cleaning in low magnification in Figure 22. The full thickness of the fracture was examined, fractographs included in this report were selected as representative of the features of interest. Examination of the ID region of the crack at low magnifications showed a flat, featureless morphology except for several radially oriented ratchet marks, one of which is shown in Figure 23. Also present in this fractograph was a prominent change in fracture orientation at the ID surface, the geometry of which appeared to mirror the geometry of the weld toe. Figure 24 shows the fracture morphology near the ID to have been consumed by oxidation and no distinct identifying features were present. The region of the fracture encompassing the mid-wall to OD surface offered more detail at low magnification, with several distinct crack arrest lines identified as shown in Figure 25. The crack arrest lines were more closely spaced nearer the OD surface, yet individually distinct. As shown in Figure 26, there were thin bands of micro-void coalescence (MVC) or dimpled rupture between some of the crack arrest lines. Much of the space between the crack arrest lines appeared brittle, and no evidence of striations (incremental cyclical crack growth) was observed, shown representatively in Figure 29. The shear overload region shown in Figure 30 was observed to consisted of characteristic micro-void coalescence (MVC), consistent with a ductile overload.

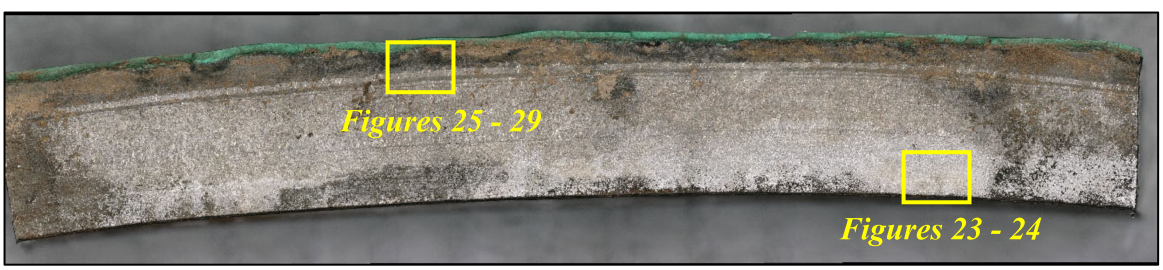


Figure 22 *– Low magnification view of Crack 1 on GWD 13530, the yellow boxes indicate locations examined in the SEM.*

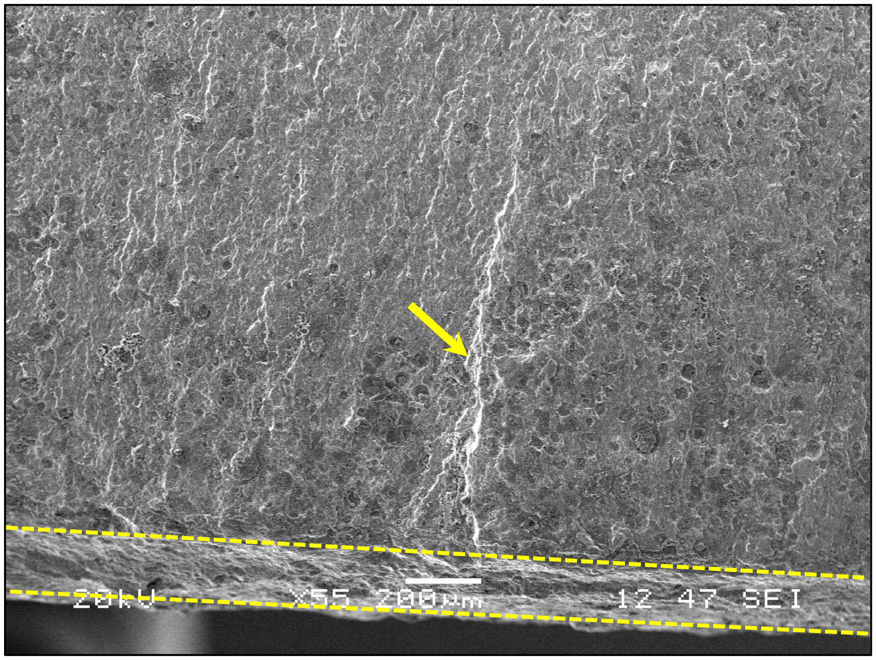


Figure 23 *– Low magnification SEM fractograph showing the ID region of GWD 13530 Crack 1. Dashed lines identify a change in fracture orientation at the ID. The change in fracture orientation appeared consistent with the geometry of the weld toe. The yellow arrow identifies a ratchet mark.*

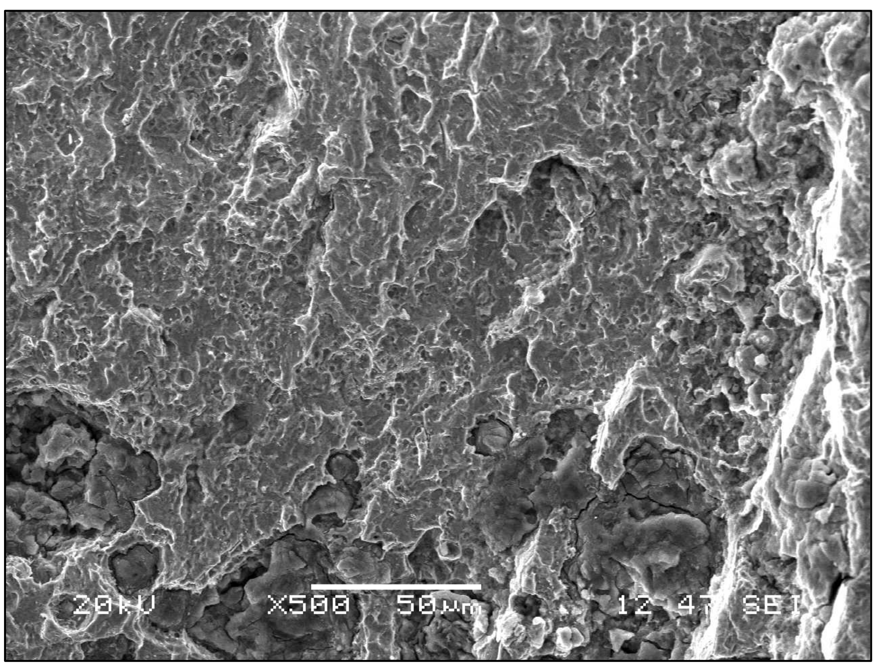


Figure 24 *– Higher magnification SEM fractograph showing the fracture morphology of GWD 13530 Crack 1 near the ID surface. The fracture surface near the ID had been consumed by oxidation and fine-scale features were not discernable.*

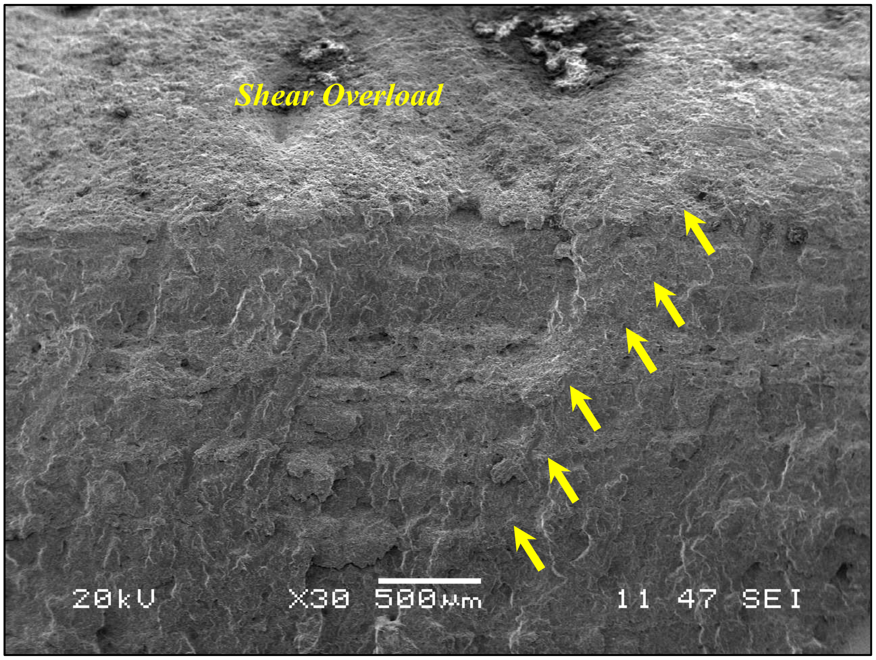


***Figure 25** – Low magnification SEM fractograph of GWD 13530 Crack 1 showing multiple crack arrest lines on the elliptical crack region near the transition to final overload.*

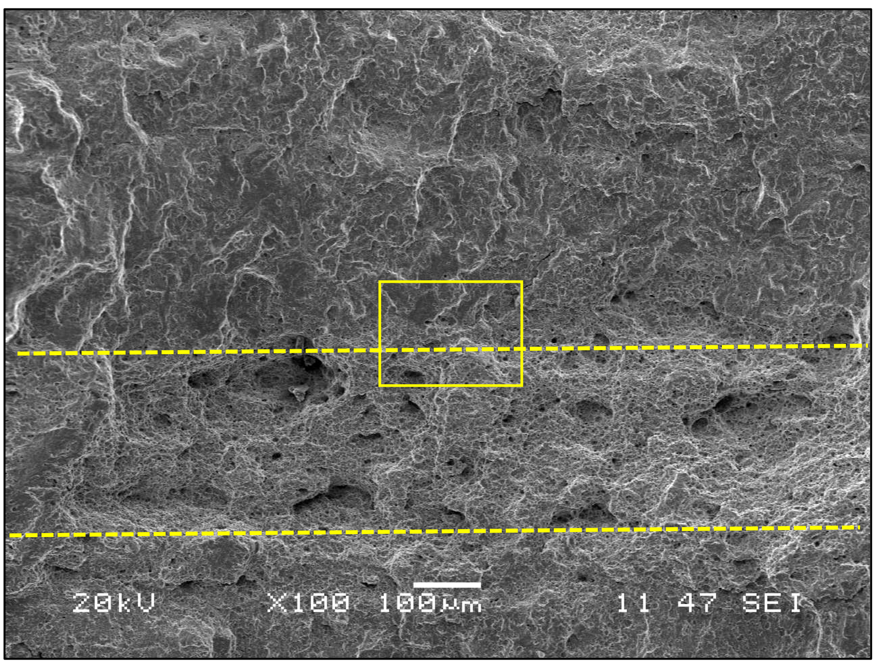


***Figure 26** – Higher magnification SEM fractograph of GWD 13530 Crack 1 showing a band of dimpled rupture associated with a crack arrest line nearer the shear overload region.*

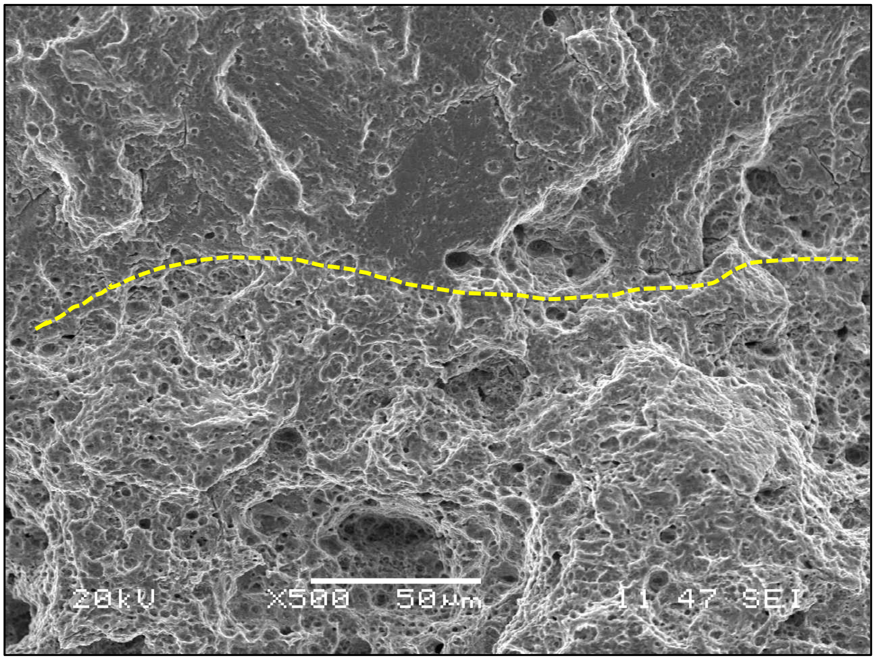


***Figure 27** – High magnification SEM fractograph of GWD 13530 Crack 1 showing the transition from ductile tearing (dimpled morphology) and flat, brittle appearing fracture.*

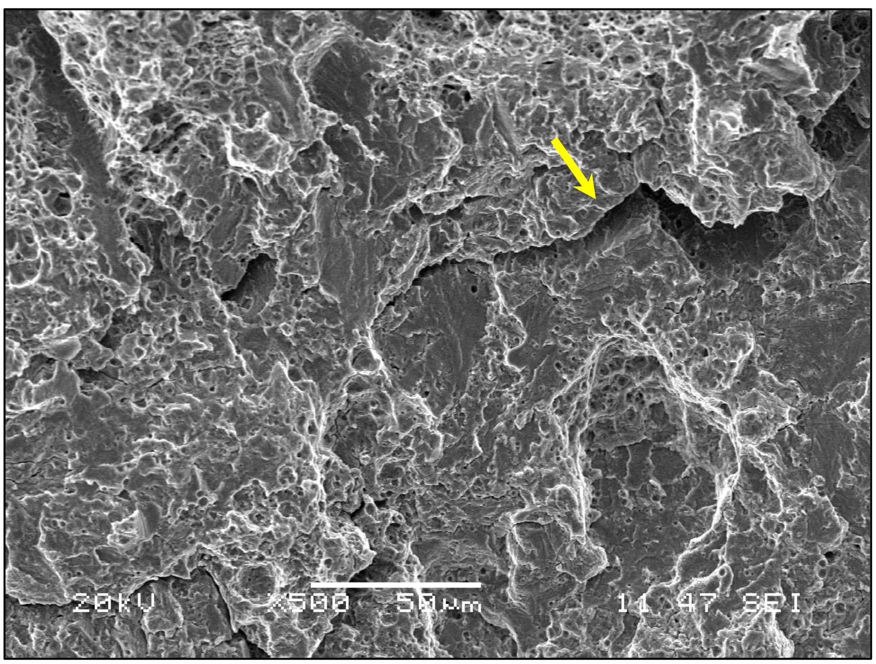


***Figure 28** – High magnification SEM fractograph of GWD 13530 Crack 1 showing the flat fracture morphology observed between crack arrest lines. Also seen was secondary cracking normal to the fracture plane (yellow arrow), a feature consistent with fatigue crack propagation.*

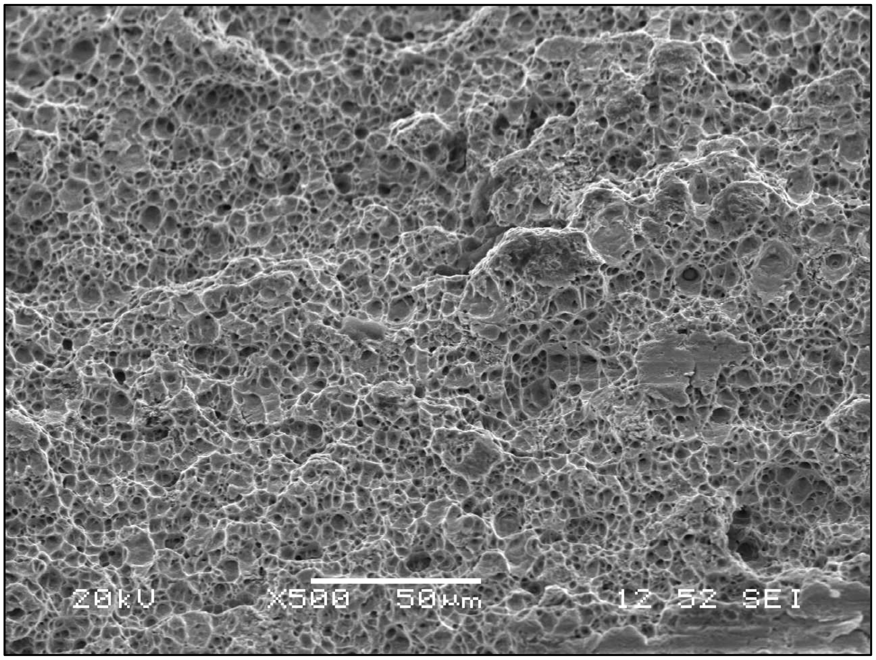


***Figure 29** – High magnification SEM fractograph showing a dimpled morphology in the shear overload region of GWD 13530 Crack 1.*

GWD 13530 Crack 2 - Sample 2-2

A low magnification stereophotograph of Sample 2-2 is shown in Figure 30. This sample was unique among those examined in this investigation as it exhibited a narrow band of transgranular cleavage fracture near the ID surface as shown in Figures 31 - 33. Transgranular cleavage is a brittle fracture morphology indicating sudden, unstable crack growth (colloquially referred to as a brittle pop).

Crack arrest lines nearer the transition from progressive cracking to sudden overload were well defined, and like Sample 1-2, there was a narrow band of dimple rupture coincident with the arrest lines.

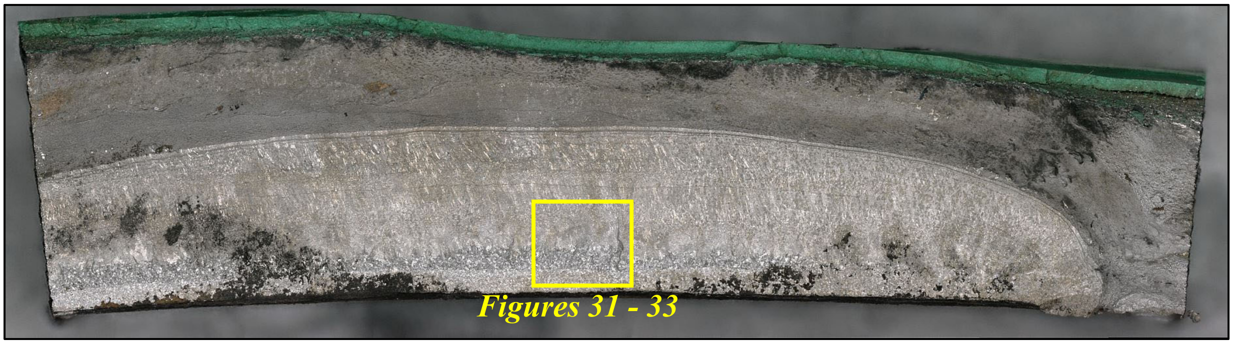


Figure 30 *– Low magnification view of the deepest portion of GWD 13530 Crack 2. There was a narrow band of brittle fracture morphology near the ID, the yellow box identifies the region examined in the SEM.*

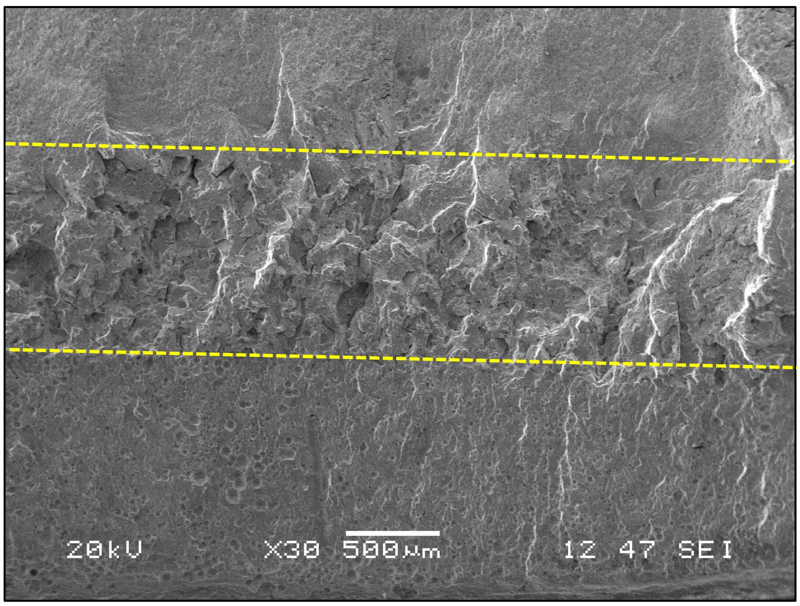


Figure 31 *– Low magnification SEM fractograph of GWD 13530 Crack 2 showing the thin band of transgranular cleavage fracture near the ID.*

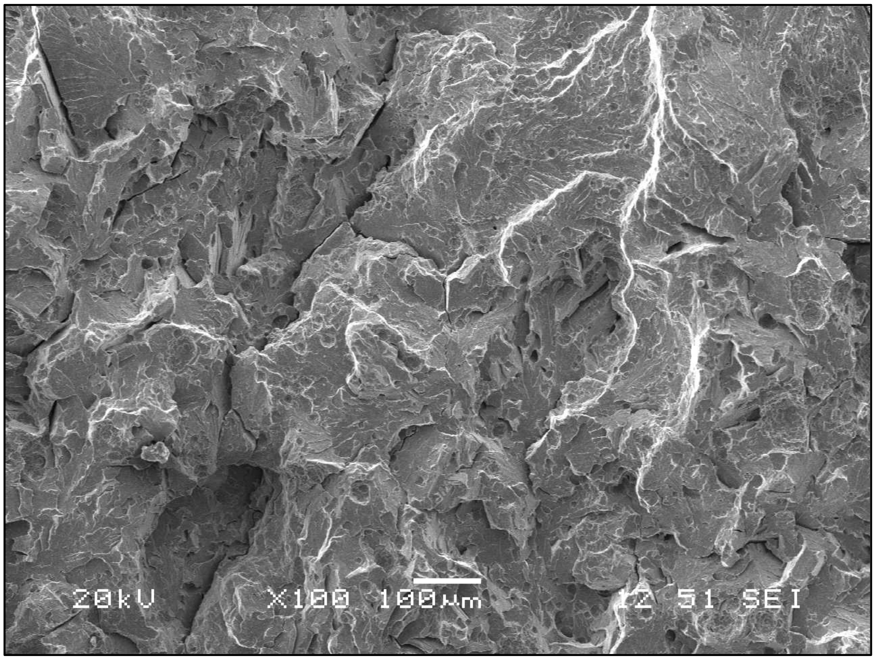


Figure 32 *– Higher magnification SEM fractograph of GWD 13530 Crack 2 showing detail of the brittle morphology. The features appeared consistent with transgranular cleavage.*

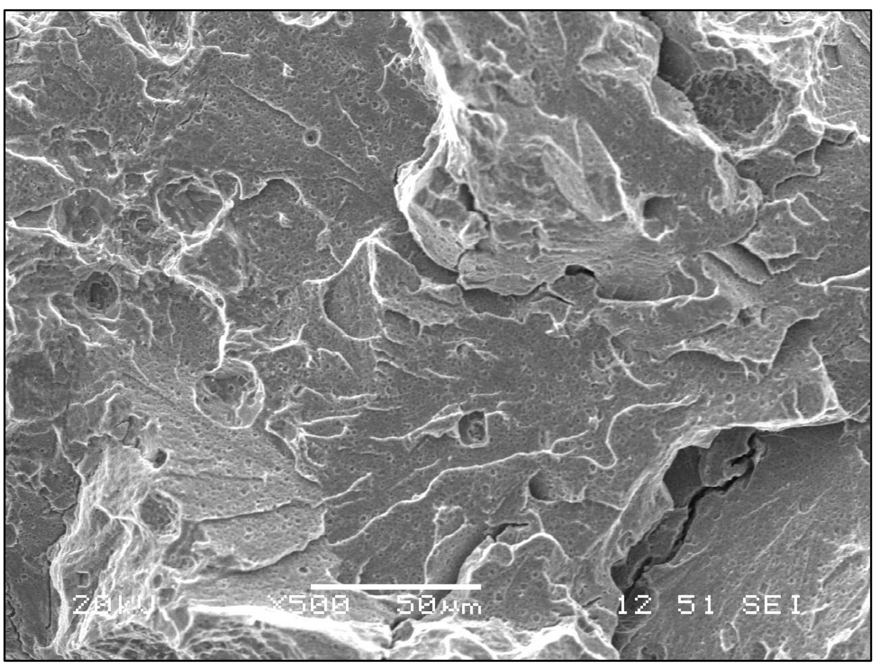


Figure 33 *– High magnification SEM fractograph of GWD 13530 Crack 2 showing typical transgranular cleavage morphology including river patterns and faceted surfaces.*

GWD 13530 Crack 3 – Sample 3 - 2

A low magnification stereophotograph of Sample 3-2 is shown in Figure 34. This crack consisted of two separate advancing cracks that had coalesced as evidenced by the two distinct elliptical "humps".

Like the other cracks examined, there were multiple distinct crack arrest lines. The number of crack arrest lines appeared consistent (between 10 – 15). At higher magnification the fracture morphology of Crack 3 appeared identical to that of Cracks 1 and 2.

Figure 34 *– Low magnification view of GWD 13530 Crack 3.*

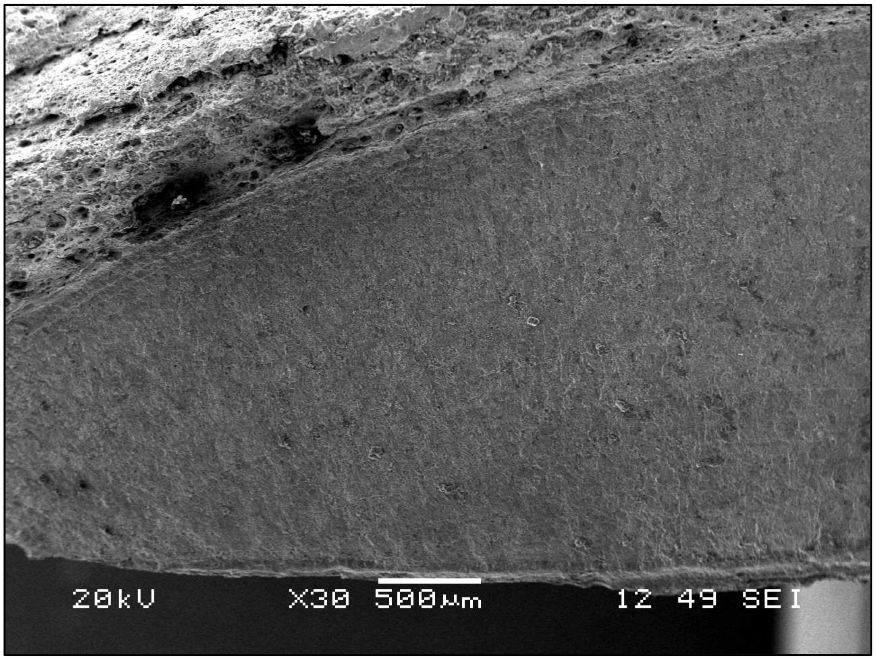


Figure 35 *– Low magnification SEM fractograph showing multiple crack arrest lines on GWD 13530 Crack 3.*

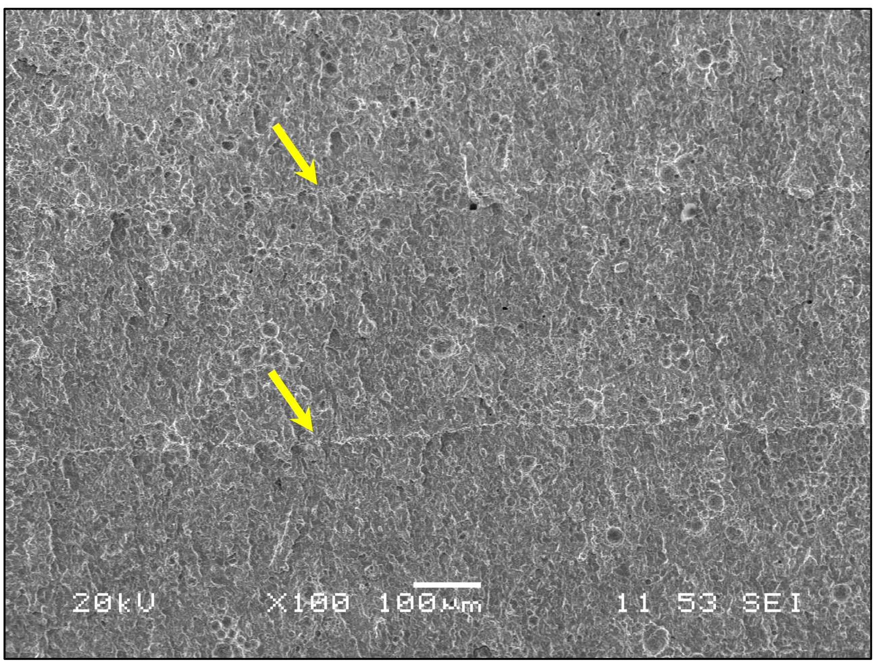


Figure 36 *– SEM fractograph showing crack arrest lines identified with yellow arrows in the central region of GWD 13530 Crack 3. The morphology otherwise appeared flat and featureless.*

METALLOGRAPHIC EXAMINATION

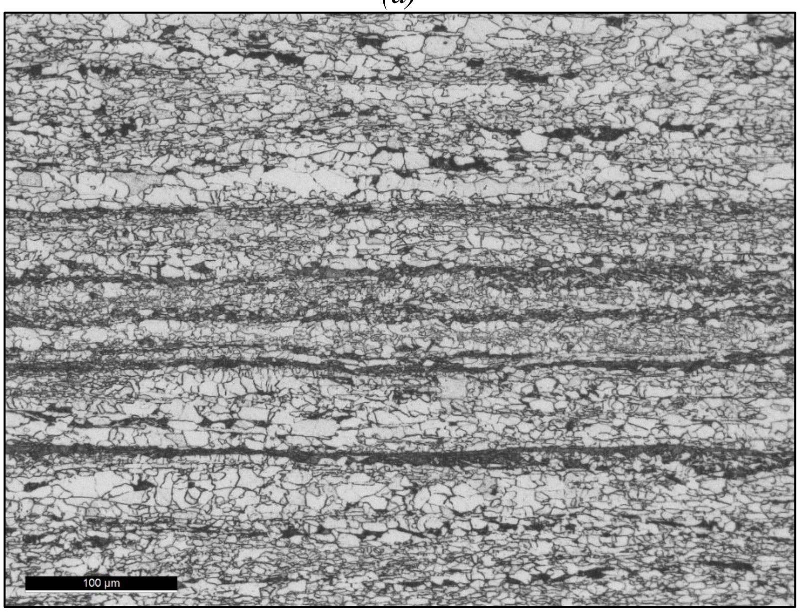
Sections for metallographic examination were removed from both GWD 13530 and GWD 13520. All sections were cut and prepared in accordance with ASTM E3 and were photodocumented in both the "as polished" and etched conditions. A 3% Nital solution was used to etch the microstructure. Specific locations of sections removed from GWD 13530 are as follows:

- Mated fracture metallographic specimens were removed from Samples 1-2, 2-2, and 3-2, Shear 1-2, and Shear 1-3.
- Weld side fracture of Sample 2-2.
- Cross-weld sections from 55°, 76°, 82°, 139°, and 270°.

The general microstructure of the pipe, heat affected zones, weld metal, and elbow was documented on all examined specimens. The general impressions of each zone were as follows:

- Figure 37 shows the pipe base metal to consist of finely banded, extremely fine-grained ferrite and pearlite (ASTM E112 grain size 10 or finer). The banding in the microstructure is attributed to micro-segregation of carbide forming elements during the initial processing of the material and is aligned axially due to the rolling process. The pipe was reportedly manufactured using thermomechanically controlled processing (TMCP) which encompasses the simultaneous hot working and heat treatment to produce higher strength steel.

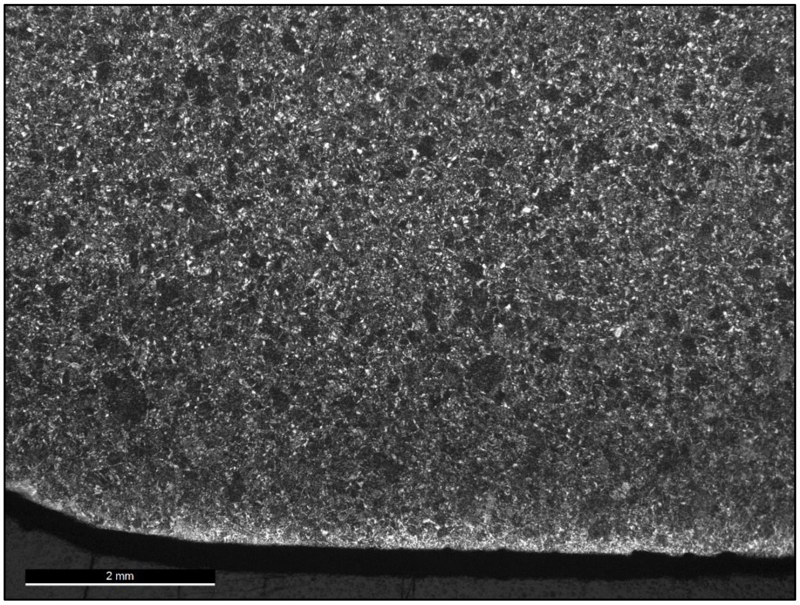
(a)



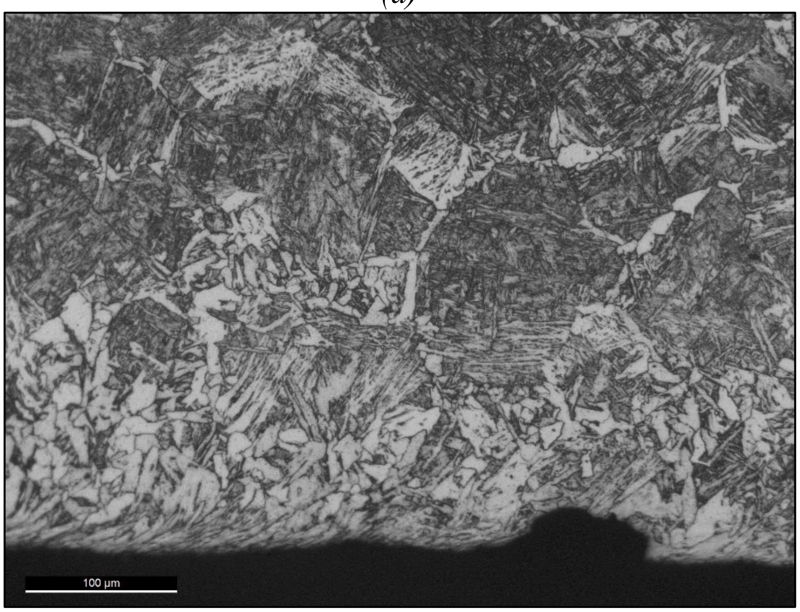
(b)

Figure 37 *– (a) 12.5x optical micrograph showing the general microstructure of the pipe to exhibit a finely-banded structure (b) 200x optical micrograph showing detail of the banded ferrite and pearlite microstructure, typical of a TMCP product. Both micrographs etched with 3% Nital.*

- The microstructure of the elbow consisted of a mixture of ferrite, acicular and proeutectoid ferrite, tempered martensite, and bainite; all of which are transformation products that form in low-alloy steels upon rapid cooling (quenching) of a steel from austenitizing temperatures (generally > 1,600°F). As shown in Figure 38a, there was slight decarburization at both the OD and ID surfaces of the elbow, most likely an artifact of heat treatment and appeared inconsequential in terms of the overall performance. The concentration of proeutectoid ferrite and bainite was higher nearer the surfaces (Figure 38b) of the elbow, likely reflecting the slightly lower carbon concentration. As shown in Figure 39, the microstructure at mid-wall appeared homogenous, consisting of tempered martensite and bainite.

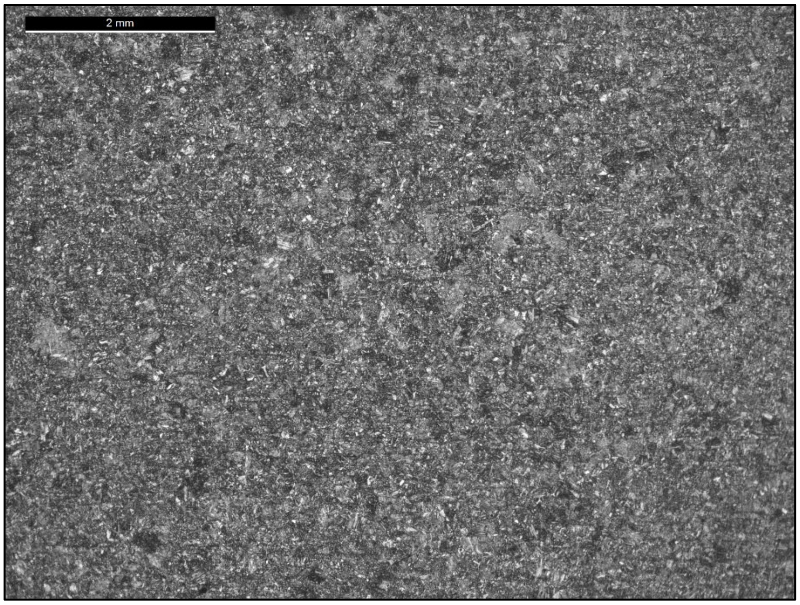


(a)

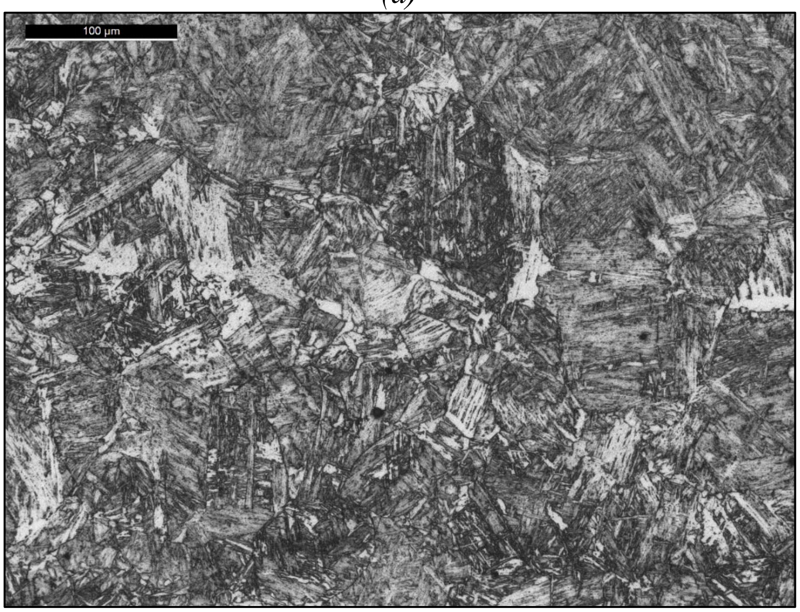


(b)

Figure 38 *– (a) 12.5x optical micrograph showing the ID region of the elbow with a thin band of light etching microstructure at the ID surface characteristic of decarburization (b) 500x optical micrograph showing the microstructure of the elbow at the ID to consist of ferrite and pearlite with some bainite. Both micrographs shown etched with 3% Nital.*



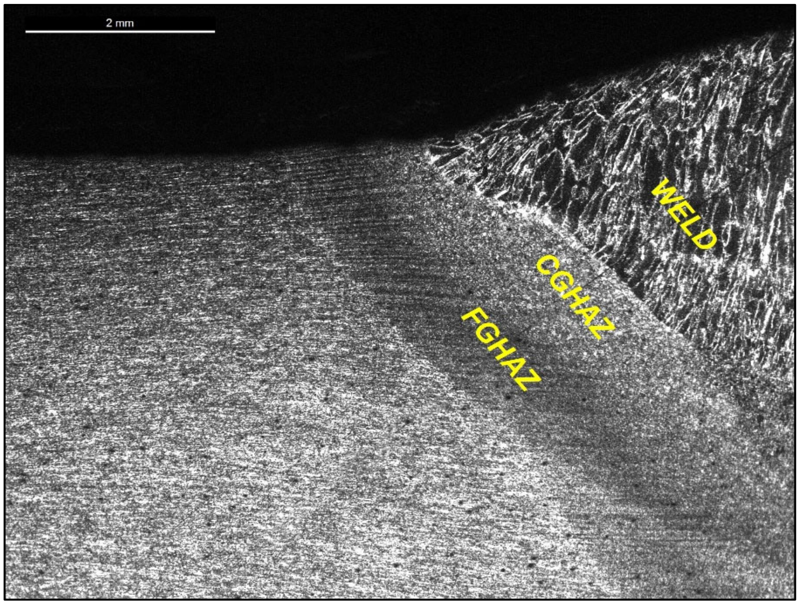
(a)



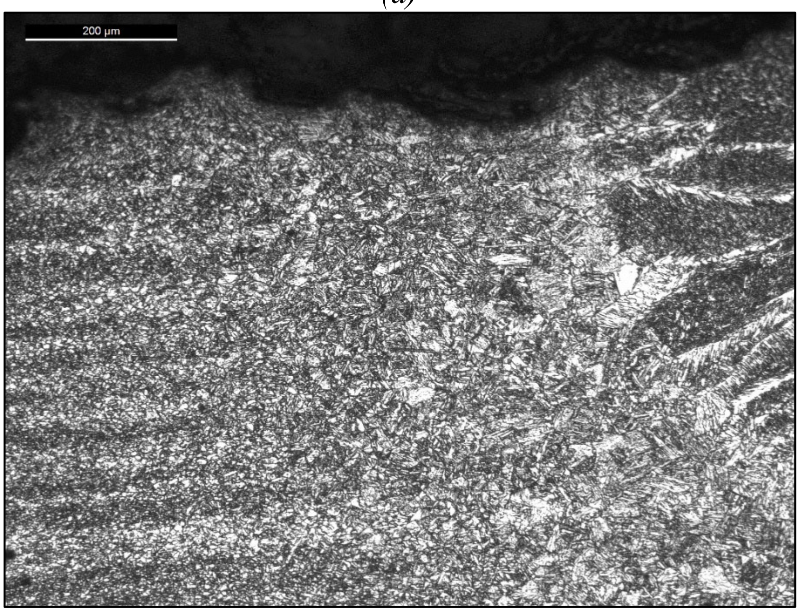
(b)

***Figure 39** – (a) 12.5x optical micrograph showing the elbow microstructure at mid-wall to appear homogenous. (b) 500x optical micrograph showing the microstructure at mid-wall to consist of tempered martensite and bainite. Both micrographs shown etched with 3% Nital.*

- The microstructures of the weld and heat affected zones (HAZ) on both the pipe (Figure 40) and elbow side (Figure 41) were also examined. Based on the physical characteristics it was evident that the girth welds were not post weld heat treated (PWHT). Specific evidence observed supporting this conclusion was the weld microstructure appearing "as-welded" or "as-cast" consisting of large columnar grains comprised of acicular ferrite and carbide. The weld root and lower hot passes appeared heavily tempered from the heat of subsequent weld passes. The cap passes did not exhibit any evidence of tempering. The HAZ on both elbow and pipe sides exhibited coarse and fine-grained microstructures (CGHAZ and FGHAZ, respectively), which are typically developed during welding and are attributed to the temperature profile (coarse-grained microstructure sees higher temperature).

