ELECTRIC POWER RESEARCH INSTITUTE

MRP Materials Reliability Program ______________________ MRP 2008-054

(via email)

August 15, 2008

US Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Two White Flint North
11545 Rockville Pike
Rockville, Maryland 20852-2738

Attn: Bob Hardies M/S T10-M05

Subject: St. Lucie Unit 1 Retired PZR Safety "A" Nozzle DM Weld Destructive Examination Report

References

1. MRP 2008-027, "Non Destructive Examination Summary of Pressurizer Safety Nozzles Removed from Service at St Lucie Unit 1"

The destructive examination report for the St. Lucie Unit 1 retired pressurizer Safety "A" nozzle dissimilar metal weld has been finalized and transmitted to the MRP members for their information as a non-proprietary letter report designated MRP 2008-053.

By this present letter, we are forwarding that letter report to you for your information and use.

If you have any questions or concerns, please contact Craig Harrington (charrington@epri.com, 972-556-6519).

Best Regards,

Denny Weakland
First Energy
Chairman MRP IIG

Attachment: MRP 2008-053

Cc: Greg Kammerdeiner, First Energy
Craig Harrington, EPRI
Joe Hagan, First Energy

ELECTRIC POWER RESEARCH INSTITUTE

MRP **Materials Reliability Program** MRP 2008-053
(via email)

August 12, 2008

To: MRP Technical Advisory Group

Subject: St. Lucie Unit 1 Retired PZR Safety "A" Nozzle DM Weld Destructive Examination Report

References

1. MRP 2008-027, "Non Destructive Examination Summary of Pressurizer Safety Nozzles Removed from Service at St Lucie Unit 1"

In the fall of 2005 the pressurizer vessel, manufactured by Combustion Engineering, from the St. Lucie Unit 1 Nuclear Power Station was removed from service and replaced. FPL donated the Alloy 82/182 dissimilar metal (DM) welded nozzles in the top and bottom heads of the retired pressurizer to the NRC Office of Research (NRC RES) in 2007. In February 2008, EPRI MRP voluntarily funded performance of a PDI-qualified manual phased array UT exam of these nozzles to screen them for flaws or other features of potential interest for further evaluation.

The inspection report, documented in Reference 1, conservatively indicated the possible existence of a 360° planar flaw of varying but locally significant depth in the three safety nozzles. The report noted that the indications were consistent with PWSCC, but also with stacked fabrication defects in the weld. In addition, application of encoded phased array examination techniques was recommended to more precisely discriminate these reflectors and determine the condition of the welds.

The potential for a large circumferential flaw, even in a retired component, cast doubt on the safety of uninspected pressurizer nozzle welds remaining in service in the US PWR fleet and led to an immediate, extensive, non-destructive re-examination of the retired pressurizer welds employing fully encoded phased array techniques, encoded ECT examination of the ID surfaces, and high resolution radiography. The methods and results of this re-examination are also fully documented in Reference 1.

These results conclusively demonstrated that while the welds contained a number of fabrication-related defects, there was no evidence of PWSCC and no conditions that would have threatened pressure boundary integrity. Upon completion of these non-destructive examinations, the portion of the "Safety A" nozzle containing the DM weld was removed and sent to a lab for destructive examination to verify the NDE results.

Attachment 1 to this letter is the complete, final lab report of the destructive examination that was performed. Attachment 2 is the final destructive examination plan that was developed by industry and the NRC to guide the lab work and is provided here for reference.

The destructive evaluation confirmed the indications and flaws found within the retired pressurizer safety "A" nozzle are fabrication defects with no evidence of PWSCC. The flaws were also confirmed to be non-safety significant and did not challenge the structural integrity of the component.

A careful evaluation of the comparative results from the NDE and DE may be useful in validating and possibly refining industry NDE capabilities. The MRP Inspection ITG has assumed responsibility for any such evaluation and will consider the scope, timing, and potential benefit within the context of their normal project planning and budgeting.

If you have any questions or concerns, please contact Craig Harrington (charrington@epri.com, 972-556-6519).

Best Regards,

Denny Weakland
First Energy
Chairman MRP IIG

Attachment: SL-1 DE Report

Cc: Greg Kammerdeiner, First Energy
Craig Harrington, EPRI
PMMP EC
MRP IIG
MRP Assessment ITG
MRP Inspection ITG

FINAL REPORT:

LABORATORY ANALYSIS OF PRESSURIZER SAFETY NOZZLE "A" FROM ST. LUCIE UNIT 1

PREPARED FOR:

AREVA, Inc.

S-1150-008-005 **JUNE 2008**

technical services group

FINAL REPORT:

LABORATORY ANALYSIS OF PRESSURIZER SAFETY NOZZLE "A" FROM ST. LUCIE UNIT 1

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S-1150-008-005 **JUNE 2008**

SUMMARY

This report describes nondestructive and destructive examinations performed on the “A” safety nozzle to flange dissimilar metal (DM) weld from the retired St. Lucie Unit 1 pressurizer. The work scope included visual and stereovisual inspections, high resolution replication, dimensional measurements, fluorescent penetrant testing (PT), visible dye penetrant testing, scanning electron microscopy (SEM), energy dispersive spectroscopy (EDS), and optical metallography. The purpose of this testing was to provide information relative to the extent and nature of the NDE indications found by others in the DM weld during field testing, which included: five ID connected penetrant indications, nine ultrasonic indications, six radiographic indications, and four eddy current indications.

Laboratory penetrant examinations confirmed the presence of three of the ID connected indications; the other two indications reported during the field inspections were not detected. These three indications were linearly aligned, located at the DM weld centerline, and measured 0.22" to 0.38" in length. Cross section examinations revealed these indications were cracks extending up to 0.16" deep in the DM weld. The cracks were generally straight and unbranched in nature. Also detected were small voids in the DM weld measuring up to 0.06" in diameter.

Higher magnification examinations by SEM/EDS and optical metallography indicated the cracks most likely occurred during original manufacture due to hot cracking. There was no evidence that the cracks initiated or propagated in-service due to primary water stress-corrosion cracking, fatigue, or other mechanism. Residual bulk compressive stresses in the DM weld appeared to inhibit the initiation of any service induced cracking mechanisms from the observed manufacturing defects.

TABLE OF CONTENTS

1.0 INTRODUCTION

This report describes nondestructive and destructive examinations performed on the “A” safety nozzle to flange dissimilar metal (DM) weld from the retired St. Lucie Unit 1 pressurizer. This test plan was intended to provide information relative to the extent and nature of the NDE indications found by others in the DM weld by a variety of inspection techniques. These indications included: five ID connected penetrant indications, nine ultrasonic indications, six radiographic indications, and four eddy current indications. Additionally, this characterization was necessary to help assess whether the flaws are manufacturing or service induced.

A portion of the nozzle was removed from the pressurizer and submitted to the Babcock & Wilcox (B&W) Technical Services Group Lynchburg Technology Center for these examinations. The work scope included visual and stereovisual inspections, high resolution replication, dimensional measurements, fluorescent penetrant testing, visible dye penetrant testing, scanning electron microscopy (SEM), energy dispersive spectroscopy (EDS), and optical metallography.

2.0 SAMPLE DESCRIPTION/ORIENTATIONS

During operation, the stainless steel flange welded to the nozzle, which extends vertically from the top of the pressurizer. The actual field orientation is shown in Figure 1. The width of the DM weld (including the butter layer) is approximately 1.5", extending from approximately 4" to 5.5" on the tape measure in the photograph. The stainless steel flange was removed at the RACE facility by flame cutting with a torch approximately 2.5" above the DM weld and all exposed surfaces were blasted with carbon steel grit. The outside surfaces of the nozzle were flapped to a shiny bare-metal condition using a round flapper wheel on a side grinder. The nozzle was removed from the pressurizer by sectioning approximately 2.5" below the DM weld with a split-lathe machine (Figure 2).

The orientation scheme developed for the safety nozzle is shown in Figure 3. The rotational orientation was established by placing the 0° position (designated Θ in Figure 3) on the downhill side of the pressurizer head and increasing degrees in the clockwise direction when looking at the pressurizer. The 0" elevation was assigned to the DM weld centerline, with elevation becoming positive toward the vessel and negative moving away from vessel. Both the 0° rotational orientation and 0" elevation were vibra-etched on the nozzle OD at the RACE facility prior to submitting the nozzle segment to B&W. Note that this orientation scheme was maintained throughout all of the NDE and DE for consistency.

Extensive non-destructive testing was performed on the DM weld prior to shipping to B&W. Figure 4 provides a plan view summary of the manual and automated ultrasonic test (UT) data for the DM weld. The automated UT technique reported nine indications, which were designated UT1 through UT9. A summary of the results for all the NDE performed on the DM weld is shown in Figure 5. This summary includes the nine UT indications, plus the indications found during radiography, penetrant, and eddy current testing.

3.0 RECEIPT VISUAL INSPECTIONS

Several photographs were taken to document the as-received condition of the nozzle segment in the laboratory. Figure 6 shows the typical appearance of the nozzle OD surface and flame cut surface. Annotated on the upper photograph in Figure 6 are the locations of the stainless steel flange, DM weld, and carbon steel nozzle. Angular orientations and the zero elevation are also shown.

Figure 7 is a series of photographs taken at 45° increments with the nozzle OD surface normal to the camera. The black circumferential markings on the OD surface at the interface between the weld and the base material were made at the RACE facility using a permanent marker.

4.0 HIGH RESOLUTION REPLICATION

A high resolution Microset© replica (101FF) was made of the ID surface to document its condition for possible future examination. The original intent of this replica was to assist in mapping ID surface connected flaws; however, after successful NDE and DE on the nozzle remnant, further examination of this replica was considered unnecessary.

5.0 OUTER DIAMETER MEASUREMENTS/INITIAL SECTIONING

The outer diameter of the nozzle was measured at several angular orientations prior to longitudinally sectioning through the 150° orientation. One measurement was taken 90° from the first cut at 150° (60°-240°); other measurements were made at standard 45° increments. These measurements were repeated after completing the first cut with a water-cooled saw equipped with a 0.065" wide abrasive blade. The results are tabulated below:

Table 1: Nozzle OD measurements.

Location	Before Section	After Section	Difference
0°-180°	6.009"	6.006"	-0.003"
45°-225°	5.992"	5.985"	-0.007"
60°-240°	5.990"	5.984"	-0.006"
90°-270°	5.962"	5.961"	-0.001"
135°-315°	6.005"	6.000"	-0.005"

A decrease in the OD measurement after sectioning indicated a bulk compressive stress was present in the nozzle. The abrasive saw blade was crimped at the conclusion of the cut, further confirmation that a compressive stress was present in this piece. A likely residual stress distribution in the weld is compression on the OD and tension on the ID, which would cause the pipe circumference to lengthen (i.e. crimp the blade) and the ID to contract after completion of the first cut.

The nozzle was then sectioned through the 330° orientation to permit direct examination of the ID surfaces. These two cuts created piece 1 (330° to 150° clockwise) and piece 2 (150° to 330° clockwise) and are shown schematically in Figure 8.

6.0 NONDESTRUCTIVE TESTING

Fluorescent Penetrant Testing

The ID surfaces of piece 1 and piece 2 were fluorescent penetrant tested using an extended 30 minute dwell and 30 minute development. This inspection was performed to verify the presence of the five ID connected PT indications (identified as PT1, PT2, PT3, PT4, and PT5) found during past inspections.

Three aligned linear indications corresponding to PT1, PT4, and PT5 were detected in piece 1 (Figure 9). All indications were circumferentially oriented at the elevation corresponding to the weld centerline. The indication sizes and locations are as follows:

Table 2: PT results for piece 1.

Indication	Length	Elevation	ID Extent
PT1	0.38"	weld centerline (0")	340-355°
PT5	0.22"	weld centerline (0")	35-45°
PT4	0.38"	weld centerline (0")	65-80°

No surface connected ID indications corresponding to PT2 and PT3 were found on piece 2 (Figure 10).

Visible Dye Penetrant

A visible dye penetrant examination was also performed on piece 2 to ensure no ID surface connected defects were preset. No indications were found on the ID surface during the laboratory test (Figure 11 upper).

Approximately 0.5T of the nozzle DM weld adjacent to the ID surface at the 150° orientation was also tested. Four small indications were detected, including rounded indications measuring 0.11" and 0.07" in diameter and linear indications measuring 0.1" and 0.05" long (Figure 11 lower). Three of these indications were located in the Alloy 182 weld metal; the fourth indication was within the Alloy 182 butter layer. None of these indications were ID surface connected.