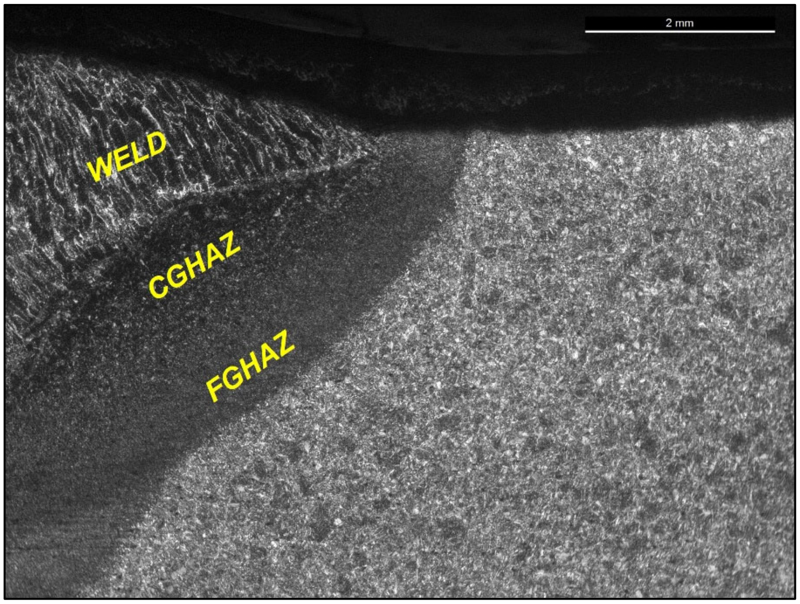


(a)

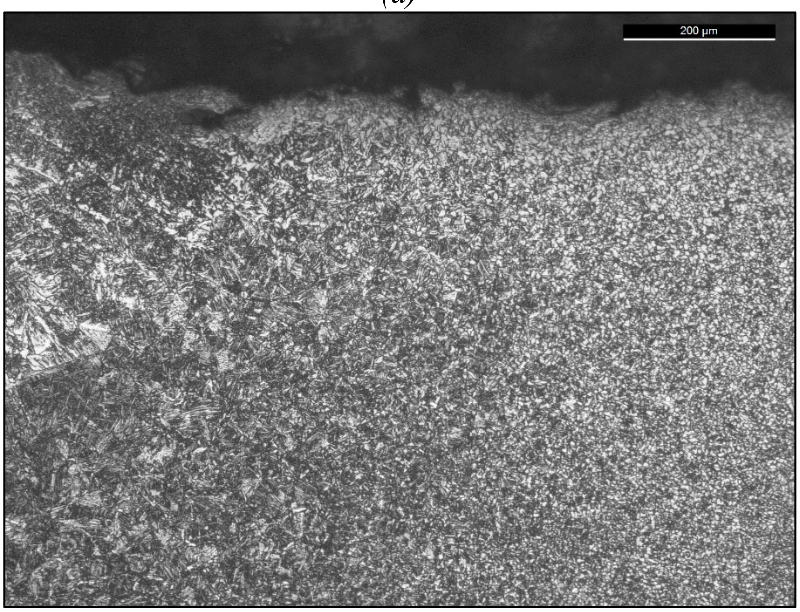


(b)

Figure 40 *– Pipe side weld and heat affected zone structures at the OD. (a) 12.5x (b) 100x, 3% Nital etch. Coarse-grained HAZ (CGHAZ)*



(a)



(b)

Figure 41 *– Elbow-side weld and HAZ structures (a) 12.5x (b) 100x. 3% Nital etch.*

GWD 13530 Sample 1-2

The mated cross-section from Sample 1-2 is shown below in Figure 42. The fracture propagated linearly through nearly the entire thickness of the pipe side, intersecting both HAZ and weld microstructures. There was no evidence observed that the fatigue crack propagated through the full thickness of the pipe and/or weld. The angular feature at the ID toe of the girth weld on the pipe side identified visually and in the SEM was also evident in cross-section. Metallographically the angular feature at the toe of the girth weld appeared to parallel the fusion line and was approximately 200 μm in length. It was evident that the fatigue crack originated from this feature as there was no additional or secondary cracking observed.

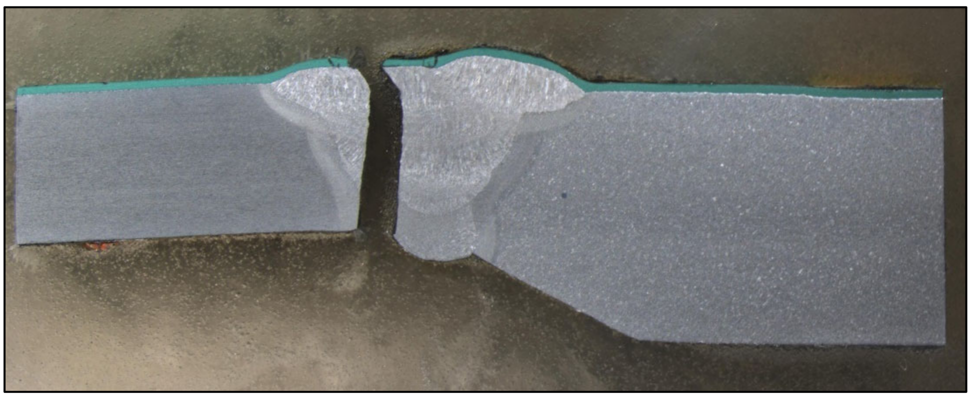


***Figure 42** – Overall view of the metallographic section prepared through GWD 13530 Crack 1.*

Figure 43 *– Photomontage of optical micrographs showing GWD 13530 Crack 1 propagation through multiple microstructural features. Originally photographed at 12.5x, 3% Nital etch.*

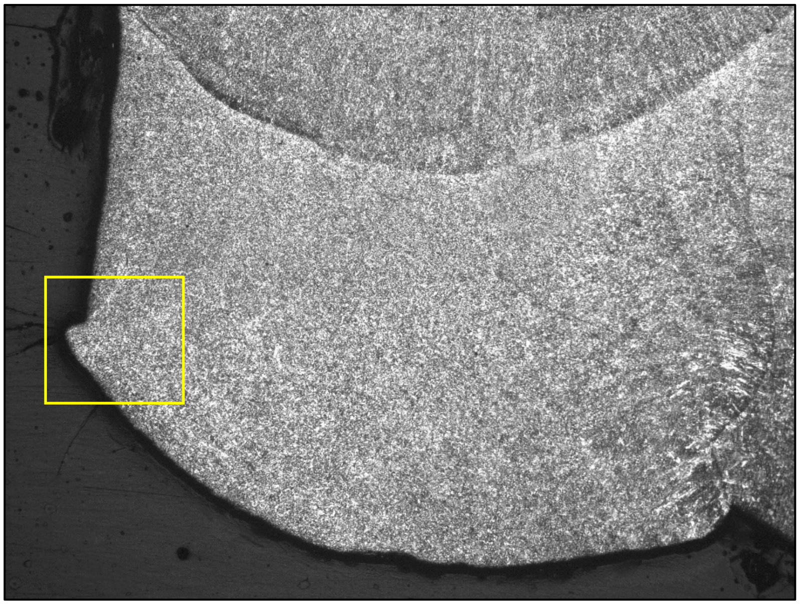


Figure 44 *– Optical micrograph showing the root pass of the GWD 13530 adjacent to the fracture. A prominent lip was observed at the ID intersection of the crack, the profile of the lip appeared to parallel the fusion line. 12.5x, 3% Nital etch.*

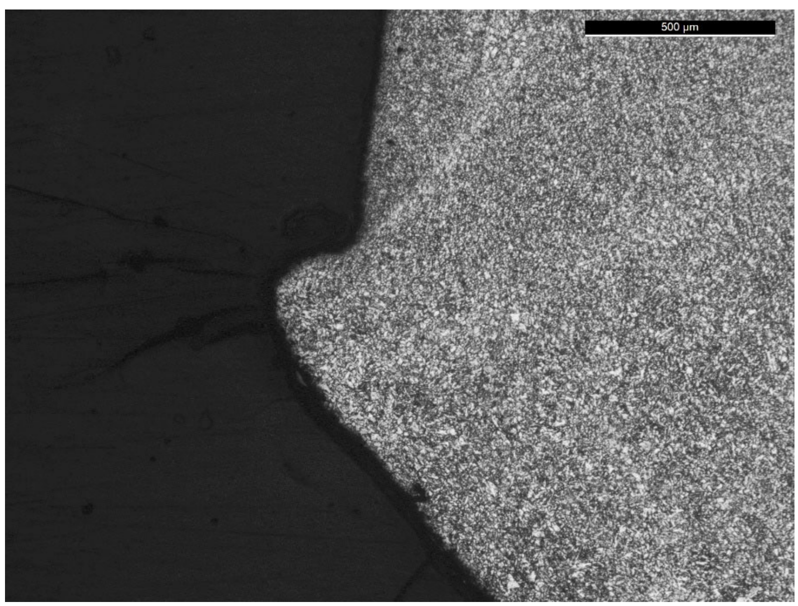


Figure 45 *– Higher magnification optical micrograph showing the ID toe lip feature on GWD 13530, Crack 1. The lip appeared coincident with the fusion line of the weld and was approximately 200 µm in length. 50x, 3% Nital etch.*

GWD 13530 Sample 439-2-2

The mated cross-section from Sample 2-2 is shown below in Figure 46. As with Crack 1, Crack 2 propagated linearly through pipe-side of the weld and originated at the ID toe. Higher magnification examination showed some transgranular branching of the brittle crack in the CGHAZ region as shown in Figures 48 - 49. There was no evidence observed that the fatigue crack propagated through the full thickness of the pipe and/or weld. The angular feature at the ID toe of the girth weld on the pipe side identified visually and in the SEM was also evident in cross-section. It was evident that the fatigue crack originated from this feature as there was no additional cracking observed.

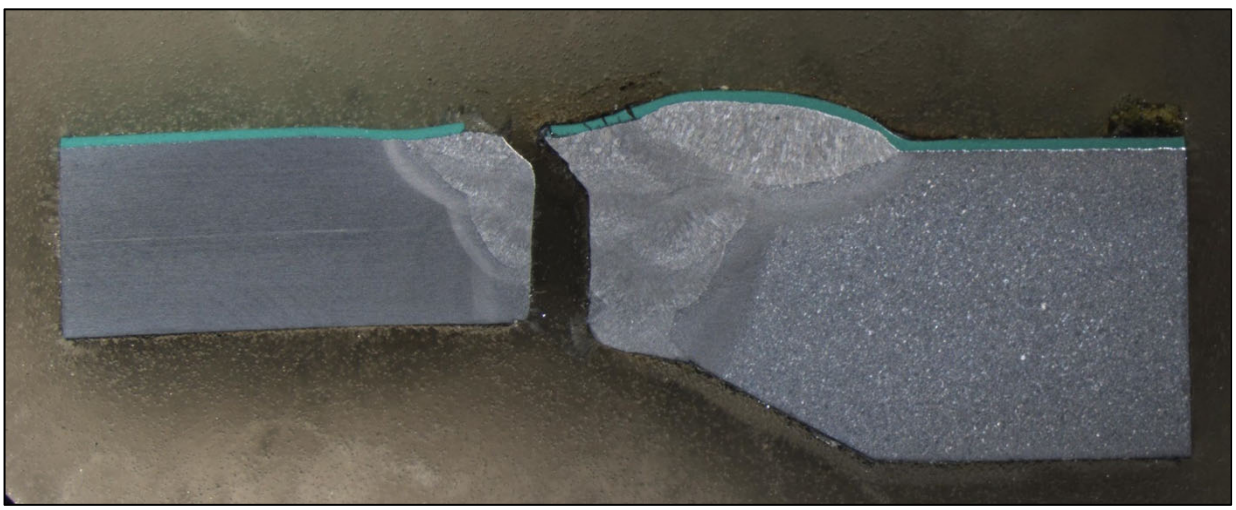


Figure 46 *– Overall view of the metallographic section prepared through GWD 13530 Crack 2.*

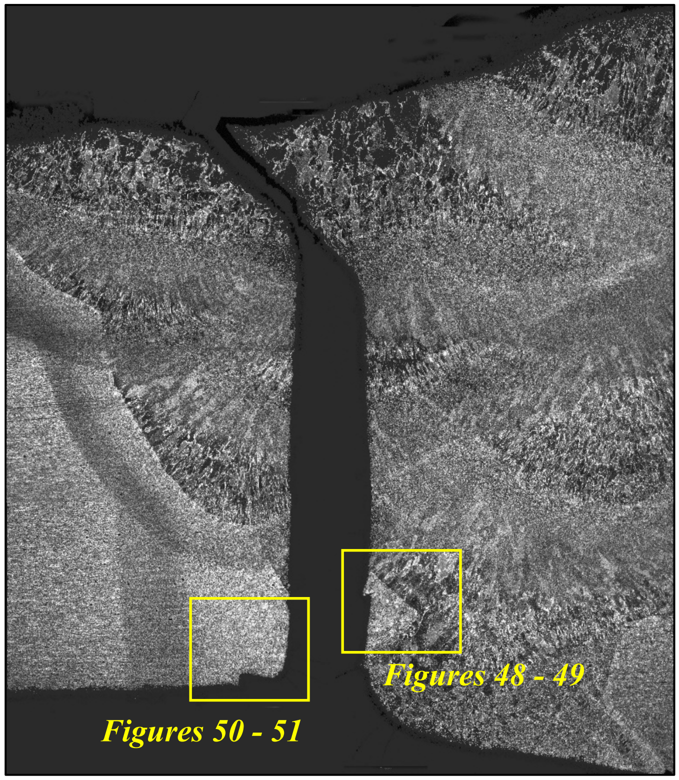


Figure 47 *– Photomontage of optical micrograph showing the full cross-section of GWD 13530 Crack 2. Originally photographed at 12.5x, 3% Nital etch.*

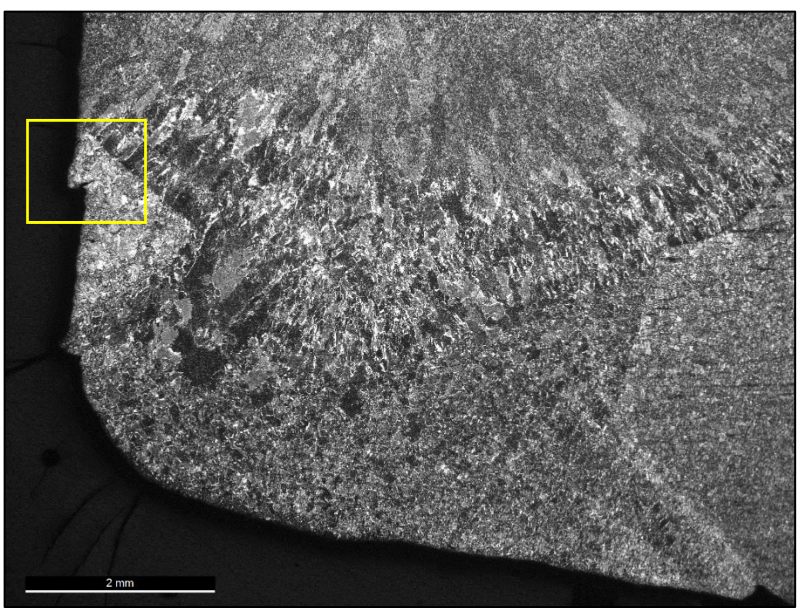


Figure 48 *– Optical micrograph showing the pipe-side weld and HAZ associated with the brittle pop in GWD 13530 Crack 2. 12.5x, 3% Nital etch.*

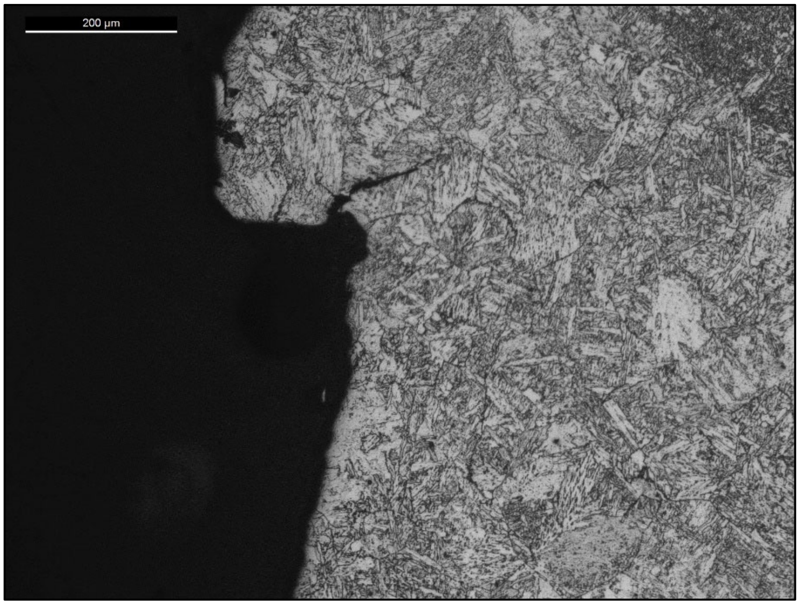


Figure 49 *– Higher magnification optical micrograph showing the coarse-grained HAZ on the pipe side of GWD 13530 Crack 2 associated with the brittle pop. 100x, 3% Nital etch.*

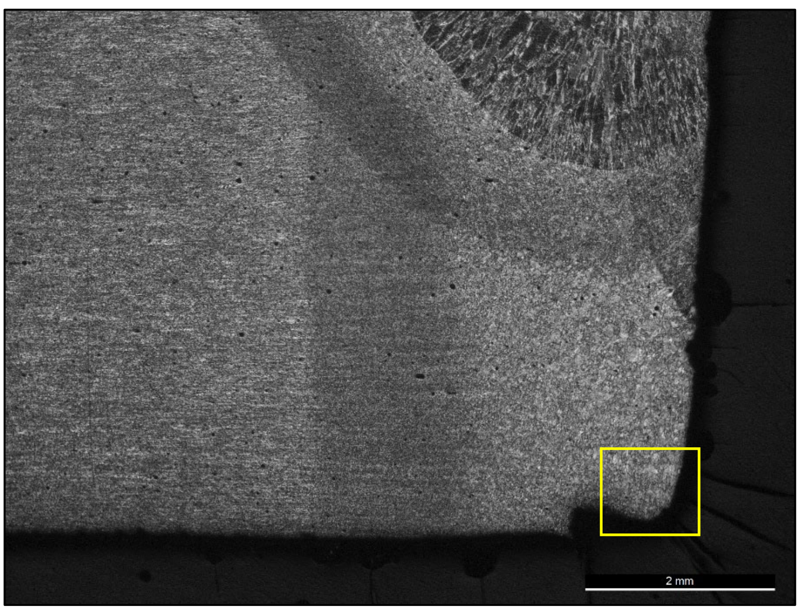


Figure 50 *– Optical micrograph showing the pipe-side of the fracture on GWD 13530 Crack 2. There was an anomaly noted with the toe of the weld that appeared consistent with lack-of-fusion. 12.5x, 3% Nital etch.*

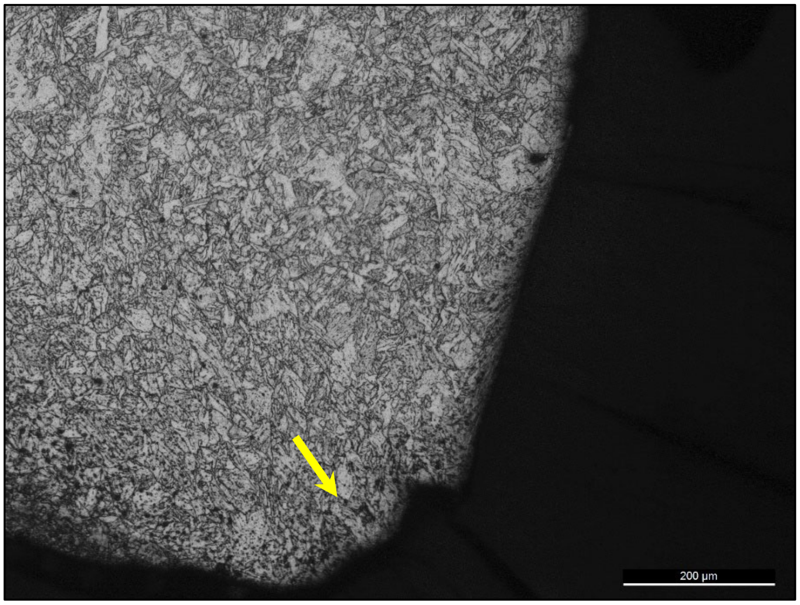


Figure 51 *– Higher magnification optical micrograph showing the ID weld anomaly profile on the pipe side of GWD 13530 Crack 2. 100x, 3% Nital etch.*

GWD 13530 Sample 439-3-2

The metallographic section prepared through the deepest portion of Crack 3 is shown in Figure 52. Similar to the other two fatigue cracks, Crack 3 initiated at the ID toe of the weld, propagated approximately 0.191” into the pipe side HAZ and then experienced a shear overload event.

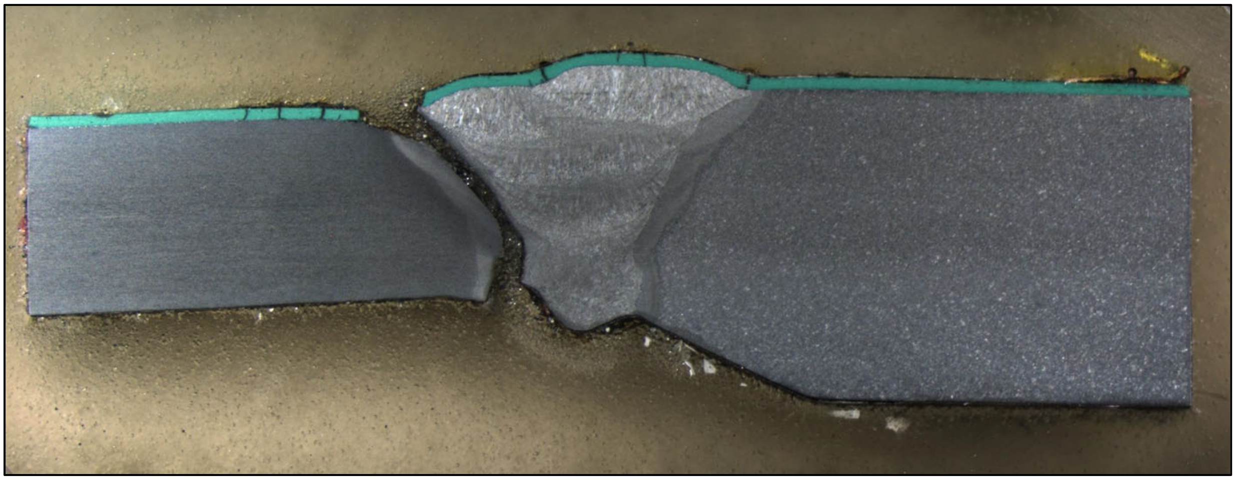


***Figure 52** – Overall view of the metallographic section prepared through GWD 13530 Crack 3.*

***Figure 53** – Photomontage of optical micrographs showing the complete wall thickness profile of the pipe through GWD 13530 Crack 3. Originally photographed at 12.5x, 3% Nital etch.*

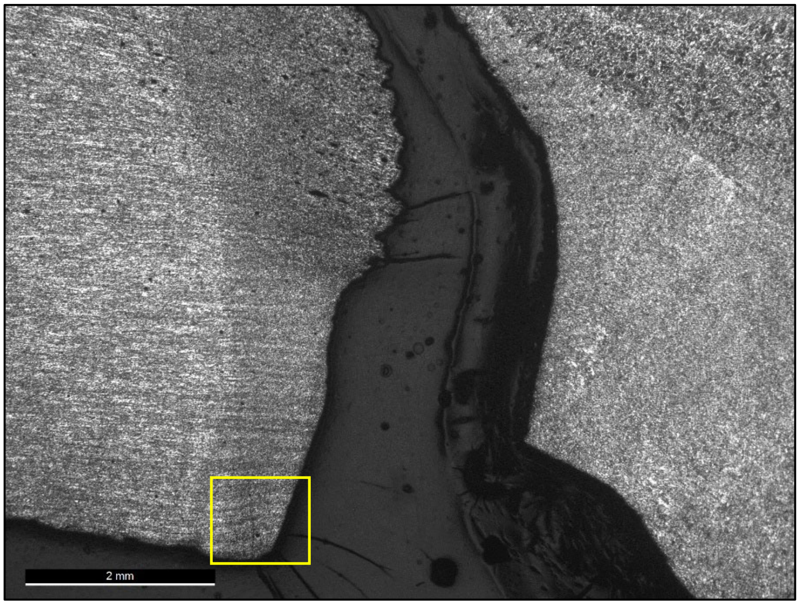


Figure 54 *– Higher magnification optical micrograph showing the ID initiation region of GWD 13530 Crack 3. 12.5x, 3% Nital etch.*

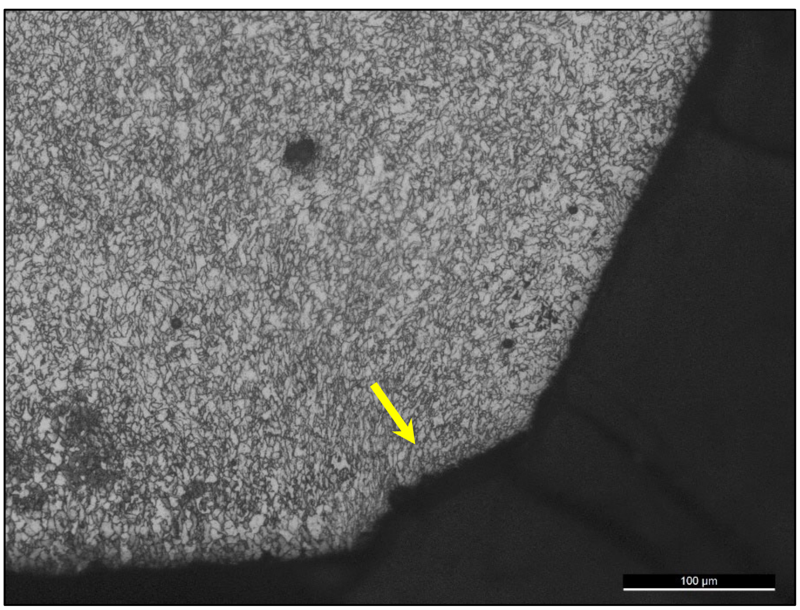


Figure 55 *– Higher magnification optical micrograph showing detail of the root anomaly identified on the pipe-side of the GWD 13530 Crack 3. The anomaly appeared to fit the profile of the toe of the root pass. 200x, 3% Nital etch.*

GWD 13530 Sample 439-139°

A metallographic section was removed across GWD 13530 at 139° from TDC, a location that was coincident with a PAUT indicated feature. As shown in Figures 57 – 58, there was an indication consistent with a lack-of-fusion (LOF) defect identified at the toe of the girth weld on the pipe side.

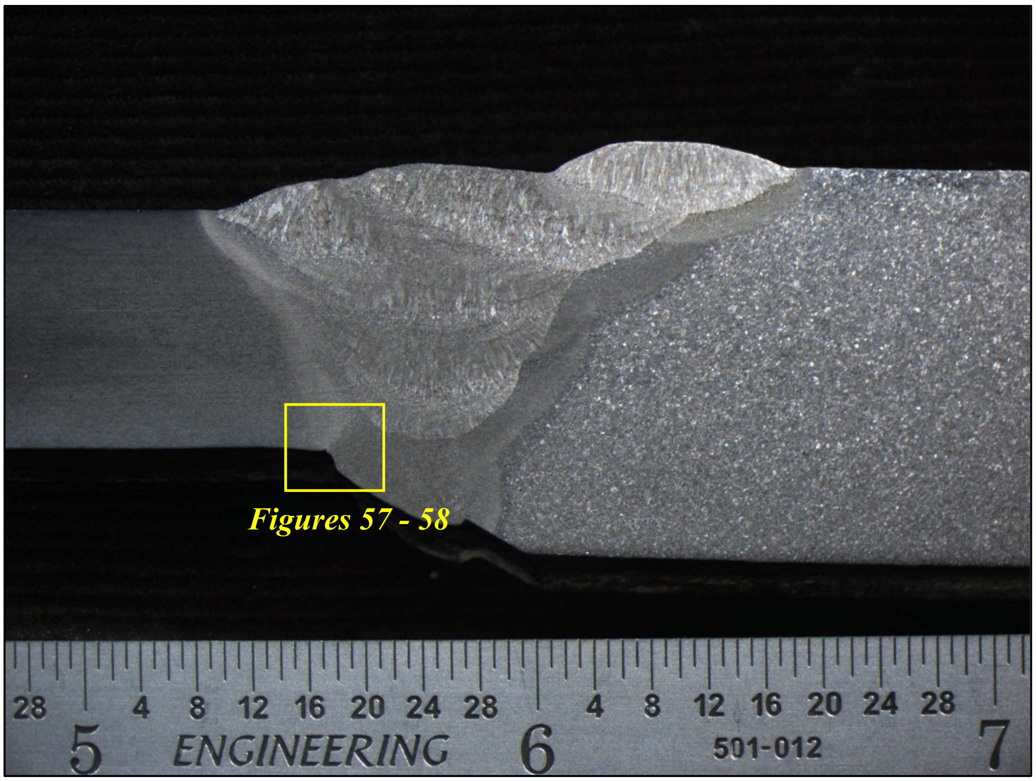
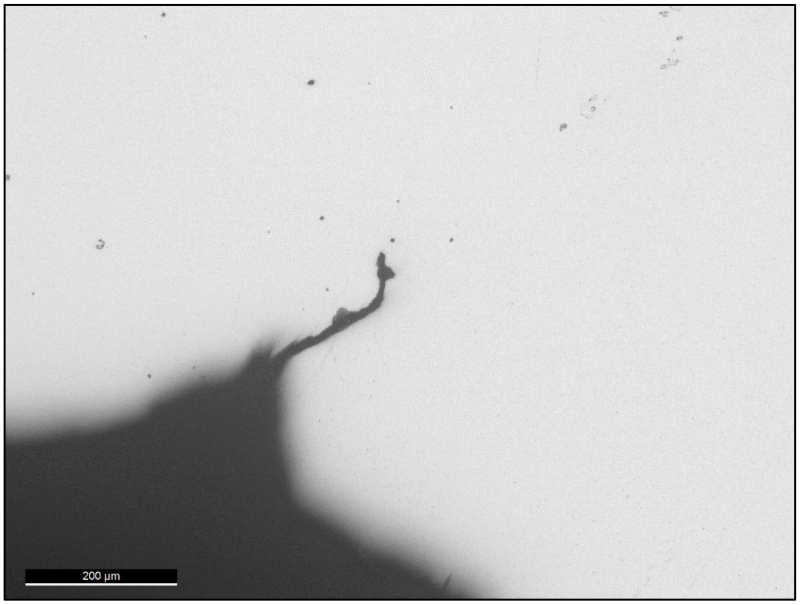
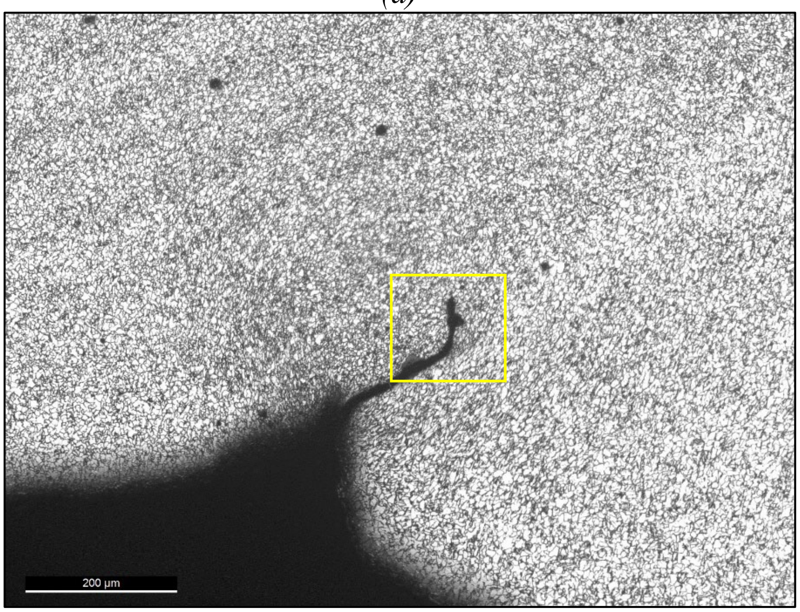


Figure 56 *– Overall view of the sample from GWD 13530 removed 139° from TDC. The feature was consistent with the location of Applus PAUT Indication 2 reported for GWD 13530.*



(a)



(b)

***Figure 57** – Optical micrographs showing a scale-filled, approximately 200µm long LOF at the pipe-side weld toe of GWD 13530. The upward curvature of the defect at the terminal end may be due to the onset of fatigue cracking. Both micrographs taken at 100x, (a) as-polished (b) 3% Nital etch.*

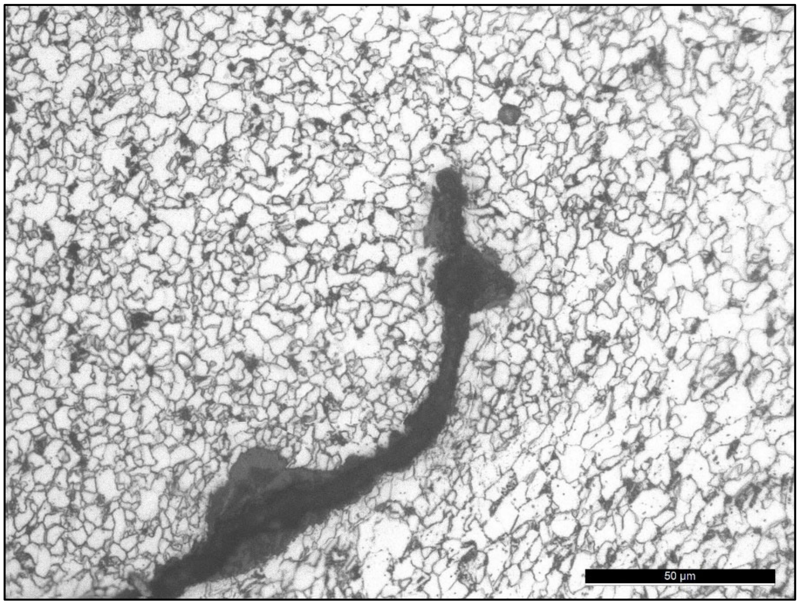


Figure 58 *– High magnification optical micrograph showing dense, tightly adhered oxide scale consistent in appearance with magnetite lining the defect surfaces on the LOF on GWD 13530. 500x, 3% Nital etch.*

Sample 439-270°

The macro-section prepared across GWD 13530 from the 270° position is shown overall in Figure 59. A small linear indication approximately 200μm in length coincident with the toe of the weld on the ID of the pipe side was identified. Upon closer examination it was observed that the indication was filled with a dense, tightly adhered oxide scale and appeared to parallel the fusion line. SEM/EDS examination show in Figure 62 of the scale adhered to the indication consisted primarily of iron, oxygen, manganese and silicon. These features indicated that this feature was most likely a LOF defect originating at the time of welding.

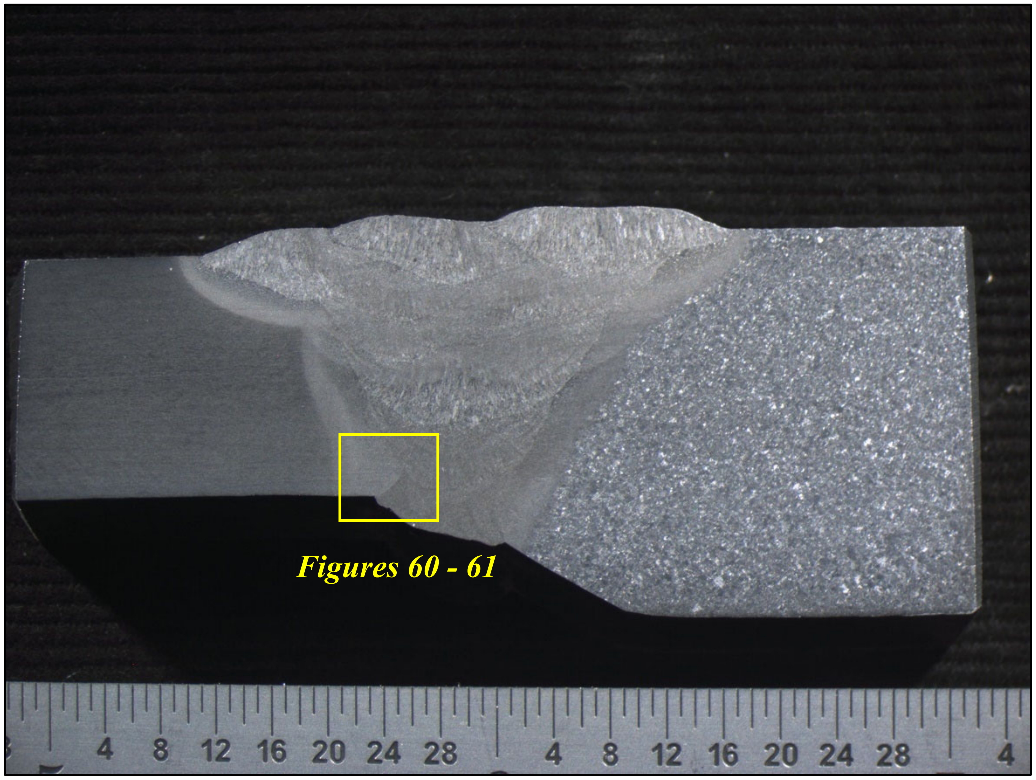
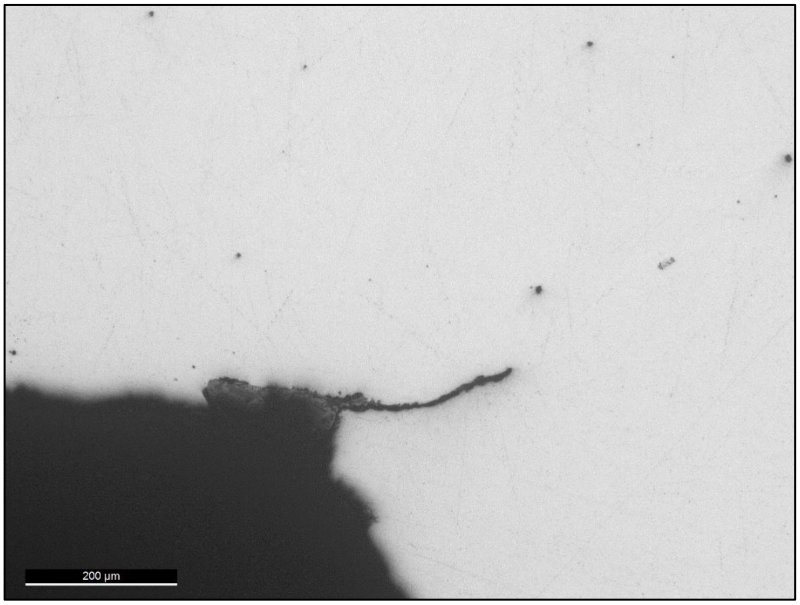
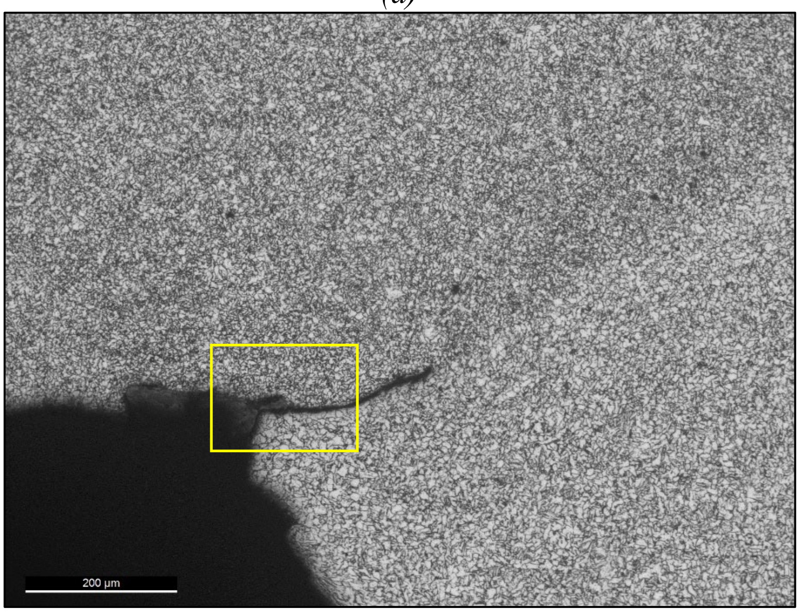


***Figure 59** – Overall view of the sample from GWD 13530 removed 270° from TDC.*



(a)



(b)

Figure 60 *– Optical micrographs showing a scale-filled, approximately 200µm long LOF defect at the pipe-side weld toe of GWD 13530. Both micrographs taken at 100x, (a) as-polished (b) 3% Nital etch.*

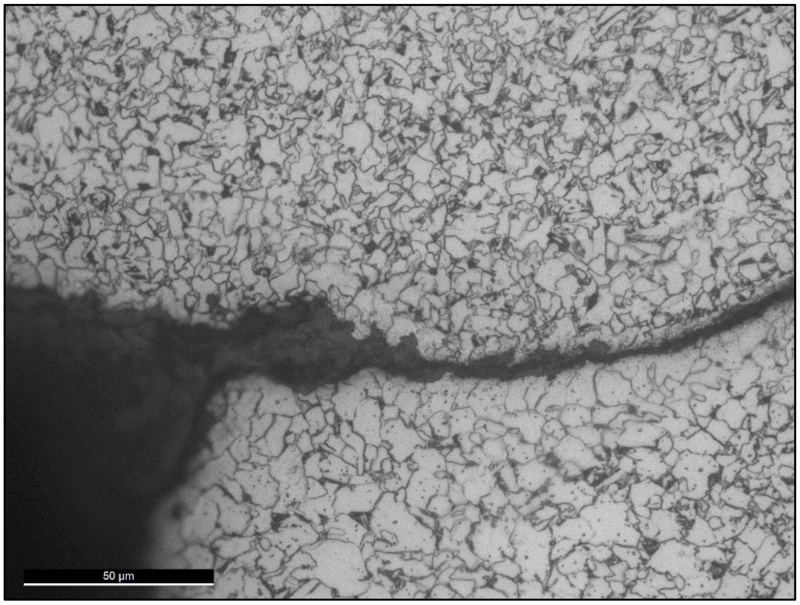
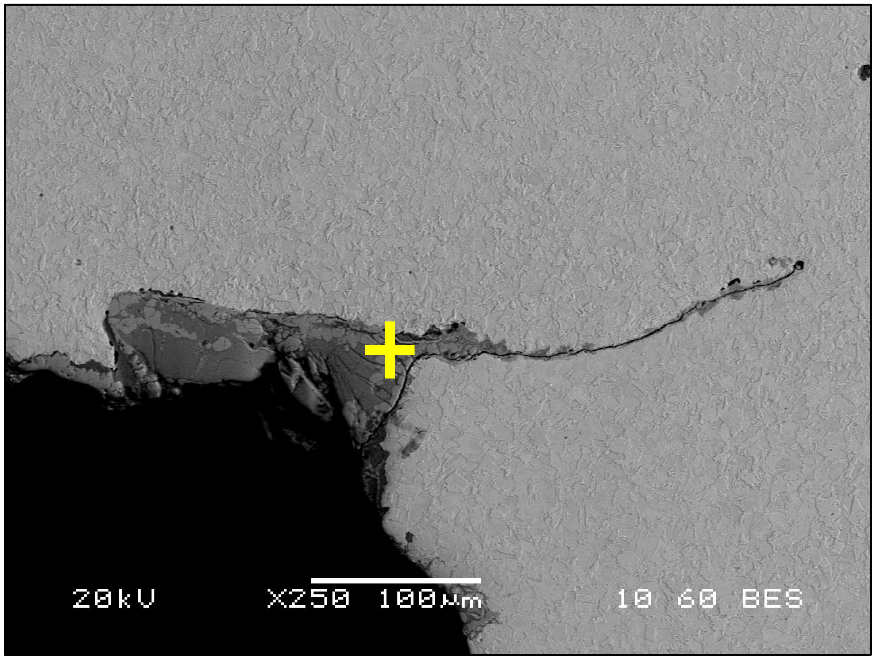
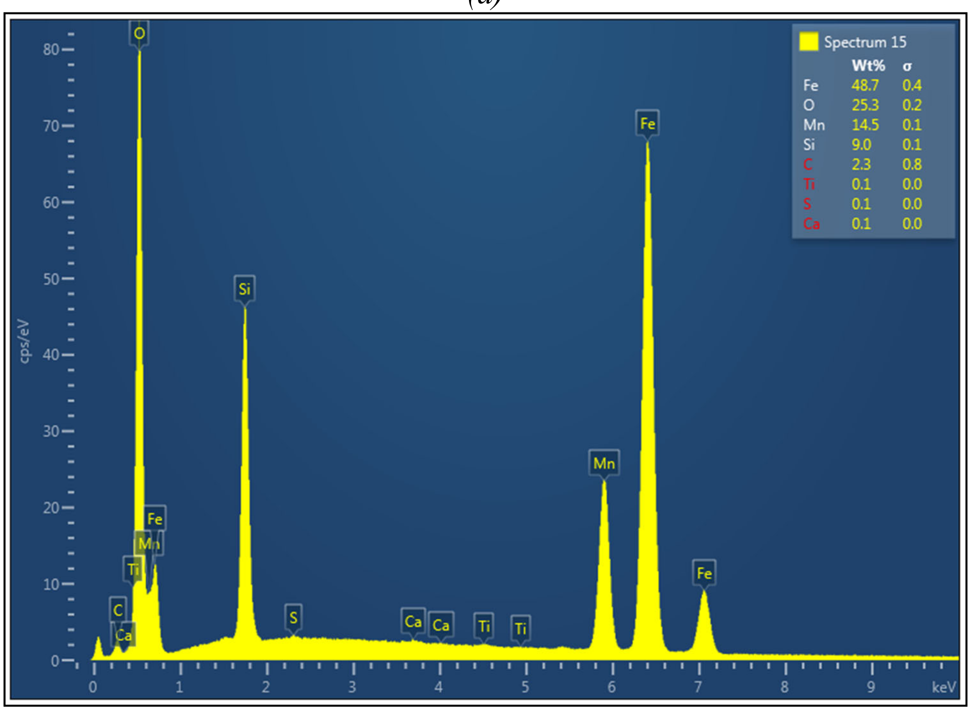


Figure 61 *– High magnification optical micrograph showing tightly adhered oxide scale to the defect surfaces indicating the feature to be a LOF defect on GWD 13530. 500x, 3% Nital etch.*



(a)



(b)

Figure 62 *– (a) Backscatter electron micrograph showing the LOF defect at the ID toe of Sample 439-270° from GWD 13530 (b) EDS spectrum collected from the scale adhered to the surfaces of the LOF defect.*

GWD 13530 Shear Regions 1-2 and 1-3

The mated cross sections through Shear 1-2 and Shear 1-3 are shown in Figures 63 and 64, respectively. Both samples exhibited substantial necking (localized reduction of thickness) on the pipe side of the weld, evidencing that the pipe underwent plastic deformation prior to rupturing. The metallurgical macrostructure of these two specimens differed largely from the other mated cross sections in that there was evidence that the root on the ID had been re-welded from the ID, evidenced by the fact that the HAZ from the root overlapped the hot passes. This finding is consistent with the visual observations made in these areas that the appearance of the weld bead on the ID (width and ripple coarseness) in comparison to the bulk of the ID root.

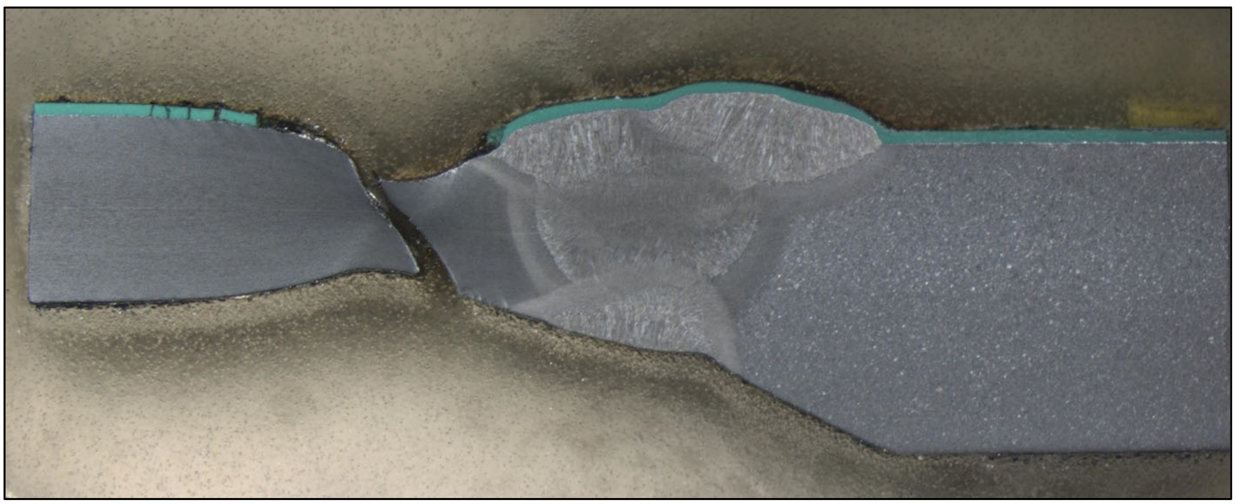


Figure 63 *– Overall view of the metallographic section prepared through GWD 13530 Shear 1 – 2 region showing characteristic ductile shear fracture morphology on the pipe side. No evidence of progressive cracking was observed in this specimen.*

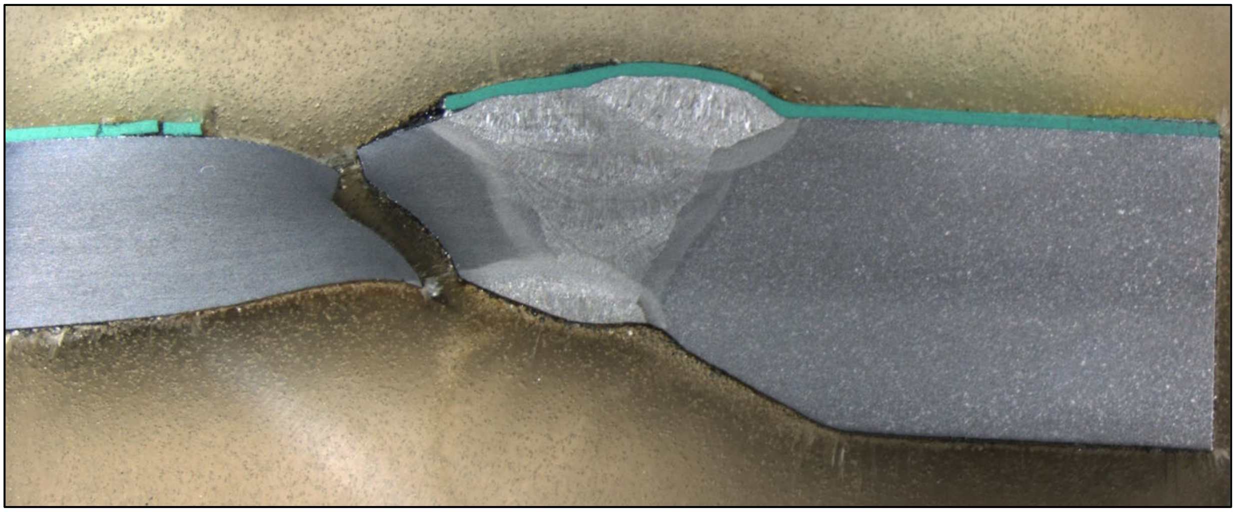


Figure 64 *– Overall view of the metallographic section prepared through GWD 13530 Shear 1 – 3 region showing characteristic ductile shear fracture morphology on the pipe side. No evidence of progressive cracking was observed in this specimen.*

GWD 13520

Cross-girth weld sections from GWD 13520 were removed from 4°, 80°, and 312° relative to TDC and were metallographically prepared and documented in the same manner as the intact sections removed from GWD 13530. The samples from 4° and 80° were coincident with rejectable indications reported by Applus RTD in the PAUT report (Feature Numbers 1 and 2, respectively). As shown in Figures 65 - 71 samples removed from the 4° and 80° locations both exhibited a lack-of-fusion feature at the ID toe of the girth weld, but unlike GWD 13530, the lack-of-fusion was located on the elbow-side toe. The sample at 4° also exhibited an ~500µm diameter porosity on the pipe-side fusion line as well as root pass lack-of-fusion defect coincident with the gas porosity. The most salient feature observed on the 4° sample was crack approximately 750µm in length originating from the lack-of-fusion feature. Both toe LOF defects were identified by Applus RTD during the PAUT examination. The sample removed from GWD 13520 at 312° exhibited evidence of having been weld repaired at the ID as shown in Figure 72.

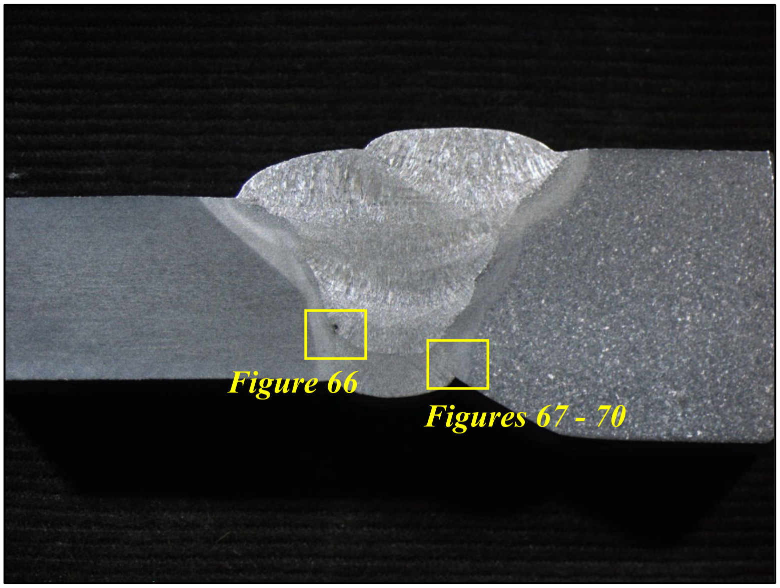


***Figure 65** – Overall view of the metallographic specimen prepared from GWD 13520 at 4° from TDC. Two notable features were identified, the first was a small gas porosity/LOF defect on the pipe-side fusion line and the second was a small linear crack originating from lack-of-fusion at the ID toe of the weld on the elbow side.*

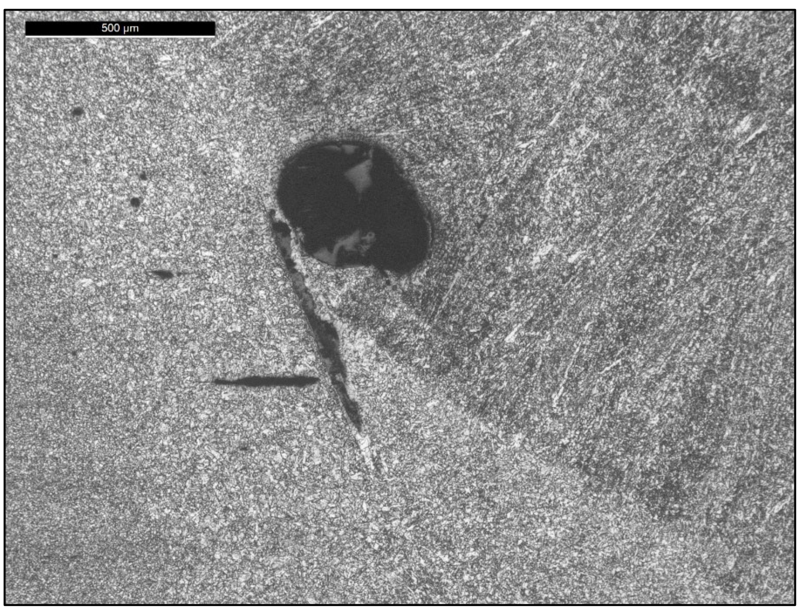
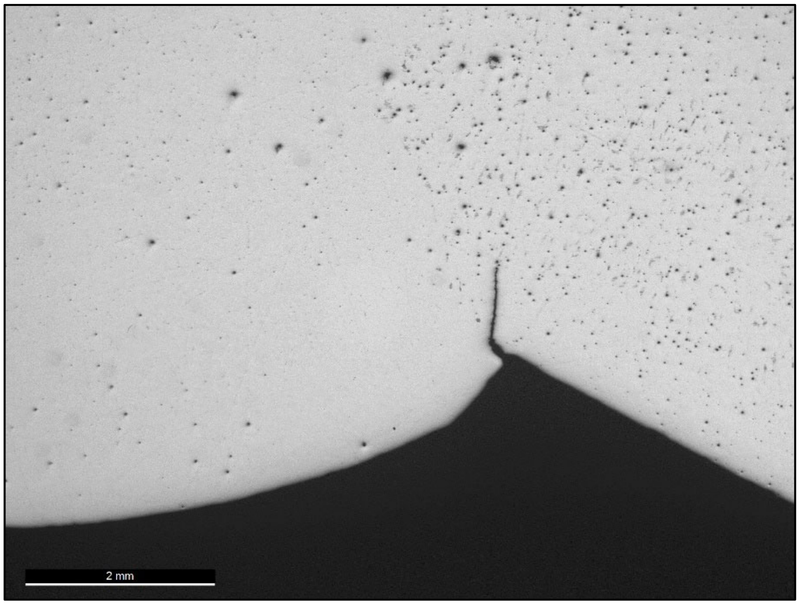
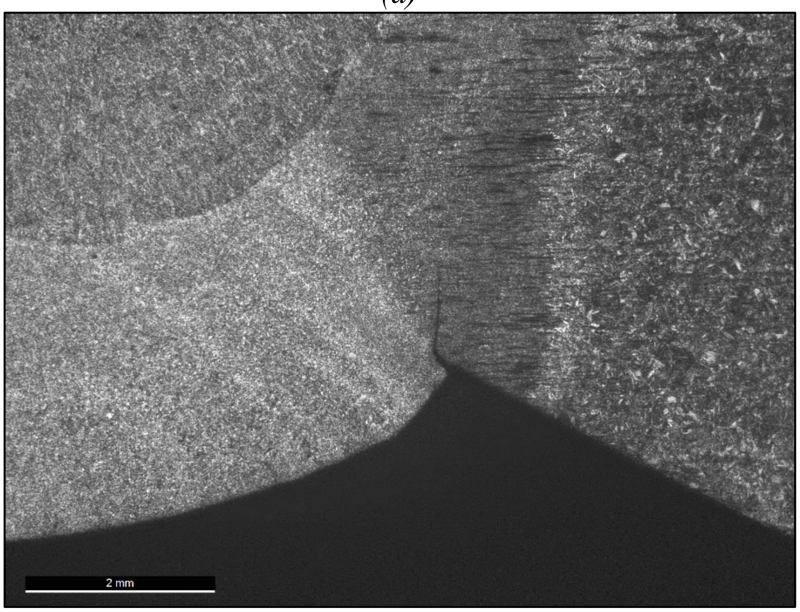


***Figure 66** – Optical micrograph showing the combination gas porosity and LOF defect identified on the GWD 13520 specimen at 4° from TDC. The defect was located between the root pass and first hot pass. 50x, 3% Nital etch.*



(a)



(b)

***Figure 67** – Optical micrographs showing a linear crack originating from a LOF defect at the ID toe of GWD 13520 on the elbow side (a) as-polished (b) 3% Nital etch. Both micrographs photographed at 12.5x.*

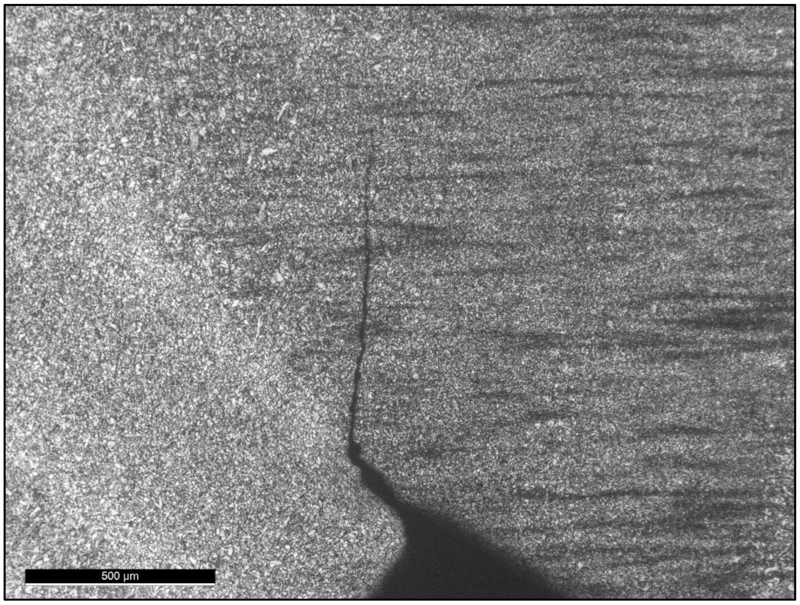


Figure 68 *– Higher magnification optical micrograph showing the linear crack originating from LOF at the ID toe of GWD 13520 on the elbow side. 50x, 3% Nital etch.*

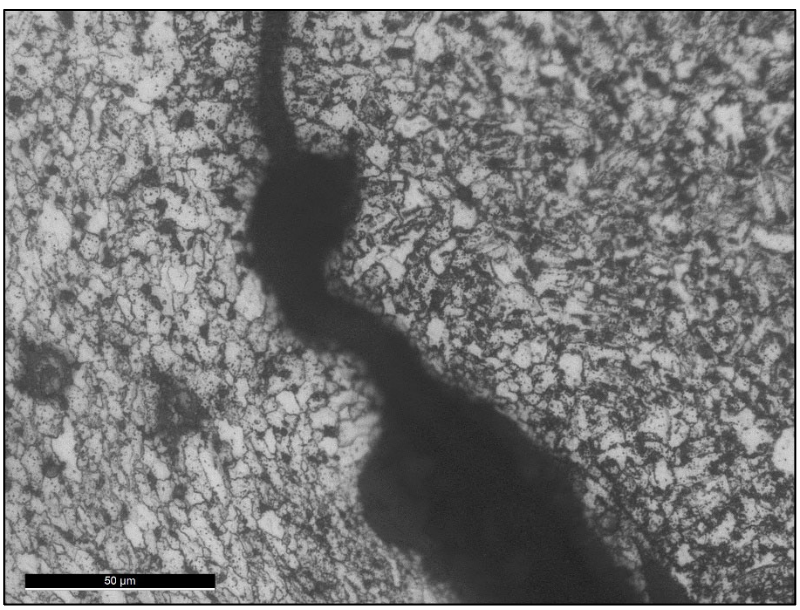


Figure 69 *– High magnification optical micrograph showing tightly adhered oxide scale to the surfaces, positively identifying the feature as LOF. 500x, 3% Nital etch.*

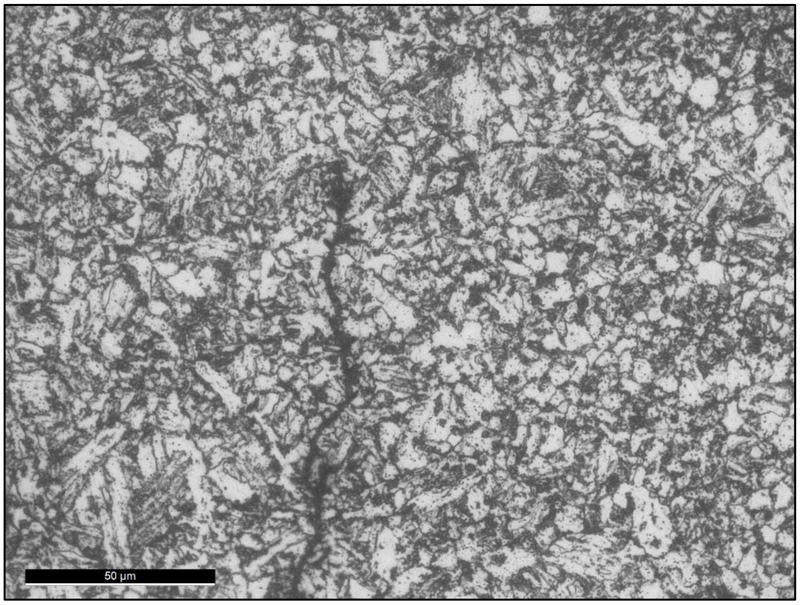
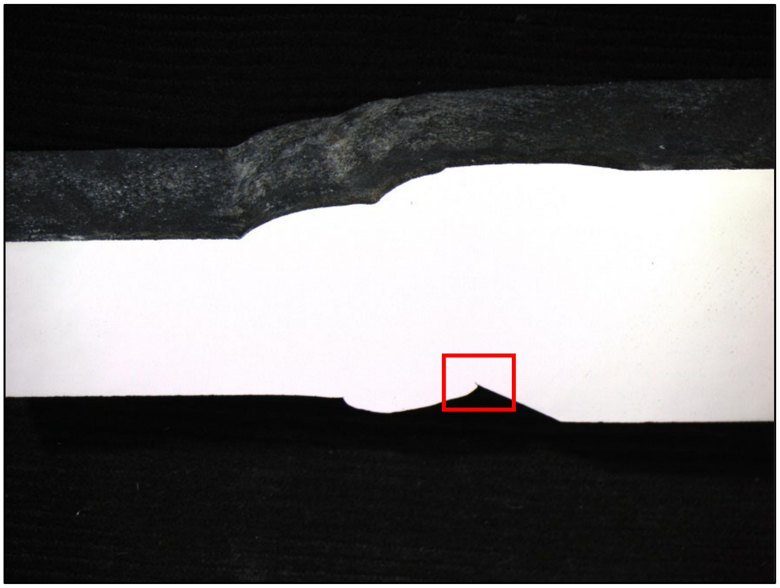
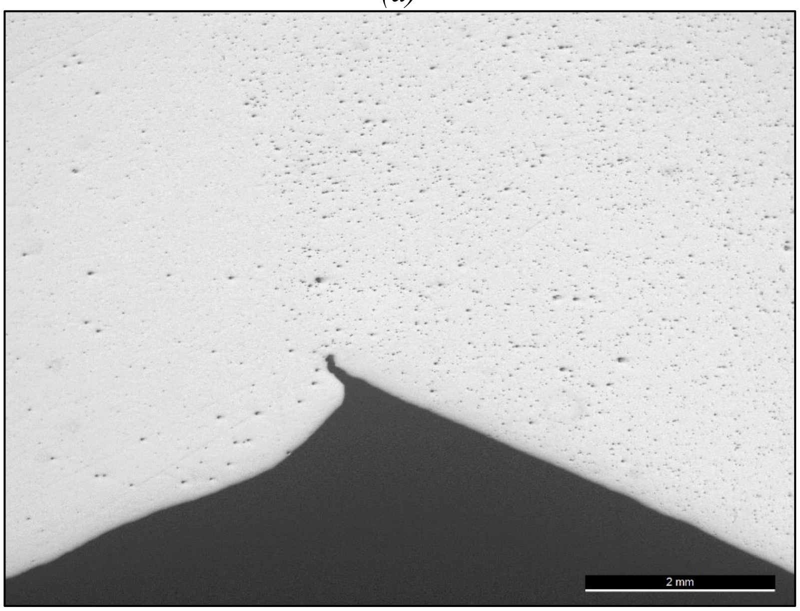


***Figure 70** – High magnification optical micrograph showing the tip of the crack originating from LOF on GWD 13520. There was no evidence of plastic deformation associated with the crack tip, and the crack propagated transgranularly, consistent with a fatigue crack. 500x, 3% Nital etch.*



(a)



(b)

Figure 71 *– (a) Overall view of the as-polished metallographic section taken from GWD 13520 at 80° clockwise from TDC (b) lack-of-fusion defect identified at the ID toe of the girth weld on the elbow side, 12.5x, as-polished.*

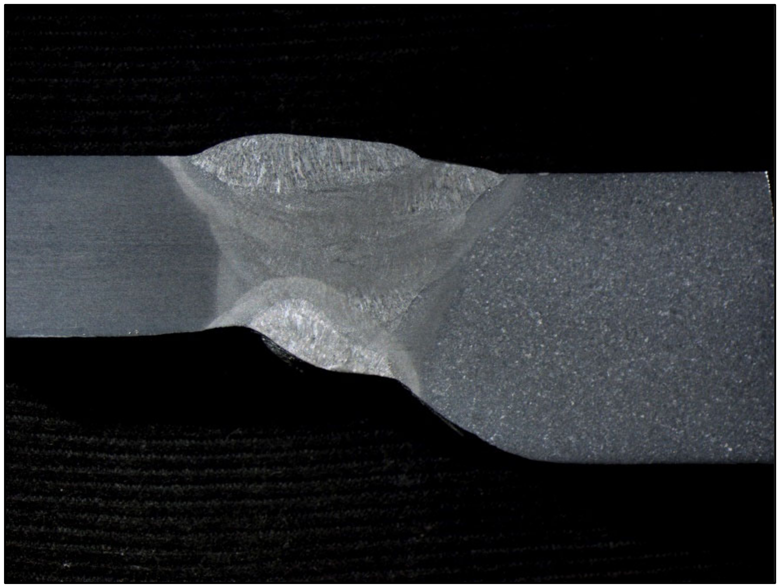


***Figure 72** – Overall view of the metallographic specimen prepared from GWD 13520, 312° from TDC. This metallographic section indicated the ID root had been repaired, evidenced by the overlay of the ID HAZ on the intermediate hot passes.*

MECHANICAL TESTING

Tensile Testing

Tensile testing of the pipe body and elbow materials was conducted in accordance with API 5L and MSS SP-75-2004. Cross girth weld tensile testing was conducted in accordance with API 1104. Tensile testing consisted of both full wall thickness and sub-size round test specimens. The results of the tests are summarized in the following tables. The tensile datasheets for the full-wall thickness pipe and elbow body specimens are included as Appendix D and the tensile datasheets for all sub-size tensile specimens are included as Appendix E.

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[1] ASME IX (2010) QW-153.1 "In order to pass the tension test, the specimen shall have a tensile strength that is not less than (a) the minimum specified tensile strength of the base metal (b) the minimum specified tensile strength of the weaker of the two, if base metals of different minimum tensile strengths are used…"

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[redacted]

---

[2] API 5L minimum elongation calculated by $e = 625{,}000\frac{Acx^{0.2}}{UTS^{0.9}}$

[3] "X-SW" = cross seam-weld

[4] MSS SP-75-2004 Section 8.4 states yield strength can be determined using either 0.2% offset or 0.5% EUL method.

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[redacted]

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[redacted]

[5] API 5L minimum elongation calculated by $e = 625{,}000 \frac{Acx^{0.2}}{UTS^{0.9}}$

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[redacted]

CVN Impact Testing

Sets of full-size, transverse oriented Charpy V-Notch (CVN) impact specimens was removed from each of the following locations of the upstream and downstream pup sections – base metal 90° from the seam weld, seam weld HAZ (FL + 1mm)[8], and seam weld centerline in accordance with API 5L. The specimens were prepared and tested in accordance with ASTM A370 at -5°C. The results demonstrate the pipe met the minimum absorbed energy requirement of 40 ft-lbs for API 5L grade X70 PSL 2 pipe.

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[redacted]

[6] CANDAOIL Forge LTD Material Test Report 6235
[7] MSS SP-75-2004 Section 8.4 states yield strength can be determined using either 0.2% offset or 0.5% EUL method.
[8] HAZ notch location (FL+1mm) measured at mid-wall.

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Girth Weld CVN Impact Testing

Sets of longitudinally oriented, full-size CVN specimens were removed from both GWD 13530 and 13520. Three sets of three CVN specimens were notched in the girth weld HAZ (FL+1mm)[9], and three sets of three CVN specimens were notched in the weld centerline. Specimens were

[9] HAZ notch location (FL+1mm) measured at mid-wall.

tested at -5°C. All tested specimens met the minimum requirements for impact toughness in API 1104 (21st Edition). It should be noted however that the edition of API 1104 that these welds would have been fabricated to (API 1104 20th Edition) did not require CVN impact testing. Photographs of the scribed notch locations are included as Appendix G.

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CTOD Testing

Six Bx2B SE(B) CTOD specimens were removed from each girth weld following the guidelines of API 1104 understanding that the entire girth weld was not available for testing. The first number corresponds to the girth weld, 20 for girth weld 13520, and 30 for girth weld 13530.

The SE(B) CTOD specimens were compression stress relieved per ISO 15653:2018 Annex C.2. All specimens pre-cracked at room temperature and tested per ISO 15653:2018 at 20°C. All but one tested specimen (439-20-16) met the minimum required CTOD value (0.005in) set forth in API 1104 (20^{th} Edition). The datasheets are included as Appendix H, notch locations and post-test fracture pictures are provided as Appendix I. The results are summarized as follows:

Girth Weld 13520			
Specimen	**Zone**	**CTOD [inches]**	**Validity**
439-20-6	Pipe HAZ	δ_m=0.020	Valid
439-20-16	Pipe HAZ	δ_u=0.0047	Valid
439-20-30	Pipe HAZ	δ_m=0.013	Valid
439-20-63	Weld	δ_m=0.0069	Valid
439-20-82	Weld	δ_m=0.0084	Valid
439-20-310	Weld	δ_m=0.017	Valid

Girth Weld 13530			
Specimen	**Zone**	**CTOD [inches]**	**Validity**
439-30-207	Pipe HAZ	δ_m=0.023	Valid
439-30-235	Pipe HAZ	δ_m=0.028	Valid
439-30-256	Pipe HAZ	δ_m=0.024	Valid
439-30-131	Weld	δ_m=0.0068	Valid
439-30-132	Weld	δ_m=0.0089	Valid
439-30-206	Weld	δ_m=0.0087	Valid

Microhardness Testing

A Vickers microhardness survey (HV10) was conducted metallographically prepared cross-sections from GWDs 13530 and 13520 in accordance with the protocol submitted by TC Energy. Results were converted to appropriate Rockwell B [HRB] and Rockwell C [HRC] scales per ASTM E140 for ease of interpretation. The results of the hardness tests on GWD 13530 showed the hardness to be uniform across the base metal, pipe-side HAZ, weld, elbow-side HAZ, and elbow. There were local hard-spots identified, however they appeared to be remote from the failure location on the elbow-HAZ associated with the cap pass. The hardness results from GWD 13520 were similar to those from GWD 13530, the notable difference being the hardness of sample GWD 13520-312° (ID weld repair), being consistently higher than the hardness at the OD and mid-wall. The results of the microhardness tests for both welds are summarized in Figures 73 – 76 below.

Customer	TC Energy	Our Job #	220439
Description	GWD 13530 Crack 2-2	Date	1-26-2023
Test Load	10KG	Technician	Thomas Tripodi
Test Magnification	100x		

Location	Vickers	HRB Converted	HRC Converted	Location	Vickers	HRB Converted	HRC Converted
Top				Middle			
1	222	96.9	--	17	212	95.3	--
2	212	95.3	--	18	216	96.0	--
3	210	95.1	--	19	210	94.9	--
4	221	96.9	--	20	190	91.1	--
5	227	97.8	--	21	197	92.4	--
6	223	97.2	--	22	260	--	24.1
7	214	95.7	--				
8	272	--	26.1	Bottom			
9	258	--	23.7	23	216	96.1	--
10	219	96.5	--	24	238	99.7	--
11	251	--	22.4	25	240	--	20.4
				26	242	--	20.8
Middle				27	206	94.3	--
12	195	92.0	--	28	227	97.8	--
13	196	92.3	--	29	209	94.7	--
14	200	93.0	--	30	223	97.2	--
15	224	97.3	--	31	202	93.4	--
16	223	97.1	--	32	201	93.2	--
				33	257	--	23.5

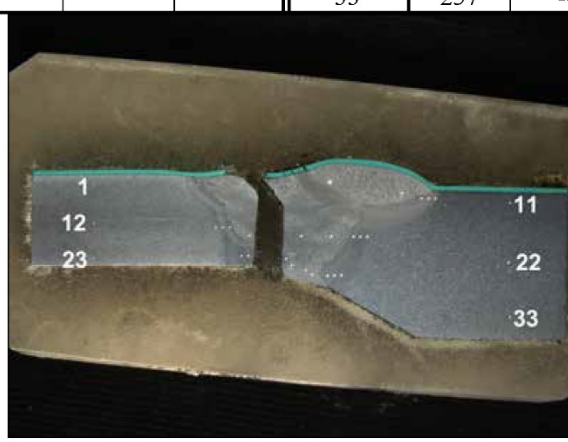

Figure 73 *– Vickers microhardness survey on metallographic specimen GWD 13530 Crack 2.*

Customer	TC Energy	Our Job #	220439
Description	GWD 13530-76°	Date	1/26/2023
Test Load	10KG	Technician	Thomas Tripodi
Test Magnification	100x		

Location	Vickers	HRB Converted	HRC Converted	Location	Vickers	HRB Converted	HRC Converted
Top				Middle			
1	221	96.7	--	17	193	91.6	--
2	232	98.7	--	18	210	95.0	--
3	249	--	22.1	19	236	99.3	--
4	246	--	21.6	20	222	97.0	--
5	225	97.4	--	21	198	92.6	--
6	225	97.5	--	22	248	--	21.9
7	226	97.6	--				
8	333	--	33.6	Bottom			
9	339	--	34.3	23	211	95.1	--
10	336	--	34.0	24	211	95.1	--
11	278	--	36.9	25	216	96.1	--
				26	217	96.2	--
Middle				27	214	95.6	--
12	214	95.6	--	28	213	95.5	--
13	197	92.3	--	29	208	94.6	--
14	193	91.5	--	30	226	97.7	--
15	196	92.1	--	31	223	97.2	--
16	194	91.9	--	32	222	97.0	--
				33	268	--	25.3

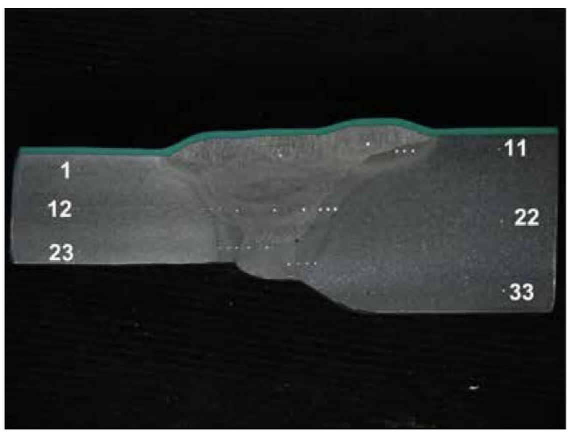

Figure 74 *– Vickers microhardness survey on metallographic specimen GWD 13530-76°.*

Customer	TC Energy	Our Job #	220439
Description	GWD 13520-80°	Date	02/03/2023
Test Load	10KG	Technician	Andrés R.
Test Magnification	100x		

Location	Vickers	HRB Converted	HRC Converted	Location	Vickers	HRB Converted	HRC Converted
Top				Middle			
1	219.1	96.5	--	17	205.0	94.0	--
2	204.0	93.8	--	18	193.9	91.8	--
3	218.9	96.5	--	19	191.7	91.3	--
4	229.0	98.2	--	20	188.0	90.6	--
5	199.6	92.9	--	21	181.4	89.3	--
6	192.2	91.4	--	22	227.2	97.9	--
7	226.9	97.8	--				
8	313.4	--	31.4	Bottom			
9	287.1	--	28.1	23	222.8	97.1	--
10	242.2	--	20.8	24	186.0	90.2	--
11	25.15	--	22.6	25	192.7	91.5	--
				26	204.2	93.8	--
Middle				27	197.7	92.5	--
12	205.3	94.1	--	28	198.2	92.6	--
13	185.1	90.0	--	29	193.9	91.8	--
14	178.3	88.6	--	30	210.4	95.1	--
15	194.9	92.0	--	31	240.0	--	20.4
16	189.8	91.0	--	32	258.8	--	23.8
				33	274.5	--	26.4

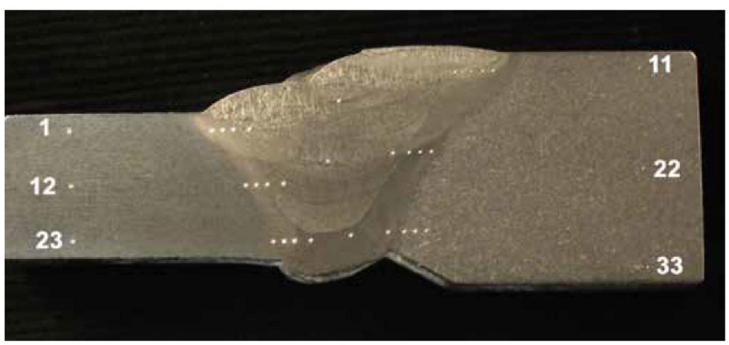

Figure 75 *– Vickers microhardness survey on metallographic specimen GWD 13520-80°.*

Customer	TC Energy	Our Job #	220439
Description	GWD 13520-312°	Date	02/03/2023
Test Load	10KG	Technician	Andrés R.
Test Magnification	100x		

Location	Vickers	HRB Converted	HRC Converted	Location	Vickers	HRB Converted	HRC Converted
Top				Middle			
1	217.8	96.3	--	17	195.9	92.2	--
2	195.4	92.1	--	18	193.5	91.7	--
3	205.2	94.0	--	19	214.6	95.8	--
4	213.0	95.5	--	20	198.8	92.8	--
5	205.5	94.1	--	21	211.3	95.2	--
6	196.8	92.4	--	22	231.6	98.6	--
7	206.3	94.2	--				
8	254.5	--	23.1	Bottom			
9	251.3	--	22.5	23	222.7	97.1	--
10	222.8	97.1	--	24	214.0	95.7	--
11	266.9	--	25.2	25	221.9	97.0	--
				26	222.6	97.1	--
Middle				27	238.2	99.7	--
12	197.2	92.4	--	28	255.4	--	23.2
13	191.4	91.3	--	29	256.3	--	23.6
14	178.3	88.6	--	30	288.2	--	28.3
15	200.1	93.0	--	31	212.0	95.3	--
16	198.8	92.8	--	32	193.1	91.6	--
				33	247.4	--	21.7

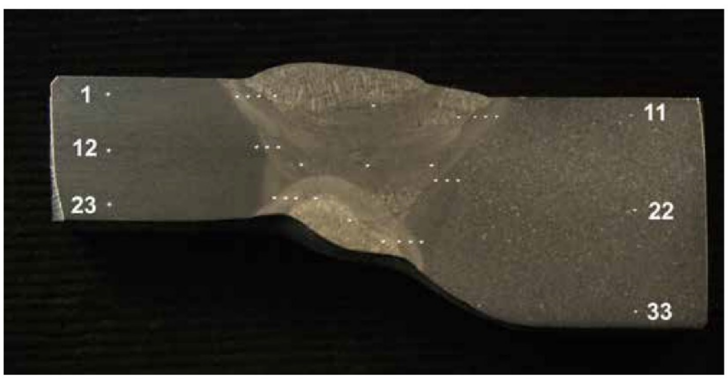

Figure 76 *– Vickers microhardness survey on metallographic specimen GWD 13520-312°.*

Chemical Analysis

Coupons from the DS and UP pups, DS and US ends of the elbow fitting, and the center of each girth weld were removed and submitted for a detailed chemical composition determination via optical emission spectroscopy (OES) per ASTM A751. The chemical compositions were compared to the specifications for API 5L grade X70 PSL 2, MSS-SP-75, and the reported welding electrodes. Additional coupons consisting of repaired and "original" welds from the ID roots of both GWD 13530 and 13520 were remove. The results of the chemical analyses are summarized below.