7.0 ADDITIONAL SECTIONING

Piece 1 was sectioned approximately 0.75" from each weld toe to isolate the weld region and facilitate cross section specimen preparation. This created pieces 1A, 1B, and 1C (Figure 12). No further work was performed on piece 1A and 1C. Longitudinal sections were made through piece 1B at 355°, 350°, 35°, 45°, and 140° (Figure 13). These cuts created cross sections to be ground and polished for metallographic analysis at the 350°, 35°, and 140° orientations. To illustrate the purpose of each section, the section locations were annotated to the UT map (Figure 14) and NDE indication summary (Figure 15). The 350° section was through PT1 and UT7, the 35° and 45° sections were through PT1 and UT2, and the 140° section was through PT3, which was not detected during the laboratory PT testing. The thin section from 355° to 350° (piece 1B2A) was sectioned further to create an open crack specimen of PT1 for SEM/EDS analysis (Figure 16). The crack profile was exposed by opening the defect with pliers.

8.0 SEM/EDS EXAMINATIONS

SEM/EDS examinations were conducted on three specimens, two polished cross sections (350° and 35° orientations) and one open crack specimen (between 340° and 350°). Both secondary electron (SE) and backscattered electron (BSE) imaging modes were utilized to characterize the specimens. SE imaging was used to document the fracture surface morphology of the mounted and open crack samples, while backscattered electron (BSE) imaging was utilized to qualitatively determine chemical composition differences present in various regions of interest. In the BSE imaging mode, gray level contrast is a function primarily of atomic number, with lower average atomic number constituents such as carbon appearing dark and higher average atomic number constituents such as tungsten appearing bright.

The energy dispersive spectrometer (EDS) attachment on the SEM was used to qualitatively identify the elemental constituents present in overall regions of the specimens; it was also used to identify the chemical composition of specific regions of interest. Area EDS dot mapping was employed to characterize the distribution of the various elements within particular regions of interest.

350° Mounted Section (Through PT1)

Low magnification SE and BSE micrographs showing the ID surface connected crack are provided in Figure 17. The ID surface of the nozzle is located along the bottom edge of each micrograph. The crack extended 0.16" into the Alloy 182 weld metal, including the weld void located ahead of the crack tip. There was no branching associated with the cracking. Higher magnification SE and BSE images of the weld void are shown in Figure 18 and Figure 19. EDS analysis of the substance within the weld void indicated the presence of elements normally associated with weld flux (oxygen, fluorine, magnesium, aluminum, calcium, and titanium). Alloy 182 constituents were also detected in this area (chromium, manganese, iron, nickel, and niobium).

In order to develop a better understanding of the spatial distribution of the elements present in this area, EDS dots maps were collected from the area of this specimen shown in Figure 19. The dot maps are presented in Figure 20. The primary elements present within the void included aluminum, carbon, calcium, fluorine, manganese, oxygen, and titanium. All of these elements can be attributed to weld flux. The surrounding weld metal contained chromium, iron, manganese, and nickel, as expected. Higher magnification micrographs taken adjacent to the void are shown in Figure 21. These micrographs depict a dendritic morphology, which is typical of weld metal that did not fuse together completely. Figure 22 highlights one such area. EDS spectra were collected from areas within a dendritic-appearing void. Area 1, near the center of this void, contained predominantly calcium and fluorine. These elements are typically associated with weld flux. Areas around the perimeter of the void contained oxygen, chromium, iron, and nickel as well as nickel-rich regions. Figure 23 highlights a second region located closer to the main weld void. This area contained two distinct chemical compositions, as suggested by the BSE gray level contrasts. Point 1 was primarily titanium and oxygen, while point 2 contained calcium and fluorine. Each of these elements is found in weld flux, as calcium fluoride and titanium oxide.

There was no evidence that the crack was active at the time of discovery or that it initiated or propagated in-service. This finding is supported by the dendritic nature of the crack and the lack of crack branching.

340°-350° Open Crack (PT1)

The open crack specimen prepared from the 340°-350° region of the weld is shown at low magnification in Figure 24. The pre-existing defect region is darker compared to the laboratory fracture region in the BSE image. This is normally due to higher oxygen levels on the pre-existing fracture surface. Two areas of this fracture surface were selected for comparative EDS analysis. Area 1 was located within the laboratory fracture, while area 2 was within the pre-existing defect region. The comparative EDS spectra indicated increased oxygen and potassium as well as decreased nickel in the pre-existing defect relative to the laboratory fracture. The potassium may have originated from the red dye.

Since the fracture surface chemical compositions are expected to be different for primary water stress corrosion cracking and hot cracking (Ref. 1), it was decided to select regions of the pre-existing crack and laboratory crack at higher magnification to minimize the impact of extraneous constituents on the fracture surface. (Note that the open crack sample was lightly UT cleaned in acetone and that some penetrant and/or developer residue was likely present in the fracture crevices.) The two areas selected for EDS are shown in Figure 25. The EDS spectrum data indicated higher levels of oxygen, niobium, titanium, and manganese in the pre-existing crack relative to the laboratory fracture. Enrichment in niobium and manganese on a crack surface relative to a clean fracture surface has been attributed to hot cracking. The enrichment of these elements suggests the existence of a liquid film wetting the surfaces of the hot-formed crack (Ref. 1).

Progressively higher magnification SE micrographs showing the typical morphology of the pre-existing fracture surface are provided in Figure 26. These micrographs illustrate the mixed-mode nature of the fracture surface, which consisted of non-fused regions (smooth texture) and ductile microvoid coalescence. Small (2-3 micron diameter) raised nodules were detected at high magnifications on the non-fused portions of the fracture surface (micrographs 132327 and 132333 in Figure 26). Comparative EDS spectra were collected from typical smooth and raised regions. The spectrum data are presented in Figure 26 (EDS 132333-1-2). Area 1 (smooth region) contained higher levels of nickel, silicon, niobium, and iron as well as lower oxygen, titanium, chromium, manganese, and aluminum concentrations relative to area 2 (raised area). These results indicate mixing between the flux and weld metal occurred during solidification.

35° Mounted Section (Through PT5)

Low magnification SE and BSE micrographs of the crack present in this specimen are provided in Figure 27. The cracking is straight and unbranched. It extends approximately 0.1" into the weld from the ID surface. Progressively higher magnification micrographs taken near the crack tip are provided in Figure 28. EDS analysis was performed on two regions within the crack. The first area contained primarily calcium and fluorine, while the second area contained primarily titanium and oxygen (Figure 28). These results were consistent with those obtained from the crack located at 350° (refer back to Figure 23). SE and BSE micrographs documenting the dendritic nature of the crack near the crack tip are presented in Figure 29.

9.0 METALLOGRAPHY

Three mounted cross sections were prepared through the DM weld. The samples were examined in the as-polished condition and after electrolytically etching with 10% oxalic acid for 30 seconds to reveal the material microstructure.

350° Mounted Section (Through PT1)

Figure 30 is a low magnification view of the polished and etched cross section prepared through the 350° orientation. The upper photograph in this figure shows the locations of the stainless steel flange, the Alloy 182 weld, the Alloy 182 butter layer, the carbon steel nozzle, and the stainless steel cladding on the nozzle ID surface. A crack measuring 0.16" deep from the ID surface and a weld void measuring 0.06" in diameter were present at this location. A higher magnification view of the crack is shown in Figure 31 (this is the same crack examined previously by SEM, see Figure 17 for comparison). It was apparent that the void was caused by weld flux entrapped between two weld beads. The weld bead deposited over the flux (top of micrograph) likely contributed to the cracking. The cracking was interdendritic, straight, and unbranched; it was consistent with hot cracking, not a crack that initiated and propagated in-service. A higher magnification micrograph taken of the crack tip and a micrograph of the weld void are shown in Figure 32.

35° Mounted Section (Through PT5)

The cross section prepared through the 35° orientation is shown in Figure 33. A crack measuring 0.1" deep extended from the ID surface into the weld metal. One small void measuring 0.03" in diameter was present in the Alloy 182 weld metal adjacent to the stainless steel flange. The crack at this location was interdendritic, straight, and unbranched (Figure 34). The weld void is shown at higher magnification in Figure 35. There was no cracking associated with this weld void.

140° Mounted Section

The third cross section, prepared through the 140° orientation, is shown in Figure 36. No cracking was present in this cross section. Two small weld voids measuring less than 0.03" in diameter were detected in the Alloy 182 weld metal adjacent to the butter layer. The larger of these voids is shown in Figure 37. The void measured 0.050" by 0.015" and had a small crack measuring 0.003" long adjacent to the void. This crack was most likely a hot crack created during manufacture, since it was internal to the weld and not exposed to the environment. The second void measured 0.030" by 0.005" and is shown in Figure 38. There was no cracking associated with this void.

10.0 SUMMARY/CONCLUSIONS

- Extended-dwell fluorescent penetrant examinations confirmed the presence of three linearly aligned circumferential indications on the ID surface of the safety nozzle. These indications were located at the DM weld centerline and measured 0.22" to 0.38" in length.

- Cross section examinations revealed these indications were cracks extending up to 0.16" deep in the DM weld from the nozzle ID surface. The cracks were generally interdendritic, straight, and unbranched in nature.

- Higher magnification examinations by SEM/EDS and optical metallography indicated the cracks most likely occurred during original manufacture due to hot cracking. This conclusion is supported by the dendritic morphology of the cracks and the EDS results, which indicated elevated levels of oxygen, niobium, titanium, and manganese on the fracture surface relative to the freshly-opened laboratory fracture surface. Elevated levels of niobium and manganese are typically associated with hot cracking (Ref. 1).

- There was no evidence that the cracks initiated or propagated in-service due to primary water stress-corrosion cracking (SCC), fatigue, or other mechanism. Moreover, the crack aspect ratio of two ID surface connected defects (PT1 and PT5) was close to 2:1, which is indicative of a fabrication flaw and not indicative of SCC. More sensitive surface analysis such as Scanning Auger Microscopy (SAM) and/or Secondary Ion Mass Spectroscopy (SIMS) could be performed to definitively prove this statement.

- Small weld voids were present in the Alloy 182 DM weld. These voids were located adjacent to the stainless steel flange or the Alloy 182 butter layer and ranged in size from less than 0.03" in diameter to 0.06" in diameter. Aside from one small hot crack (0.003" long), there was no cracking associated with these voids.

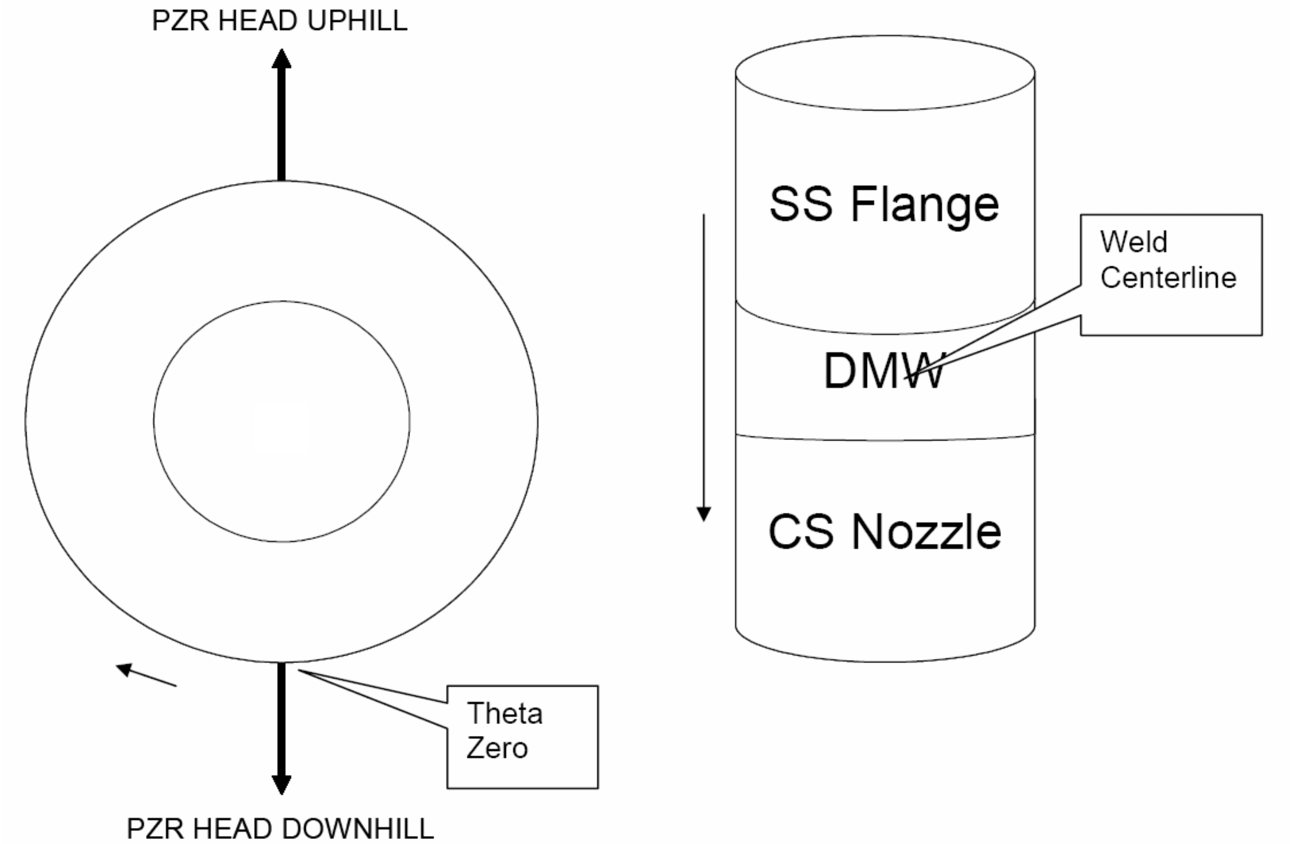
- Bulk compressive residual stresses present in the DM weld appeared to inhibit the initiation of any service induced cracking mechanisms from the observed manufacturing defects.

11.0 REFERENCE

1. J. M. Boursier, et al., "Differentiation between Hot Cracking and Stress Corrosion Cracking in PWR Primary Water of Alloy 182 Weld Material," EUROCORR '99, September 1999.

Figure 1: Photograph showing in-service position of safety nozzle "A".

Figure 2: Photograph taken at the RACE facility showing removal of the safety nozzle with a split-lathe machine operated by AREVA.



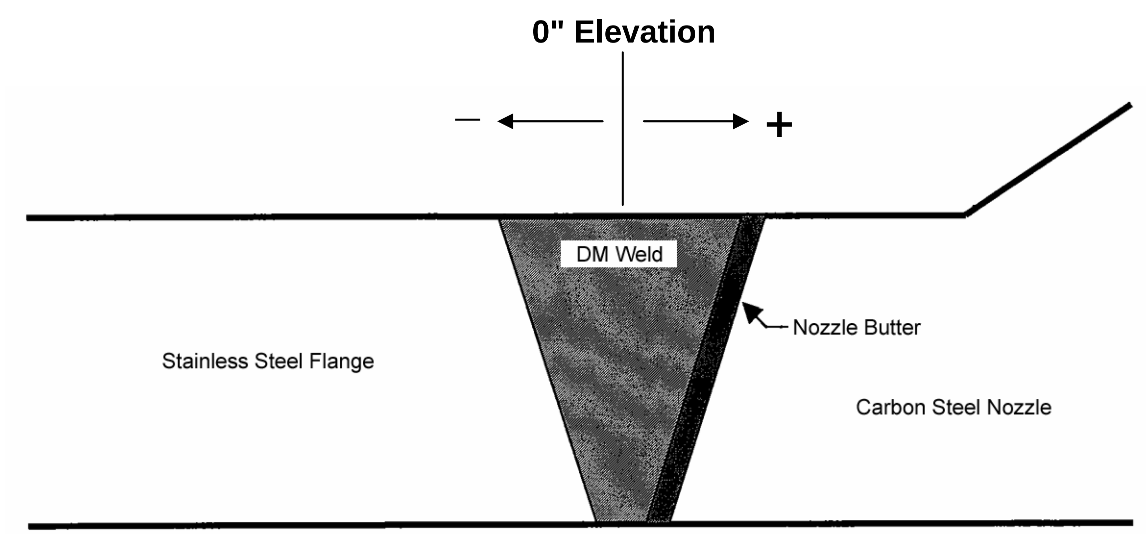


Figure 3: Orientation scheme and general configuration for nozzle/flange dissimilar metal weld. Degrees are increased in the clockwise direction when looking into head. The weld centerline was assigned the zero elevation, with elevation increasing when moving toward the head.

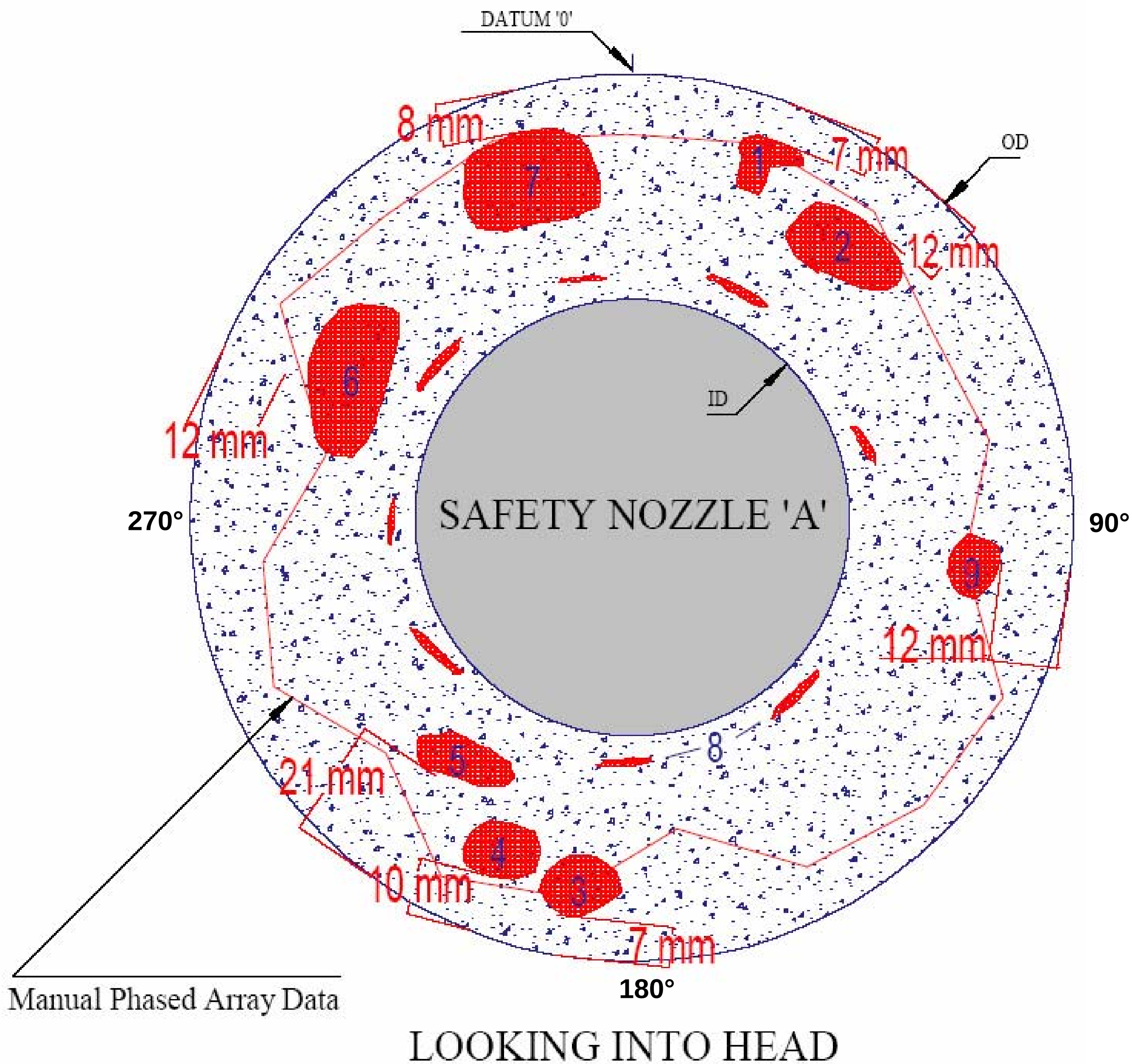


Figure 4: UT (manual and automatic) data for nozzle "A". ***(NOTE: According to UT inspection personnel, the indications shown above in red are strictly pictorial and not intended to convey actual size or shape.)***

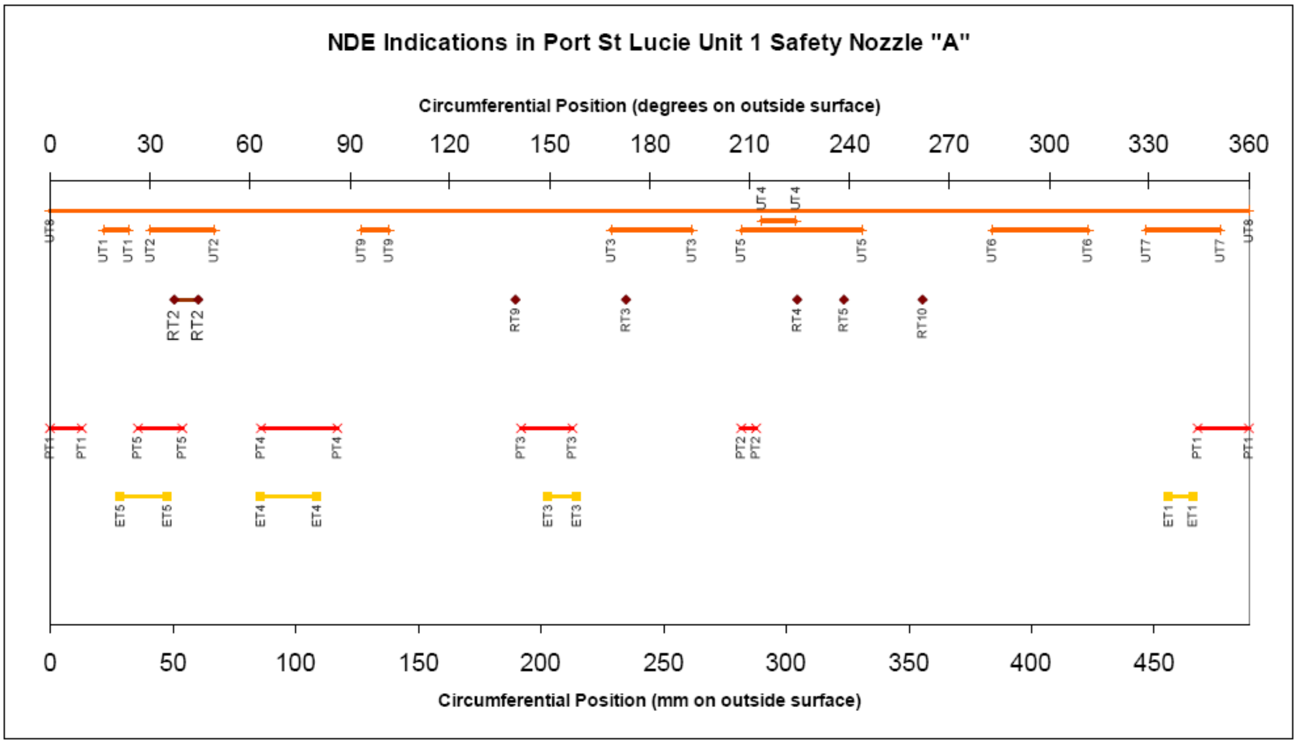
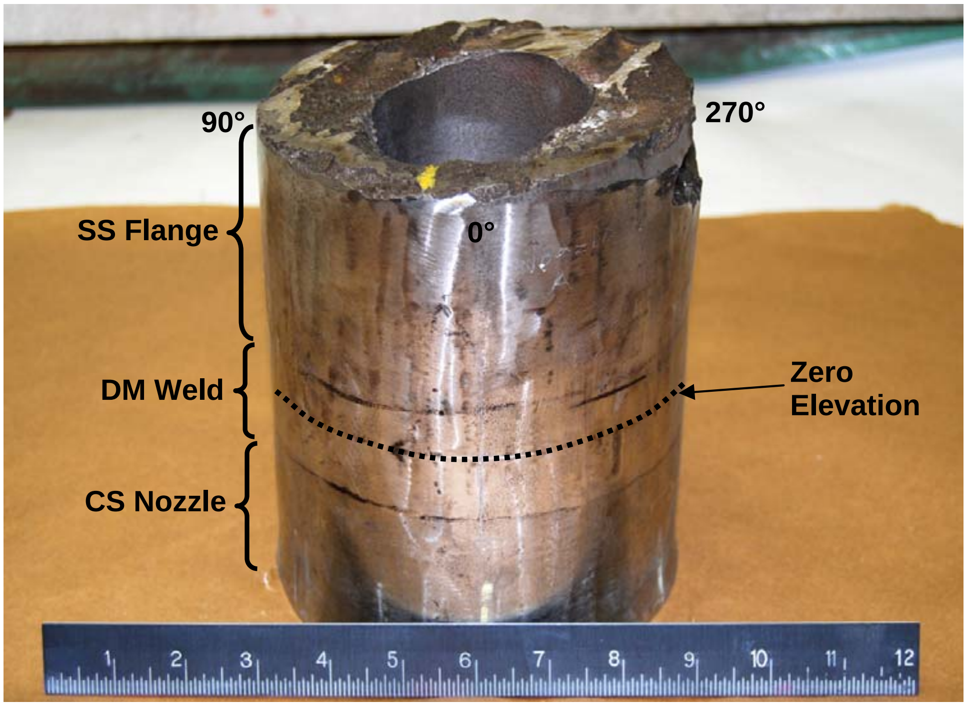


Figure 5: Summary of NDE data for nozzle.