Element	DS Pup [weight %]	US Pup [weight %]	API 5L grade X70 PSL 2 [weight %]
Carbon	0.060	0.059	0.22 max
Manganese	1.57	1.55	1.65 max
Phosphorus	0.016	0.016	0.025
Sulfur	0.003	0.003	0.015
Silicon	0.25	0.25	-
Nickel	0.03	0.03	*h*
Molybdenum	<0.01	<0.01	*h*
Chromium	0.19	0.19	*h*
Copper	0.02	0.02	*h*
Aluminum	0.029	0.029	-
Vanadium	0.003	0.039	*g*
Titanium	0.021	0.021	0.06 max
Niobium	0.046	0.044	-
Cobalt	<0.005	<0.005	*l*
Boron	<0.0005	<0.0005	-
Zirconium	<0.01	<0.01	-
Tungsten	<0.01	<0.01	-
Tin	<0.005	<0.005	-
Arsenic	<0.002	<0.002	-
Antimony	0.004	0.003	-
Calcium	0.0023	<0.0005	-
CE_{Pcm}	0.159	0.158	0.25 max
Iron	Balance	Balance	Balance

g) Unless otherwise agreed: Nb + V + Ti ≤ 0.15%
h) Unless otherwise agreed: Cu ≤ 0.50%, Ni ≤ 0.50%, Cr ≤ 0.50%, and Mo ≤ 0.50%
l) No intentional additions of B, B ≤ 0.001%

Element	DS Elbow [weight %]	US Elbow [weight %]	MSS-SP-75 Composition [weight %]
Carbon	0.13	0.14	0.30 max
Manganese	1.35	1.14	1.60 max
Phosphorus	0.012	0.010	0.035 max
Sulfur	0.002	0.012	0.035 max
Silicon	0.32	0.23	0.50 max
Nickel	0.03	0.05	0.50 max*
Molybdenum	0.01	0.01	0.13 max*
Chromium	0.23	0.18	0.25 max*
Copper	0.04	0.09	0.50 max
Aluminum	0.035	0.026	-
Vanadium	0.050	0.039	0.13 max
Titanium	0.003	<0.002	0.05 max
Niobium	<0.002	<0.002	0.10 max
Cobalt	0.005	0.005	-
Boron	<0.0005	<0.0005	-
Zirconium	<0.01	<0.01	-
Tungsten	<0.01	<0.01	-
Tin	<0.005	0.007	-
Arsenic	<0.002	0.002	-
Antimony	<0.002	<0.002	-
Calcium	<0.0005	<0.0005	-
Iron	Balance	Balance	Balance

* $\sum$ *(Cu, Ni, Mo)* $\leq$ *1%*

Element	GWD 13520 Center [weight %]	GWD 13530 Center [weight %]	E81T1-Ni1 Composition [weight %][10]
Carbon	0.058	0.070	0.03
Manganese	1.25	1.26	1.15
Phosphorus	0.009	0.009	0.008
Sulfur	0.007	0.007	0.008
Silicon	0.42	0.44	0.41
Nickel	0.91	0.81	0.91
Molybdenum	0.01	0.01	-
Chromium	0.05	0.07	-
Copper	0.03	0.03	-
Aluminum	<0.005	0.006	-
Vanadium	0.023	0.026	-
Titanium	0.030	0.034	-
Niobium	0.012	0.013	-
Cobalt	<0.005	<0.005	-
Boron	<0.0005	<0.0005	-
Zirconium	<0.01	<0.01	-
Tungsten	<0.01	<0.01	-
Tin	0.007	0.006	-
Arsenic	<0.002	<0.002	-
Antimony	0.004	<0.002	-
Calcium	<0.0005	<0.0005	-
Iron	Balance	Balance	Balance

[10] *Composition from Pinnacle Alloys E81T1-Ni1 Data Sheet 0514REV0. Typical deposit composition using 100% CO_2.*

Element	GWD 13520 Original Root [weight %]	GWD 13520 Repair Root [weight %]	GWD 13530 Original Root [weight %]	GWD 13530 Repair Root [weight %]	E80S-Ni1 Composition [weight %][11]
Carbon	0.089	0.070	0.13	0.062	0.10
Manganese	0.70	1.11	1.04	0.95	1.10
Phosphorus	0.009	0.010	0.011	0.010	0.01
Sulfur	0.010	0.011	0.015	0.011	0.01
Silicon	0.27	0.52	0.26	0.39	0.60
Nickel	0.77	0.82	0.23	0.71	1.00
Molybdenum	0.22	0.19	0.08	0.20	0.10
Chromium	0.09	0.14	*0.15*	0.12	-
Copper	0.19	0.23	0.12	0.22	0.12
Aluminum	0.015	0.024	0.029	0.005	-
Vanadium	0.003	0.004	0.027	0.005	-
Titanium	<0.002	0.006	0.002	0.003	-
Niobium	0.002	0.005	<0.002	0.005	-
Cobalt	0.007	0.007	0.005	0.006	-
Boron	0.0005	0.0006	0.0005	0.0005	-
Zirconium	<0.01	<0.01	<0.01	<0.01	-
Tungsten	<0.01	<0.01	<0.01	<0.01	-
Tin	0.007	0.006	0.007	0.007	-
Arsenic	0.003	0.002	0.002	0.002	-
Antimony	0.004	0.004	0.003	0.004	-
Calcium	0.0023	0.0051	0.0013	0.0011	-
Iron	Balance	Balance	Balance	Balance	Balance

DISCUSSION and CONCLUSIONS

The cause of the rupture in GWD 13530 was attributed to fatigue (progressive) cracking. There were three, circumferentially oriented individual fatigue cracks identified; the largest being centered approximately 4.5” clockwise from TDC. The circumferential orientation of the cracks suggests a bending stress to be the driving mechanism. The fatigue cracks originated from a lack-of-fusion region at the ID toe of the girth weld on the pipe-side. The individual fatigue cracks propagated linearly through the pipe side of the weld, intersecting multiple microstructural features in the process. There was no evidence observed that any of the fatigue cracks penetrated the full wall thickness, indicating the final overload and subsequent petroleum

[11] *Composition from Pinnacle Alloys E80S-Ni1 Data Sheet 0514REV0. Typical deposit composition.*

release was an instantaneous event that occurred when the remaining ligament could no longer support the applied load.

The primary evidence observed that identified the initiating feature/s as lack-of-fusion was the tightly adhered oxide scale lining the surfaces of the features. Tightly adhered oxide scale (magnetite or Fe_3O_4) forms preferentially at higher temperatures, typically higher than 600°C. This temperature would likely have been achieved and or exceeded during welding operations. The presence of this magnetite scale indicates that the surfaces were exposed to an oxygen atmosphere while still at high temperature.

The fatigue cracks in GWD 13530 appeared to progress via an unstable (brittle) crack extension mechanism consisting of a series of advance/arrest events. There was evidence of dimpled rupture observed coincident with several of the arrest features, indicating there may have been ductile tearing preceding unstable crack extension.

There was no evidence found to support a finding that the pipe material was deficient. The microstructure of the pups consisted of finely banded, fine-grained ferrite and pearlite, typical of a low carbon, microalloyed steel used to fabricate high strength line pipe. The bulk weld microstructure appeared sound, though there was intermittent interpass lack-of-fusion, gas porosity, and slag entrapment separate from the lack-of-fusion identified at the ID weld toes. The interpass defects were determined to be acceptable discontinuities per the inspection report prepared by Applus RTD. The mechanical properties and chemical composition of the pipe met the minimum specifications for API 5L grade X70 PSL 2, though there is evidence that some of the HAZ hardness exceeded the maximum set forth for grade X70. Similarly, cross-girth weld mechanical testing showed there were no deficiencies with the mechanical properties of GWD 13530 and 13520 with respect to the minimums set forth in API 1104. The exception to this was one HAZ notched CTOD specimen from GWD 13520 (439-20-16) that failed to meet the minimum CTOD value of 0.005in.

The initiating features appeared consistent with lack-of-fusion at the ID toe approximately 200µm in length. Lack-of-fusion and cracking extending from the LOF was observed on both

GWD 13530 and 13520. The toe cracking on GWD 13520 was associated with the elbow-side toe. Of importance, all indications identified by PAUT were verified metallographically.

In summary, the cause of this rupture was attributed to fatigue cracking. The fatigue cracks propagated circumferentially from a series of ID intermittent weld-toe lack-of-fusion on the pipe-side. Fatigue cracking propagated until the final overload event that resulted in the rupture and subsequent spillage of the contents of the pipe. There was no evidence that there was a leak prior to the rupture event e.g., fatigue cracking did not penetrate the full wall thickness.

If you have any questions, or need any additional information, please let us know. The samples from this investigation will be held until instructions for material disposition are provided by TC Energy.

Respectfully submitted February 7, 2023.

ANDERSON & ASSOCIATES, INC.
Engineering Firm Registration # F-816

____

Andrés Rodela, Ph.D., P.E.
Vice President of Engineering
TX Lic. #127892

APPENDICES

Appendix A – *ILVA SPA Material Test Report 2010/00007605/01 (Pups)*

Appendix B *– CANDAOIL Forge LTD. Material Test Report 6235 (Elbow)*

Appendix C *– Applus RTD Non-Destructive Test Report*

Appendix D *– Full wall thickness tensile datasheets*

Appendix E *– Sub-size pipe body tensile datasheets*

Appendix F *– Sub-size cross girth weld and all-weld tensile datasheets*

Appendix G *- CVN notch location photographs*

Appendix H *– CTOD datasheets*

Appendix I *– CTOD notch location and fracture photographs*

Appendix A
ILVA SPA Material Test Report 2010/00007605/01 (Pups)

25472-GE2-GQT-GAQ-00001 r00

A01 Manufacture's works
ILVA SPA - VIALE CERTOSA, 249 - 20151 MILANO
SOCIETA' SOGGETTA ALL'ATTIVITA' DI DIREZIONE E COORDINAMENTO DI RIVA FIRE S.P.A.
ILVA STAB. DI TARANTO VIA APPIA SS7 Km648

A02 Type of document
INSPECTION CERTIFICATE
ISO 10474 - 3.1.B

A05 Originator of the document
QUALITY CONTROL ILVA

A03 Document Nr [redacted] | Z02.1 Date of issue 22/04/2010 | A04 I/TA

A07 Customer's Order nr [redacted] | Item | Date 20/02/2009

A08 ILVA Order Item [redacted] | A09 Customer reference

A12 Vessel Name CIELO DI VANCOUVE | A13 Code 10123 | A14 Date 21/04/2010

A06.1 Customer
TRANSCANADA KEYSTONE PIPELINE LP
450 - 1ST STREET S.W.
00000 CALGARY ALBERTA - T2P 5H1 CANADA

A06.2 Consignee
TRANSCANADA KEYSTONE PIPELINE LP
C/O THE BAYOU COMPANIES LLC
07056 NEW IBERIA, LOUISIANA USA

A06.3 Consignee of the document
TRANSCANADA PIPELINES LIMITED
450 - 1ST STREET S.W.
00000 CALGARY ALBERTA - T2P 5H1 CANADA

A10 Supplementary commercial information
36" PIPELINE PROJECT - PROJECT:KEYSTONE XL ; [redacted]
ORDER FOR PIPE NO.:001
ITEM A, EXHIBIT 2: HEAVY WALL HCA ; DESIGN FACTOR: 0,72.
INTERNAL AND EXTERNAL BARE IN ACCORDANCE WITH: API 5L 44TH EDITION;
TES-PIPE-SAW-US Rev.01 --- (See Annex for acceptance limits)

B01 Product : SAWL STEEL PIPES COLD EXPANDED
B02 Steel quality : API 5L 44TH EDITION - 2007
L485M/X70M PSL2
B03 Supplementary requirements :
B04 Delivery condition : THERMO-MECHANICAL CONTROL PROCESS

B06 Marking

NOM. DIMENSIONS:
Units IN.
B09 Thickness 0,5150
B10 Diameter O 36,0000
B11 Length 480,0000
B12 Theor.Mass 7811 LBS
B16 Heat nr. 991579

DELIVERED MATERIAL

B07 Pipe no	Heat	B13 Mass	Leng.	Starting Material	C04 Reference test sample PdC	PLC	PP1	PP2	PD	PS	PW	D09 Test Pr. /PSI	Time Sec.
0030380	991579	8091	39,53	443501201	030431	030435			030283		030384	1890	10
0030382	991579	8201	39,94	443508101	030431	030435			030301		030311	1890	10
0030421	991579	7859	38,52	443505201	030431	030435			030283		030054	1890	10
0030431	991579	7782	38,09	443504101	030431	030435			030282		030317	1890	10
0030435	991579	7727	37,81	443494201	030431	030435			030301		030098	1890	10
0030444	991579	8201	39,90	443503101	030431	030435			030469		030050	1890	10
0030464	991579	8058	39,21	443495101	030431	030435			030469		030177	1890	10
0030473	991579	8201	39,91	443495201	030431	030435			030474		030052	1890	10
0030474	991579	6911	33,84	443502201	030431	030435			030474		030317	1890	10
0030475	991579	7474	36,55	443509101	030431	030435			030301		030573	1890	10
0030489	991579	7793	38,07	443486101	030431	030435			030469		030099	1890	10
0030494	991579	7727	37,91	444420101	030431	030435			030469		030050	1890	10
0030507	991579	7683	37,71	443506201	030431	030435			030282		030051	1890	10
0030516	991579	6922	33,89	443503201	030431	030435			030469		030177	1890	10
0030519	991579	8003	39,03	443500201	030431	030435			030469		030050	1890	10
0030521	991579	8003	39,14	443487101	030431	030435			030474		030052	1890	10
0030525	991579	7496	36,55	443507201	030431	030435			030474		030052	1890	10
0030647	991579	8135	39,83	443512101	030431	030435			030623		030051	1890	10
0030705	991579	6967	34,27	443511101	030431	030435			030640		030310	1890	10
0030712	991579	7110	34,94	443505101	030431	030435			030623		030051	1890	10
0030720	991579	8201	39,99	443493201	030431	030435			030640		030278	1890	10
0030732	991579	8091	39,45	443492201	030431	030435			030623		030317	1890	10
0030769	991579	8036	39,16	443506101	030431	030435			030633		030050	1890	10
0030780	991579	8146	39,60	443511201	030431	030435			030623		030317	1890	10
0030794	991579	8135	39,47	443510201	030431	030435			030633		030294	1890	10
0030809	991579	8190	39,91	443500101	030431	030435			030625		030573	1890	10
0030828	991579	8179	39,96	443499101	030431	030435			030633		030384	1890	10
0030832	991579	7981	39,04	443501101	030431	030435			030623		030317	1890	10
0030873	991579	8124	39,55	443494101	030431	030435			030469		030050	1890	10
0030897	991579	8179	39,98	443497201	030431	030435			030880		032130	1890	10
0030921	991579	8223	39,94	444421101	030431	030435			030962		030908	1890	10
0030943	991579	8025	39,32	443498201	030431	030435			030987		031362	1890	10
0031071	991579	7892	38,53	444418101	030431	030435			031197		030907	1890	10
0031149	991579	7628	37,25	443508201	030431	030435			030962		031194	1890	10
0031177	991579	7485	36,48	443496101	030431	030435			031068		030999	1890	10
0031191	991579	7694	37,63	443513201	030431	030435			031067		031230	1890	10
0031210	991579	8080	39,53	443499201	030431	030435			031093		031406	1890	10
0031234	991579	7430	36,53	443510101	030431	030435			031093		031194	1890	10
0031378	991579	8058	39,35	443493101	030431	030435			031365		030908	1890	10
0031383	991579	8179	39,93	443489101	030431	030435			031312		031189	1890	10
0031384	991579	8113	39,58	443490201	030431	030435			031452		031253	1890	10
0031389	991579	8190	39,94	443490101	030431	030435			031365		030970	1890	10
0031443	991579	8036	39,24	443488101	030431	030435			031365		030908	1890	10
0031481	991579	7915	38,68	443491201	030431	030435			031452		031075	1890	10
0031709	991579	7760	37,91	444418201	030431	031771			031664		030904	1890	10
0031752	991579	7716	37,48	443512201	030431	031771			031664		030999	1890	10
0031795	991579	8179	39,71	444419101	030431	031771			031760		031064	1890	10
0031934	991579	7738	37,65	443507101	030431	031771			031759		031219	1890	10

C04 Frequency code
PdC = Heat
PLC = Lot of heat
PP1 = Prod. lot 1
PP2 = Prod. lot 2
PD = Per Day
PS = Per shift
PW = Per Week

C10 Shape of the test piece
P = Prismatic
C = Round bar

* = Mill No.
F = Reject
R = Retest

Skt 728724

Z03 Inspection Body Stamp

Z02.2 QC Validation

M. BUCCI

Z05 Ms Certifications

IQNet IGQ ISO 9001:2008 ISO/TS 16949 ISO 14001 OHSAS 18001 SINCERT

25472-GE2-GQT-GAQ-00001 r00

A01 Manufacture's works
ILVA SPA - VIALE CERTOSA, 249 - 20151 MILANO
SOCIETA' SOGGETTA ALL'ATTIVITA' DI DIREZIONE E COORDINAMENTO DI RIVA FIRE S.P.A.
ILVA
STAB. DI TARANTO VIA APPIA SS7 Km648

A02 Type of document
INSPECTION CERTIFICATE
ISO 10474 - 3.1.B

A05 Originator of the document
QUALITY CONTROL ILVA

A03 Document Nr. [redacted]
Z02.1 Date of issue 22/04/2010
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A07 Customer's Order nr [redacted] Item Date 20/02/2009
A08 ILVA Order Item [redacted]
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A12 Vessel Name CIELO DI VANCOUVE
A13 Code 10123
A14 Date 21/04/2010

A06.1 Customer
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450 - 1ST STREET S.W.
00000 CALGARY ALBERTA - T2P 5H1 CANADA

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450 - 1ST STREET S.W.
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A10 Supplementary commercial information
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ORDER FOR PIPE NO.:001
ITEM A, EXHIBIT 2: HEAVY WALL HCA ; DESIGN FACTOR: 0,72.
INTERNAL AND EXTERNAL BARE IN ACCORDANCE WITH: API 5L 44TH EDITION;
TES-PIPE-SAW-US Rev.01 --- (See Annex for acceptance limits)

B01 Product : SAWL STEEL PIPES COLD EXPANDED
B02 Steel quality : API 5L 44TH EDITION - 2007
L485M/X70M PSL2
B03 Supplementary requirements :
B04 Delivery condition : THERMO-MECHANICAL CONTROL PROCESS

B06 Marking

NOM. DIMENSIONS:
Units IN.
B09 Thickness 0,5150
B10 Diameter O 36,0000
B11 Length 480,0000
B12 Theor.Mass 7811 LBS
B16 Heat nr. 991579

DELIVERED MATERIAL

B07 Pipe no	Heat	B13 Mass	Leng.	Starting Material	C04 Reference test sample PdC	PLC	PP1	PP2	PD	PS	PW	D09 Test Pr. /PSI	Time Sec.
0031958	991579	8168	39,90	443496201	030431	031771			031759		030999	1890	10
0031990	991579	8190	39,68	443486201	030431	031771			032013		*764487	1890	10
0031991	991579	8146	39,93	443502101	030431	031771			032041		*763010	1890	10
0032001	991579	8168	39,78	443504201	030431	031771			032013		*764487	1890	10
0032002	991579	8146	39,86	443509201	030431	031771			031760		031406	1890	10
0032121	991579	8025	39,04	444419201	030431	031771			032109		031189	1890	10

B08 Total pieces : 54 B14 Total mass LBS: 426790 Total Length FT : 2083,62

CHEMICAL COMPOSITION AND STEELMAKING PROCESS

C70 Steelmaking process : Y (Basic Oxygen) C94 Casting method : Continuous Casting

C00 Sample Identif.	C01 Test Location	C04 Code	C71 C %	C72 Si %	C73 Mn %	C74 P %	C75 S %	C76 Al %	C77 Nb %	C78 V %	C79 Mo %	C80 Ni %	C81 Cr %	C82 Cu %
	Ladle		0,063	0,230	1,640	0,015	0,0050	0,030	0,041	0,002	0,008	0,033	0,173	0,023
030431	Product	PdC	0,065	0,235	1,634	0,015	0,0047	0,029	0,040	0,002	0,007	0,032	0,171	0,022
030435	Product	PLC	0,064	0,235	1,632	0,015	0,0045	0,029	0,041	0,002	0,007	0,032	0,179	0,022
031771	Product	PLC	0,064	0,235	1,632	0,016	0,0045	0,031	0,040	0,002	0,007	0,032	0,169	0,021

C00 Sample Identif.	C01 Test Location	C04 Code	C83 Ti %	C84 N ppm	C85 B ppm	C86 Ca ppm	C87 Sn %	C88 H ppm	C89 V1	C90 V2	C91 V3	C92 V4	C93 CEQ % ITO	IIW
	Ladle		0,023	70	1	31			0,0660	0,0430	1,8210	0,3910	0,165	
030431	Product	PdC	0,021	62	2	30			0,0630	0,0420	1,8120	0,3910	0,166	
030435	Product	PLC	0,021	62	2	28			0,0640	0,0430	1,8180	0,3900	0,166	
031771	Product	PLC	0,021	60	2	28			0,0630	0,0420	1,8080	0,3900	0,166	

Restrictions	Heat Min	Heat Max	Product Min	Product Max
V1 = Nb + Ti + V		0,150		0,150
V2 = Nb + V		0,120		0,120
V3 = Mn + Cr + Mo		1,950		1,950
V4 = C + Mn / 5		0,410		0,410
ITO		0,200		0,200

TENSILE TEST

C00 Sample Identif.	C01 Loc.	C04 Code	C02 Dir	C03 Temp°C	B05 Heat Treatment	C10 Shape	C24 W/Ømm	C23 : L0 [xSQR(S0)]	C09 Unit	C11 YS RT0.5	C12 UTS	C13 EL. %	C14 Y/T	C15 Z %	C16 RMxA
030431	T180	PdC	T	+ 20		P	38,10	50,80mm	MPa	517	636	37,80	0,81		
030431	TW	PdC	T	+ 20		P	38,10	50,80mm	MPa		648	16,00			

IMPACT TEST

C00 Sample Identif.	C01	C45	C04 Code	C02 Dir	C40 T. Type	B05 Heat Treatment	C41 Width	C09 Unit	C03 Te°C	C42 Energy Val K1	K2	K3	C43 Ave	C44 Shear a D1	D2	D3	C43 Ave	C46 En.	S.A
030431	T90	surface	PdC	T	KV 2 mm		10	J	- 5	210	200	198	202	100	100	100	100	55	

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R = Retest

Skt 728724

Z03 Inspection Body Stamp

Z02.2 QC Validation

M. BUCCI

Z05 Ms Certifications
IQNet
IGQ
ISO 9001:2008
ISO/TS 16949
ISO 14001
OHSAS 18001
CERTIFIED QUALITY MANAGEMENT SYSTEM ISO 9001:2008
SINCERT

25472-GE2-GQT-GAQ-00001 r00

A01 Manufacture's works
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SOCIETA' SOGGETTA ALL'ATTIVITA' DI DIREZIONE E COORDINAMENTO DI RIVA FIRE S.P.A.
ILVA STAB. DI TARANTO VIA APPIA SS7 Km648

A02 Type of document
INSPECTION CERTIFICATE
ISO 10474 - 3.1.B

A05 Originator of the document
QUALITY CONTROL ILVA

A03 Document Nr. [redacted]
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A13 Code 10123
A14 Date 21/04/2010

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TRANSCANADA KEYSTONE PIPELINE LP
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450 - 1ST STREET S.W.
00000 CALGARY ALBERTA - T2P 5H1 CANADA

A10 Supplementary commercial information
36" PIPELINE PROJECT - PROJECT:KEYSTONE XL ; [redacted]
ORDER FOR PIPE NO.:001
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B02 Steel quality : API 5L 44TH EDITION - 2007
L485M/X70M PSL2
B03 Supplementary requirements :
B04 Delivery condition : THERMO-MECHANICAL CONTROL PROCESS

B06 Marking

NOM. DIMENSIONS:
Units IN.
B09 Thickness 0,5150
B10 Diameter O 36,0000
B11 Length 480,0000
B12 Theor.Mass 7811 LBS
B16 Heat nr. 991579

IMPACT TEST

C00 Sample Identif.	C01	C45	C04 Code	C02 Dir	C40 T. Type	B05 Heat Treatment	C41 Width	C09 Unit	C03 Te°C	C42 Energy Val K1	K2	K3	C43 Ave	C44 Shear a D1	D2	D3	C43 Ave	C46 En.	S.A
030431	WM	surface	PdC	T	KV 2 mm		10	J	- 5	86	92	114	97	100	100	100	100	55	1
030431	HAZ	2 mm	PdC	T	KV 2 mm		10	J	- 5	138	146	132	138	100	100	100	100	55	1

HARDNESS TEST

C00 Sample Sample	C01 Loc.	C04 Code	C30 Method	C33 Load (Kg)	C31 WM min	max	mean	HAZ min	max	mean	BM min	max	mean
030431	TW	PdC	VICKERS	1	222	228	224	208	219	211	193	199	196

BEND TEST

C00 Sample Identif.	C01 Loc.	C04 Code	C02 Dir	C53 Kind of Test	C51 Angle	C52 Male	C50 Result
030435	TW	PLC	T	Face-Root API 5L	180°	157,5	OK
031771	TW	PLC	T	Face-Root API 5L	180°	157,5	OK

DWTT TEST - PRESSED NOTCH

C00 Sample Identif.	C01 Loc.	C04 Code	C02 Dir	C41 Thickness	C03 Temp°C	C44 Shear area % S1	S2	S3	C43 Ave
030431	T90	PdC	T	Full	- 5	100	100		100

MACROGRAPHIC INVESTIGATION

C00 Sample Sample		C04 Code	Outside weld Width	Height	Depth	Inside weld Width	Height	Depth	Out of line	Cross pen.	
030431		PdC	23,1	13,7	10,8	24,3	8,9	6,3	0,8	3,1	

D01 Visual,marking and dimensional inspection : OK
D07 Method of Non Destructive weld inspection: Ultrasonic - notch N5 - hole 1,6
Z01 We hereby certify that the material complies with the terms of the order.

C04 Frequency code
PdC = Heat
PLC = Lot of heat
PP1 = Prod. lot 1
PP2 = Prod. lot 2
PD = Per Day
PS = Per shift
PW = Per Week

C10 Shape of the test piece
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C = Round bar

* = Mill No.
F = Reject
R = Retest

Skt 728724

Z05 Ms Certifications
IQNet IGQ ISO 9001:2008 ISO/TS 16949 ISO 14001 OHSAS 18001 SINCERT

Z03 Inspection Body Stamp

Z02.2 QC Validation
M. BUCCI

Appendix B
CANDAOIL Forge LTD. Material Test Report 6235 (Elbow)

5/2

CANADOIL FORGE LTD.
805 Boul. Alphonse Deshaies
Bécancour, Québec G9H 2Y8 CANADA
Tel : (819) 294-6600 Fax : (819) 294-6189

MATERIAL TEST REPORT

To 3.1.B, EN 10 204 (1991)

ISO 9001:2008 Certificate Number: **6235** Date: **2010/11/15** Page 1 of 2

Customer: **CFC INC.** P. O.: [redacted]

Sales Order: **10367** Packing List: **18752 - 01**

Product Specification: **MSS SP-75 (08) WPHY-70 Welded**
Trans-Canada US TES-FITG-LD-US

Item	Item Description	Quantity	Canadoil Heat Code	Heat Treatment Type	Temp (F°)
2	ELL 36" 3D 30º 0,515 WPHY70-W	2	NPY-C	Quench & Tempering	Tempering
Piece Number	174458 - 174459 38F, 109				1110
2	ELL 36" 3D 30º 0,515 WPHY70-W	5	NQF-C	Quench & Tempering	Tempering
Piece Number	174462 - 174463 - 174452 - 174453 - 174461 126, 114E, 126A, 140				1110
2.1	ELL 36" 3D 30º 0,515 WPHY70-W	1	NOP-C	Quench & Tempering	Tempering
Piece Number	174469 98				1110
2.1	ELL 36" 3D 30º 0,515 WPHY70-W	1	NRM-C	Quench & Tempering	Tempering
Piece Number	- 174477				1110
2.1	ELL 36" 3D 30º 0,515 WPHY70-W	3	NRN-C	Quench & Tempering	Tempering
Piece Number	- 174470 - 174474 - 174491				1110
4	ELL 36" 3D 34º 0,465 WPHY70-W	1	NQG-C	Quench & Tempering	Tempering
Piece Number	- 174498				1110

Notes

Tests

1. All butt welds were radiographed and acceptable to UW-51 of ASME, SECTION VIII, DIVISION 1
2. HardnessTest Performed ✓ Report Ref. #: **1875201**
3. Other NDE Performed: Report Ref. #: **N/A**
4. Indicated specification limits of tensile tests (if any) are for longitudinal tests on base material only.
5. Indicated specification limits of impact tests (if any) are for base material only.

Legend

- L - Heat (ladle) analysis N/A - Not applicable
- P - Product analysis
- Long. - Base material, longitudinal
- Trans. - Base material, transversal
- HAZ. - Heat affected zone
- Weld L - Weld, longitudinal

Results of Chemical Analysis (%)

Item / Heat		CE	C	Mn	Si	P	S	Cr	Ni	Mo	Al	Cu	Cb	V	B	Ti	N
Spec. Limits	Min																
	Max		0.3	1.6	0.5	0.04	0.04	0.25	0.5	0.25		0.5	0.1	0.13		0.05	
2	L		0.16	1.15	0.23	0.006	0.002	0.17	0.04	0.01	0.017	0.09	0.001	0.044	0.0005	0.002	
NPY-C	P	0.4358	0.181	1.19	0.247	0.0063	0.005	0.175	0.055	0.016	0.014	0.096	0.0022	0.041	0.0011	0.0015	0.019
2	L		0.16	1.15	0.23	0.01	0.003	0.17	0.06	0.02	0.018	0.12	0.001	0.04	0.0007	0.002	
NQF-C	P	0.4195	0.168	1.17	0.236	0.011	0.006	0.172	0.07	0.018	0.015	0.124	0.0018	0.038	0.0008	0.0013	0.019
2.1	L		0.19	1.34	0.33	0.011	0.003	0.23	0.03	0.01	0.033	0.04	0.001	0.051		0.004	
NOP-C	P	0.4433	0.159	1.33	0.321	0.012	0.005	0.232	0.034	0.0087	0.027	0.04	0.0025	0.048	0.0008	0.0033	0.0049
2.1	L		0.16	1.17	0.24	0.012	0.003	0.18	0.13	0.03	0.015	0.14	0.002	0.044	0.0005	0.002	
NRM-C	P	0.4436	0.179	1.18	0.243	0.011	0.005	0.174	0.138	0.031	0.012	0.147	0.0024	0.04	0.0009	0.0014	0.019
2.1	L		0.16	1.16	0.23	0.0103	0.004	0.17	0.1	0.04	0.021	0.18	0.001	0.043	0.0008	0.002	
NRN-C	P	0.4410	0.17	1.19	0.242	0.015	0.008	0.175	0.116	0.046	0.017	0.192	0.002	0.041	0.001	0.0015	0.019
4	L		0.16	1.11	0.34	0.013	0.004	0.19	0.05	0.07	0.031	0.05	0.032	0.049		0.004	
NQG-C	P	0.3962	0.149	1.1	0.32	0.016	0.007	0.16	0.053	0.081	0.024	0.048	0.033	0.045	0.0007	0.0039	0.0064

Tensile Test Results / **Impact Test Results**

Item / Heat	Loc.	Tensile [Ksi]	Yield [Ksi]	% Elong (2")	Loc.	Energy [lb-ft]	Shear [%]	Temp F°
Min 4		82.00	70.00		Min Ave 5			
Max					Min Low	20		
2 NPY-C	Long.	90.79	72.81	41	Base	29.5- 39.1- 40.6	52 - 52 - 50	-51
	Weld	90.21	73.39	31	Weld	86.3- 78.9- 78.2		-51
	N/A				N/A			
2 NQF-C	Long.	88.33	70.92	44	Base	125.4-193.2-133.5	57 - 62 - 63	-51
	Weld	88.62	71.36	45	Weld	65.6- 79.7- 70.8		-51
	N/A				N/A			
2.1 NOP-C	Long.	97.61	75.56	45	Base	112.1-115.8-129.8	36 - 38 - 50	-51
	Weld	93.26	73.24	33	Weld	64.2- 62.0- 68.6		-51
	N/A				N/A			
2.1 NRM-C	Long.	108.78	98.19	35	Base	115.8- 92.2-106.9	50 - 50 - 52	-51
	Weld	97.32	78.18	33	Weld	69.3- 85.6- 67.9		-51
	N/A				N/A			
2.1 NRN-C	Long.	101.67	84.56	38	Base	113.6-100.3-103.3	55 - 52 - 52	-51
	Weld	98.05	78.47	39	Weld	44.3- 66.4- 70.1		-51
	N/A				N/A			
4 NQG-C	Long.	93.69	80.21	44	Base	115.1-130.5-130.5	50 - 52 - 50	-51
	Weld	86.88	73.97	36	Weld	73.8- 78.2- 78.2		-51
	N/A				N/A			

WE HEREBY CERTIFY THAT THE MATERIALS LISTED ABOVE HAVE BEEN MADE IN STRICT ACCORDANCE WITH STATED SPECIFICATIONS AND THAT THE RESULT OF THE CHEMICAL ANALYSIS (HEAT) IS A TRUE AND CORRECT COPY OF THE MILL CERTIFICATE ISSUED BY THE MANUFACTURER OF THE PLATE.

Reviewed BECHTEL 1116

APPROVED BY: Quality Assurance Manager DATE 2010/11/15

CANADOIL FORGE LTD.
805 Boul. Alphonse Deshaies
Bécancour, Québec G9H 2Y8 CANADA
Tel : (819) 294-6600 Fax : (819) 294-6189

MATERIAL TEST REPORT
To 3.1.B, EN 10 204 (1991)

ISO 9001:2008 Certificate Number: 6235 Date: 2010/11/15

Customer: CFC INC. P. O.: [redacted]

Note: The Traceability table is attached to the report for the tagging references. Transverse Guided Weld Bend Tests are acceptable for each Heat lot. Cracking Test CF-18# : Material A 572 Gr.50 modified, Heat Code HRV-C / CFT-2904 rev.1. The starting plate thickness for Heat code: NQG-C -0.866"; NQF-C - 0.79"; NPY-C - 0.79"; NOP-C - 0.866"; NRN-C -0.71"; NRM-C - 0.71" . Quench & tempered 1110 Deg. Fahrenheit for 30min. Cooled in ambient air. The WPS/PQRs used for these fittings are CF 1080-2007 rev.0 and repair (if applicable) WPS/PQR CF-1052-2007 rev0. Charpy V-notch tests were taken in the tranversal rolling direction of the plate. The Charpy V-notch specimens have 0.39" x0.39" x 2.17". The heat treatment lot is defined as "lot b "as per clause 8.5.1 of the client's specification. The Fittings in this certificate have been manufactured, sampled, tested, and inspected and found acceptable as per MSS SP-75 (2008) and TES-FITG-LD-US rev.0 2007/02/09 specifcations and they meet the requirements established in theBechtel PO# 25472-100-POA-PV04-U001.

Reviewed BECHTEL 1116

WE HEREBY CERTIFY THAT THE MATERIALS LISTED ABOVE HAVE BEEN MADE IN STRICT ACCORDANCE WITH STATED SPECIFICATIONS AND THAT THE RESULT OF THE CHEMICAL ANALYSIS (HEAT) IS A TRUE AND CORRECT COPY OF THE MILL CERTIFICATE ISSUED BY THE MANUFACTURER OF THE PLATE.

APPROVED BY: Quality Assurance Manager DATE 2010/11/15

Appendix C
Applus RTD Non-Destructive Test Report

Applus

EXAMINATION OVERVIEW

PROJECT INFORMATION

CLIENT:	TC ENERGY
JOB LOCATION:	ANDERSON & ASSOCIATES, PEARLAND, TX
PROJECT:	KEYSTONE NPS36 OUT-OF-SERVICE PIPE FRACTURE INVESTIGATION
APPLUS JOB NO.:	2008000
PO / WO NO.:	N/A
INSPECTION DATE(S):	01/11/2023 - 01/13/2023
REPORT DATE:	1/18/2023

INDIVIDUALS INVOLVED

NAME	ROLE	METHOD(S)
Dennis Teeter, Jr.	Operations Manager	N/A
Cameron Seward	Advanced Lead	MT, UT, PAUT, ToFD, IWEX, HandyScan
Bobby Shrout	Lead	RT, RTR
Grayson Davies	Lead	IWEX
Nick Balzer	Assistant	RT, RTR
Josh Rangel	Assistant	IWEX

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PROJECT / CLIENT INFORMATION

CLIENT:	TC Energy	REPORT NUMBER:	1		
JOB LOCATION:	Anderson & Associates, Pearland, TX	REPORT DATE:	1/18/2023	PAGE NO.:	1 of 1
PROJECT:	Keystone NPS36 Pipe Fracture Investigation	PROCEDURE NO.:	N/A	REV. NO.:	N/A
APPLUS JOB NO.:	2008000	TECHNIQUE NO.:	N/A	REV. NO.:	N/A
NDE REQUEST NO.:	N/A	CODE/STANDARD:	N/A - Information Only		
PO / WO NO.:	N/A	SPECIFICATION:	N/A		

TABLE OF CONTENTS

SUPPLEMENTAL REPORTS

	NAME	SIGNATURE	CERTIFICATION	DATE
Technician:	Cameron Seward		IWEX, HandyScan **SNT-TC-1A** LVL II MT, ToFD **PCN** LVL II UT, PAUT	1/18/2023

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EVALUATION SUMMARY

PROJECT / CLIENT INFORMATION

CLIENT:	TC Energy	REPORT NUMBER:	1		
JOB LOCATION:	Anderson & Associates, Pearland, TX	REPORT DATE:	1/18/2023	PAGE NO.:	1 of 1
PROJECT:	Keystone NPS36 Pipe Fracture Investigation	PROCEDURE NO.:	N/A	REV. NO.:	N/A
APPLUS JOB NO.:	2008000	TECHNIQUE NO.:	N/A	REV. NO.:	N/A
NDE REQUEST NO.:	N/A	CODE/STANDARD:	N/A - Information Only		
PO / WO NO.:	N/A	SPECIFICATION:	N/A		

INSPECTION SUMMARY

Assessment Information:
Non-Destructive Evaluation (NDE) was performed by Applus on TC Energy's Keystone 36NPS Pipe Fracture Investigation located at Anderson & Associates, Inc. between January 13, 2023 and January 15,2023. Additionally, Applus representatives were present for unboxing of the segment on January 11, 2023 to gain an understanding of the segment geometry.

Inspection was carried out in accordance with Applus written practice and procedures in conformance with TC Energy guidelines.

All bare pipe areas were abrasive blast bleaned to near white finish (NACE 2/SSPC 10) for inspection. Coating was not removed or blasted in the area in proximity to the fracture location.

The pipe segment contained one (1) 3D bend pipe fitting of 0.850" NWT, two (2) adjacent pups of 0.550" NWT, and one (1) segment of linear transmission piping of 0.500" NWT. Additionally, one (1) field girth weld and two (2) factory welds were present.

Assessment Scope:
Visual inpsection was performed on the abrasive blasted pipe for the extent of the bare pipe area.

Magnetic Particle Inspection (MPI) was performed on the full circumference of the blasted area on the OD surface including all exposed seams and girth welds. Additionally, MPI was performed on the full circumference of the ID root pass and HAZ of GW13510, 13520. GW13530 was assessed for approximantely 75% of the circumferential extent due to not wanting to intruduce any contaminants in the fracture region.

Zero degree ultrasonic inspection was performed to measure actual wall thickness and scan for laminations near the weld.

Phased array ultrasonic inspection, with supplemental ToFD inspection, was performed on all three exposed girth welds.

Applus IWEX full-matrix capture ultrasonic inspection was performed on all three exposed girth welds. However, after analysis of the collected data, due to the complex geometry of the pipe segment, IWEX was determined to not provide any additional beneficial information over PAUT/ToFD inspection.

RT/RTR was performed on all three exposed girthwelds. GW13520 was not able to be scanned with RTR. RT/RTR results are provided in supplementary reports.

Creaform HandyScan mapping of both the ID and OD surface was collected for further modeling and analysis.

Hi-Lo measurements were taken utilizing a Hi-Lo guage taken from the centerline of the weld for both the upstream and downstream extents of the three exposed girthwelds.