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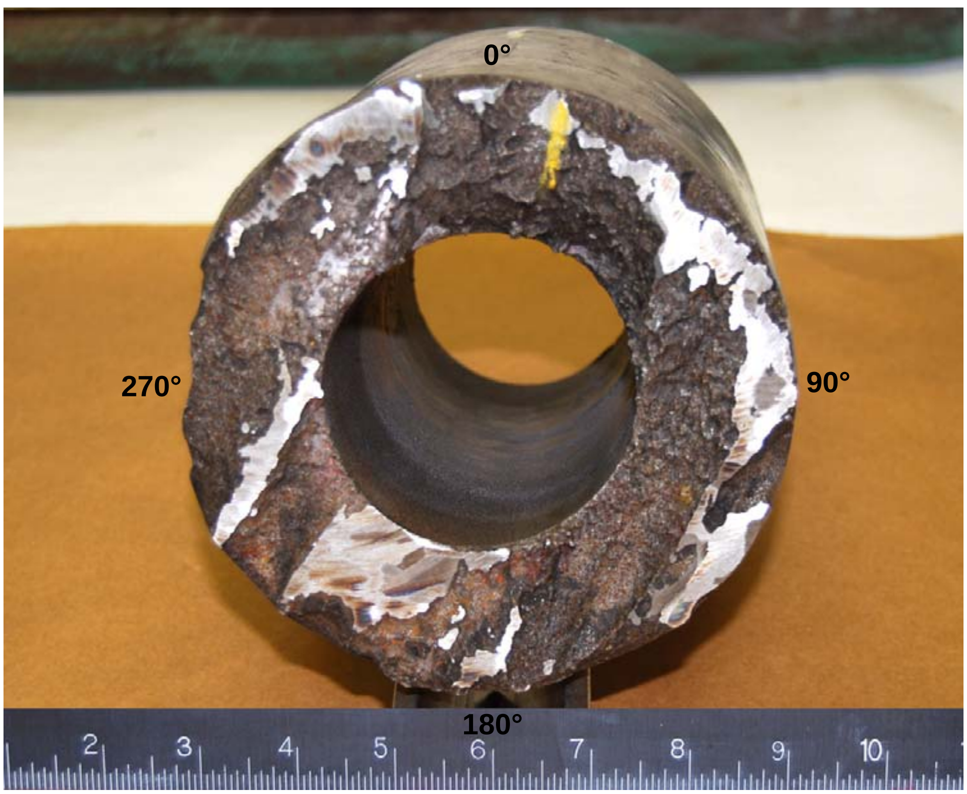


0.5X

Figure 6: Photographs of the as-received piece showing typical OD appearance (top) and flame cut surface (bottom).

90°

0°

270°

0.6X

135°

45°

315°

0.6X

Figure 7: As-received photographs of safety nozzle OD surface.

180°

90°

0°

0.6X

225°

135°

45°

0.6X

Figure 7 (cont.): As-received photographs of safety nozzle OD surface.

270°

180°

90°

0.6X

315°

225°

135°

0.6X

Figure 7 (cont.): As-received photographs of safety nozzle OD surface.

0°
270°
180°

0.6X

45°
315°
225°

0.6X

Figure 7 (cont.): As-received photographs of safety nozzle OD surface.

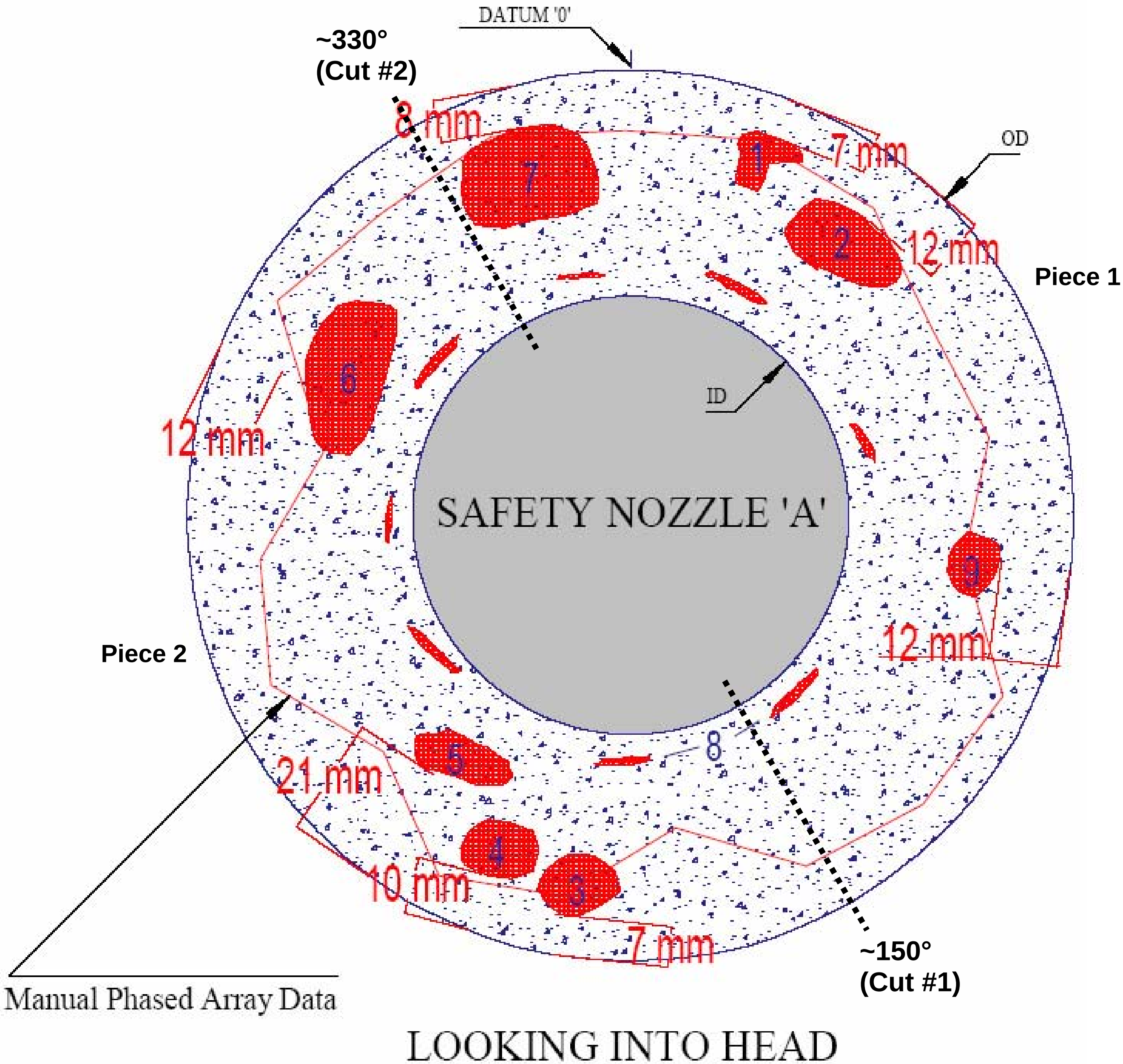
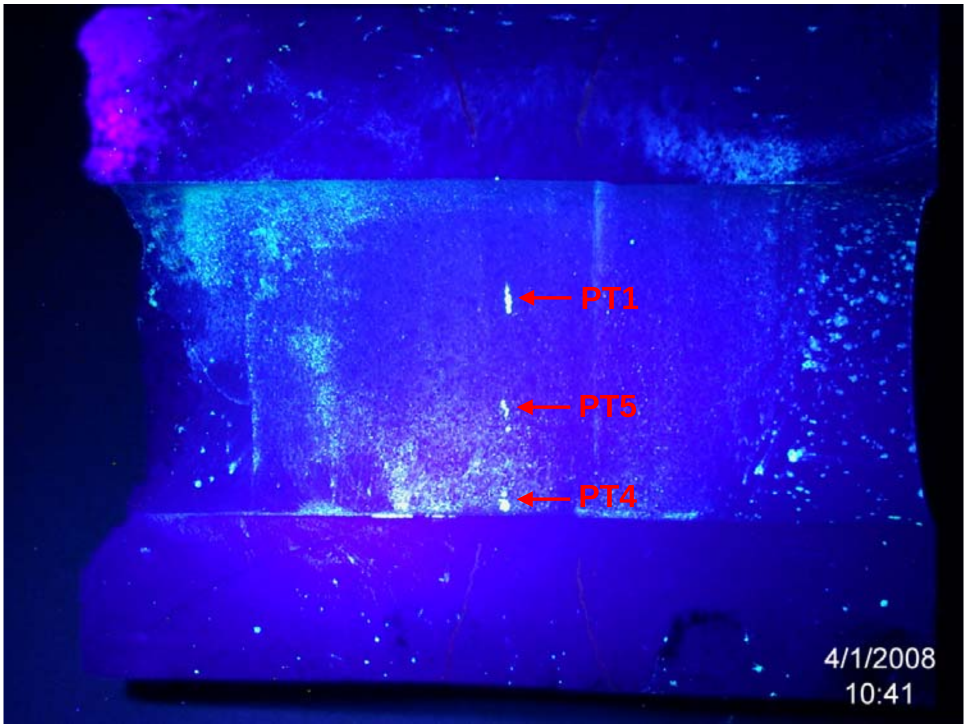
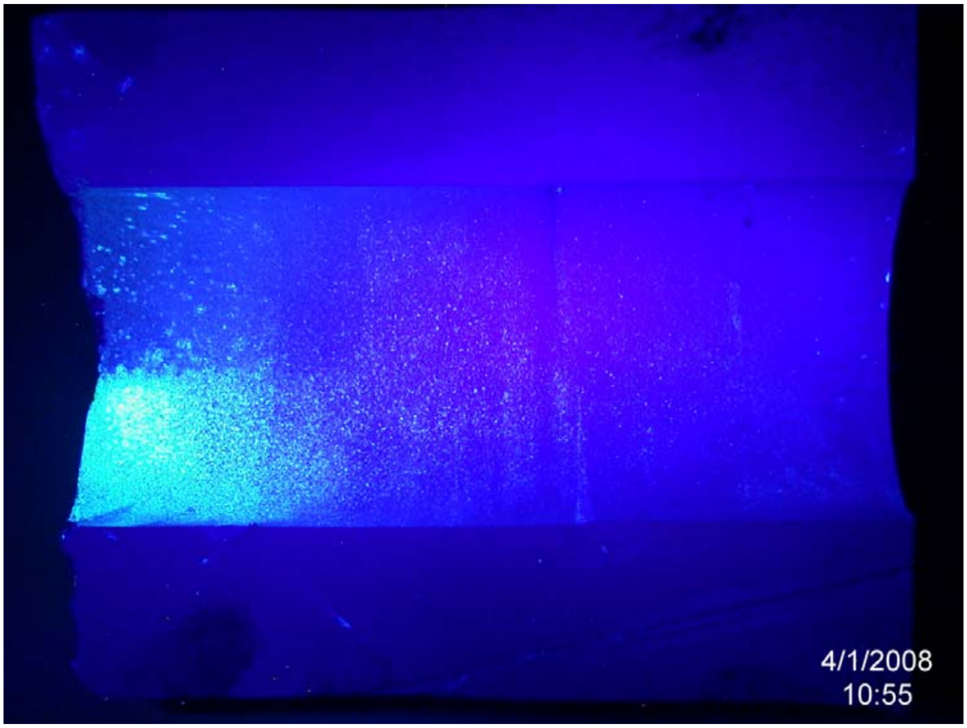


Figure 8: UT map previously shown in Figure 4 showing the first two longitudinal sections made in the laboratory. The first cut was made through the ~150° orientation. The OD was measured after making this cut and then the piece was split open clamshell-style through the ~330° orientation, creating piece 1 (330° to 150° clockwise) and piece 2 (150° to 330° clockwise).



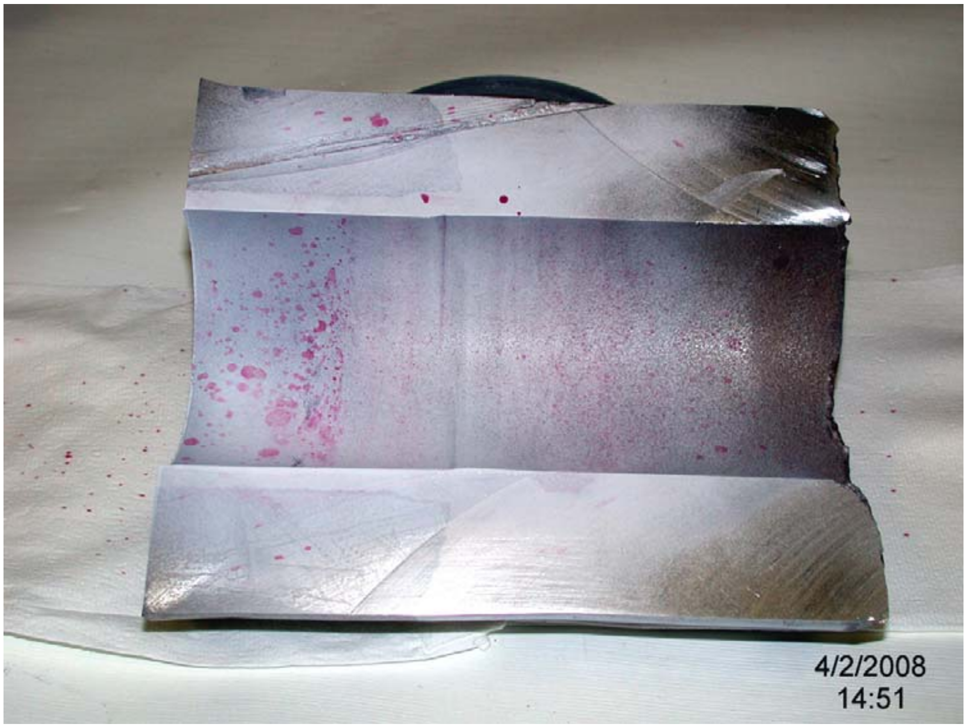
0.6X

Figure 9: PT photographs of Piece 1 showing three aligned linear indications. These indications corresponded to PT1, PT4, and PT5 shown in Figure 5.



0.6X

Figure 10: PT photographs of piece 2. No ID-connected indications were detected, even though earlier PT results indicated two surface connected indications (PT2 and PT3 in Figure 5).



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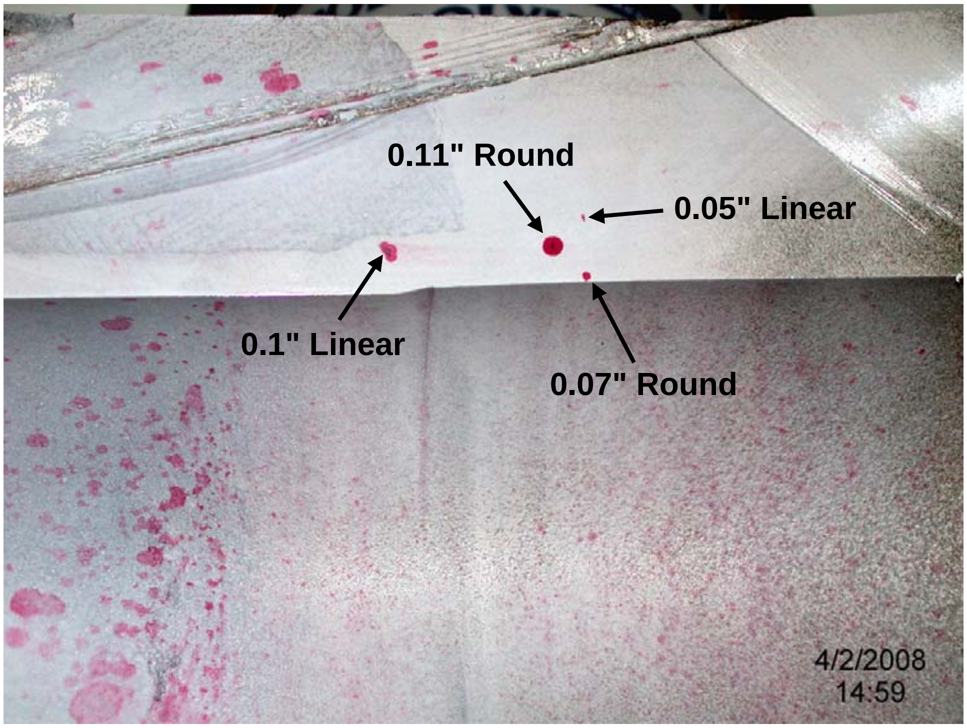
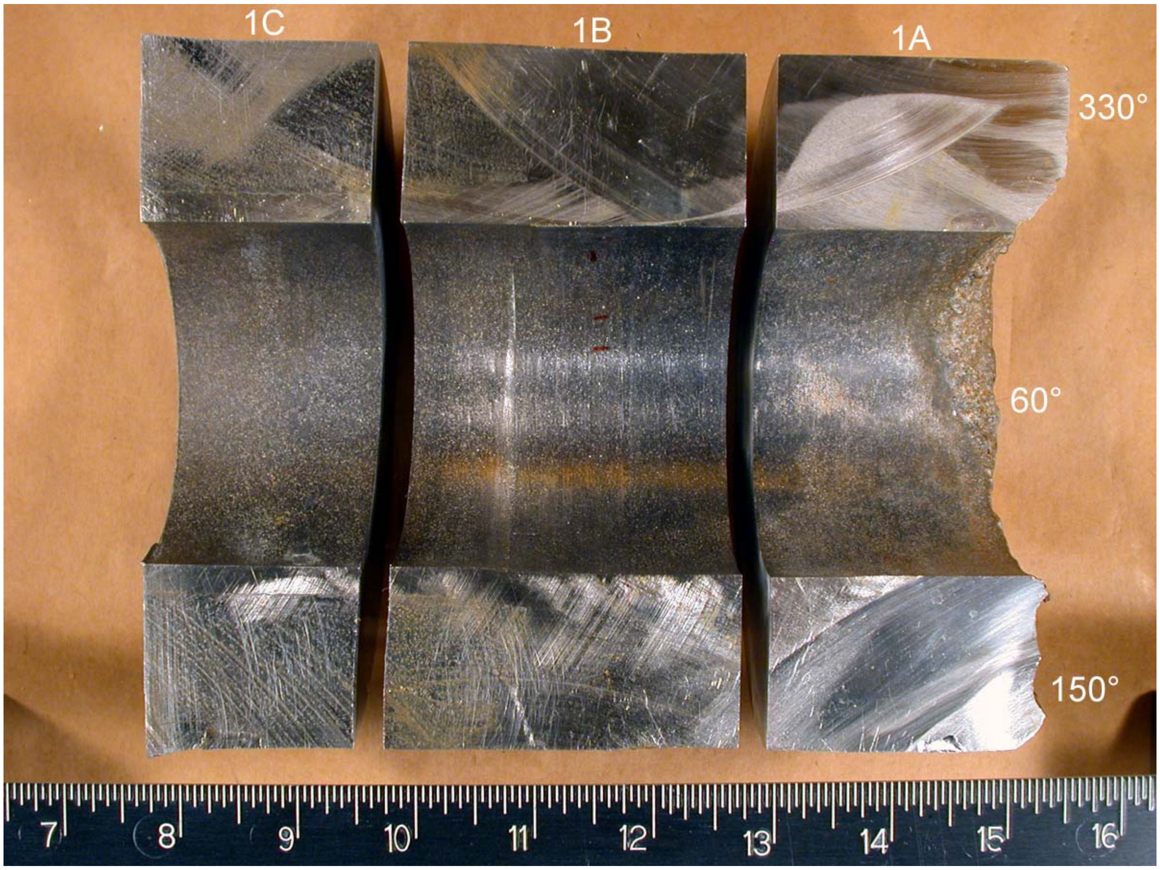


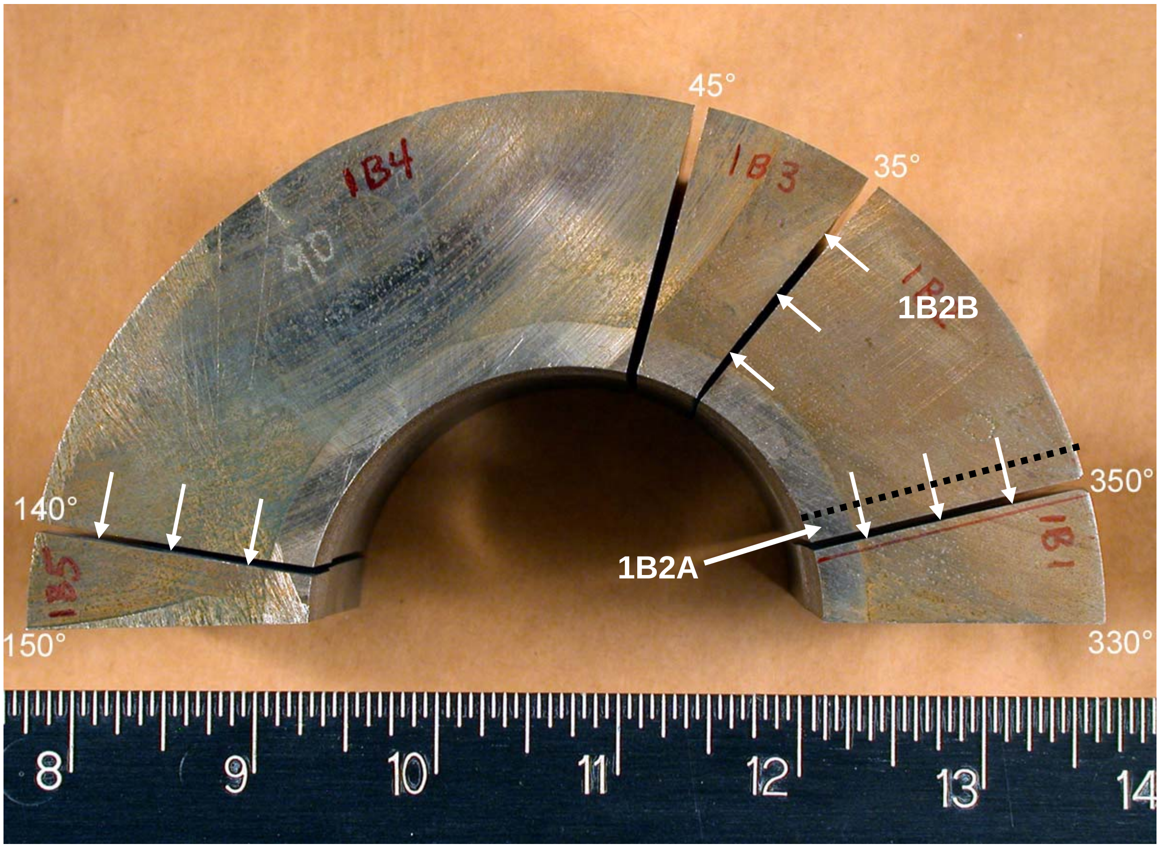
Close-up of 150° cut surface (0.9X)

Figure 11: Visible dye PT photographs of piece 2. Four small indications were detected on the 150° cut face; no ID-connected indications were found. No further work was performed on piece 2.



Piece 1A - Spare
Piece 1B - Sectioned for SEM and metallography
Piece 1C - Spare

Figure 12: Piece 1 section photograph. Transverse sections were made approximately 0.75" from each weld toe to reduce the sample size and facilitate metallographic specimen preparation. The section photograph for piece 1B is shown in Figure 13.



Piece 1B1 - Metallographic cross section through 350° (PT1)
Piece 1B2A - Sectioned further for open crack SEM at 350° (PT1)
Piece 1B2B - Spare
Piece 1B3 - Metallographic cross section through 35° (PT5)
Piece 1B4 - Spare
Piece 1B5 - Metallographic cross section through 140° (PT3*)
*** PT3 not detected in laboratory**

Figure 13: Piece 1B section photograph. Arrows indicate surfaces polished for SEM and metallographic examinations. Piece 1B2A was sectioned further to create an open crack specimen (see Figure 16).