	NAME	SIGNATURE	CERTIFICATION	DATE
Technician:	Cameron Seward		IWEX, HandyScan **SNT-TC-1A** LVL II MT, ToFD **PCN** LVL II UT, PAUT	1/18/2023

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PHOTO REPORT

PROJECT / CLIENT INFORMATION

CLIENT:	TC Energy	REPORT NUMBER:	1		
JOB LOCATION:	Anderson & Associates, Pearland, TX	REPORT DATE:	1/18/2023	PAGE NO.:	1 of 7
PROJECT:	Keystone NPS36 Pipe Fracture Investigation	PROCEDURE NO.:	N/A	REV. NO.:	N/A
APPLUS JOB NO.:	2008000	TECHNIQUE NO.:	N/A	REV. NO.:	N/A
NDE REQUEST NO.:	N/A	CODE/STANDARD:	N/A - Information Only		
PO / WO NO.:	N/A	SPECIFICATION:	N/A		

Photograph Report

12 O'clock Specimen Overview

6 O'clock Specimen Overview

	NAME	SIGNATURE	CERTIFICATION	DATE
Technician:	Cameron Seward		IWEX, HandyScan **SNT-TC-1A** LVL II MT, ToFD **PCN** LVL II UT, PAUT	1/18/2023

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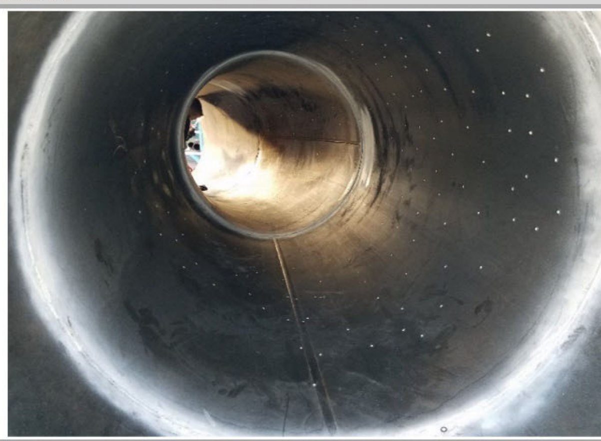
PROJECT / CLIENT INFORMATION

CLIENT:	TC Energy	REPORT NUMBER:	1		
JOB LOCATION:	Anderson & Associates, Pearland, TX	DATE:	1/13/2023	PAGE NO.:	2 of 7
PROJECT:	Keystone NPS36 Pipe Fracture Investigation	PROCEDURE NO.:	N/A	REV. NO.:	N/A
APPLUS JOB NO.:	2008000	TECHNIQUE NO.:	N/A	REV. NO.:	N/A
NDE REQUEST NO.:	N/A	CODE/STANDARD:	N/A - Information Only		
PO / WO NO.:	N/A	SPECIFICATION:	N/A		

Photograph Report

Upstream Internal Specimen Overview

Downstream Internal Specimen Overview



	NAME	SIGNATURE	CERTIFICATION	DATE
Technician:	Cameron Seward		IWEX, HandyScan **SNT-TC-1A** LVL II MT, ToFD **PCN** LVL II UT, PAUT	1/18/2023

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PROJECT / CLIENT INFORMATION

CLIENT:	TC Energy	REPORT NUMBER:	1		
JOB LOCATION:	Anderson & Associates, Pearland, TX	DATE:	1/13/2023	PAGE NO.:	3 of 7
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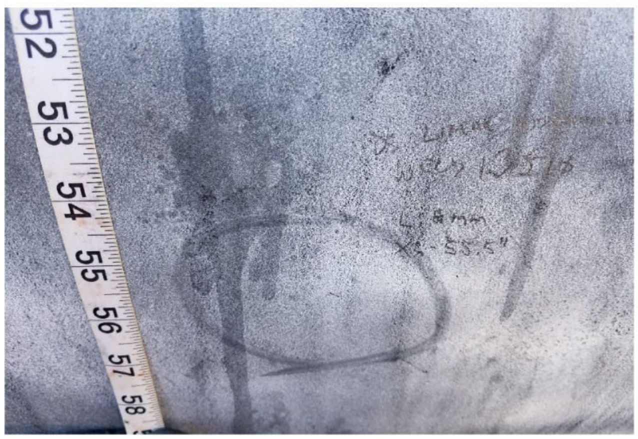
NDE REQUEST NO.:	N/A	CODE/STANDARD:	N/A - Information Only		
PO / WO NO.:	N/A	SPECIFICATION:	N/A		

Photograph Report

OD MPI Indication #1 Overview



OD MPI Indicaiton #2 Overview

	NAME	SIGNATURE	CERTIFICATION	DATE
Technician:	Cameron Seward		IWEX, HandyScan **SNT-TC-1A** LVL II MT, ToFD **PCN** LVL II UT, PAUT	1/18/2023

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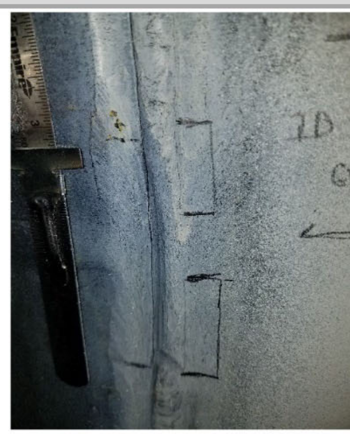
PROJECT / CLIENT INFORMATION

CLIENT:	TC Energy	REPORT NUMBER:	1		
JOB LOCATION:	Anderson & Associates, Pearland, TX	DATE:	1/13/2023	PAGE NO.:	4 of 7
PROJECT:	Keystone NPS36 Pipe Fracture Investigation	PROCEDURE NO.:	N/A	REV. NO.:	N/A
APPLUS JOB NO.:	2008000	TECHNIQUE NO.:	N/A	REV. NO.:	N/A
NDE REQUEST NO.:	N/A	CODE/STANDARD:	N/A - Information Only		
PO / WO NO.:	N/A	SPECIFICATION:	N/A		

Photograph Report

OD MPI Indication #3 Overview

ID MPI Indicaiton #1 Overview & Close-up



	NAME	SIGNATURE	CERTIFICATION	DATE
Technician:	Cameron Seward		IWEX, HandyScan **SNT-TC-1A** LVL II MT, ToFD **PCN** LVL II UT, PAUT	1/18/2023

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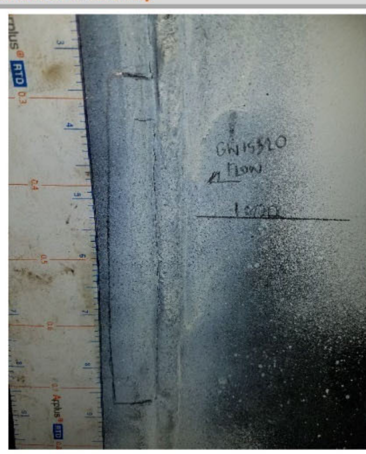
PROJECT / CLIENT INFORMATION

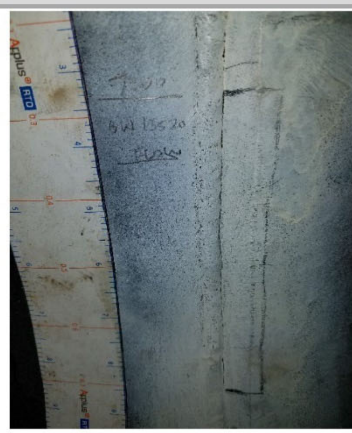
CLIENT:	TC Energy	REPORT NUMBER:	1		
JOB LOCATION:	Anderson & Associates, Pearland, TX	DATE:	1/13/2023	PAGE NO.:	5 of 7
PROJECT:	Keystone NPS36 Pipe Fracture Investigation	PROCEDURE NO.:	N/A	REV. NO.:	N/A
APPLUS JOB NO.:	2008000	TECHNIQUE NO.:	N/A	REV. NO.:	N/A
NDE REQUEST NO.:	N/A	CODE/STANDARD:	N/A - Information Only		
PO / WO NO.:	N/A	SPECIFICATION:	N/A		

Photograph Report

ID MPI Indicaiton #2 Overview & Close-up



ID MPI Indication #3 Overview



	NAME	SIGNATURE	CERTIFICATION	DATE
Technician:	Cameron Seward		IWEX, HandyScan **SNT-TC-1A** LVL II MT, ToFD **PCN** LVL II UT, PAUT	1/18/2023

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PROJECT / CLIENT INFORMATION

CLIENT:	TC Energy	REPORT NUMBER:	1		
JOB LOCATION:	Anderson & Associates, Pearland, TX	DATE:	1/13/2023	PAGE NO.:	6 of 7
PROJECT:	Keystone NPS36 Pipe Fracture Investigation	PROCEDURE NO.:	N/A	REV. NO.:	N/A
APPLUS JOB NO.:	2008000	TECHNIQUE NO.:	N/A	REV. NO.:	N/A
NDE REQUEST NO.:	N/A	CODE/STANDARD:	N/A - Information Only		
PO / WO NO.:	N/A	SPECIFICATION:	N/A		

Photograph Report

ID MPI Indicaiton #4 Overview

ID MPI Indication #5 Overview

	NAME	SIGNATURE	CERTIFICATION	DATE
Technician:	Cameron Seward		IWEX, HandyScan **SNT-TC-1A** LVL II MT, ToFD **PCN** LVL II UT, PAUT	1/18/2023

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PHOTO REPORT

PROJECT / CLIENT INFORMATION

CLIENT:	TC Energy	REPORT NUMBER:	1		
JOB LOCATION:	Anderson & Associates, Pearland, TX	DATE:	1/13/2023	PAGE NO.:	7 of 7
PROJECT:	Keystone NPS36 Pipe Fracture Investigation	PROCEDURE NO.:	N/A	REV. NO.:	N/A
APPLUS JOB NO.:	2008000	TECHNIQUE NO.:	N/A	REV. NO.:	N/A
NDE REQUEST NO.:	N/A	CODE/STANDARD:	N/A - Information Only		
PO / WO NO.:	N/A	SPECIFICATION:	N/A		

Photograph Report

ID MPI Indicaiton #6 Overview

	NAME	SIGNATURE	CERTIFICATION	DATE
Technician:	Cameron Seward		IWEX, HandyScan **SNT-TC-1A** LVL II MT, ToFD **PCN** LVL II UT, PAUT	1/18/2023

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MAGNETIC PARTICLE EXAMINATION REPORT

PROJECT / CLIENT INFORMATION

CLIENT:	TC Energy	REPORT NUMBER:	1		
JOB LOCATION:	Anderson & Associates, Pearland, TX	DATE:	1/13/2023	PAGE NO.:	1 of 1
PROJECT:	Keyston NPS36 Pipe Fracture Investigation	PROCEDURE NO.:	MT 01 NDE USA	REV. NO.:	8
APPLUS JOB NO.:	2008000	TECHNIQUE NO.:	MT 01	REV. NO.:	8
NDE REQUEST NO.:	N/A	CODE/STANDARD:	N/A - Information Only		
PO / WO NO.:	N/A	SPECIFICATION:	N/A		

ITEM(S) EXAMINED AND SURFACE CONDITIONS

PART(S) EXAMINED: OD surface of out-of-service piping segment | PART NO. / ID: N/A

MATERIAL: Mild Carbon Steel | THICKNESS: 0.550" - 0.850" | SURFACE CONDITION: NACE 2 | SURFACE TEMP: Ambient

LIGHTING CONDITIONS: ☐ UV Intensity ≥ 1000 μW/cm² @ test surface ☑ White Light Intensity ≥ 100 fc @ test surface

EQUIPMENT

Equipment/Cal. Block(s)	Asset / Serial No.	Calibration Date
AC Yoke	22322	12/13/2022
AC Yoke	37346	12/13/2022
10 lb Block	17989	6/10/2022

MATERIALS

Material Batch Number	Product ID	Manufacturer
22G11C	WCP-2	Magnaflux
21078	820A	CircleSafe

MAGNETIC PARTICLE INSPECTION TECHNIQUE

CURRENT: AC - Continuous

INSPECTION MEDIUM: Wet color contrast (water-based)

MAGNETIC PARTICLE APPLICATION: ☑ Spray ☐ Powder Applicator

DEMAGNETIZATION: ☐ Completed / Accept ☑ Not Required

MAGNETIC FIELD VERIFICATION: ☐ Accept ☐ Reject ☑ N/A

YOKE LIFT TEST VERIFICATION: ☑ Accept ☐ Reject ☐ N/A

MAGNETIC PARTICLE REMOVAL: ☐ Accept ☐ Reject ☑ N/A

POST CLEANING: ☐ Completed ☑ Not Required

INSPECTION DETAILS - RESULTS

GIRTHWELD NUMBER	AXIAL LOCATION (FT.)	OREINTATION	FEATURE #	START OF INDICATION (IN.)	END OF INDICATION (IN.)	LENGTH (IN.)	ACCEPT	REJECT	COMMENTS
13510	1.62	Axial	1	-55.500	-63.500	8.000			Mill Scab in the BM
13520	-0.03	Circ	2	-53.625	-66.625	13.000			Linear Indication in the US weld cap toe
13520	-0.03	Circ	3	-55.500	-66.500	10.000			Linear Indication in the US weld cap toe

NOTES

Full circumference MPI was perfomed on all exposed and sandblasted areas. Coating was not removed on GW 13530 in the region surrounding the fracture and thus was not assessed.

	NAME	SIGNATURE	CERTIFICATION	DATE
Technician:	Cameron Seward	Cameron Seward	IWEX, HandyScan **SNT-TC-1A** LVL II MT, ToFD **PCN** LVL II UT, PAUT	1/18/2023

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MAGNETIC PARTICLE EXAMINATION REPORT

PROJECT / CLIENT INFORMATION

CLIENT:	TC Energy	REPORT NUMBER:	1		
JOB LOCATION:	Anderson & Associates, Pearland, TX	DATE:	1/15/2023	PAGE NO.:	1 of 1
PROJECT:	Keyston NPS36 Pipe Fracture Investigation	PROCEDURE NO.:	MT 01 NDE USA	REV. NO.:	8
APPLUS JOB NO.:	2008000	TECHNIQUE NO.:	MT 01	REV. NO.:	8
NDE REQUEST NO.:	N/A	CODE/STANDARD:	N/A - Information Only		
PO / WO NO.:	N/A	SPECIFICATION:	N/A		

ITEM(S) EXAMINED AND SURFACE CONDITIONS

PART(S) EXAMINED: ID Root & HAZ of GW13510, 13520, 13530 — PART NO. / ID: N/A

MATERIAL: Mild Carbon Steel — THICKNESS: 0.550" - 0.850" — SURFACE CONDITION: NACE 2 — SURFACE TEMP: Ambient

LIGHTING CONDITIONS: ☐ UV Intensity ≥ 1000 µW/cm² @ test surface ☑ White Light Intensity ≥ 100 fc @ test surface

EQUIPMENT / MATERIALS

Equipment/Cal. Block(s)	Asset / Serial No.	Calibration Date	Material Batch Number	Product ID	Manufacturer
AC Yoke	22322	12/13/2022	22G11C	WCP-2	Magnaflux
AC Yoke	37346	12/13/2022	21078	820A	CircleSafe
10 lb Block	17989	6/10/2022			

MAGNETIC PARTICLE INSPECTION TECHNIQUE

CURRENT: AC - Continuous

INSPECTION MEDIUM: Wet color contrast (water-based)

MAGNETIC PARTICLE APPLICATION: ☑ Spray ☐ Powder Applicator

DEMAGNETIZATION: ☐ Completed / Accept ☑ Not Required

MAGNETIC FIELD VERIFICATION: ☐ Accept ☐ Reject ☑ N/A

YOKE LIFT TEST VERIFICATION: ☑ Accept ☐ Reject ☐ N/A

MAGNETIC PARTICLE REMOVAL: ☐ Accept ☐ Reject ☑ N/A

POST CLEANING: ☐ Completed ☑ Not Required

INSPECTION DETAILS - RESULTS

GIRTHWELD NUMBER	AXIAL LOCATION (FT.)	OREINTATION	FEATURE #	START OF INDICATION (IN.)	END OF INDICATION (IN.)	LENGTH (IN.)	ACCEPT	REJECT	COMMENTS
13520	0.03	Circ	1	-2.750	3.875	6.625			Edge of both side of root pass
13520	0.03	Circ	2	8.000	12.800	4.800			Edge of DS root pass
13520	0.03	Circ	3	68.000	73.900	5.900			Edge of DS root pass
13520	-0.03	Circ	4	77.400	83.800	6.300			Edge of US root pass
13530	0.03	Circ	5	19.500	25.750	6.250			Edge of DS root pass
13530	0.03	Circ	6	90.300	96.300	6.000			Edge of DS root pass

NOTES

MPI was performed on the full circumference of the ID root pass and HAZ of GW13510, 13520. GW13530 was assessed for approximantely 75% of the circumferential extent due to not wanting intruduce any contaminants in the fracture region. Circumferential locations are approximate as precise TDC measurement was not able to be obtained due to the orientation of the pipe segment.

	NAME	SIGNATURE	CERTIFICATION	DATE
Technician:	Cameron Seward	Cameron Seward	IWEX, HandyScan **SNT-TC-1A** LVL II MT, ToFD **PCN** LVL II UT, PAUT	1/18/2023

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ULTRASONIC THICKNESS REPORT

PROJECT / CLIENT INFORMATION

CLIENT:	TC Energy	REPORT NUMBER:	1		
JOB LOCATION:	Anderson & Associates, Pearland, TX	DATE:	1/13/2023	PAGE NO.:	1 of 1
PROJECT:	Keyston NPS36 Pipe Fracture Investigation	PROCEDURE NO.:	UT 07 NDE USA	REV. NO.:	0
APPLUS JOB NO.:	2008000	TECHNIQUE NO.:	UT 01	REV. NO.:	1
NDE REQUEST NO.:	N/A	CODE/STANDARD:	N/A - Information Only		
PO / WO NO.:	N/A	SPECIFICATION:	N/A		

ITEM(S) EXAMINED AND SURFACE CONDITIONS

PART(S) EXAMINED:	Out of service fitting and piping			PART NO. / ID:	N/A		
MATERIAL:	Mild Carbon Steel	THICKNESS:	0.550" - 0.850"	SURFACE CONDITION:	NACE 2	SURFACE TEMP:	Ambient
DESCRIPTION:	Out of service pipe segment consisting of one 3D bend fitting and three pup joints of varying nominal thickness's						

EQUIPMENT

Equipment/Cal. Block(s)	Asset / Serial No.	Calibration Date
Olympus DL38 Plus	20357102	11/10/2022
Step Wedge	45896	N/A

MATERIALS

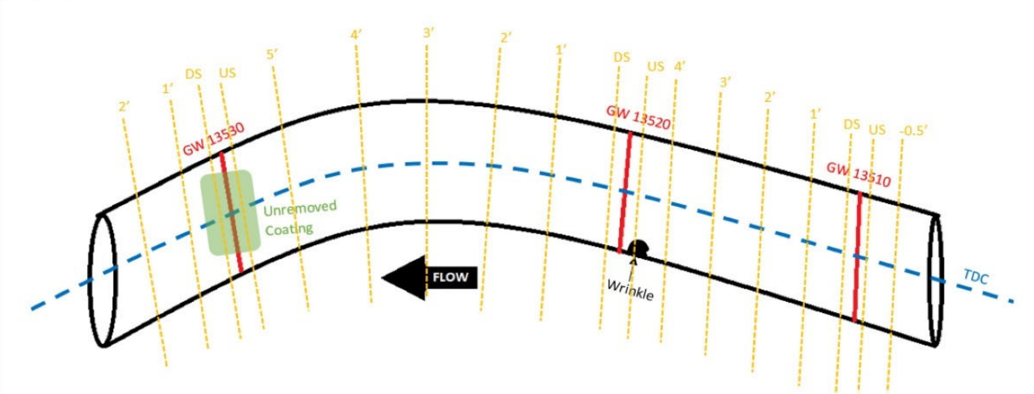
Material Batch Number	Product ID	Manufacturer
1155991	UT-X	Magnaflux
-	-	-

ULTRASONIC INSPECTION TECHNIQUE

TRANSDUCER FREQUENCY:	5 MHz	TRANSDUCER SIZE:	0.250"	TRANSDUCER TYPE:	DUAL

INSPECTION DETAILS - RESULTS

MEASUREMENT SCHEMATIC



THICKNESS READINGS TABLE (IN.)

Clock Position \ Axial (ft.)	-0.5	GW 13510 HAZ US	GW 13510 HAZ DS	1	2	3	4	GW13520 HAZ US	GW13520 HAZ DS	Outer Radius 1	Outer Radius 2	Outer Radius 3	Outer Radius 4	Outer Radius 5	GW13530 HAZ US	GW13530 HAZ DS	1	2
12	0.472	0.465	0.542	0.540	0.540	0.544	0.542	0.541	0.863	0.857	0.863	0.869	0.863	0.874	0.867	0.541	0.544	0.541
1	0.467	0.454	0.539	0.533	0.541	0.542	0.542	0.543	0.857	0.861	0.871	0.875	0.876	0.877	0.870	0.534	0.544	0.548
2	0.466	0.460	0.542	0.531	0.538	0.537	0.537	0.536	0.860	0.861	0.884	0.871	0.869	0.874	0.866	0.513	0.542	0.546
3	0.465	0.463	0.549	0.532	0.536	0.537	0.539	0.538	0.855	0.879	0.871	0.876	0.873	0.874	0.873	0.534	0.539	0.532
4	0.467	0.468	0.537	0.535	0.544	0.542	0.547	0.560	0.857	0.874	0.878	0.880	0.877	0.876	0.876	0.540	0.540	0.539
5	0.470	0.467	0.540	0.541	0.542	0.545	0.544	0.552	0.854	0.873	0.877	0.877	0.874	0.877	0.872	0.541	0.541	0.544
6	0.474	0.469	0.541	0.545	0.547	0.544	0.545	0.557	0.862	0.875	0.857	0.858	0.856	0.859	0.863	0.537	0.539	0.542
7	0.471	0.467	0.544	0.537	0.541	0.545	0.545	0.553	0.854	0.861	0.866	0.861	0.863	0.862	0.862	0.542	0.545	0.542
8	0.473	0.467	0.544	0.543	0.541	0.544	0.545	0.546	0.852	0.887	0.866	0.891	0.872	0.892	0.871	0.542	0.544	0.539
9	0.470	0.468	0.540	0.540	0.541	0.541	0.546	0.539	0.858	0.860	0.858	0.860	0.861	0.861	0.864	0.543	0.546	0.546
10	0.473	0.466	0.542	0.535	0.539	0.541	0.539	0.538	0.861	0.852	0.855	0.876	0.845	0.879	0.859	0.531	0.546	0.544
11	0.485	0.461	0.541	0.538	0.542	0.542	0.540	0.538	0.858	0.858	0.876	0.875	0.874	0.881	0.867	0.533	0.546	0.544

Legend:
- Thickness Reading taken through coating
- Thickness Reading taken on wrinkle
- HAZ Thickness Reading

	NAME	SIGNATURE	CERTIFICATION	DATE
Technician:	Cameron Seward		IWEX, HandyScan **SNT-TC-1A** LVL II MT, ToFD **PCN** LVL II UT, PAUT	1/18/2023

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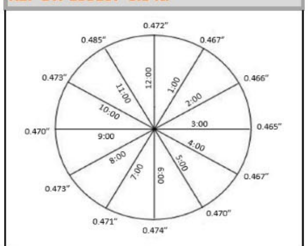
ULTRASONIC THICKNESS REPORT - DRAWINGS

PROJECT / CLIENT INFORMATION

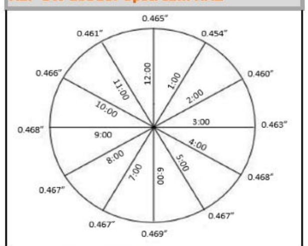
CLIENT:	TC Energy	REPORT NUMBER:	1		
JOB LOCATION:	Anderson & Associates, Pearland, TX	DATE:	1/13/2023	PAGE NO.:	1 of 2
PROJECT:	Keystone NPS36 Pipe Fracture Investigation	PROCEDURE NO.:	UT 07 NDE USA	REV. NO.:	0
APPLUS JOB NO.:	2008000	TECHNIQUE NO.:	UT 01	REV. NO.:	1
NDE REQUEST NO.:	N/A	CODE/STANDARD:	N/A - Information Only		
PO / WO NO.:	N/A	SPECIFICATION:	N/A		

DRAWINGS

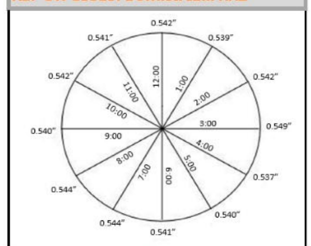
REF GW 13510: -0.5 ft.



REF GW 13510: Upstream HAZ

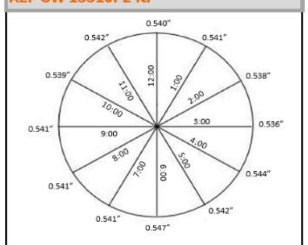


REF GW 13510: Downstream HAZ



REF GW 13510: 1 ft.

REF GW 13510: 2 ft.



REF GW 13510: 3 ft.

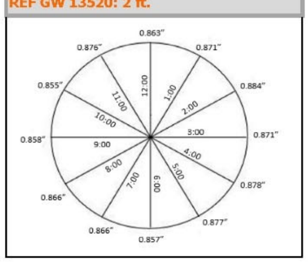
REF GW 13510: 4 ft.

REF GW 13520: Upstream HAZ

REF GW 13520: Downstream HAZ

REF GW 13520: 1 ft.

REF GW 13520: 2 ft.



REF GW 13520: 3 ft.

	NAME	SIGNATURE	CERTIFICATION	DATE
Technician:	Cameron Seward		IWEX, HandyScan **SNT-TC-1A** LVL II MT, ToFD **PCN** LVL II UT, PAUT	1/18/2023

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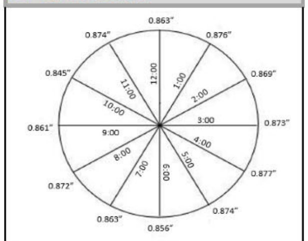
ULTRASONIC THICKNESS REPORT - DRAWINGS

PROJECT / CLIENT INFORMATION

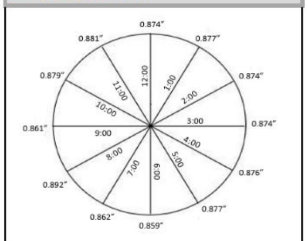
CLIENT:	TC Energy	REPORT NUMBER:	1		
JOB LOCATION:	Anderson & Associates, Pearland, TX	DATE:	1/13/2023	PAGE NO.:	2 of 2
PROJECT:	Keystone NPS36 Pipe Fracture Investigation	PROCEDURE NO.:	UT 07 NDE USA	REV. NO.:	0
APPLUS JOB NO.:	2008000	TECHNIQUE NO.:	UT 01	REV. NO.:	1
NDE REQUEST NO.:	N/A	CODE/STANDARD:	N/A - Information Only		
PO / WO NO.:	N/A	SPECIFICATION:	N/A		

DRAWINGS

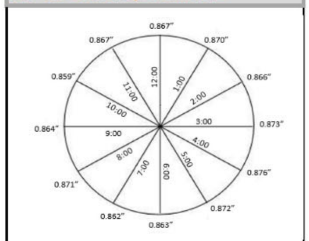
REF GW 13520: 4 ft.



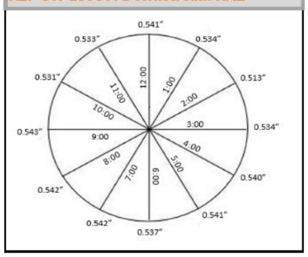
REF GW 13520: 5 ft.



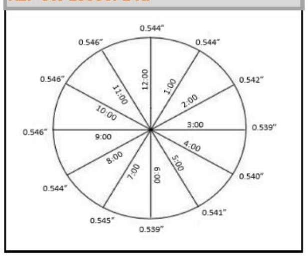
REF GW 13530: Upstream HAZ



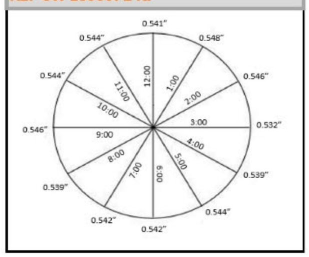
REF GW 13530: Downstream HAZ



REF GW 13530: 1 ft.



REF GW 13530: 2 ft.



	NAME	SIGNATURE	CERTIFICATION	DATE
Technician:	Cameron Seward		IWEX, HandyScan **SNT-TC-1A** LVL II MT, ToFD **PCN** LVL II UT, PAUT	1/18/2023

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HI-LO MEASUREMENT REPORT

PROJECT / CLIENT INFORMATION

CLIENT:	TC Energy	REPORT NUMBER:	1		
JOB LOCATION:	Anderson & Associates, Pearland, TX	DATE:	1/13/2023	PAGE NO.:	1 of 1
PROJECT:	Keyston NPS36 Pipe Fracture Investigation	PROCEDURE NO.:	N/A	REV. NO.:	N/A
APPLUS JOB NO.:	2008000	TECHNIQUE NO.:	N/A	REV. NO.:	N/A
NDE REQUEST NO.:	N/A	CODE/STANDARD:	N/A - Information Only		
PO / WO NO.:	N/A	SPECIFICATION:	N/A		

INSPECTION DETAILS - RESULTS

HI-LO READINGS TABLE (IN.)

Clock Position	13510			13520			13530		
	US	DS	Hi-Lo	US	DS	Hi-Lo	US	DS	Hi-Lo
12	- 1/8	- 1/8	0	- 1/16	- 5/32	3/32	- 1/32	- 3/32	1/16
1	0	- 1/16	1/16	0	- 5/32	5/32	- 1/8	- 1/32	3/32
2	- 1/32	- 1/16	1/32	- 1/32	- 5/32	1/8	- 1/32	- 1/16	1/32
3	- 1/16	- 1/16	0	1/16	- 5/32	3/32	- 1/8	1/32	3/32
4	- 1/8	- 1/16	1/16	- 1/16	W	-	- 1/8	1/32	3/32
5	- 1/16	- 1/32	1/32	0	W	-	- 1/32	- 5/32	1/8
6	- 1/16	- 1/32	1/32	- 1/16	W	-	- 1/16	- 1/16	0
7	- 1/16	0	1/16	0	W	-	- 1/32	- 1/32	0
8	- 3/32	- 1/16	1/32	1/16	W	-	- 1/32	0	1/32
9	- 1/16	- 1/32	1/32	- 1/32	W	-	- 1/16	1/32	1/32
10	- 1/32	- 1/32	0	1/16	- 1/16	0	- 1/8	- 1/32	3/32
11	- 1/32	- 1/16	1/32	- 3/32	- 1/16	1/32	- 1/32	- 3/32	1/16

(yellow)	Coating & Tape Interference
W	Measurement Not Able to be Taken Due to Presnece of Wrinkle

	NAME	SIGNATURE	CERTIFICATION	DATE
Technician:	Cameron Seward		IWEX, HandyScan **SNT-TC-1A** LVL II MT, ToFD **PCN** LVL II UT, PAUT	1/18/2022

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HI-LO MEASUREMENT REPORT - DRAWINGS

PROJECT / CLIENT INFORMATION

CLIENT:	TC Energy	REPORT NUMBER:	1		
JOB LOCATION:	Anderson & Associates, Pearland, TX	DATE:	1/13/2023	PAGE NO.:	1 of 3
PROJECT:	Keystone NPS36 Pipe Fracture Investigation	PROCEDURE NO.:	N/A	REV. NO.:	N/A
APPLUS JOB NO.:	2008000	TECHNIQUE NO.:	N/A	REV. NO.:	N/A
NDE REQUEST NO.:	N/A	CODE/STANDARD:	N/A - Information Only		
PO / WO NO.:	N/A	SPECIFICATION:	N/A		

DRAWINGS

REF GW 13510

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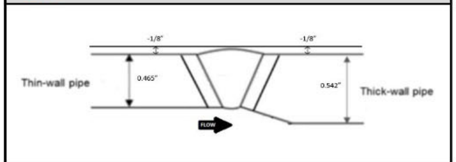
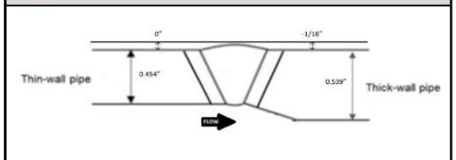


1:00



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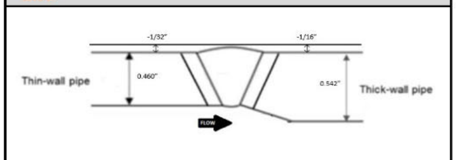

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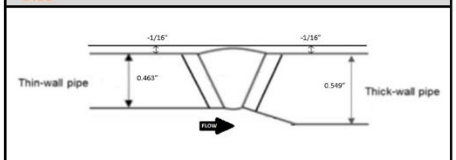

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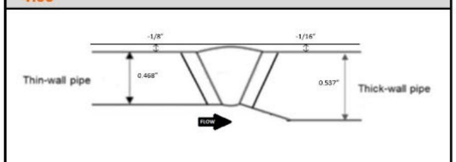

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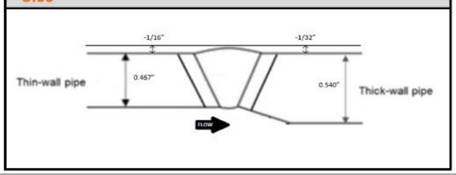

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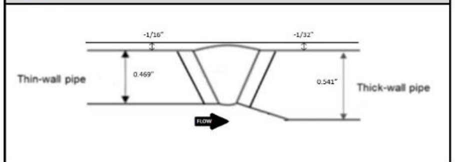

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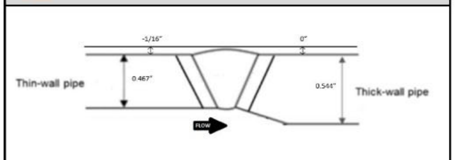

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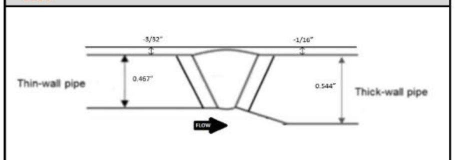

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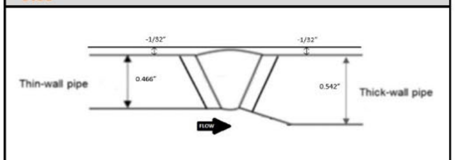

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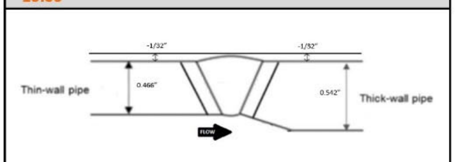

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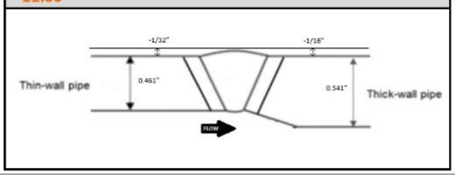

	NAME	SIGNATURE	CERTIFICATION	DATE
Technician:	Cameron Seward		IWEX, HandyScan **SNT-TC-1A** LVL II MT, ToFD **PCN** LVL II UT, PAUT	1/18/2023

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HI-LO MEASUREMENT REPORT - DRAWINGS

PROJECT / CLIENT INFORMATION

CLIENT:	TC Energy	REPORT NUMBER:	1		
JOB LOCATION:	Anderson & Associates, Pearland, TX	DATE:	1/13/2023	PAGE NO.:	2 of 3
PROJECT:	Keystone NPS36 Pipe Fracture Investigation	PROCEDURE NO.:	N/A	REV. NO.:	N/A
APPLUS JOB NO.:	2008000	TECHNIQUE NO.:	N/A	REV. NO.:	N/A
NDE REQUEST NO.:	N/A	CODE/STANDARD:	N/A - Information Only		
PO / WO NO.:	N/A	SPECIFICATION:	N/A		

DRAWINGS

REF GW 13520

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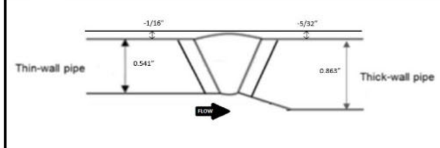

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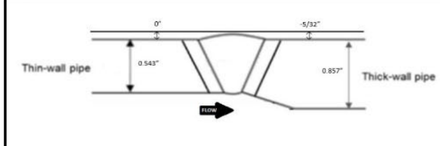

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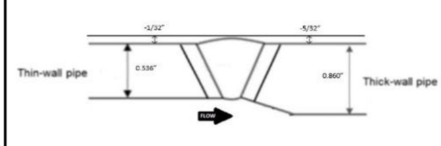

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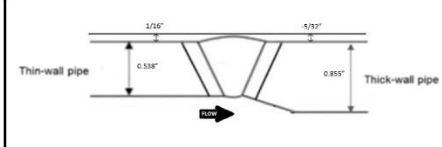

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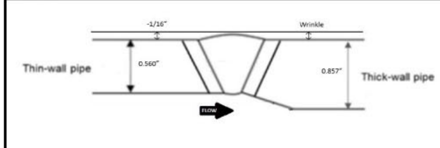

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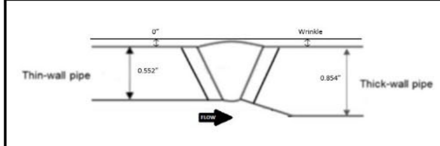

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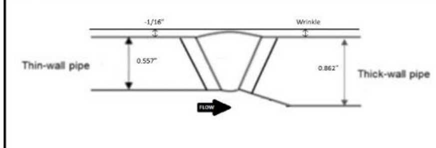

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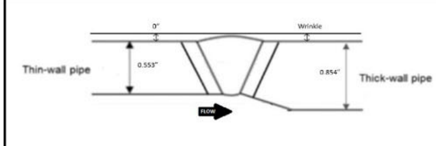

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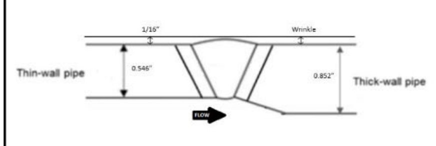

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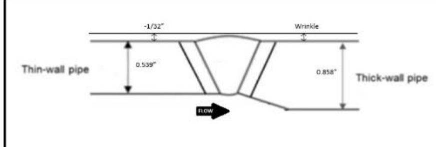

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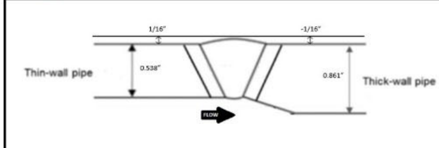

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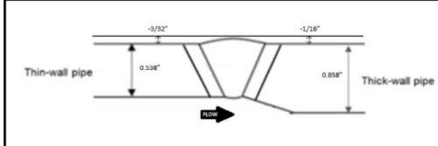

	NAME	SIGNATURE	CERTIFICATION	DATE
Technician:	Cameron Seward		IWEX, HandyScan **SNT-TC-1A** LVL II MT, ToFD **PCN** LVL II UT, PAUT	1/18/2023

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HI-LO MEASUREMENT REPORT - DRAWINGS

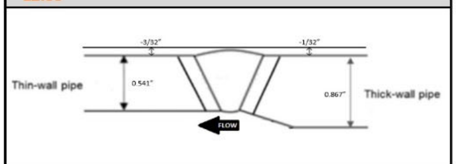
PROJECT / CLIENT INFORMATION

CLIENT:	TC Energy	REPORT NUMBER:	1		
JOB LOCATION:	Anderson & Associates, Pearland, TX	DATE:	1/13/2023	PAGE NO.:	3 of 3
PROJECT:	Keystone NPS36 Pipe Fracture Investigation	PROCEDURE NO.:	N/A	REV. NO.:	N/A
APPLUS JOB NO.:	2008000	TECHNIQUE NO.:	N/A	REV. NO.:	N/A
NDE REQUEST NO.:	N/A	CODE/STANDARD:	N/A - Information Only		
PO / WO NO.:	N/A	SPECIFICATION:	N/A		

DRAWINGS

REF GW 13530

12:00



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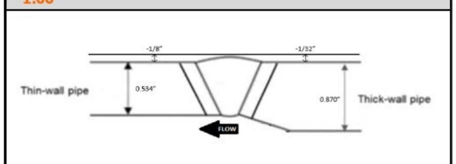

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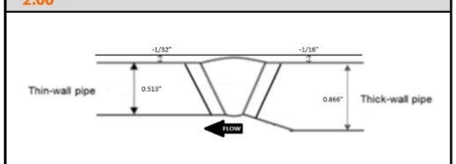

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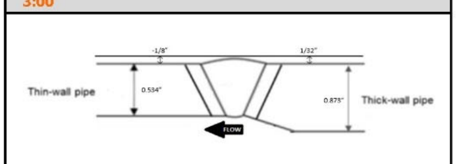

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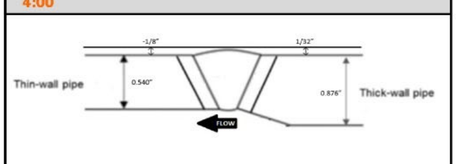

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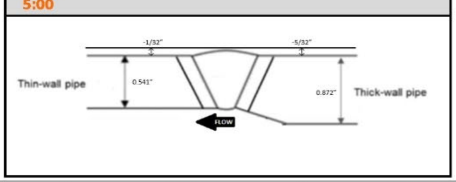

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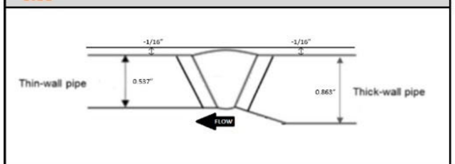

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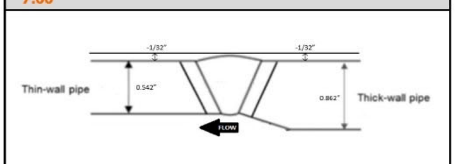

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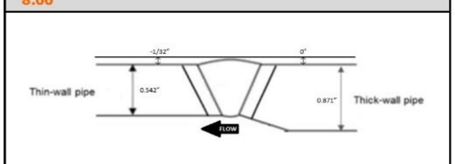

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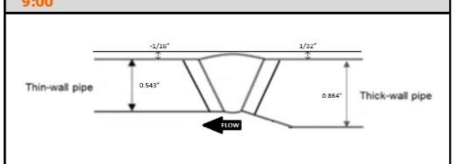

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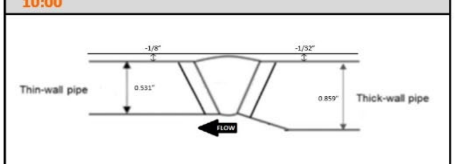

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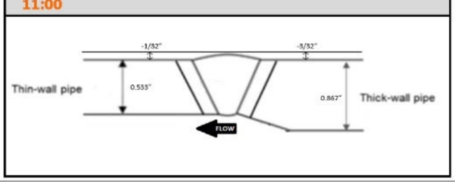

	NAME	SIGNATURE	CERTIFICATION	DATE
Technician:	Cameron Seward		IWEX, HandyScan **SNT-TC-1A** LVL II MT, ToFD **PCN** LVL II UT, PAUT	1/18/2023

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PHASED ARRAY ULTRASONIC (PAUT) / TIME OF FLIGHT DIFFRACTION (TOFD) WELD EXAMINATION REPORT

PROJECT / CLIENT INFORMATION

CLIENT:	TC Energy	REPORT NUMBER:	GW 13510, GW 13520, GW 13530		
JOB LOCATION:	Anderson & Associates, Pearland, TX	DATE:	1/12/2023	PAGE NO.:	1 of 1
PROJECT:	Keystone NPS36 Pipe Fracture Investigation	PROCEDURE NO.:	UT 46 NDE USA	REV. NO.:	2
APPLUS JOB NO.:	2008000	TECHNIQUE NO.:	PIA 200.1	REV. NO.:	2
NDE REQUEST NO.:	N/A	CODE / STANDARD:	N/A - Information Only		
PO / WO NO.:	N/A	SPECIFICATION:	N/A		

TESTING EQUIPMENT AND SET-UP PARAMETERS

ACQUISITION UNIT		PROBE AND WEDGE	SKEW 90	SKEW 270	TOFD	GROUP SETTINGS	1	2	3	4	MATERIAL INFORMATION	REF STD	ITEM
MODEL:	Olympus X3	PROBE:	10L32	10L32	1/8" Single	SCAN:	90	90	270	270	MATERIAL TYPE:	Carbon Steel	Mild Carbon Steel
MODULE TYPE:	32:128PR	PROBE MODEL:	A10	A10	C563	ANGLE:	40-70	40-70	40-70	40-70	VELOCITY:	0.1276 in/µs	0.1276 in/µs
MAIN FRAME SERIAL NO.:	QC-0073503	SERIAL NO.:	U1307	V1692	1273389	START:	0.0"	0.0"	0.0"	0.0"	SURFACE COND:	Polished	NACE 2
CAL DUE DATE:	8/17/2023	FREQUENCY:	10 MHz	10 MHz	10 MHz	RANGE:	2.4"	4.9"	2.4"	4.9"	COUPLANT:	Water	Water
MODULE SERIAL NO.:	QC-0073503	CABLE LENGTH:	6 ft.	6 ft.	6 ft.	REF dB:	44.9	43.8	43.1	46.8	TEMPERATURE:	Ambient	Ambient
INSPECTION VERSION:	MXU 5.11.1	WEDGE MODEL:	SA10-N55S	SA10-N55S	ST1-70L	TRAN dB:	0	0	0	0	SPECIMEN		
ENCODER RESOLUTION:	414.52 stps/in.	MATERIAL:	Rexolite	Rexolite	Steel	SCAN + 6 dB:	50.9	49.8	49.1	52.8	PIPE DIAMETER (NPS)	NPS36	
SCAN RESOLUTION:	0.039"	RADIUS:	Flat	Flat	Flat	CAL IN / CAL OUT:	11:00 AM / 4:30 PM				THICKNESS (in.)	0.550" - 0.850"	
PRF:	Auto	EQUIP. REF. BLOCK:	IIW Block S/N 12-2363, Carbon Steel PACS Block S/N 2020-5431								WELDING PROCESS	(1) GMAW, (2) SMAW	

EXAMINATION DETAILS AND RESULTS

GIRTHWELD NUMBER	NOMINAL WALL THICKNESS (IN.)	AXIAL LOCATION (FT.)	SKEW	FEATURE NUMBER	SCAN LENGTH (IN.)	START OF INDICATION (IN.)	END OF INDICATION (IN.)	LENGTH (IN.)	HEIGHT (IN.)	DEPTH START (IN.)	DEPTH END (IN.)	ACUTAL THICKNESS (IN.)	ACCEPT	REJECT	DISCONTINUITY TYPE
GW 13510															
13510	0.550	0.00	90	1	117.008	0.102	2.833	2.731	0.138	0.268	0.406	0.542	X		Intermittent Interpass LOF
13510	0.550	0.00	90	2	117.008	5.399	24.840	19.441	0.093	0.356	0.449	0.537	X		Intermittent Interpass LOF
13510	0.550	0.00	90	3	117.008	58.104	98.592	40.489	0.086	0.396	0.485	0.540	X		Intermittent Interpass LOF
13510	0.550	0.00	90	4	117.008	113.293	113.568	0.275	0.040	0.484	0.523	0.542	X		Slag Inclusion
GW 13520															
13520	0.550 - 0.850	0.00	90	1	117.008	7.370	15.311	7.941	0.149	0.718	0.867	0.863		X	Intermittent Root Toe Crack
13520	0.550 - 0.850	0.00	90	2	117.008	16.842	32.294	15.452	0.149	0.701	0.850	0.850		X	Root Toe Crack
13520	0.550 - 0.850	0.00	90	3	117.008	35.017	61.911	26.894	0.106	0.749	0.855	0.855		X	Root Toe Crack
13520	0.550 - 0.850	0.00	90	4	117.008	69.102	96.551	27.449	0.113	0.748	0.861	0.861		X	Intermittent Root Fusion

13520	0.550 - 0.850	0.00	90	5	117.008	101.887	109.685	7.798	0.086	0.751	0.837	0.837		X	Intermittent Root Fusion
13520	0.550 - 0.850	0.00	90	6	117.008	112.447	5.904	6.551	0.126	0.731	0.857	0.857		X	Intermittent Root Crack
GW 13530															
13530	0.550 - 0.850	0.00	90	1	117.008	31.119	33.639	2.519	0.071	0.461	0.532	0.532		X	Incomplete Root Fusion
13530	0.550 - 0.850	0.00	90	2	117.008	38.797	46.204	7.407	0.076	0.444	0.520	0.520		X	Intermittent Root Fusion
13530	0.550 - 0.850	0.00	90	3	117.008	48.694	57.091	8.397	0.138	0.415	0.553	0.553		X	Root Toe Crack
13530	0.550 - 0.850	0.00	90	4	117.008	62.369	66.808	4.439	0.089	0.458	0.547	0.547		X	Root Crack
13530	0.550 - 0.850	0.00	90	5	117.008	70.166	86.421	16.255	0.116	0.426	0.542	0.542		X	Intermittent Root Crack

NOTES

Due to the complex geometry of the part examined and significant wall thickness variation, depth and height positioning is an estimate based on a theoretical approximation of how the ultrasonic signals propogated through the area of inspection. Assessment of GW13510 was deemed acceptable per API 1104 criterion. Assessment of GW13530 in the area around the thru-wall fracture was impeded by the presense of coating and non-uniform surface condition. Reported indications are those which have the highest confidence of being "real" due the presence in both PAUT and supplementary ToFD. Additional ultrasonic responses are present, however, can not be reported with confidence due to the lack of confirmation by supplementary inspection methods.