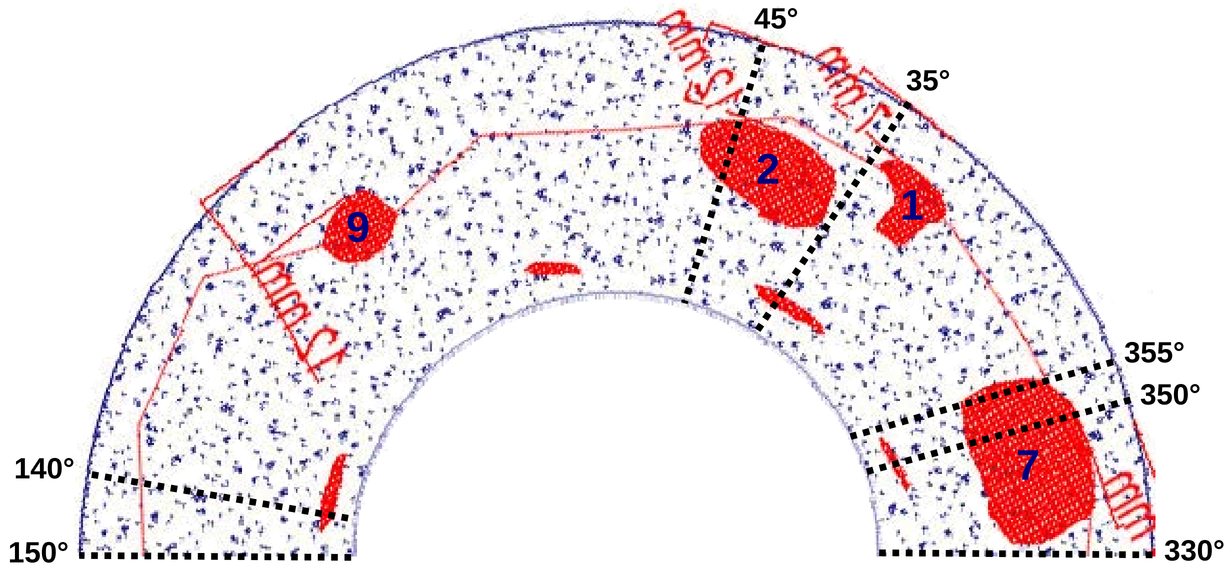


Figure 14: Piece 1B cut locations added schematically to the UT map shown previously in Figure 8. ***(NOTE: The map mirror image is shown to match the orientation of the photograph on the previous page.)***

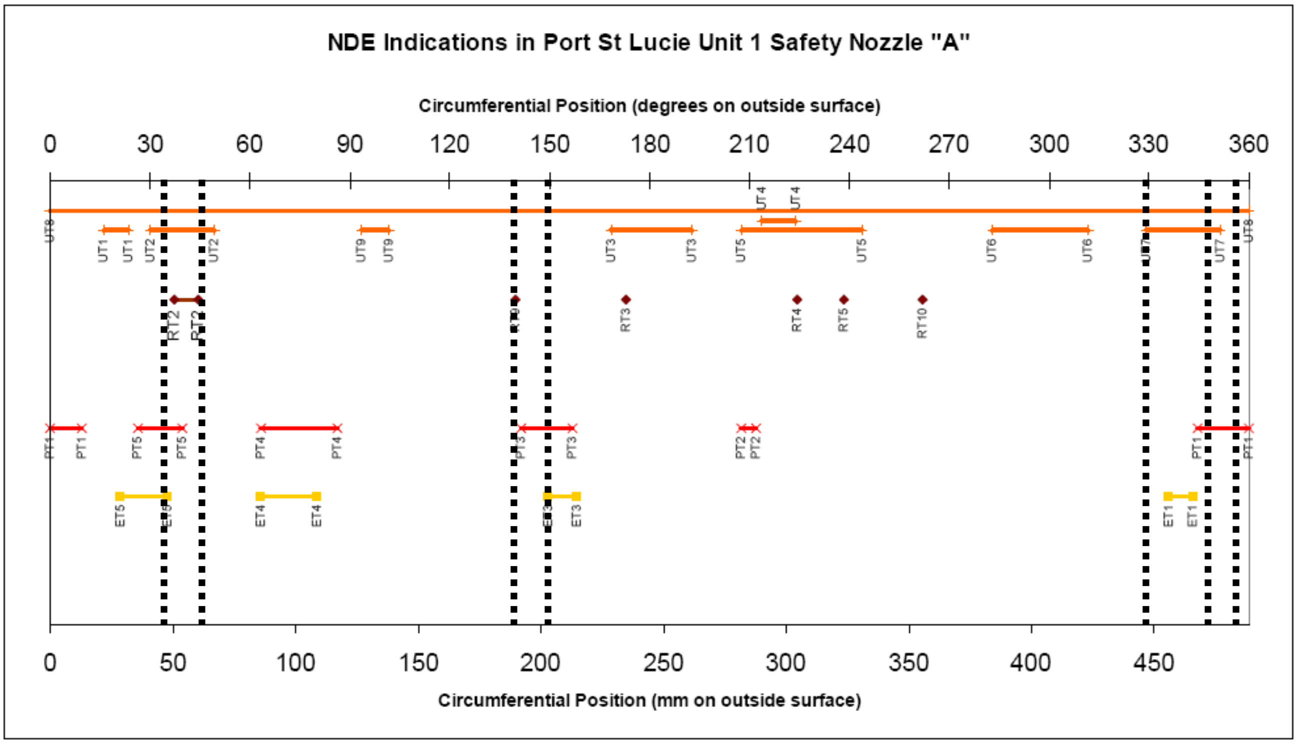
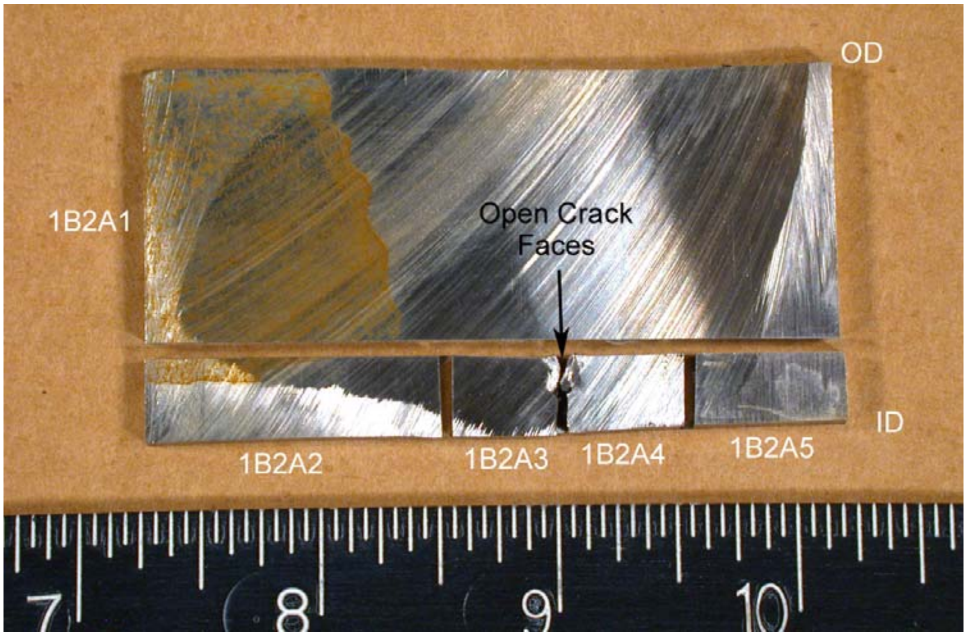


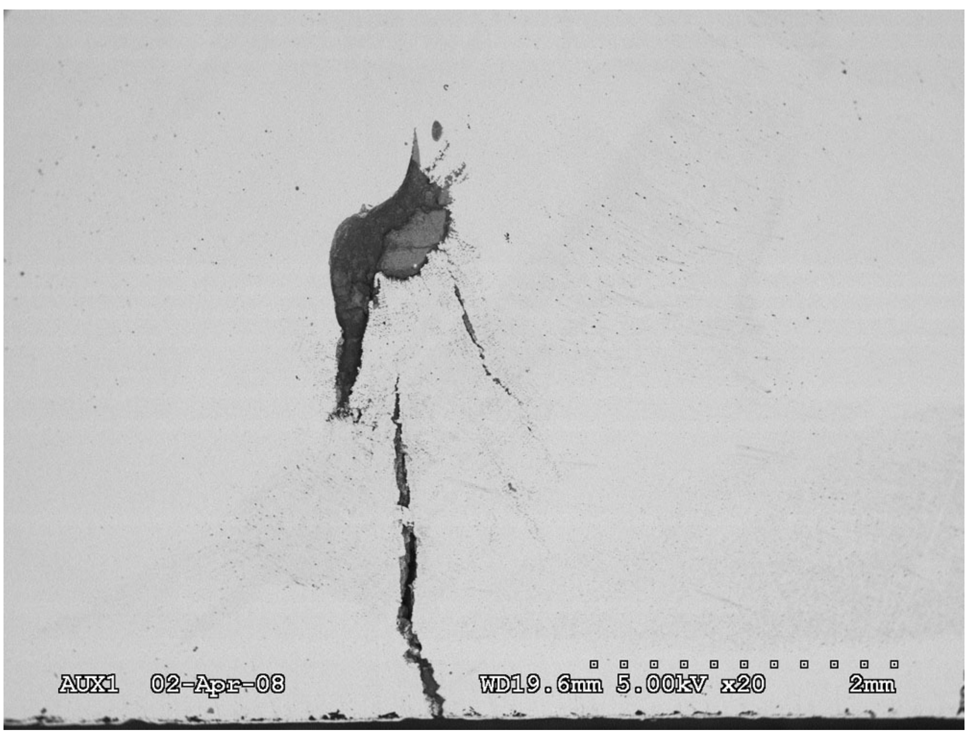
Figure 15: Piece 1 cut locations added schematically to the NDE shown previously in Figure 5.



Piece 1B2A1 - Spare
Piece 1B2A2 - Spare
Piece 1B2A3 - Open crack (spare)
Piece 1B2A4 - Open crack SEM/EDS specimen
Piece 1B2A5 - Spare

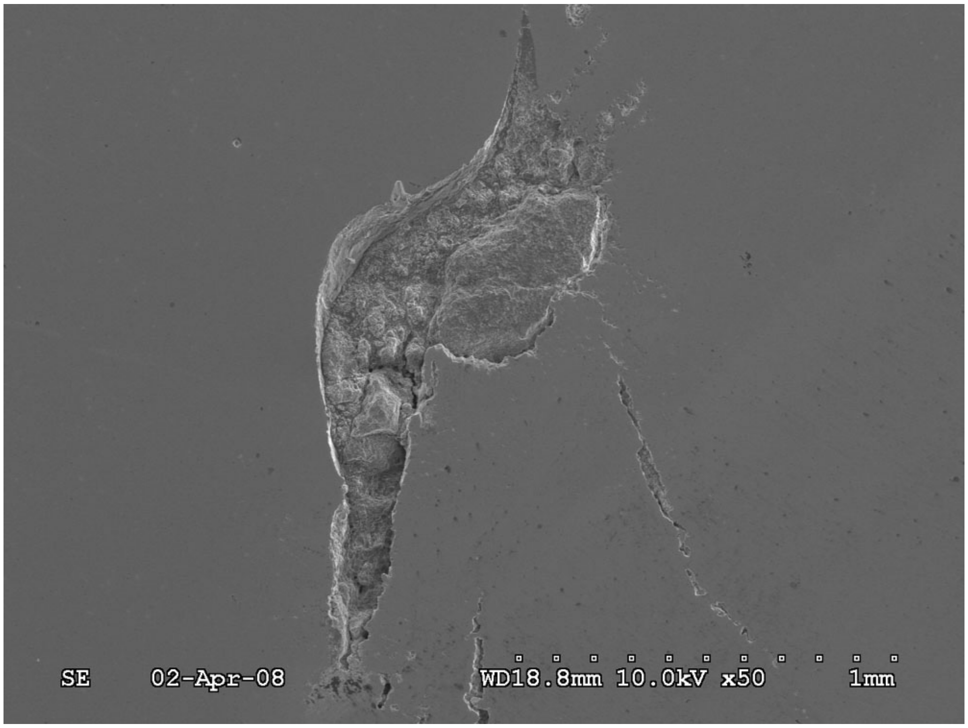
Figure 16: Piece 1B2A section photograph. The piece 1B2A4 open crack face was examined by SEM/EDS.