	NAME	SIGNATURE	CERTIFICATION	DATE
Technician:	Cameron Seward		IWEX, HandyScan **SNT-TC-1A** LVL II MT, ToFD **PCN** LVL II UT, PAUT	1/18/2023

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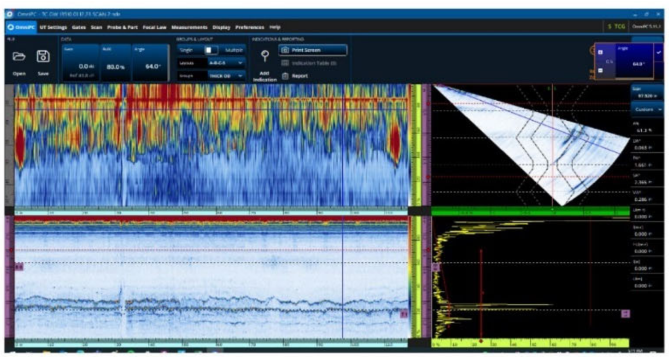
PHASED ARRAY ULTRASONIC (PAUT) / TIME OF FLIGHT DIFFRACTION (TOFD) WELD EXAMINATION SCREENSHOTS

PROJECT / CLIENT INFORMATION

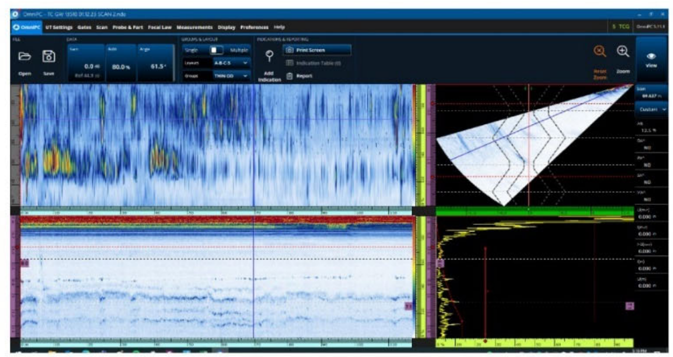
CLIENT:	TC Energy	REPORT NUMBER:	GW 13510, GW 13520, GW 13530		
JOB LOCATION:	Anderson & Associates, Pearland, TX	DATE:	1/12/2023	PAGE NO.:	1 of 20
PROJECT:	Keystone NPS36 Pipe Fracture Investigation	PROCEDURE NO.:	UT 46 NDE USA	REV. NO.:	2
APPLUS JOB NO.:	2008000	TECHNIQUE NO.:	PIA 200.1	REV. NO.:	2
NDE REQUEST NO.:	N/A	CODE / STANDARD:	N/A - Information Only		
PO / WO NO.:	N/A	SPECIFICATION:	N/A		

SCREENSHOTS

GW13510 SKEW 90 Scan Overview



GW13510 SKEW 270 Overview



	NAME	SIGNATURE	CERTIFICATION	DATE
Technician:	Cameron Seward		IWEX, HandyScan **SNT-TC-1A** LVL II MT, ToFD **PCN** LVL II UT, PAUT	1/18/2023

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PHASED ARRAY ULTRASONIC (PAUT) / TIME OF FLIGHT DIFFRACTION (TOFD) WELD EXAMINATION SCREENSHOTS

PROJECT / CLIENT INFORMATION

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JOB LOCATION:	Anderson & Associates, Pearland, TX	DATE:	1/12/2023	PAGE NO.:	2 of 20
PROJECT:	Keystone NPS36 Pipe Fracture Investigation	PROCEDURE NO.:	UT 46 NDE USA	REV. NO.:	2
APPLUS JOB NO.:	2008000	TECHNIQUE NO.:	PIA 200.1	REV. NO.:	2
NDE REQUEST NO.:	N/A	CODE / STANDARD:	N/A - Information Only		
PO / WO NO.:	N/A	SPECIFICATION:	N/A		

SCREENSHOTS

GW13510 ToFD Scan Overview	GW13510 F01 PAUT Overview
	

	NAME	SIGNATURE	CERTIFICATION	DATE
Technician:	Cameron Seward		IWEX, HandyScan **SNT-TC-1A** LVL II MT, ToFD **PCN** LVL II UT, PAUT	1/18/2023

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CLIENT:	TC Energy	REPORT NUMBER:	GW 13510, GW 13520, GW 13530		
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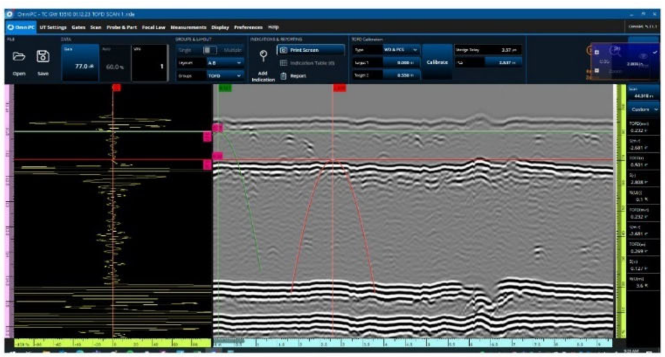
APPLUS JOB NO.:	2008000	TECHNIQUE NO.:	PIA 200.1	REV. NO.:	2
NDE REQUEST NO.:	N/A	CODE / STANDARD:	N/A - Information Only		
PO / WO NO.:	N/A	SPECIFICATION:	N/A		

SCREENSHOTS

GW13510 F01 ToFD Overview



GW13510 F02 PAUT Overview

	NAME	SIGNATURE	CERTIFICATION	DATE
Technician:	Cameron Seward	Cameron Seward	IWEX, HandyScan **SNT-TC-1A** LVL II MT, ToFD **PCN** LVL II UT, PAUT	1/18/2023

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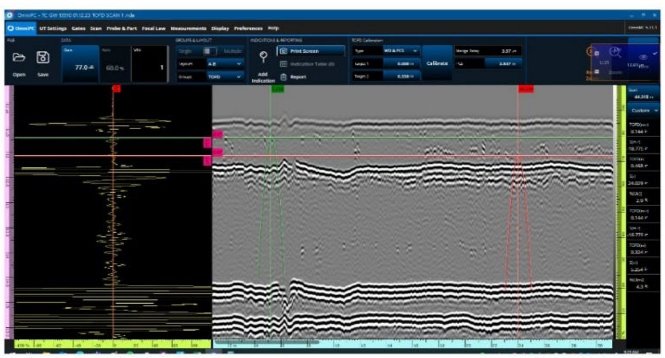
PHASED ARRAY ULTRASONIC (PAUT) / TIME OF FLIGHT DIFFRACTION (TOFD) WELD EXAMINATION SCREENSHOTS

PROJECT / CLIENT INFORMATION

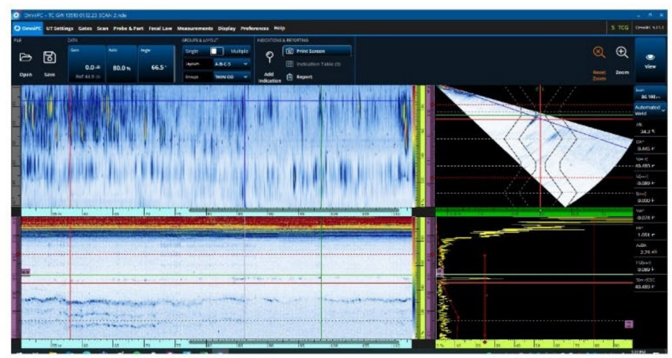
CLIENT:	TC Energy	REPORT NUMBER:	GW 13510, GW 13520, GW 13530		
JOB LOCATION:	Anderson & Associates, Pearland, TX	DATE:	1/12/2023	PAGE NO.:	4 of 20
PROJECT:	Keystone NPS36 Pipe Fracture Investigation	PROCEDURE NO.:	UT 46 NDE USA	REV. NO.:	2
APPLUS JOB NO.:	2008000	TECHNIQUE NO.:	PIA 200.1	REV. NO.:	2
NDE REQUEST NO.:	N/A	CODE / STANDARD:	N/A - Information Only		
PO / WO NO.:	N/A	SPECIFICATION:	N/A		

SCREENSHOTS

GW13510 F02 ToFD Overview



GW13510 F03 PAUT Overview



	NAME	SIGNATURE	CERTIFICATION	DATE
Technician:	Cameron Seward		IWEX, HandyScan **SNT-TC-1A** LVL II MT, ToFD **PCN** LVL II UT, PAUT	1/18/2023

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PROJECT / CLIENT INFORMATION

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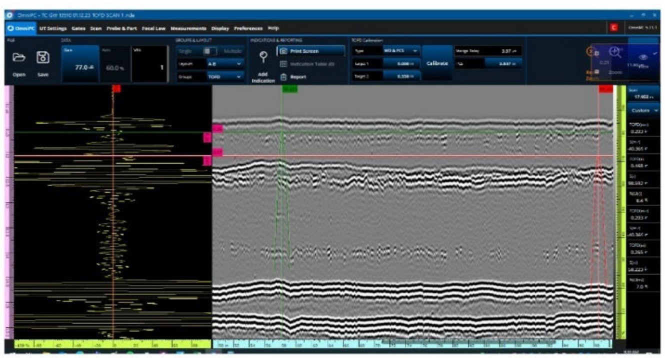
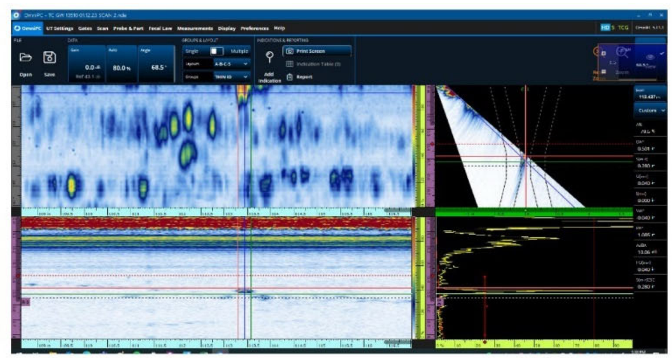
JOB LOCATION:	Anderson & Associates, Pearland, TX	DATE:	1/12/2023	PAGE NO.:	5 of 20
PROJECT:	Keystone NPS36 Pipe Fracture Investigation	PROCEDURE NO.:	UT 46 NDE USA	REV. NO.:	2
APPLUS JOB NO.:	2008000	TECHNIQUE NO.:	PIA 200.1	REV. NO.:	2
NDE REQUEST NO.:	N/A	CODE / STANDARD:	N/A - Information Only		
PO / WO NO.:	N/A	SPECIFICATION:	N/A		

SCREENSHOTS

GW13510 F03 ToFD Overview



GW13510 F04 PAUT Overview



	NAME	SIGNATURE	CERTIFICATION	DATE
Technician:	Cameron Seward		IWEX, HandyScan **SNT-TC-1A** LVL II MT, ToFD **PCN** LVL II UT, PAUT	1/18/2023

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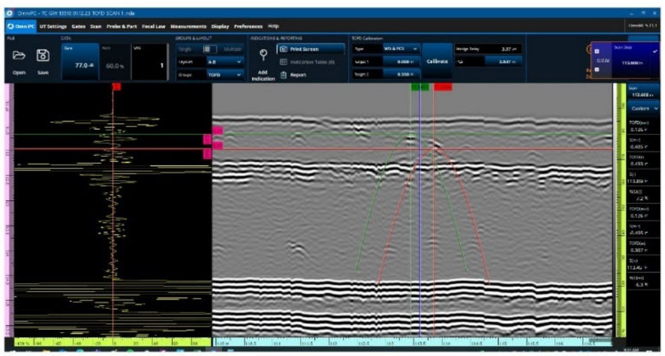
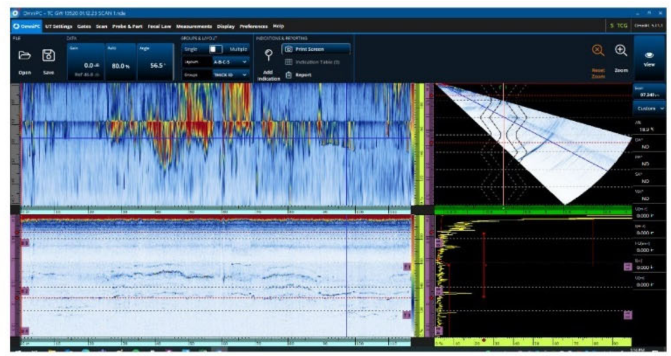
APPLUS JOB NO.:	2008000	TECHNIQUE NO.:	PIA 200.1	REV. NO.:	2
NDE REQUEST NO.:	N/A	CODE / STANDARD:	N/A - Information Only		
PO / WO NO.:	N/A	SPECIFICATION:	N/A		

SCREENSHOTS

GW13510 F04 ToFD Overview



GW13520 SKEW90 Overview



	NAME	SIGNATURE	CERTIFICATION	DATE
Technician:	Cameron Seward	[signature]	IWEX, HandyScan **SNT-TC-1A** LVL II MT, ToFD **PCN** LVL II UT, PAUT	1/18/2023

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PHASED ARRAY ULTRASONIC (PAUT) / TIME OF FLIGHT DIFFRACTION (TOFD) WELD EXAMINATION SCREENSHOTS

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CLIENT:	TC Energy	REPORT NUMBER:	GW 13510, GW 13520, GW 13530		
JOB LOCATION:	Anderson & Associates, Pearland, TX	DATE:	1/12/2023	PAGE NO.:	7 of 20
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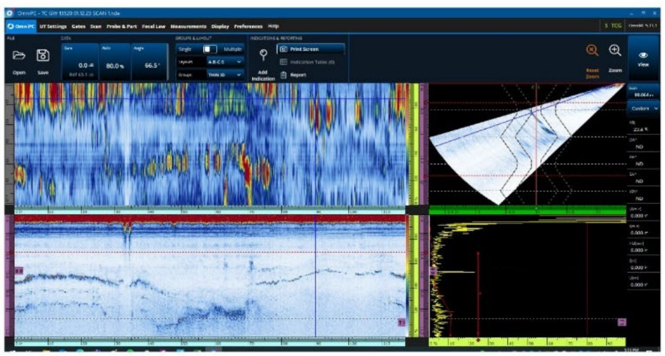
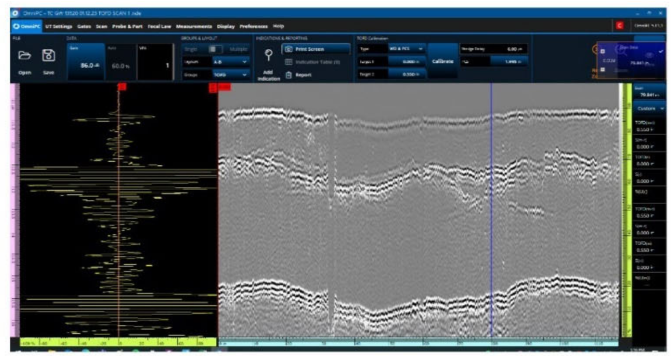
NDE REQUEST NO.:	N/A	CODE / STANDARD:	N/A - Information Only		
PO / WO NO.:	N/A	SPECIFICATION:	N/A		

SCREENSHOTS

GW13520 SKEW 270 Overview



GW13520 ToFD Overview



	NAME	SIGNATURE	CERTIFICATION	DATE
Technician:	Cameron Seward		IWEX, HandyScan **SNT-TC-1A** LVL II MT, ToFD **PCN** LVL II UT, PAUT	1/18/2023

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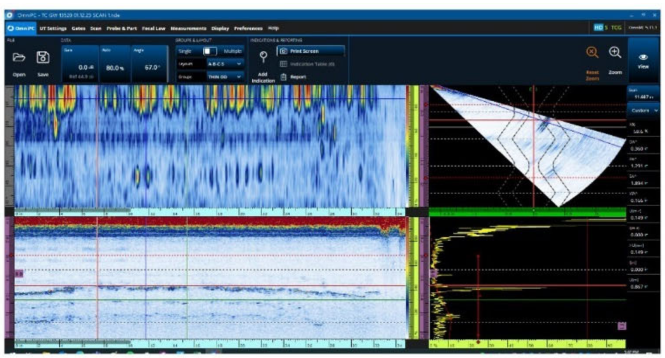
PO / WO NO.:	N/A	SPECIFICATION:	N/A		

SCREENSHOTS

GW13520 F01 PAUT Overview



GW13520 F01 ToFD Overview

	NAME	SIGNATURE	CERTIFICATION	DATE
Technician:	Cameron Seward		IWEX, HandyScan **SNT-TC-1A** LVL II MT, ToFD **PCN** LVL II UT, PAUT	1/18/2023

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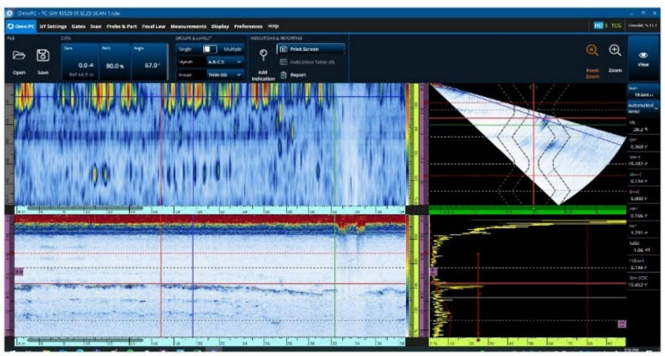
NDE REQUEST NO.:	N/A	CODE / STANDARD:	N/A - Information Only		
PO / WO NO.:	N/A	SPECIFICATION:	N/A		

SCREENSHOTS

GW13520 F02 PAUT Overview



GW13520 F02 ToFD Overview

	NAME	SIGNATURE	CERTIFICATION	DATE
Technician:	Cameron Seward		IWEX, HandyScan **SNT-TC-1A** LVL II MT, ToFD **PCN** LVL II UT, PAUT	1/18/2023

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CLIENT:	TC Energy	REPORT NUMBER:	GW 13510, GW 13520, GW 13530		
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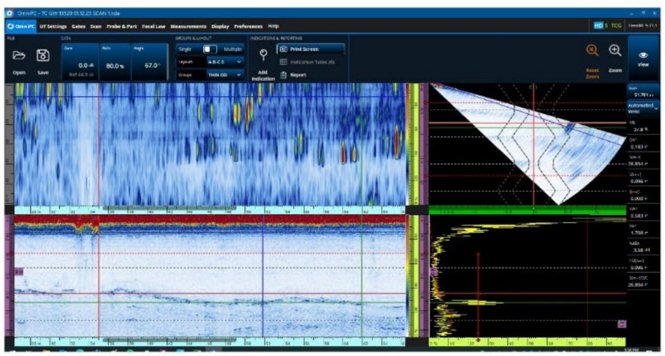
APPLUS JOB NO.:	2008000	TECHNIQUE NO.:	PIA 200.1	REV. NO.:	2
NDE REQUEST NO.:	N/A	CODE / STANDARD:	N/A - Information Only		
PO / WO NO.:	N/A	SPECIFICATION:	N/A		

SCREENSHOTS

GW13520 F03 PAUT Overview



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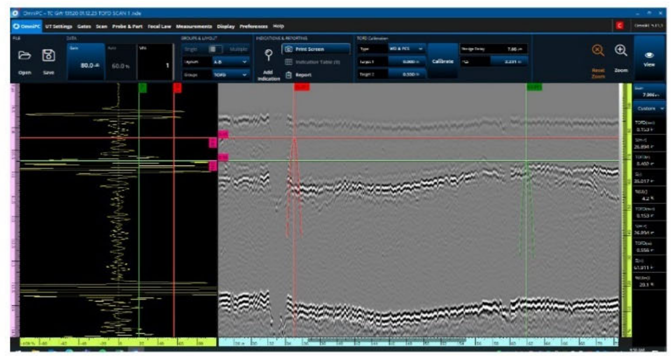

	NAME	SIGNATURE	CERTIFICATION	DATE
Technician:	Cameron Seward		IWEX, HandyScan **SNT-TC-1A** LVL II MT, ToFD **PCN** LVL II UT, PAUT	1/18/2023

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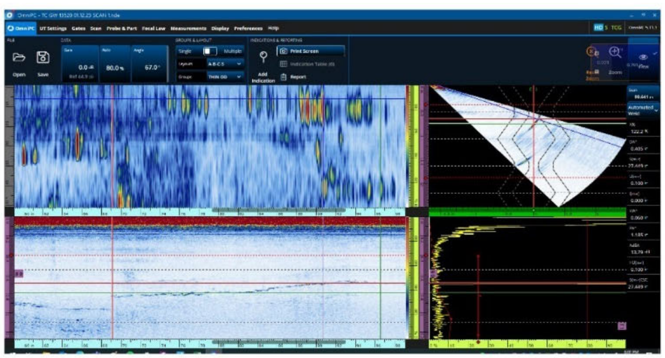
PHASED ARRAY ULTRASONIC (PAUT) / TIME OF FLIGHT DIFFRACTION (TOFD) WELD EXAMINATION SCREENSHOTS

PROJECT / CLIENT INFORMATION

CLIENT:	TC Energy	REPORT NUMBER:	GW 13510, GW 13520, GW 13530		
JOB LOCATION:	Anderson & Associates, Pearland, TX	DATE:	1/12/2023	PAGE NO.:	11 of 20
PROJECT:	Keystone NPS36 Pipe Fracture Investigation	PROCEDURE NO.:	UT 46 NDE USA	REV. NO.:	2
APPLUS JOB NO.:	2008000	TECHNIQUE NO.:	PIA 200.1	REV. NO.:	2
NDE REQUEST NO.:	N/A	CODE / STANDARD:	N/A - Information Only		
PO / WO NO.:	N/A	SPECIFICATION:	N/A		

SCREENSHOTS

GW13520 F04 PAUT Overview



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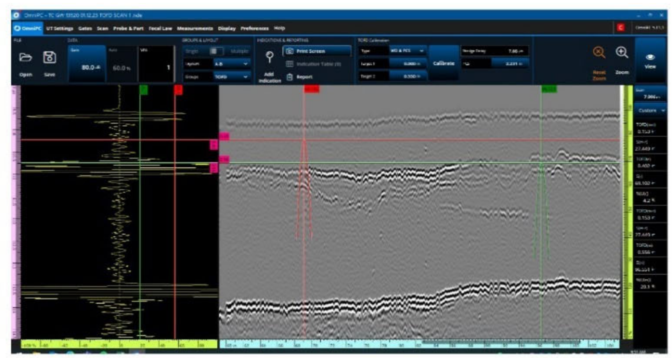

	NAME	SIGNATURE	CERTIFICATION	DATE
Technician:	Cameron Seward		IWEX, HandyScan **SNT-TC-1A** LVL II MT, ToFD **PCN** LVL II UT, PAUT	1/18/2023

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PROJECT / CLIENT INFORMATION

CLIENT:	TC Energy	REPORT NUMBER:	GW 13510, GW 13520, GW 13530		
JOB LOCATION:	Anderson & Associates, Pearland, TX	DATE:	1/12/2023	PAGE NO.:	12 of 20
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APPLUS JOB NO.:	2008000	TECHNIQUE NO.:	PIA 200.1	REV. NO.:	2
NDE REQUEST NO.:	N/A	CODE / STANDARD:	N/A - Information Only		
PO / WO NO.:	N/A	SPECIFICATION:	N/A		

SCREENSHOTS

GW13510 F05 PAUT Overview

GW13520 F05 ToFD Overview

	NAME	SIGNATURE	CERTIFICATION	DATE
Technician:	Cameron Seward	Cameron Seward	IWEX, HandyScan **SNT-TC-1A** LVL II MT, ToFD **PCN** LVL II UT, PAUT	1/18/2023

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PROJECT / CLIENT INFORMATION

CLIENT:	TC Energy	REPORT NUMBER:	GW 13510, GW 13520, GW 13530		
JOB LOCATION:	Anderson & Associates, Pearland, TX	DATE:	1/12/2023	PAGE NO.:	13 of 20
PROJECT:	Keystone NPS36 Pipe Fracture Investigation	PROCEDURE NO.:	UT 46 NDE USA	REV. NO.:	2
APPLUS JOB NO.:	2008000	TECHNIQUE NO.:	PIA 200.1	REV. NO.:	2
NDE REQUEST NO.:	N/A	CODE / STANDARD:	N/A - Information Only		
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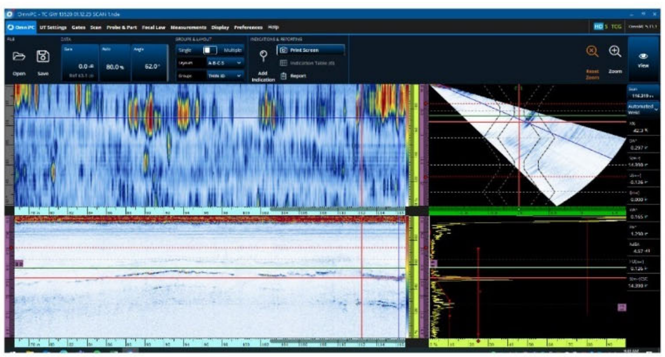
SCREENSHOTS

GW13520 F06 PAUT Overview



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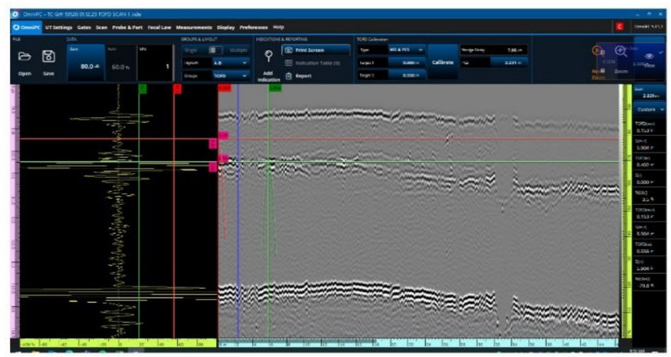

	NAME	SIGNATURE	CERTIFICATION	DATE
Technician:	Cameron Seward		IWEX, HandyScan **SNT-TC-1A** LVL II MT, ToFD **PCN** LVL II UT, PAUT	1/18/2023

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PROJECT / CLIENT INFORMATION

CLIENT:	TC Energy	REPORT NUMBER:	GW 13510, GW 13520, GW 13530		
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APPLUS JOB NO.:	2008000	TECHNIQUE NO.:	PIA 200.1	REV. NO.:	2
NDE REQUEST NO.:	N/A	CODE / STANDARD:	N/A - Information Only		
PO / WO NO.:	N/A	SPECIFICATION:	N/A		

SCREENSHOTS

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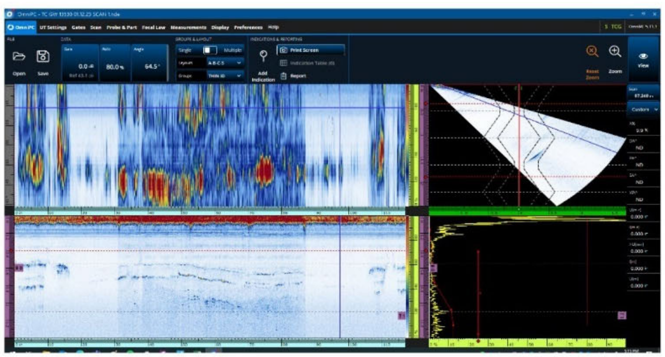

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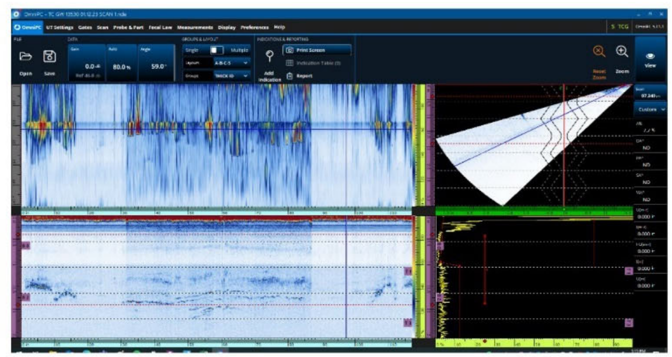

	NAME	SIGNATURE	CERTIFICATION	DATE
Technician:	Cameron Seward		IWEX, HandyScan **SNT-TC-1A** LVL II MT, ToFD **PCN** LVL II UT, PAUT	1/18/2023

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PROJECT / CLIENT INFORMATION

CLIENT:	TC Energy	REPORT NUMBER:	GW 13510, GW 13520, GW 13530		
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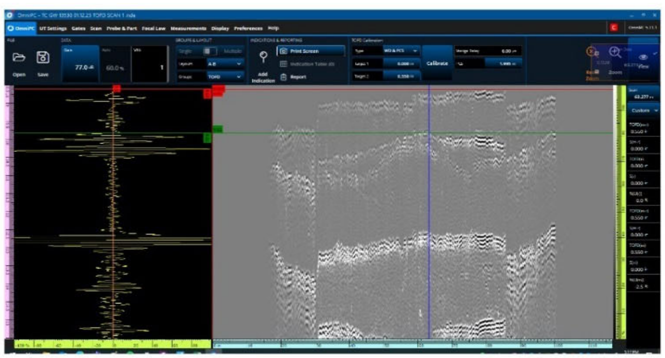
PROJECT:	Keystone NPS36 Pipe Fracture Investigation	PROCEDURE NO.:	UT 46 NDE USA	REV. NO.:	2
APPLUS JOB NO.:	2008000	TECHNIQUE NO.:	PIA 200.1	REV. NO.:	2
NDE REQUEST NO.:	N/A	CODE / STANDARD:	N/A - Information Only		
PO / WO NO.:	N/A	SPECIFICATION:	N/A		

SCREENSHOTS

GW13530 ToFD Overview



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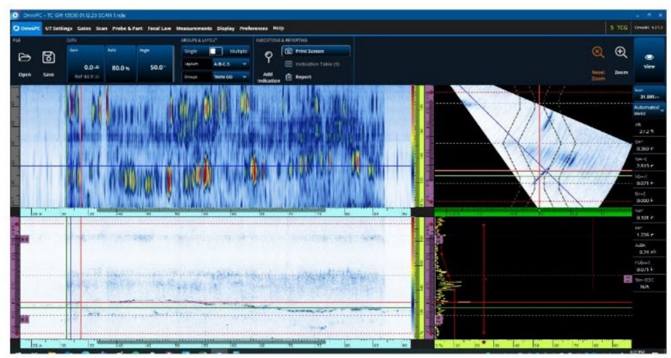

	NAME	SIGNATURE	CERTIFICATION	DATE
Technician:	Cameron Seward		IWEX, HandyScan **SNT-TC-1A** LVL II MT, ToFD **PCN** LVL II UT, PAUT	1/18/2023

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PROJECT / CLIENT INFORMATION

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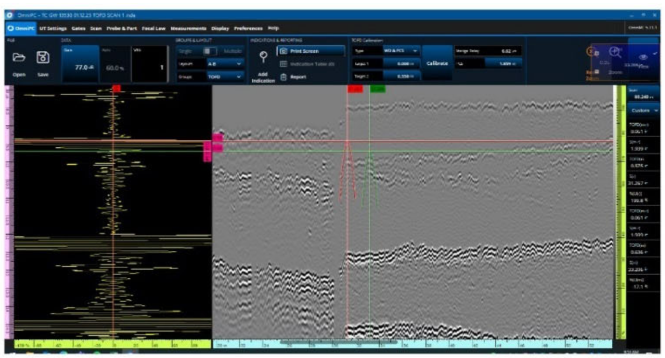
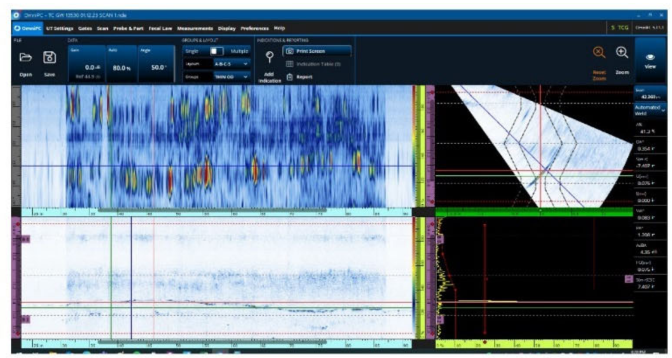
APPLUS JOB NO.:	2008000	TECHNIQUE NO.:	PIA 200.1	REV. NO.:	2
NDE REQUEST NO.:	N/A	CODE / STANDARD:	N/A - Information Only		
PO / WO NO.:	N/A	SPECIFICATION:	N/A		

SCREENSHOTS

GW13530 F01 ToFD Overview



GW13530 F02 PAUT Overview



	NAME	SIGNATURE	CERTIFICATION	DATE
Technician:	Cameron Seward		IWEX, HandyScan **SNT-TC-1A** LVL II MT, ToFD **PCN** LVL II UT, PAUT	1/18/2023

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PROJECT / CLIENT INFORMATION

CLIENT:	TC Energy	REPORT NUMBER:	GW 13510, GW 13520, GW 13530		
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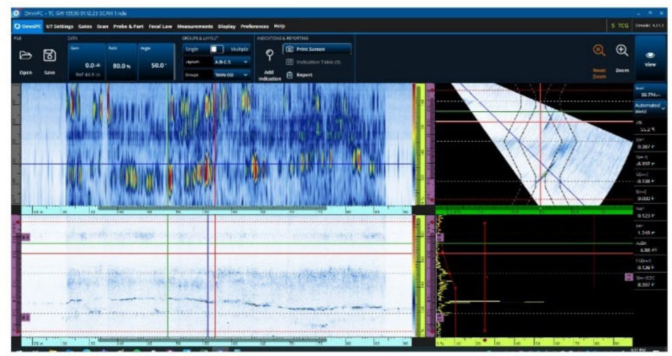
APPLUS JOB NO.:	2008000	TECHNIQUE NO.:	PIA 200.1	REV. NO.:	2
NDE REQUEST NO.:	N/A	CODE / STANDARD:	N/A - Information Only		
PO / WO NO.:	N/A	SPECIFICATION:	N/A		

SCREENSHOTS

GW13530 F02 ToFD Overview

GW13530 F03 PAUT Overview



	NAME	SIGNATURE	CERTIFICATION	DATE
Technician:	Cameron Seward	[signature]	IWEX, HandyScan **SNT-TC-1A** LVL II MT, ToFD **PCN** LVL II UT, PAUT	1/18/2023

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PROJECT / CLIENT INFORMATION

CLIENT:	TC Energy	REPORT NUMBER:	GW 13510, GW 13520, GW 13530		
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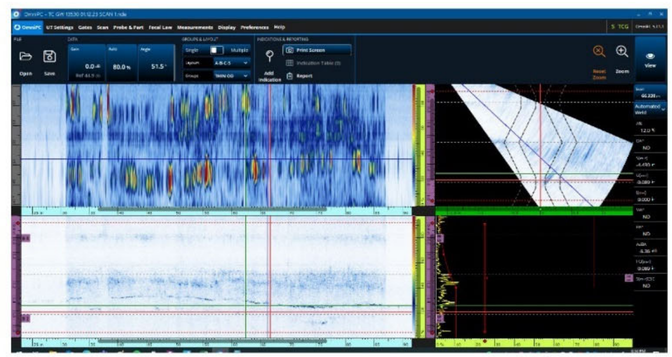
NDE REQUEST NO.:	N/A	CODE / STANDARD:	N/A - Information Only		
PO / WO NO.:	N/A	SPECIFICATION:	N/A		

SCREENSHOTS

GW13530 F03 ToFD Overview

GW13530 F04 PAUT Overview



	NAME	SIGNATURE	CERTIFICATION	DATE
Technician:	Cameron Seward	[signature]	IWEX, HandyScan **SNT-TC-1A** LVL II MT, ToFD **PCN** LVL II UT, PAUT	1/18/2023

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PROJECT / CLIENT INFORMATION