SE 20X 132309

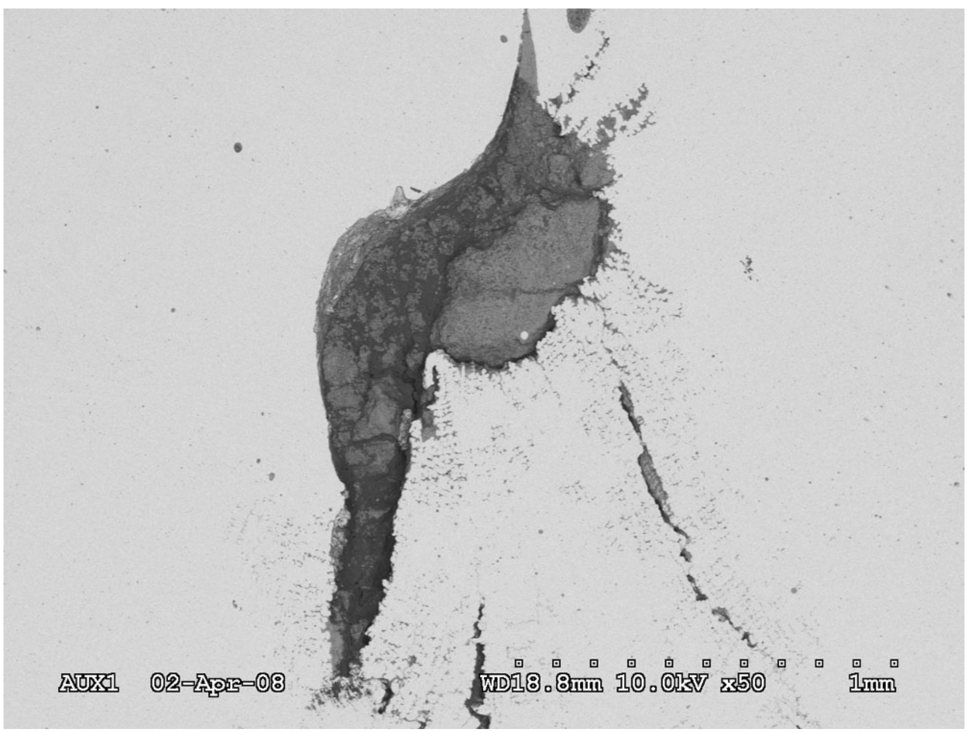


BSE 20X 132310

Figure 17: Low magnification SE and BSE micrographs showing the crack present in the cross section prepared through the 350° orientation.

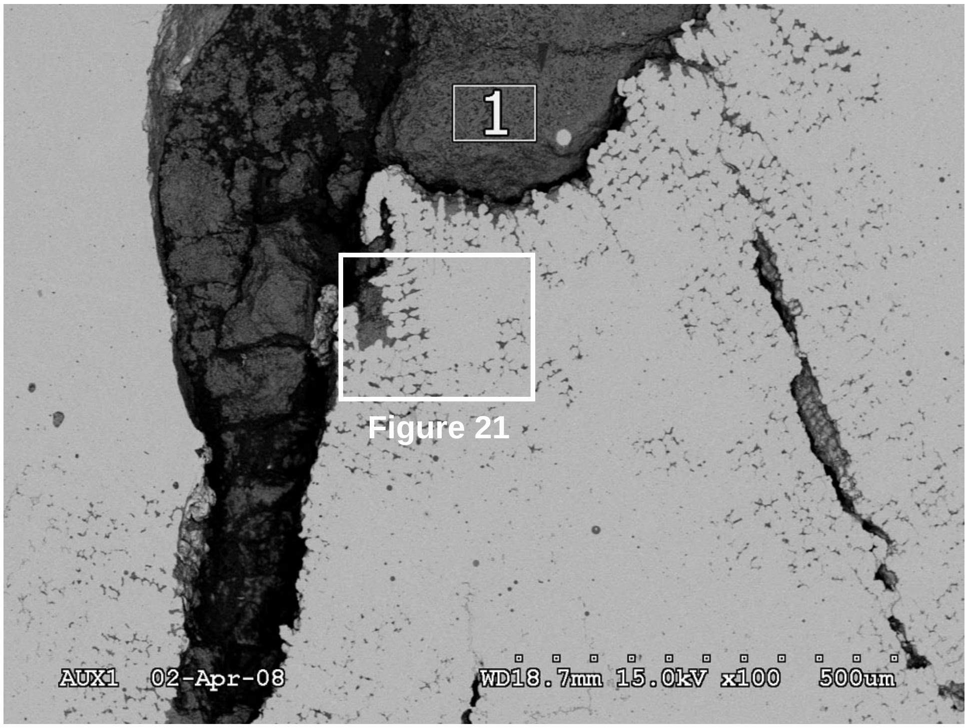


SE 50X 132311

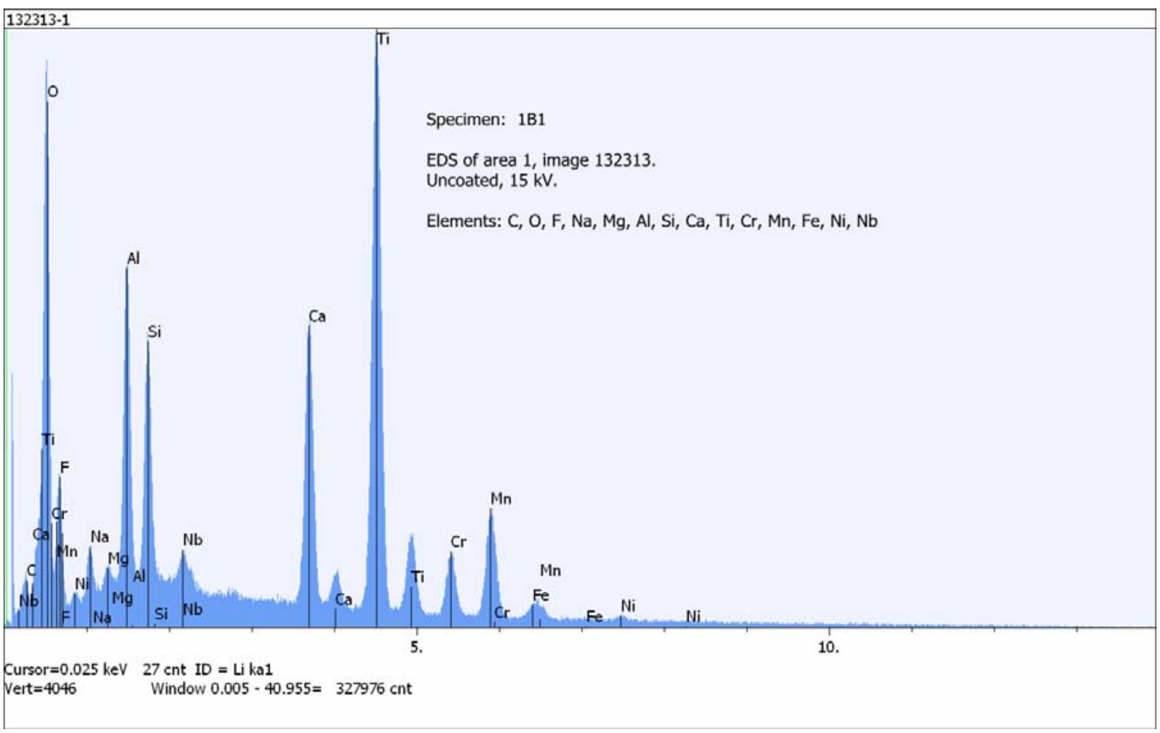


BSE 50X 132312

Figure 18: Slightly higher magnification SE and BSE micrographs taken near the crack tip.

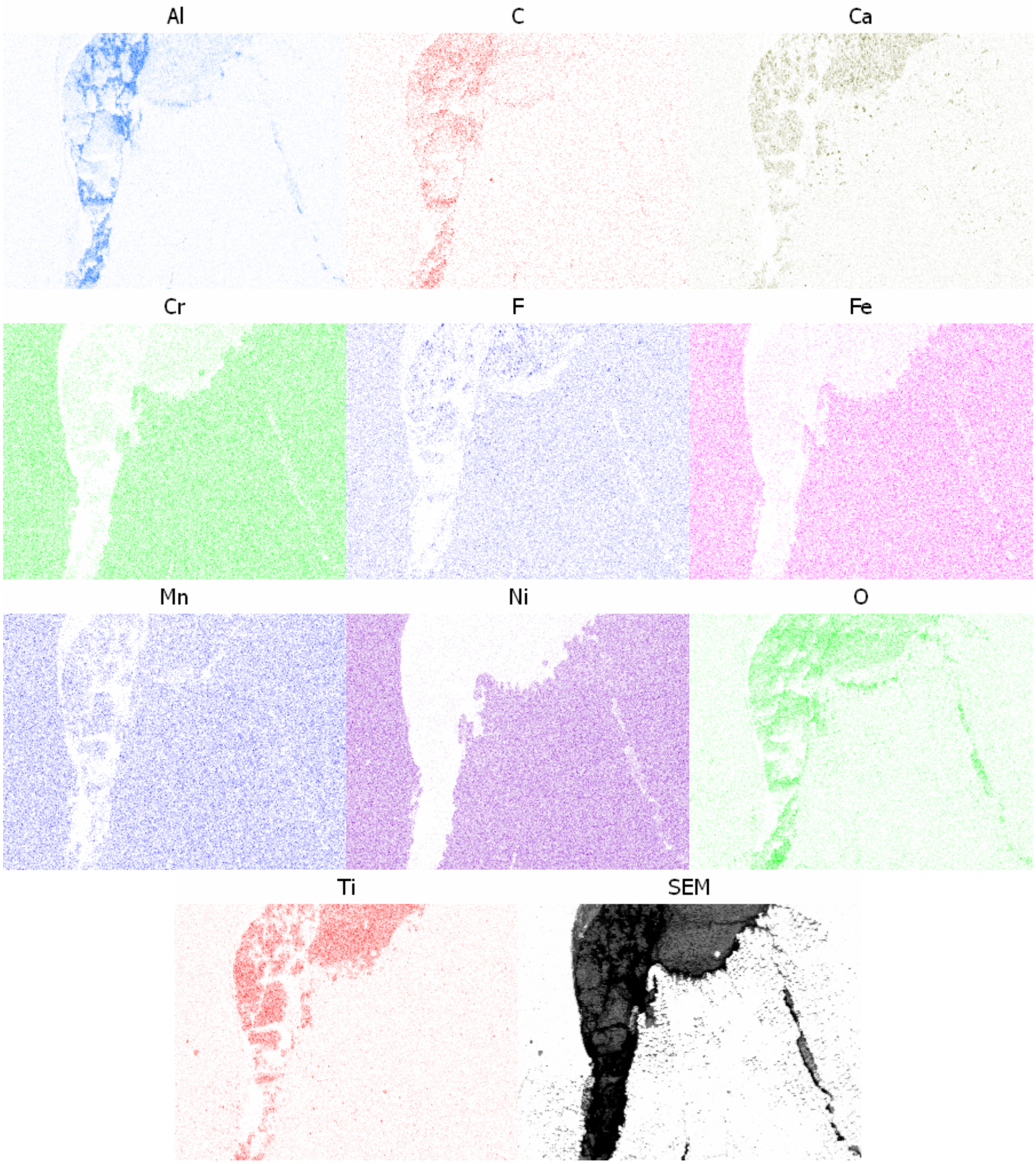


BSE 100X 132313_A



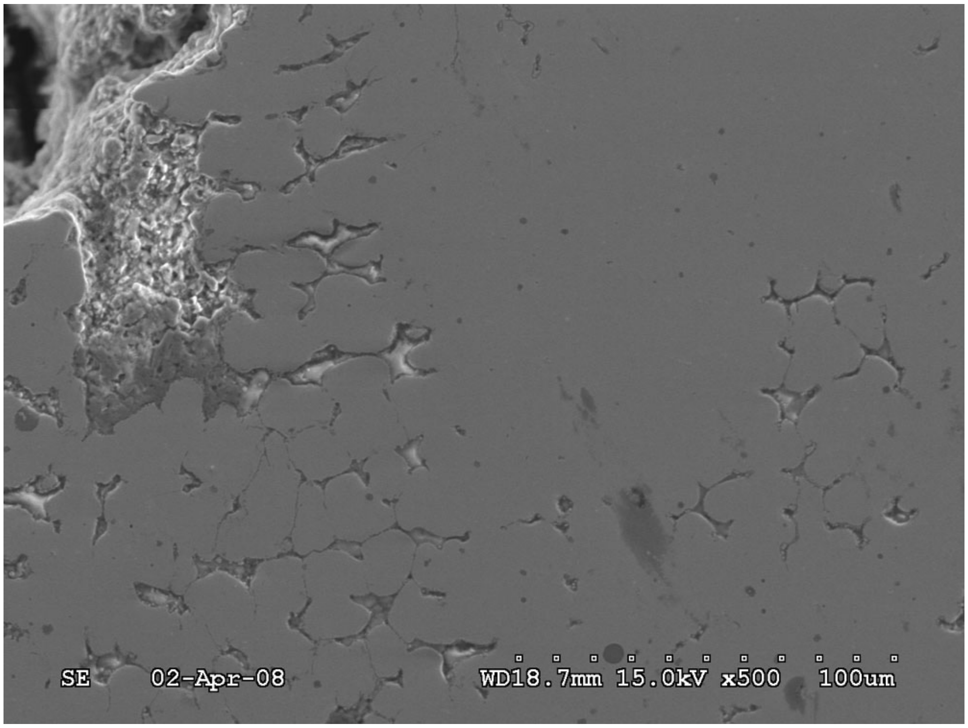
132313-1

Figure 19: EDS results for area 1 shown in upper micrograph. This area, which was located within a weld void, contained carbon, oxygen, fluorine, sodium, magnesium, aluminum, silicon, calcium, titanium, chromium, manganese, iron, nickel, and niobium.