CLIENT:	TC Energy	REPORT NUMBER:	GW 13510, GW 13520, GW 13530		
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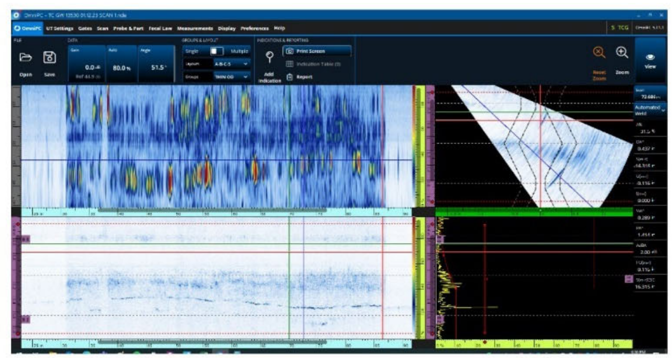
APPLUS JOB NO.:	2008000	TECHNIQUE NO.:	PIA 200.1	REV. NO.:	2
NDE REQUEST NO.:	N/A	CODE / STANDARD:	N/A - Information Only		
PO / WO NO.:	N/A	SPECIFICATION:	N/A		

SCREENSHOTS

GW13530 F04 ToFD Overview

GW13530 F05 PAUT Overview



	NAME	SIGNATURE	CERTIFICATION	DATE
Technician:	Cameron Seward	Cameron Seward	IWEX, HandyScan **SNT-TC-1A** LVL II MT, ToFD **PCN** LVL II UT, PAUT	1/18/2023

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JOB LOCATION:	Anderson & Associates, Pearland, TX	DATE:	1/12/2023	PAGE NO.:	20 of 20
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APPLUS JOB NO.:	2008000	TECHNIQUE NO.:	PIA 200.1	REV. NO.:	2
NDE REQUEST NO.:	N/A	CODE / STANDARD:	N/A - Information Only		
PO / WO NO.:	N/A	SPECIFICATION:	N/A		

SCREENSHOTS

GW13530 F05 ToFD Overview

	NAME	SIGNATURE	CERTIFICATION	DATE
Technician:	Cameron Seward		IWEX, HandyScan **SNT-TC-1A** LVL II MT, ToFD **PCN** LVL II UT, PAUT	1/18/2023

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HANDYSCAN SUMMARY REPORT

PROJECT / CLIENT INFORMATION

CLIENT:	TC Energy	REPORT NUMBER:	1		
JOB LOCATION:	Anderson & Associates, Pearland, TX	DATE:	1/13/2023	PAGE NO.:	1 of 1
PROJECT:	Keystone NPS36 Pipe Fracture Investigation	PROCEDURE NO.:	PIA 011.15 USA	REV. NO.:	1
APPLUS JOB NO.:	2008000	TECHNIQUE NO.:	PIA 011.15	REV. NO.:	1
NDE REQUEST NO.:	N/A	CODE/STANDARD:	N/A - Information Only		
PO / WO NO.:	N/A	SPECIFICATION:	N/A		

ITEM(S) EXAMINED AND SURFACE CONDITIONS

PART(S) EXAMINED: OD surface of out-of-service pipe segment — PART NO. / ID: N/A

MATERIAL: Mild Carbon Steel — THICKNESS: 0.550" - 0.850" — SURFACE CONDITION: NACE 2 — SURFACE TEMP: Ambient

DESCRIPTION: Out of service pipe segment consisting of one 3D bend fitting and three pup joints of varying nominal thickness's

EQUIPMENT

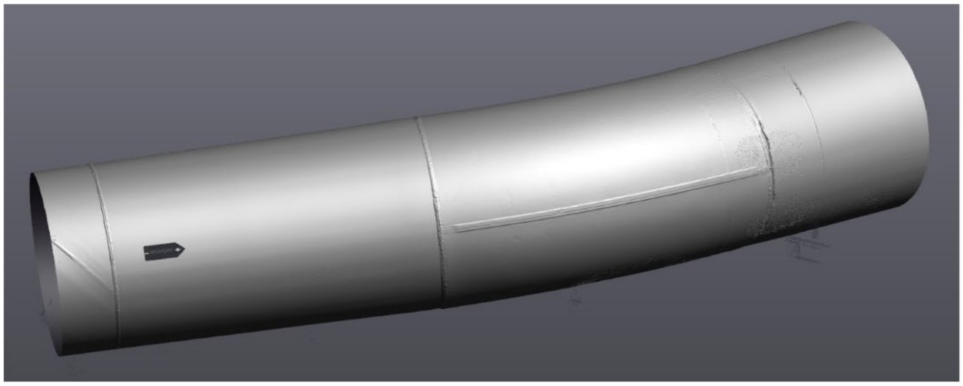
Equipment	Asset / Serial No.	Calibration Date
Creaform HandyScan Black Elite	9270229	9/8/2022
Creaform Reference Arrow	850347	N/A

HANDYSCAN INSPECTION TECHNIQUE

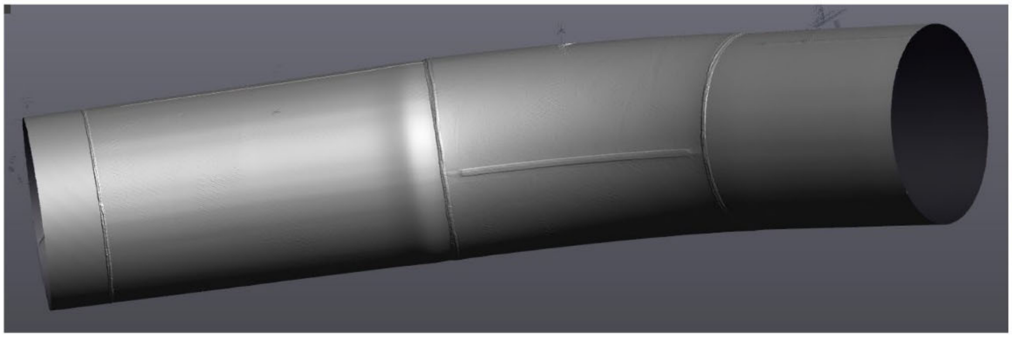
SCAN SURFACE: OUTER — INTERACTION RULE: N/A — PIT-GUAGE TYPE: N/A

INSPECTION SUMMARY

SCAN OVERVIEW 12:00



SCAN OVERVIEW 6:00



	NAME	SIGNATURE	CERTIFICATION	DATE
Technician:	Cameron Seward		IWEX, HandyScan **SNT-TC-1A** LVL II MT, ToFD **PCN** LVL II UT, PAUT	1/18/2023

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HANDYSCAN SUMMARY REPORT

PROJECT / CLIENT INFORMATION

CLIENT:	TC Energy	REPORT NUMBER:	1		
JOB LOCATION:	Anderson & Associates, Pearland, TX	DATE:	1/15/2023	PAGE NO.:	1 of 1
PROJECT:	Keystone NPS36 Pipe Fracture Investigation	PROCEDURE NO.:	PIA 011.15 USA	REV. NO.:	1
APPLUS JOB NO.:	2008000	TECHNIQUE NO.:	PIA 011.15	REV. NO.:	1
NDE REQUEST NO.:	N/A	CODE/STANDARD:	N/A - Information Only		
PO / WO NO.:	N/A	SPECIFICATION:	N/A		

ITEM(S) EXAMINED AND SURFACE CONDITIONS

PART(S) EXAMINED: ID surface of out-of-service pipe segment PART NO. / ID: N/A

MATERIAL: Mild Carbon Steel THICKNESS: 0.550" - 0.850" SURFACE CONDITION: As Found SURFACE TEMP: Ambient

DESCRIPTION: Out of service pipe segment consisting of one 3D bend fitting and three pup joints of varying nominal thickness's

EQUIPMENT

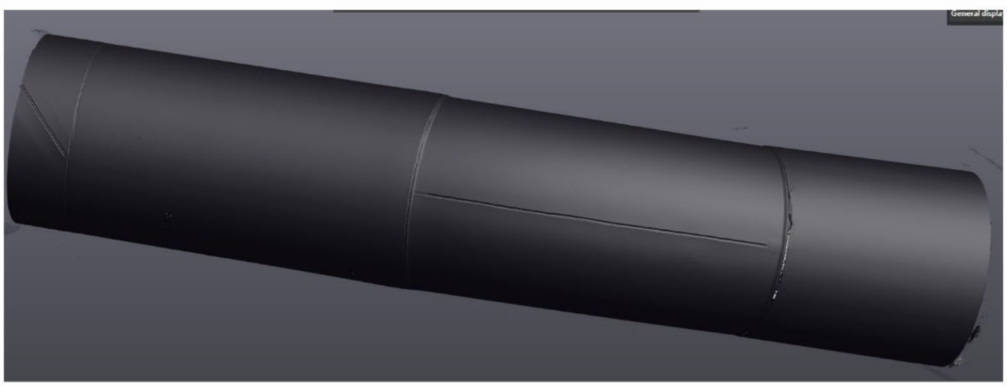
Equipment	Asset / Serial No.	Calibration Date
Creaform HandyScan Black Elite	9270229	9/8/2022
Creaform Reference Arrow	850347	N/A

HANDYSCAN INSPECTION TECHNIQUE

SCAN SURFACE: INNER INTERACTION RULE: N/A PIT-GUAGE TYPE: N/A

INSPECTION SUMMARY

SCAN OVERVIEW 12:00



SCAN OVERVIEW 6:00

	NAME	SIGNATURE	CERTIFICATION	DATE
Technician:	Cameron Seward		IWEX, HandyScan **SNT-TC-1A** LVL II MT, ToFD **PCN** LVL II UT, PAUT	1/18/2023

Appendix D
Full-Wall Thickness Tensile Datasheets

Redacted by TC Energy

[redacted]

Redacted by TC Energy

[redacted]

Redacted by TC Energy

[redacted]

Redacted by TC Energy

[redacted]

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[redacted]

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Appendix E
Sub-size pipe body tensile datasheets

Redacted by TC Energy

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Redacted by TC Energy

[redacted]

Redacted by TC Energy

[redacted]

Redactions made by TC Energy

Redacted by TC Energy

[redacted]

Redactions made by TC Energy

Redacted by TC Energy

[redacted]

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Redacted by TC Energy

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Appendix F
Sub-Size Cross Girth Weld and All-Weld Tensile Datasheets

[redacted]

Redacted by TC Energy

Redacted by TC Energy

[redacted]

Redacted by TC Energy

[redacted]

Redacted by TC Energy

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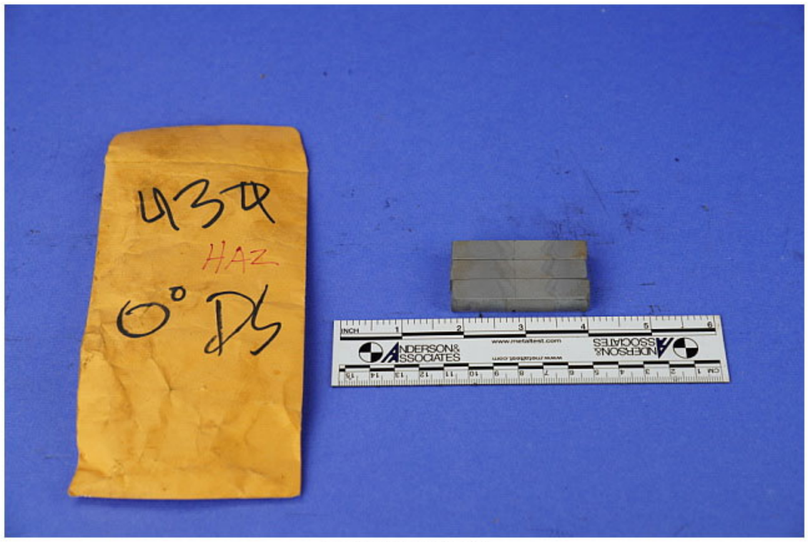
Appendix G
CVN Notch Location Photographs



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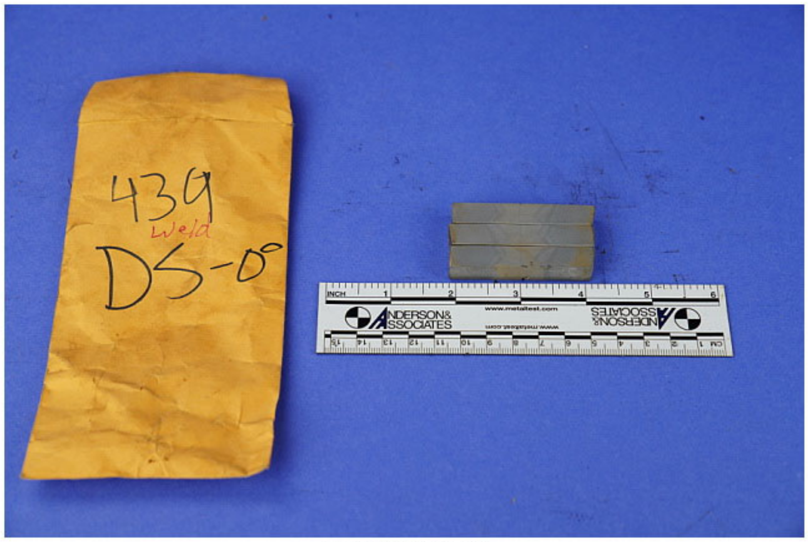

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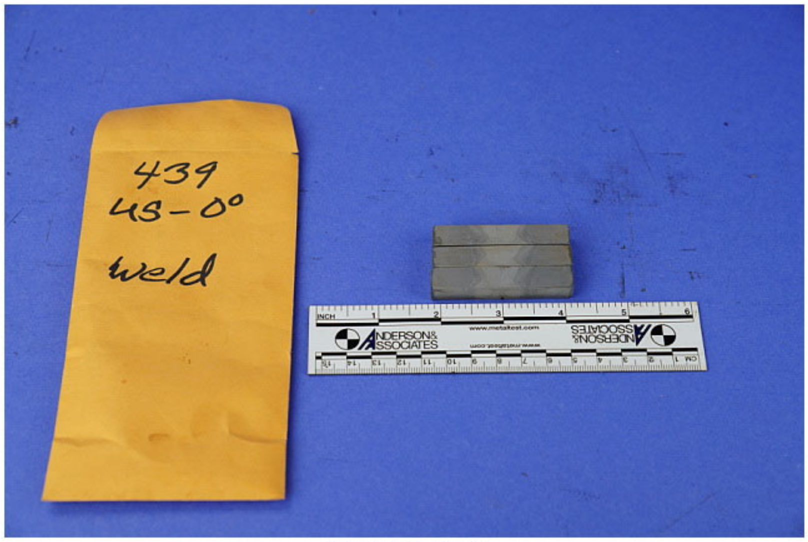

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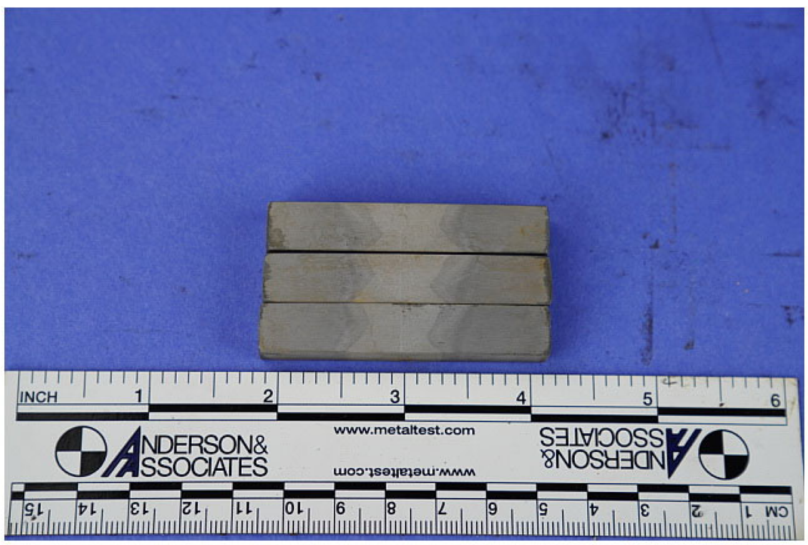

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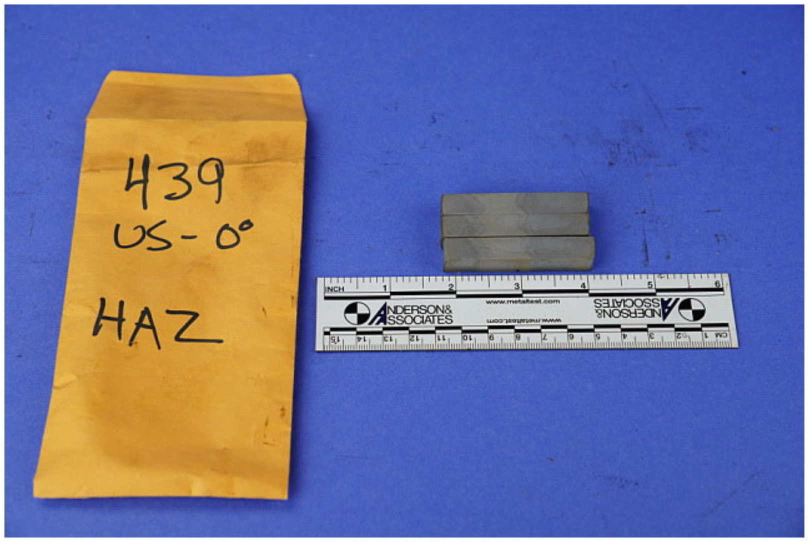

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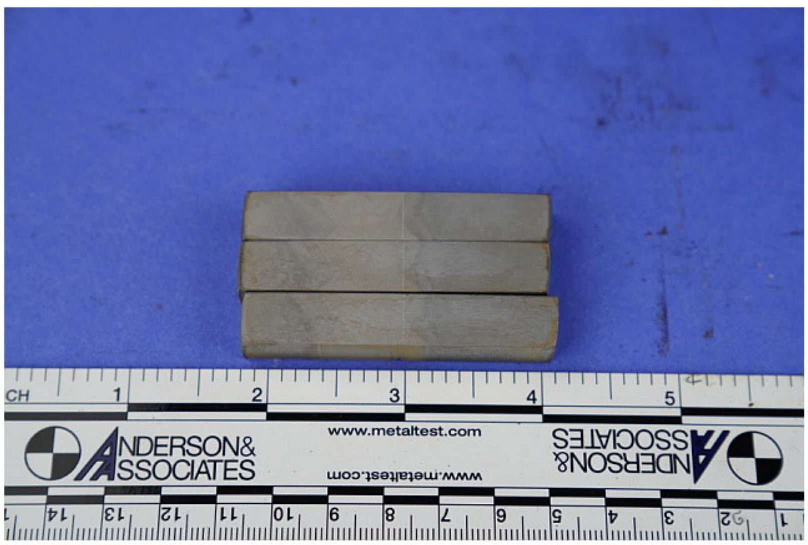

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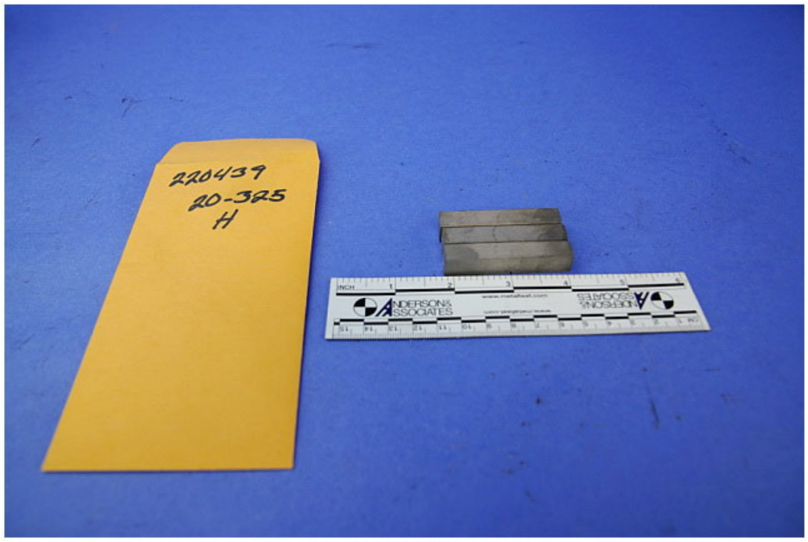

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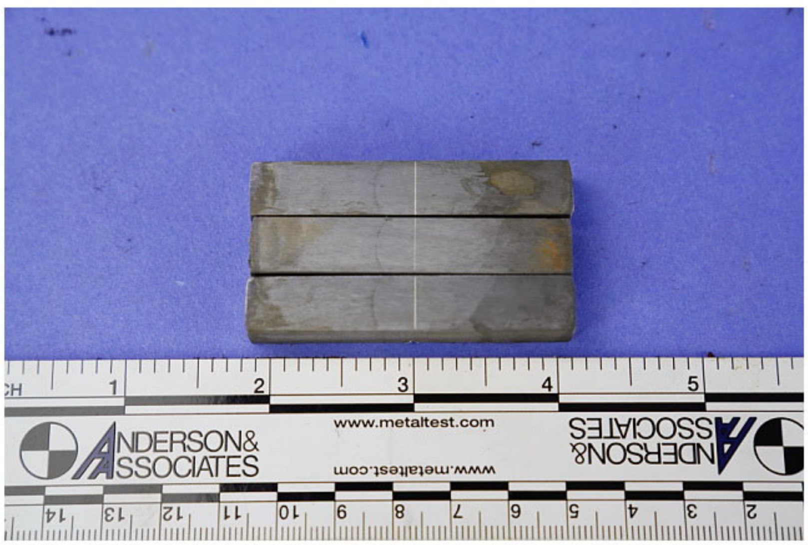
DSC04776

DSC04777



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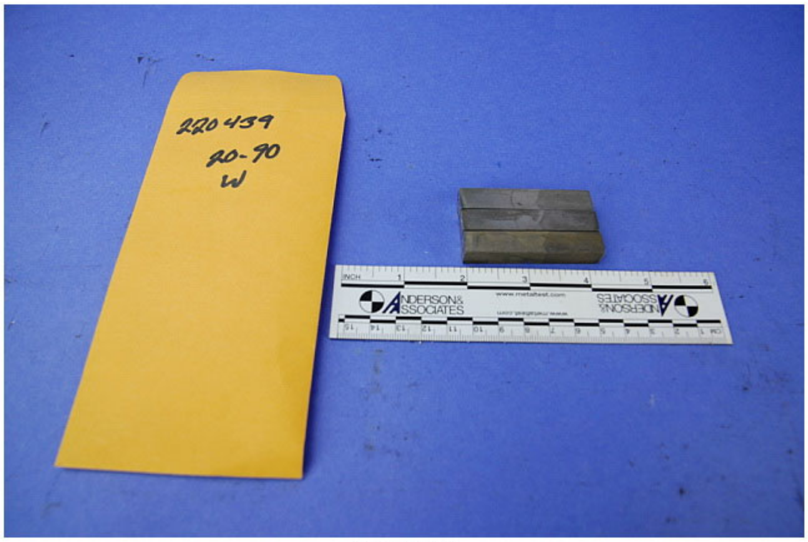

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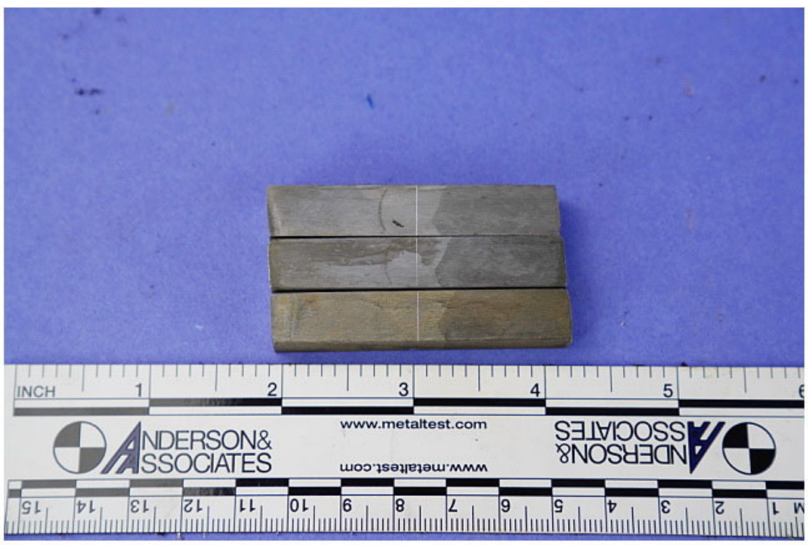

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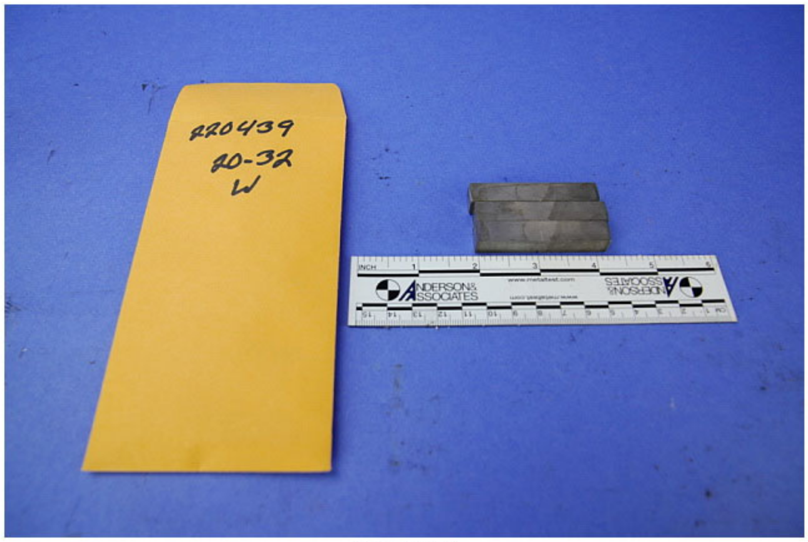

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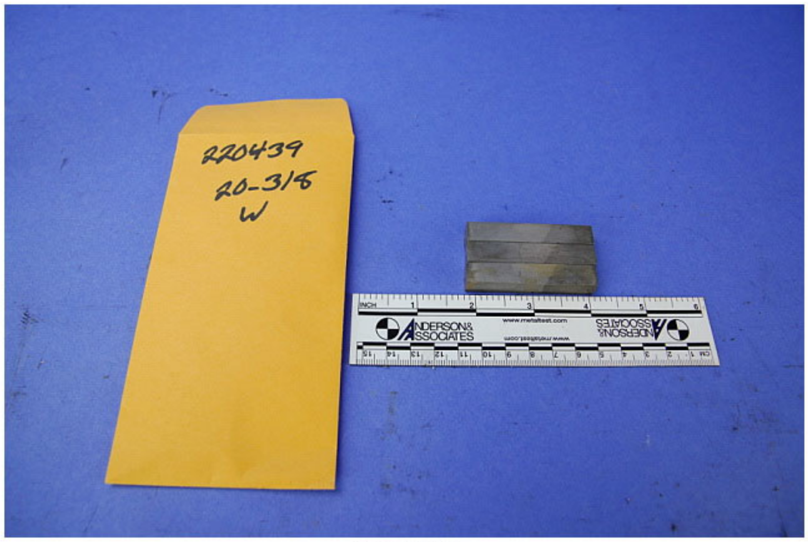

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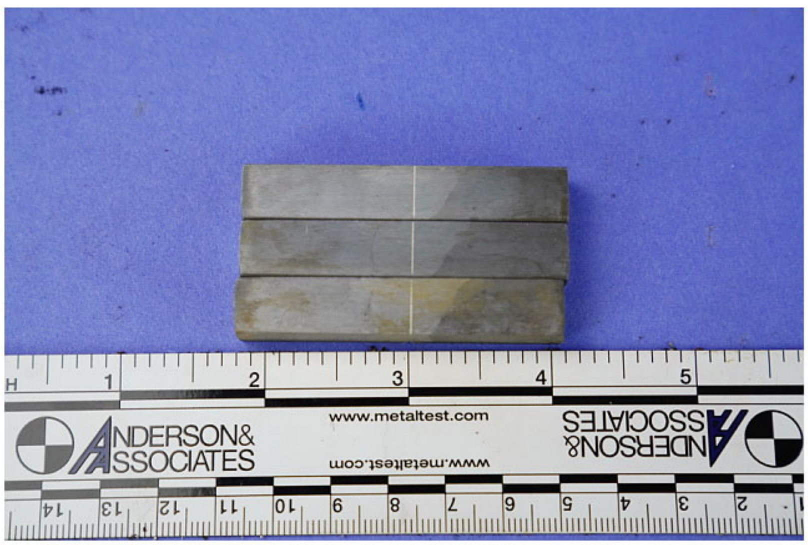

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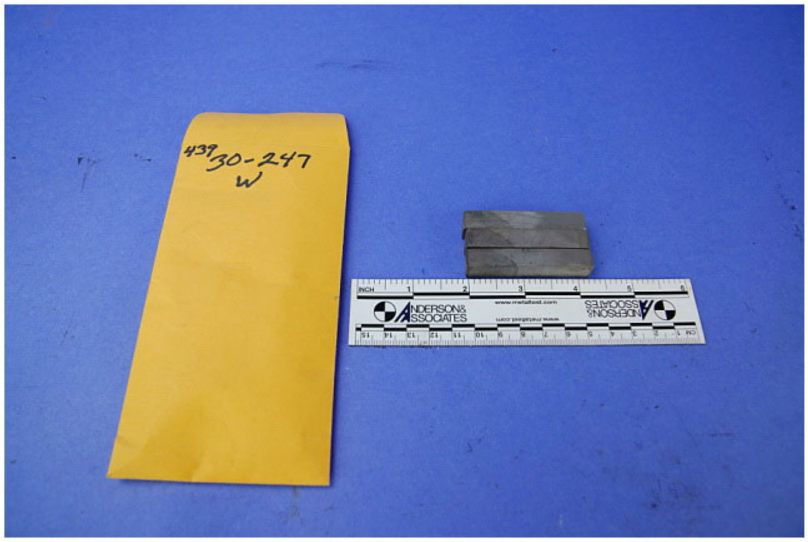

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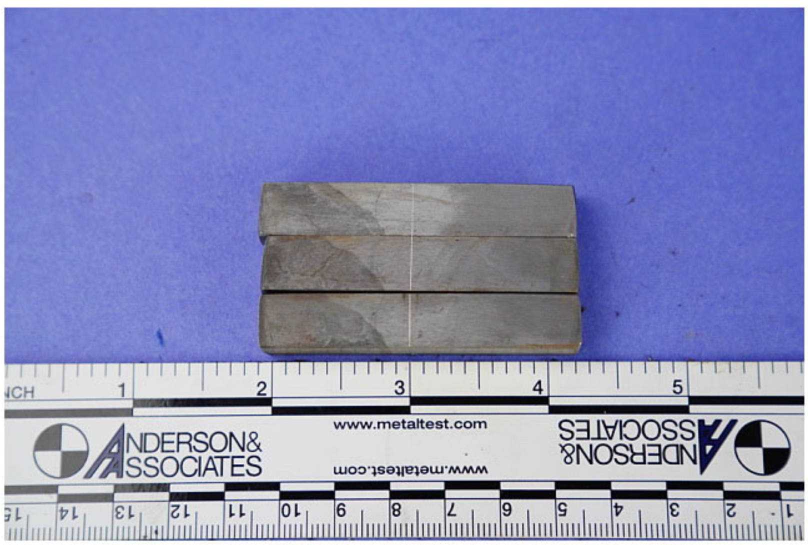

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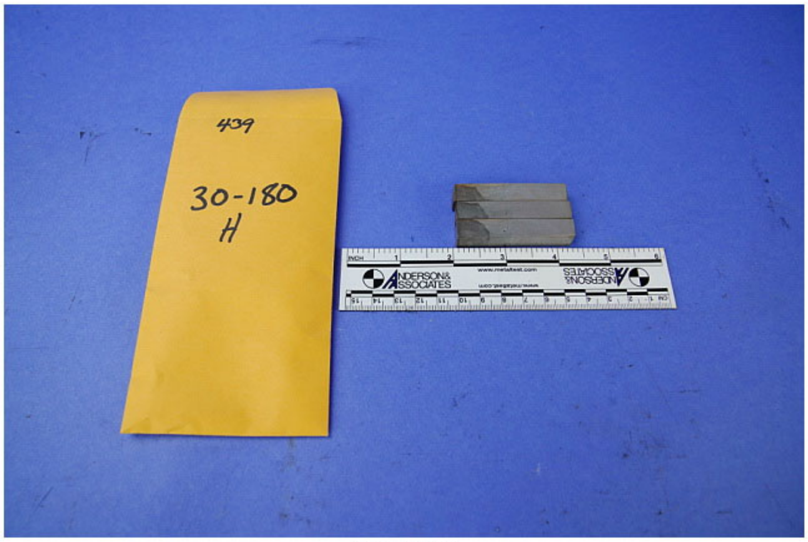

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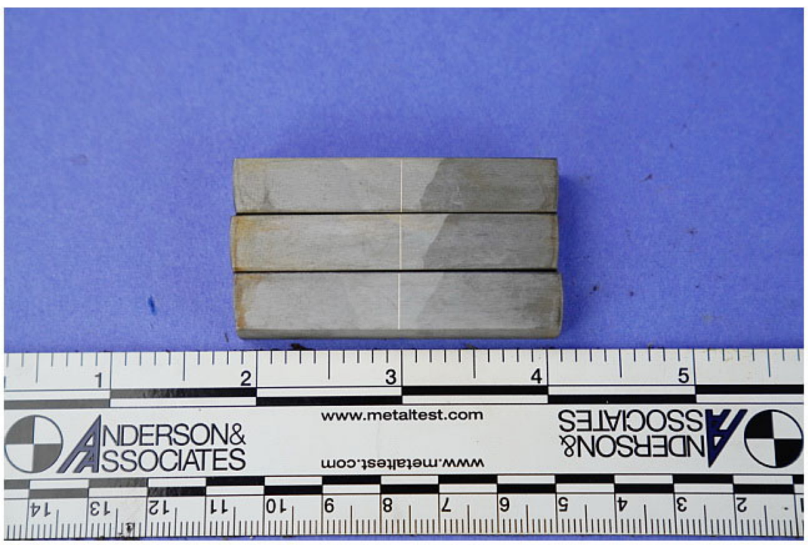

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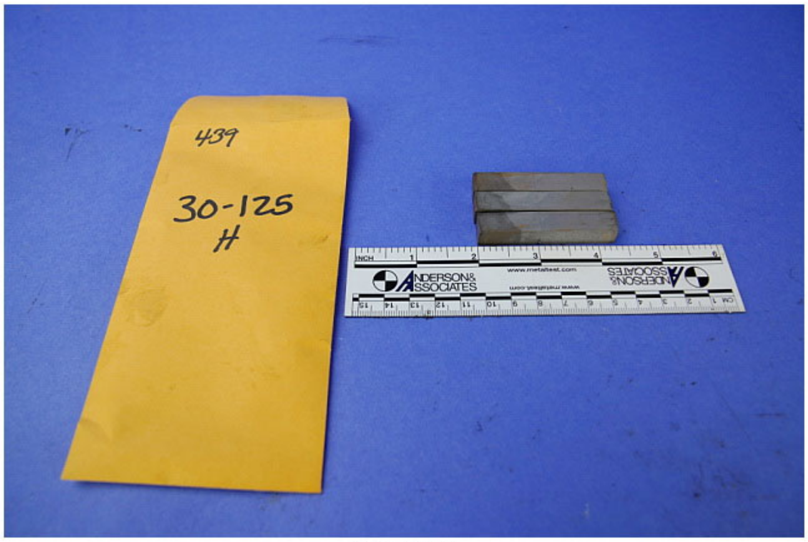

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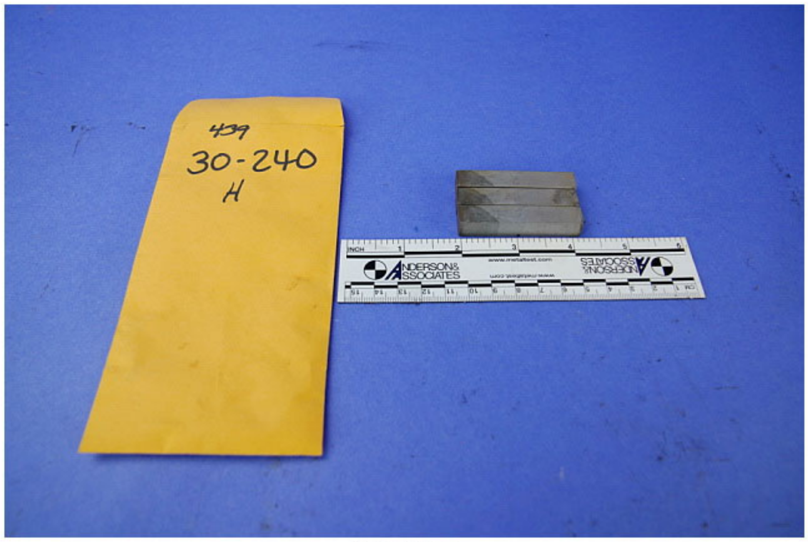

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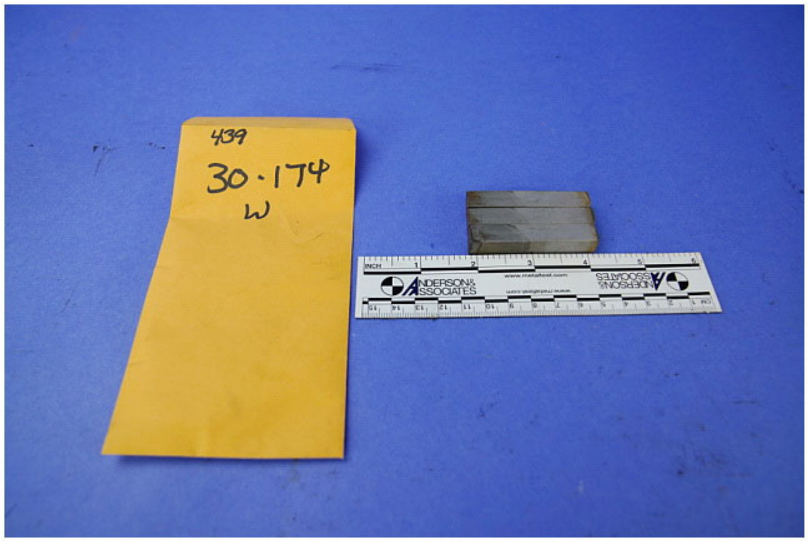

DSC04798

DSC04799

Appendix H
CTOD Datasheets

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ISO-15653-18 [in]	**19.94E-3**	[in]
ISO-15653-18 [mm]	**0.5066**	[mm]
J-Integral	**2533.9**	[lb/in]
Kj	**289.0**	[Ksi √in]

Specimen	439-20-6		
Material			
Other ID	P-HAZ		
Test Temp [F]	68	a_1 [inch]	0.4270
Yield Strength Sy [psi]	74,200	a_2 [inch]	0.4460
Tensile Strength UTS [psi]	87,300	a_3 [inch]	0.4640
Modulus of Elasticity E [psi]	30.0E+6	a_4 [inch]	0.4750
Poisson's Ratio nu	0.3	a_5 [inch]	0.4700
Thickness B [inches]	0.4471	a_6 [inch]	0.4620
Net Thickness Bc [inch]	0.4394	a_7 [inch]	0.4520
Width W [inch]	0.9000	a_8 [inch]	0.4420
Knife Edge Height Z [inches]	0.0000	a_9 [inch]	0.4420
Span S	3.6000	aedge [inch]	0.4345
Plastic rotation factor	0.4	aavg [inch]	0.4557
Max Load P [lbs]	3,139	a0/W	0.5063
Vp [inches]	0.0582	f(a0W)	2.7167
Fracture Type	m		
Validity	Valid	Precrack Cycles	28,553
		Final Precrack Load [lbf]	908
		Loading Rate [Ksi √in/min]	82.0

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ISO-15653-18 [in]	**4.65E-3** [in]
ISO-15653-18 [mm]	**0.1180** [mm]
J-Integral	**519.7** [lb/in]
Kj	**130.9** [Ksi √in]

Specimen	439-20-16
Material	
Other ID	P-HAZ
Test Temp [F]	68
Yield Strength Sy [psi]	74,200
Tensile Strength UTS [psi]	87,300
Modulus of Elasticity E [psi]	30.0E+6
Poisson's Ratio nu	0.3
Thickness B [inches]	0.4514
Net Thickness Bc [inch]	0.4484
Width W [inch]	0.8990
Knife Edge Height Z [inches]	0.0000
Span S	3.6000
Plastic rotation factor	0.4
Max Load P [lbs]	2,765
Vp [inches]	0.0113
Fracture Type	u (Pop-in)
Validity	Valid

a_1 [inch]	0.4380
a_2 [inch]	0.4500
a_3 [inch]	0.4540
a_4 [inch]	0.4640
a_5 [inch]	0.4660
a_6 [inch]	0.4610
a_7 [inch]	0.4560
a_8 [inch]	0.4540
a_9 [inch]	0.4460
aedge [inch]	0.4420
aavg [inch]	0.4559
a0/W	0.5071
f(a0W)	2.7234
Precrack Cycles	27,418
Final Precrack Load [lbf]	912
Loading Rate [Ksi √in/min]	76.0

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ISO-15653-18 [in]	12.63E-3	[in]
ISO-15653-18 [mm]	0.3209	[mm]
J-Integral	1471.4	[lb/in]
Kj	220.2	[Ksi √in]

Specimen	439-20-30		
Material			
Other ID	P-HAZ		
Test Temp [F]	68	a_1 [inch]	0.4250
Yield Strength Sy [psi]	74,200	a_2 [inch]	0.4280
Tensile Strength UTS [psi]	87,300	a_3 [inch]	0.4380
Modulus of Elasticity E [psi]	30.0E+6	a_4 [inch]	0.4490
Poisson's Ratio nu	0.3	a_5 [inch]	0.4500
Thickness B [inches]	0.4514	a_6 [inch]	0.4480
Net Thickness Bc [inch]	0.4472	a_7 [inch]	0.4460
Width W [inch]	0.8990	a_8 [inch]	0.4450
Knife Edge Height Z [inches]	0.0000	a_9 [inch]	0.4320
Span S	3.6000	aedge [inch]	0.4285
Plastic rotation factor	0.4	aavg [inch]	0.4416
Max Load P [lbs]	3,053	a0/W	0.4912
Vp [inches]	0.0345	f(a0W)	2.5895
Fracture Type	m		
Validity	Valid	Precrack Cycles	26,415
		Final Precrack Load [lbf]	906
		Loading Rate [Ksi √in/min]	78.0

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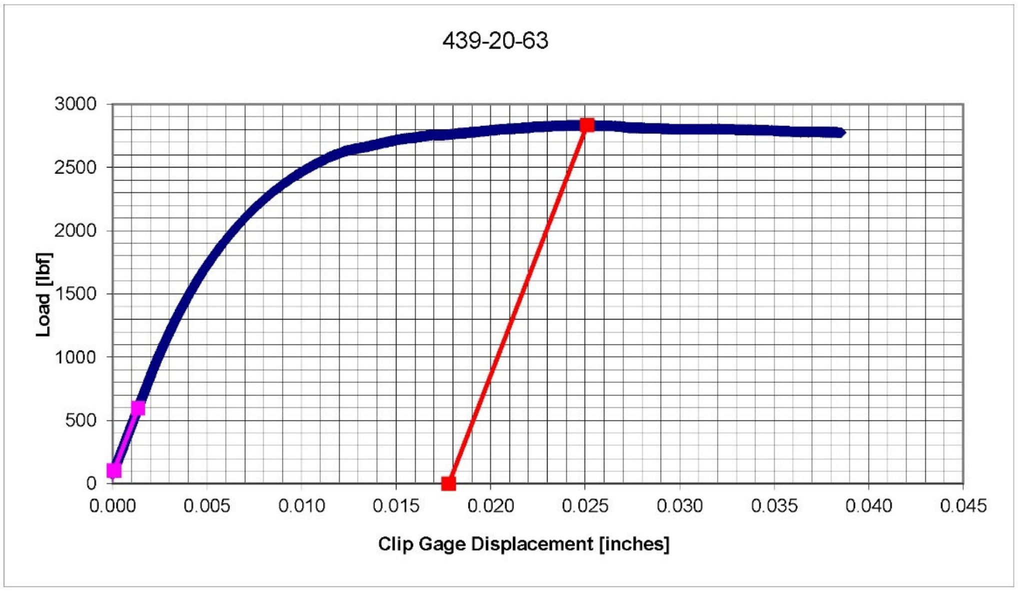

ISO-15653-18 [in]	6.90E-3	[in]
ISO-15653-18 [mm]	0.1752	[mm]
J-Integral	773.4	[lb/in]
Kj	159.7	[Ksi √in]

Specimen	439-20-63		
Material			
Other ID	Weld		
Test Temp [F]	68	a_1 [inch]	0.4190
Yield Strength Sy [psi]	77,500	a_2 [inch]	0.4330
Tensile Strength UTS [psi]	90,000	a_3 [inch]	0.4450
Modulus of Elasticity E [psi]	30.0E+6	a_4 [inch]	0.4550
Poisson's Ratio nu	0.3	a_5 [inch]	0.4540
Thickness B [inches]	0.4518	a_6 [inch]	0.4590
Net Thickness Bc [inch]	0.4475	a_7 [inch]	0.4620
Width W [inch]	0.8980	a_8 [inch]	0.4520
Knife Edge Height Z [inches]	0.0000	a_9 [inch]	0.4460
Span S	3.6000	aedge [inch]	0.4325
Plastic rotation factor	0.4	aavg [inch]	0.4491
Max Load P [lbs]	2,836	a0/W	0.5001
Vp [inches]	0.0180	f(a0W)	2.6631
Fracture Type	m		
Validity	Valid	Precrack Cycles	28,203
		Final Precrack Load [lbf]	910
		Loading Rate [Ksi √in/min]	77.4

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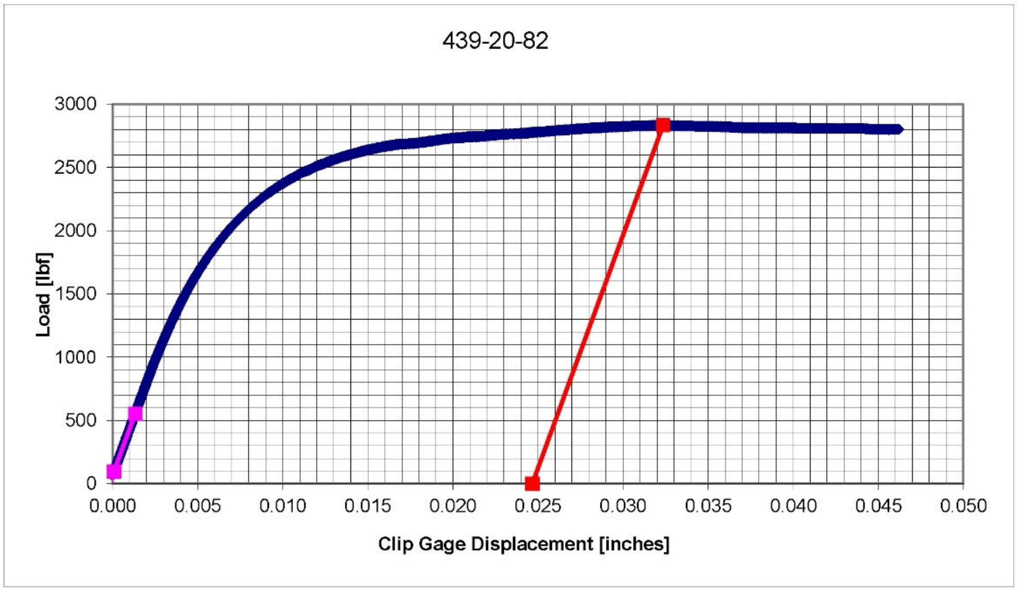

ISO-15653-18 [in]	**8.39E-3**	[in]
ISO-15653-18 [mm]	**0.2132**	[mm]
J-Integral	**1159.4**	[lb/in]
Kj	**195.5**	[Ksi √in]

Specimen	439-20-82		
Material			
Other ID	Weld		
Test Temp [F]	68	a_1 [inch]	0.4300
Yield Strength Sy [psi]	77,500	a_2 [inch]	0.4360
Tensile Strength UTS [psi]	90,000	a_3 [inch]	0.4590
Modulus of Elasticity E [psi]	30.0E+6	a_4 [inch]	0.4660
Poisson's Ratio nu	0.3	a_5 [inch]	0.4680
Thickness B [inches]	0.4513	a_6 [inch]	0.6900
Net Thickness Bc [inch]	0.4477	a_7 [inch]	0.5800
Width W [inch]	0.8980	a_8 [inch]	0.4600
Knife Edge Height Z [inches]		a_9 [inch]	0.4480
Span S	3.6000	aedge [inch]	0.4390
Plastic rotation factor	0.4	aavg [inch]	0.4998
Max Load P [lbs]	2,835	a0/W	0.5565
Vp [inches]	0.0248	f(a0W)	3.2146
Fracture Type	m		
Validity	Valid	Precrack Cycles	29,867
		Final Precrack Load [lbf]	911
		Loading Rate [Ksi √in/min]	88.6

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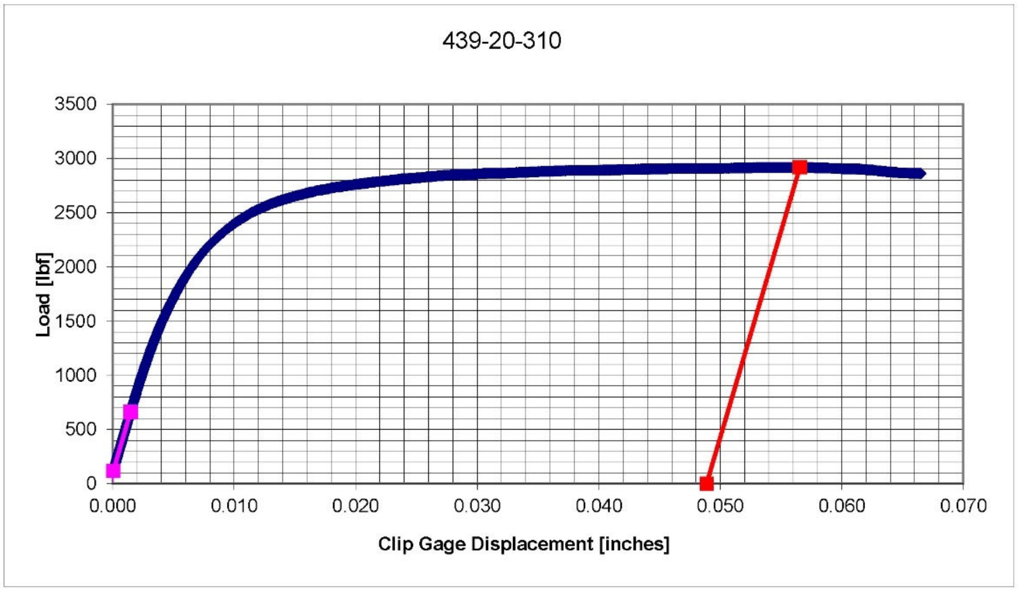

ISO-15653-18 [in]	**17.07E-3**	[in]
ISO-15653-18 [mm]	**0.4336**	[mm]
J-Integral	**1978.9**	[lb/in]
Kj	**255.4**	[Ksi √in]

Specimen	439-20-310		
Material			
Other ID	Weld		
Test Temp [F]	68	a_1 [inch]	0.4420
Yield Strength Sy [psi]	75,600	a_2 [inch]	0.4530
Tensile Strength UTS [psi]	87,100	a_3 [inch]	0.4530
Modulus of Elasticity E [psi]	30.0E+6	a_4 [inch]	0.4580
Poisson's Ratio nu	0.3	a_5 [inch]	0.4620
Thickness B [inches]	0.4513	a_6 [inch]	0.4650
Net Thickness Bc [inch]	0.4481	a_7 [inch]	0.4530
Width W [inch]	0.8980	a_8 [inch]	0.4390
Knife Edge Height Z [inches]		a_9 [inch]	0.4240
Span S	3.6000	aedge [inch]	0.4330
Plastic rotation factor	0.4	aavg [inch]	0.4520
Max Load P [lbs]	2,919	a0/W	0.5033
Vp [inches]	0.0491	f(a0W)	2.6910
Fracture Type	m		
Validity	Valid	Precrack Cycles	28,267
		Final Precrack Load [lbf]	906
		Loading Rate [Ksi √in/min]	82.9

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ISO-15653-18 [in]	**6.81E-3** [in]
ISO-15653-18 [mm]	**0.1729** [mm]
J-Integral	**755.9** [lb/in]
Kj	**157.9** [Ksi √in]

Specimen	439-30-131		
Material			
Other ID	Weld		
Test Temp [F]	68	a_1 [inch]	0.4340
Yield Strength Sy [psi]	80,900	a_2 [inch]	0.4470
Tensile Strength UTS [psi]	91,000	a_3 [inch]	0.4420
Modulus of Elasticity E [psi]	30.0E+6	a_4 [inch]	0.4560
Poisson's Ratio nu	0.3	a_5 [inch]	0.4590
Thickness B [inches]	0.4512	a_6 [inch]	0.4560
Net Thickness Bc [inch]	0.4470	a_7 [inch]	0.4530
Width W [inch]	0.9000	a_8 [inch]	0.4530
Knife Edge Height Z [inches]		a_9 [inch]	0.4300
Span S	3.6000	aedge [inch]	0.4320
Plastic rotation factor	0.4	aavg [inch]	0.4498
Max Load P [lbs]	2,826	a0/W	0.4997
Vp [inches]	0.0175	f(a0W)	2.6602
Fracture Type	m		
Validity	Valid	Precrack Cycles	25,007
		Final Precrack Load [lbf]	910
		Loading Rate [Ksi √in/min]	93.4

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ISO-15653-18 [in]	**8.94E-3** [in]
ISO-15653-18 [mm]	**0.2271** [mm]
J-Integral	**1011.0** [lb/in]
Kj	**182.6** [Ksi √in]

Specimen	439-30-132		
Material			
Other ID	Weld		
Test Temp [F]	68	a_1 [inch]	0.4300
Yield Strength Sy [psi]	80,900	a_2 [inch]	0.4490
Tensile Strength UTS [psi]	91,000	a_3 [inch]	0.4560
Modulus of Elasticity E [psi]	30.0E+6	a_4 [inch]	0.4600
Poisson's Ratio nu	0.3	a_5 [inch]	0.4590
Thickness B [inches]	0.4505	a_6 [inch]	0.4590
Net Thickness Bc [inch]	0.4483	a_7 [inch]	0.4520
Width W [inch]	0.9000	a_8 [inch]	0.4500
Knife Edge Height Z [inches]		a_9 [inch]	0.4450
Span S	3.6000	aedge [inch]	0.4375
Plastic rotation factor	0.4	aavg [inch]	0.4528
Max Load P [lbs]	2,840	a0/W	0.5031
Vp [inches]	0.0241	f(a0W)	2.6891
Fracture Type	m		
Validity	Valid	Precrack Cycles	23,737
		Final Precrack Load [lbf]	925
		Loading Rate [Ksi √in/min]	81.0

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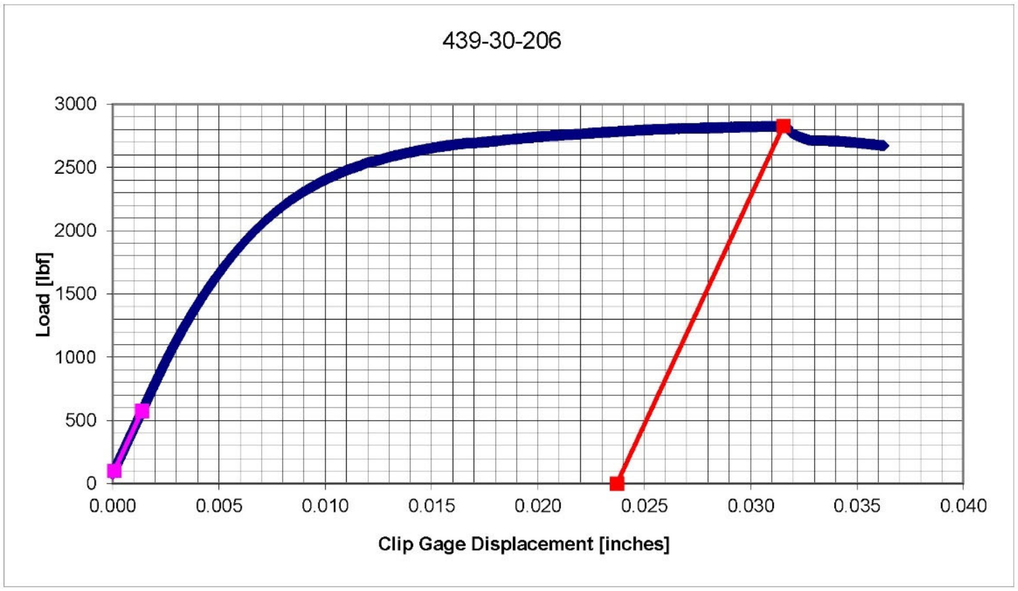

ISO-15653-18 [in]	**8.70E-3** [in]
ISO-15653-18 [mm]	**0.2210** [mm]
J-Integral	**1015.4** [lb/in]
Kj	**183.0** [Ksi √in]

Specimen	439-30-206		
Material			
Other ID	Weld		
Test Temp [F]	68	a_1 [inch]	0.4520
Yield Strength Sy [psi]	82,300	a_2 [inch]	0.4620
Tensile Strength UTS [psi]	91,800	a_3 [inch]	0.4650
Modulus of Elasticity E [psi]	30.0E+6	a_4 [inch]	0.4690
Poisson's Ratio nu	0.3	a_5 [inch]	0.4700
Thickness B [inches]	0.4506	a_6 [inch]	0.4680
Net Thickness Bc [inch]	0.4479	a_7 [inch]	0.4630
Width W [inch]	0.9000	a_8 [inch]	0.4600
Knife Edge Height Z [inches]		a_9 [inch]	0.4510
Span S	3.6000	aedge [inch]	0.4515
Plastic rotation factor	0.4	aavg [inch]	0.4636
Max Load P [lbs]	2,828	a0/W	0.5151
Vp [inches]	0.0239	f(a0W)	2.7946
Fracture Type	m		
Validity	Valid	Precrack Cycles	29,301
		Final Precrack Load [lbf]	910
		Loading Rate [Ksi √in/min]	78.2

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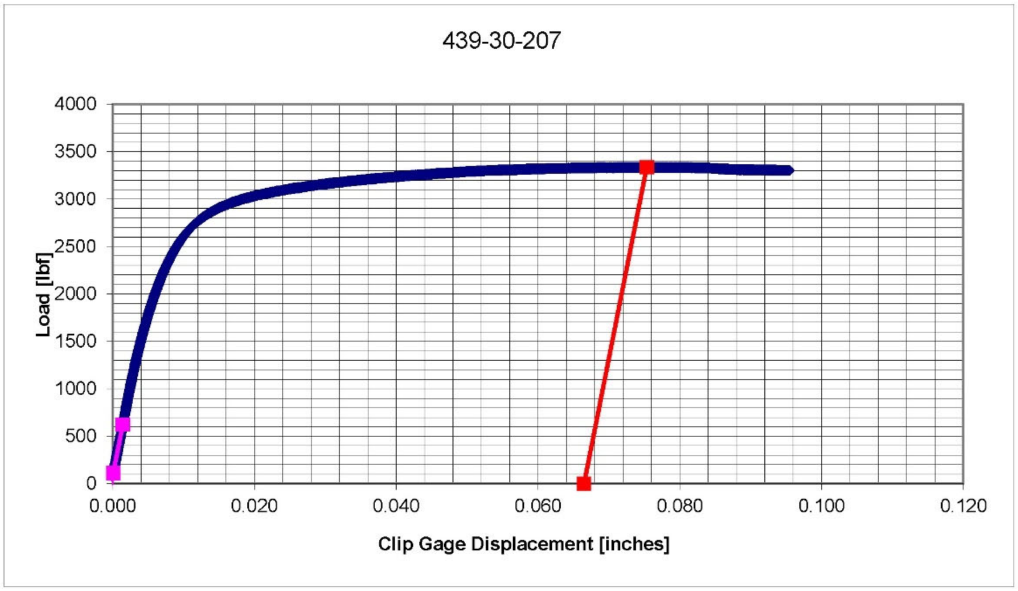

ISO-15653-18 [in]	**22.70E-3** [in]
ISO-15653-18 [mm]	**0.5766** [mm]
J-Integral	**3057.0** [lb/in]
Kj	**317.5** [Ksi √in]

Specimen	439-30-207		
Material	Pipe		
Other ID	Haz		
Test Temp [F]	68	a_1 [inch]	0.4370
Yield Strength Sy [psi]	76,200	a_2 [inch]	0.4500
Tensile Strength UTS [psi]	88,400	a_3 [inch]	0.4650
Modulus of Elasticity E [psi]	30.0E+6	a_4 [inch]	0.4650
Poisson's Ratio nu	0.3	a_5 [inch]	0.4660
Thickness B [inches]	0.4501	a_6 [inch]	0.4680
Net Thickness Bc [inch]	0.4475	a_7 [inch]	0.4650
Width W [inch]	0.9000	a_8 [inch]	0.4570
Knife Edge Height Z [inches]		a_9 [inch]	0.4350
Span S	3.6000	aedge [inch]	0.4360
Plastic rotation factor	0.4	aavg [inch]	0.4590
Max Load P [lbs]	3,337	a0/W	0.5100
Vp [inches]	0.0667	f(a0W)	2.7491
Fracture Type	m		
Validity	Valid	Precrack Cycles	27,121
		Final Precrack Load [lbf]	913
		Loading Rate [Ksi √in/min]	82.7

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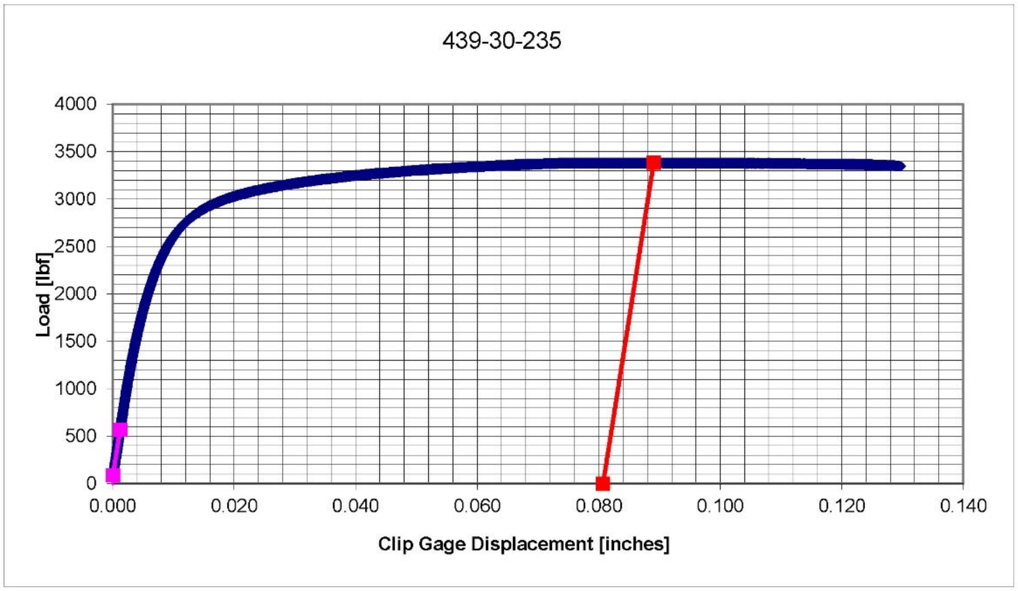

ISO-15653-18 [in]	27.89E-3	[in]
ISO-15653-18 [mm]	0.7085	[mm]
J-Limit	3595.6	[lb/in]
Kj	344.3	[Ksi √in]

Specimen	439-30-235		
Material	Pipe		
Other ID	Haz		
Test Temp [F]	68	a_1 [inch]	0.4300
Yield Strength Sy [psi]	73,100	a_2 [inch]	0.4350
Tensile Strength UTS [psi]	86,100	a_3 [inch]	0.4530
Modulus of Elasticity E [psi]	30.0E+6	a_4 [inch]	0.4580
Poisson's Ratio nu	0.3	a_5 [inch]	0.4580
Thickness B [inches]	0.4511	a_6 [inch]	0.4570
Net Thickness Bc [inch]	0.4476	a_7 [inch]	0.4520
Width W [inch]	0.9000	a_8 [inch]	0.4410
Knife Edge Height Z [inches]		a_9 [inch]	0.4280
Span S	3.6000	aedge [inch]	0.4290
Plastic rotation factor	0.4	aavg [inch]	0.4479
Max Load P [lbs]	3,385	a0/W	0.4976
Vp [inches]	0.0809	f(a0W)	2.6427
Fracture Type	m		
Validity	Valid	Precrack Cycles	24,596
		Final Precrack Load [lbf]	917
		Loading Rate [Ksi √in/min]	74.4

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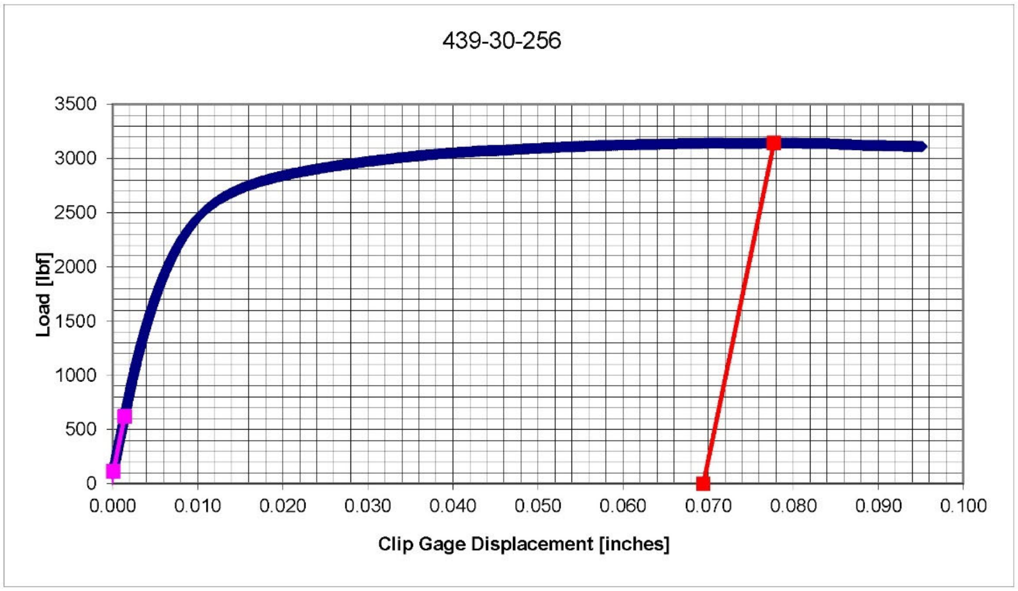


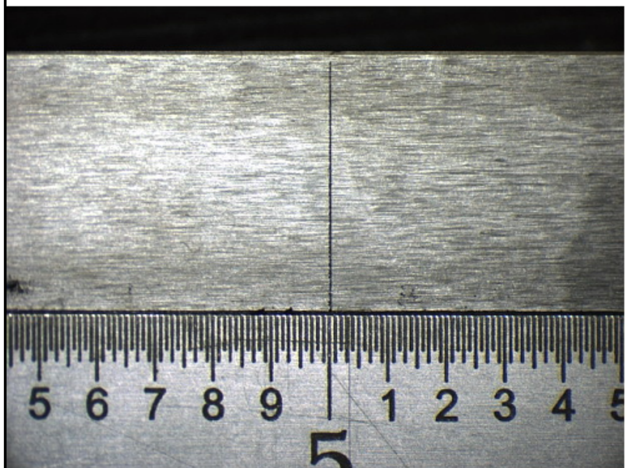
ISO-15653-18 [in]	**23.68E-3** [in]
ISO-15653-18 [mm]	**0.6015** [mm]
J-Integral	**2943.9** [lb/in]
Kj	**311.5** [Ksi √in]

Specimen	439-30-256
Material	Pipe
Other ID	Haz
Test Temp [F]	68
Yield Strength Sy [psi]	73,100
Tensile Strength UTS [psi]	86,100
Modulus of Elasticity E [psi]	30.0E+6
Poisson's Ratio nu	0.3
Thickness B [inches]	0.4500
Net Thickness Bc [inch]	0.4478
Width W [inch]	0.9010
Knife Edge Height Z [inches]	
Span S	3.6000
Plastic rotation factor	0.4
Max Load P [lbs]	3,143
Vp [inches]	0.0697
Fracture Type	m
Validity	Valid

a_1 [inch]	0.4390
a_2 [inch]	0.4400
a_3 [inch]	0.4520
a_4 [inch]	0.4700
a_5 [inch]	0.4700
a_6 [inch]	0.4650
a_7 [inch]	0.4530
a_8 [inch]	0.4480
a_9 [inch]	0.4330
aedge [inch]	0.4360
aavg [inch]	0.4543
a0/W	0.5042
f(a0W)	2.6980
Precrack Cycles	26,651
Final Precrack Load [lbf]	916
Loading Rate [Ksi √in/min]	79.8

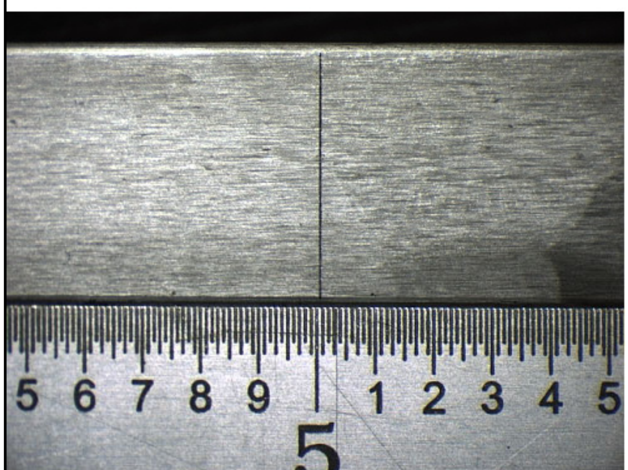
Appendix I
CTOD Notch Location and Fracture Photographs

220439 Notch Positions and Fracture Surfaces

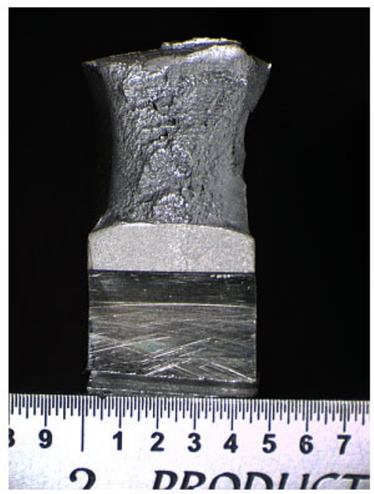


20-6 P-HAZ

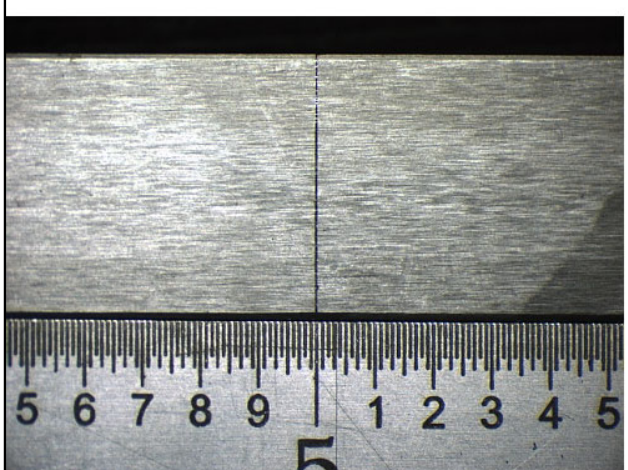
20-6 P-HAZf



20-16 P-HAZ



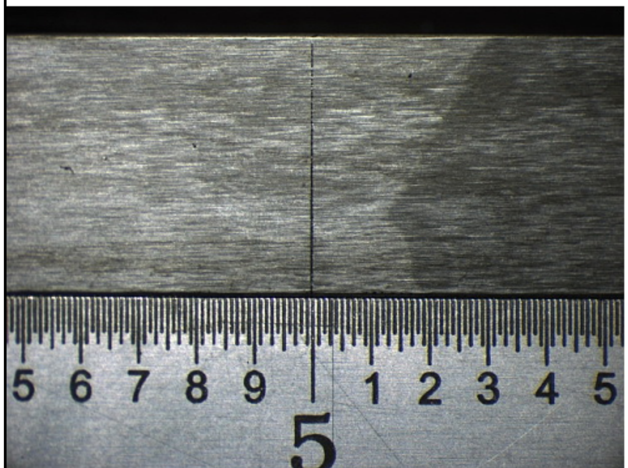
20-16 P-HAZf



20-30 P-HAZ

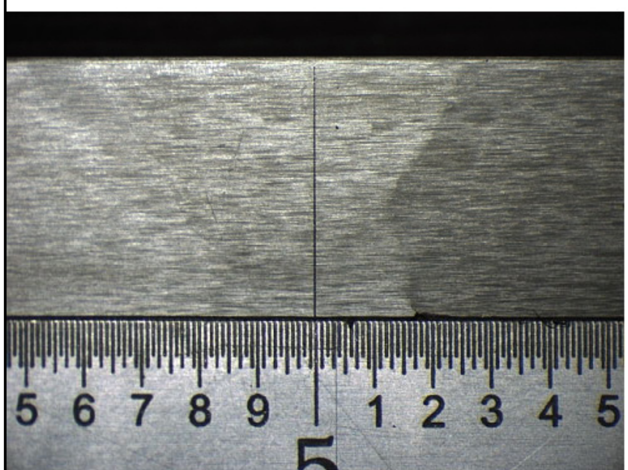
20-30 P-HAZf

220439 Notch Positions and Fracture Surfaces

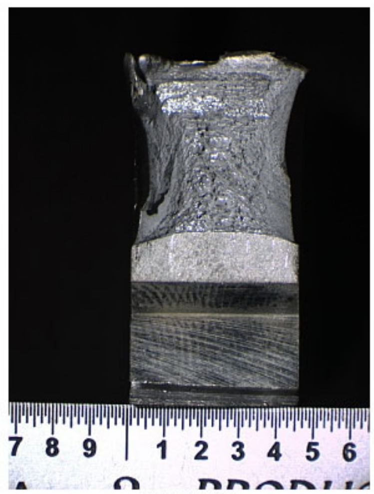


20-63 CW

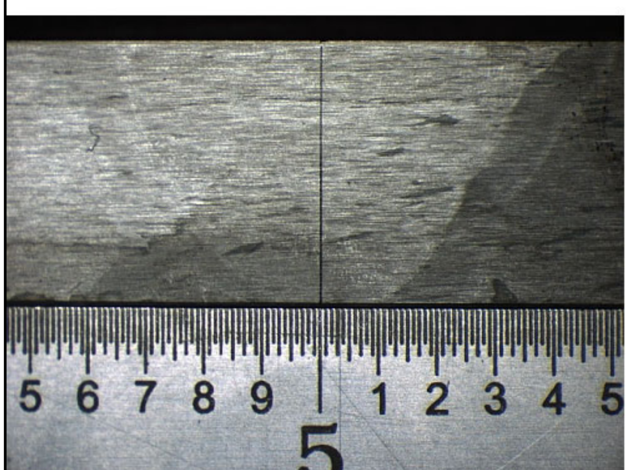
20-63 CWf



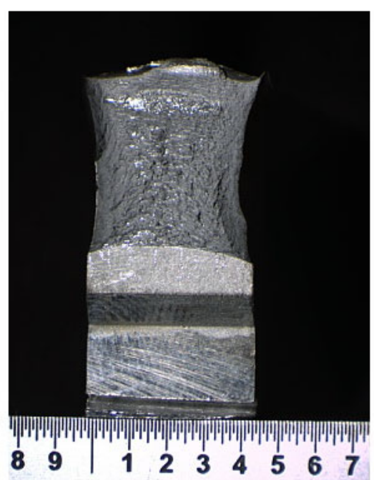
20-82 CW



20-82 CWf

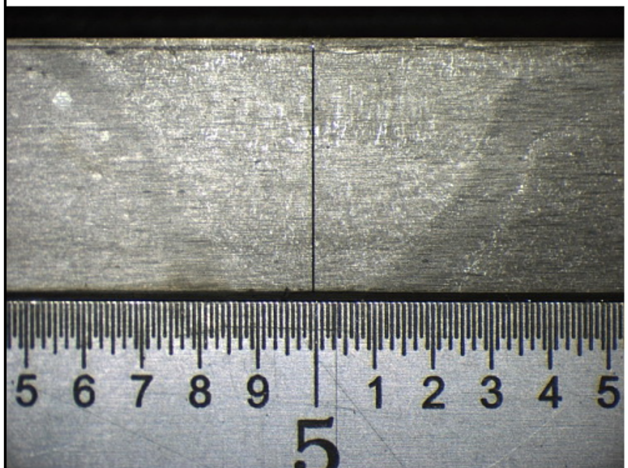


20-310 CW

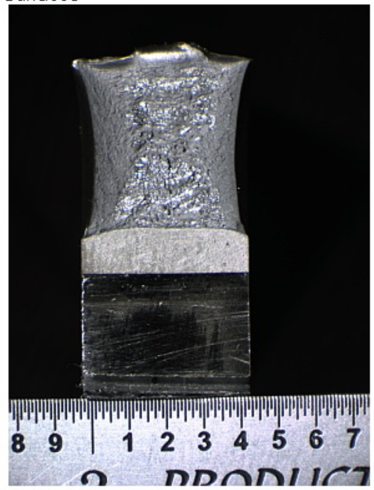


20-310 CWf

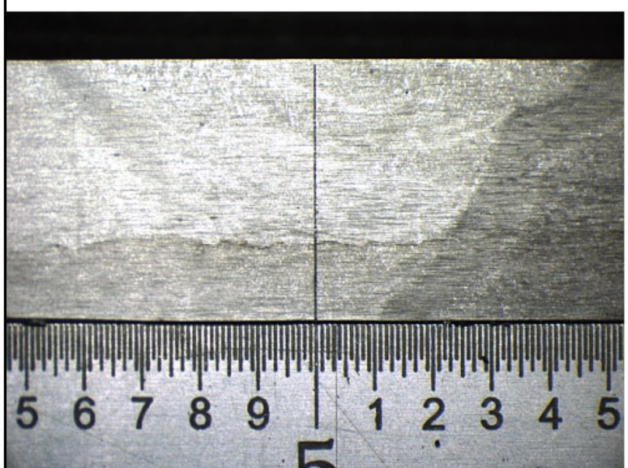
220439 Notch Positions and Fracture Surfaces



30-131 CW

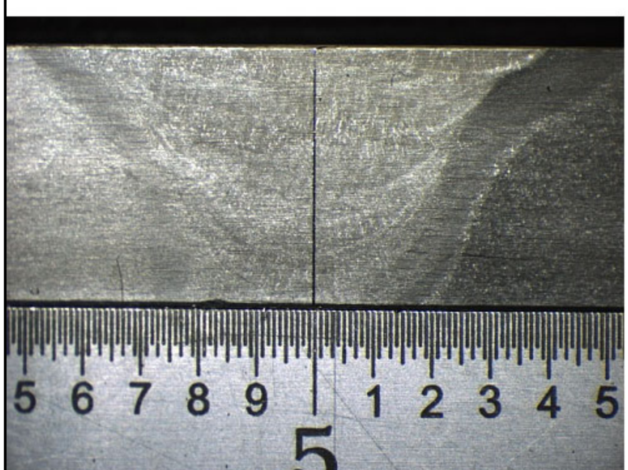


30-131 CWf

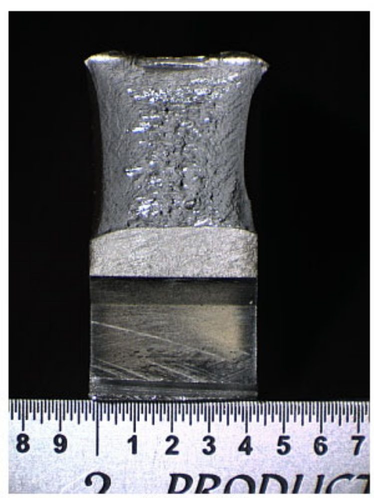


30-132 CW

30-132 CWf

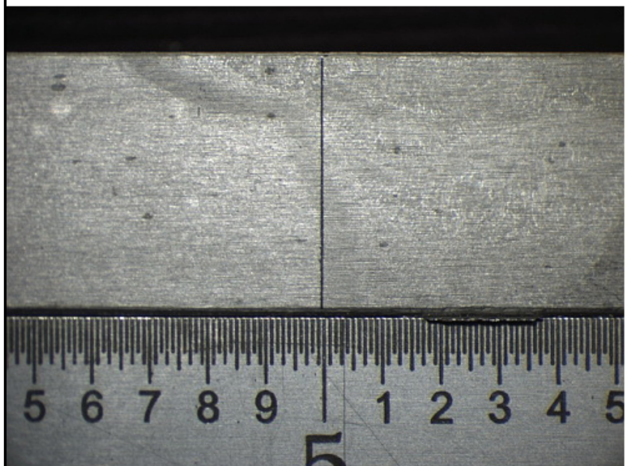


30-206 CW

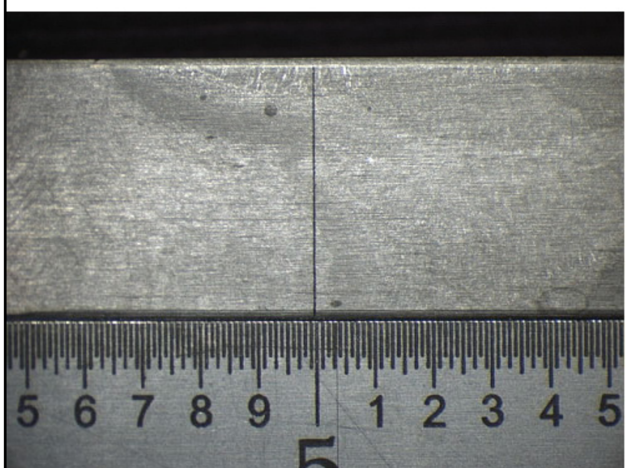


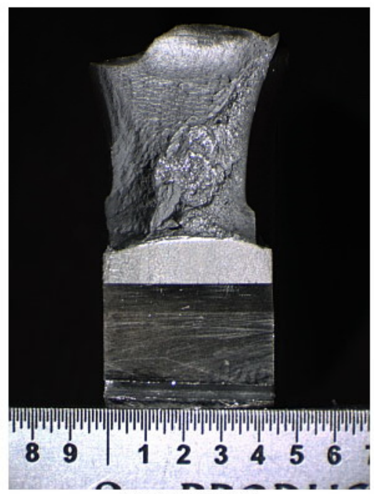
30-206 CWf

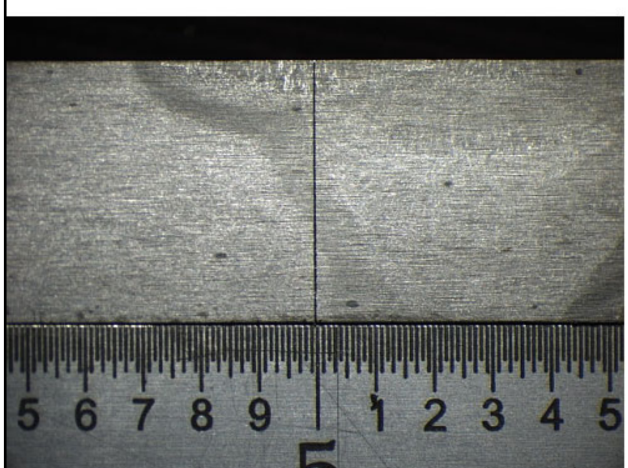
220439 Notch Positions and Fracture Surfaces

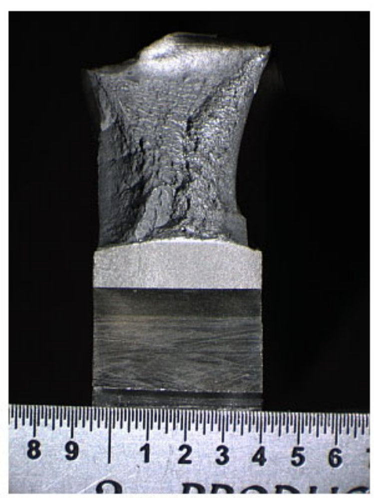

30-207 P-HAZ


30-207 P-HAZf


30-235 P-HAZ


30-235 P-HAZf


30-256 P-HAZ


30-256 P-HAZf