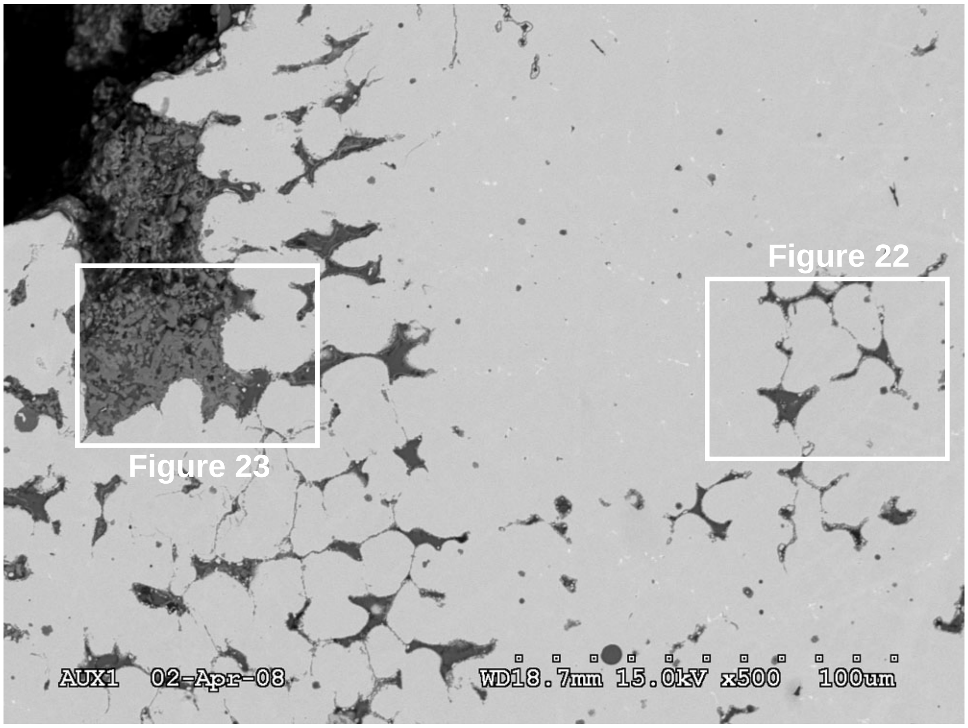


132313_EL

Figure 20: EDS dot map results for the area shown in Figure 18. The weld void contained primarily aluminum, carbon, calcium, fluorine, manganese, oxygen, and titanium. It appeared that the aluminum was an artifact from the polishing process. The weld metal contained the expected elements, chromium, nickel, iron, and manganese. *(NOTE: There is an overlap between the fluorine and iron energy levels. The fluorine is not uniformly distributed on the sample, but rather it is located where there is an absence of iron, i.e. within the weld void.)*

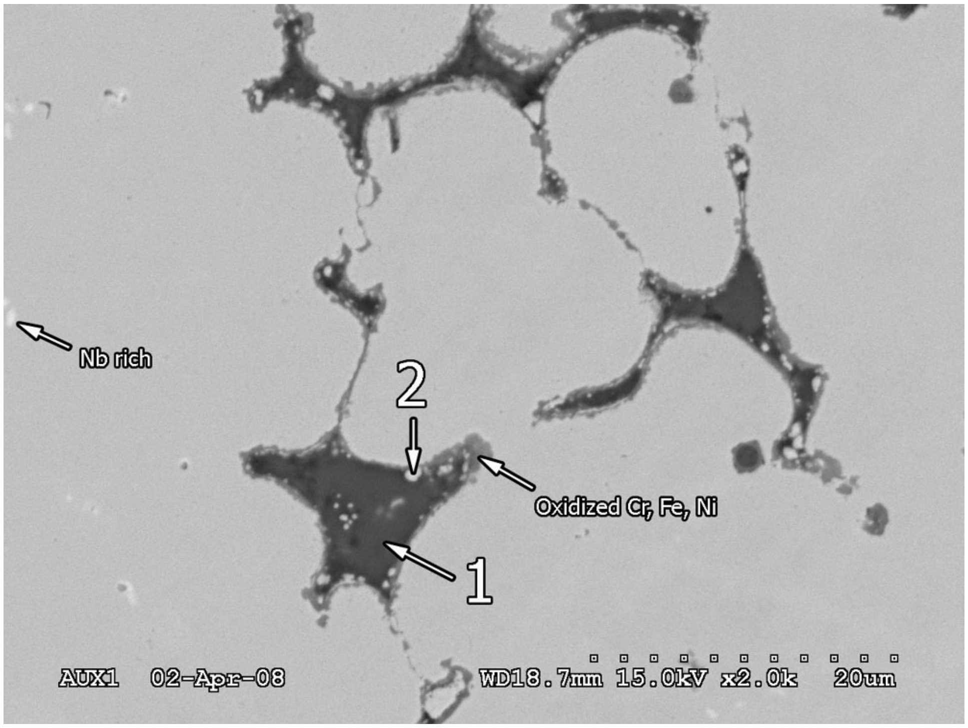


SE 500X 132314



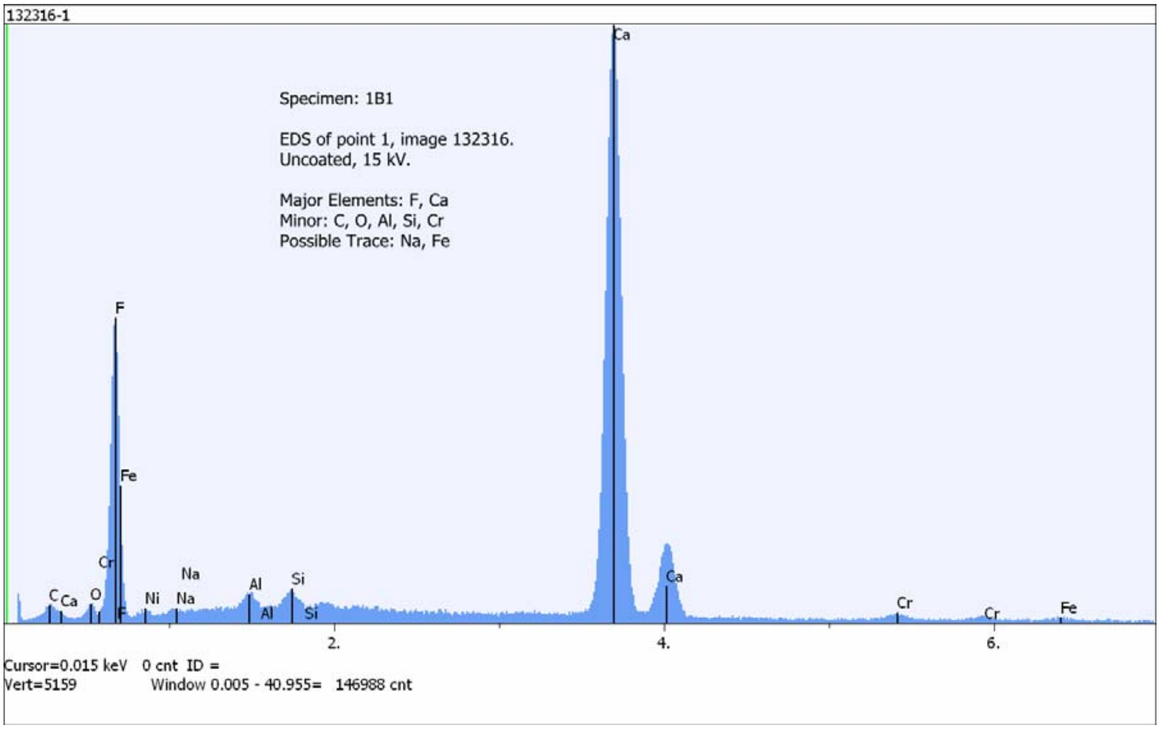
BSE 500X 132315

Figure 21: Higher magnification micrographs taken of the affected weld structure adjacent to the weld void.

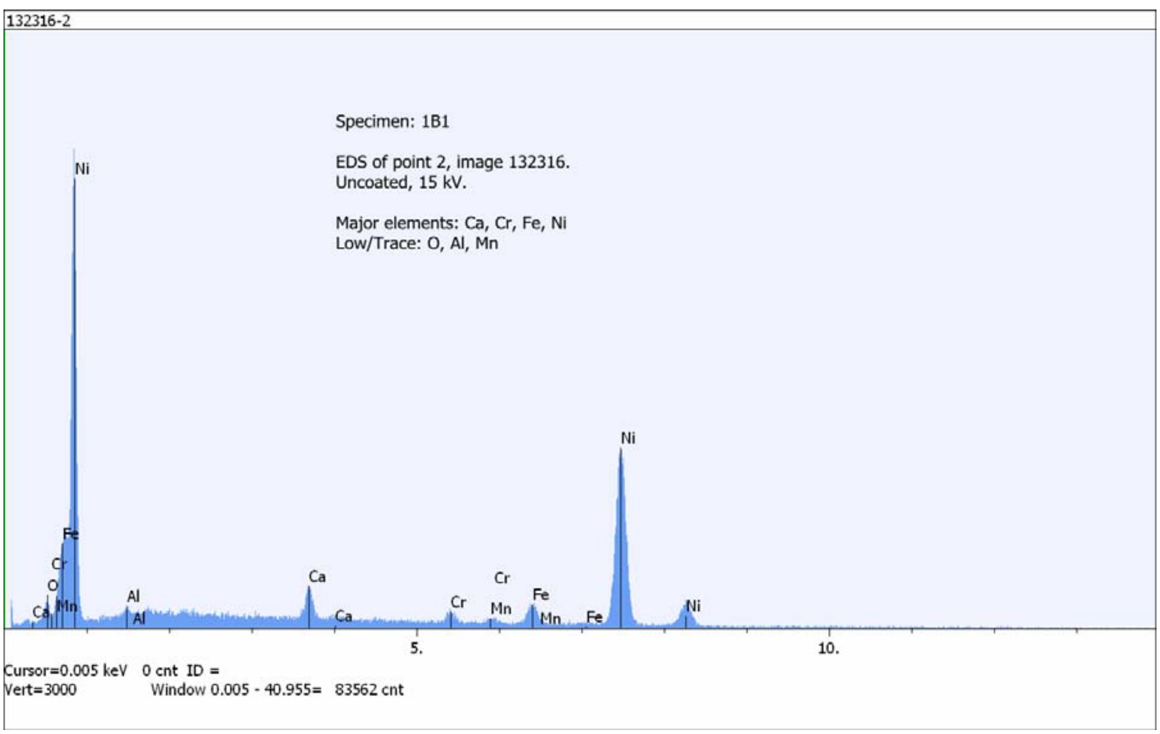


BSE 2,000X 132316_A

Figure 22: Higher magnification micrograph showing areas selected for EDS analysis. Oxidized weld metal (chromium, iron, and nickel) was present along the perimeter of the dendritic structure.

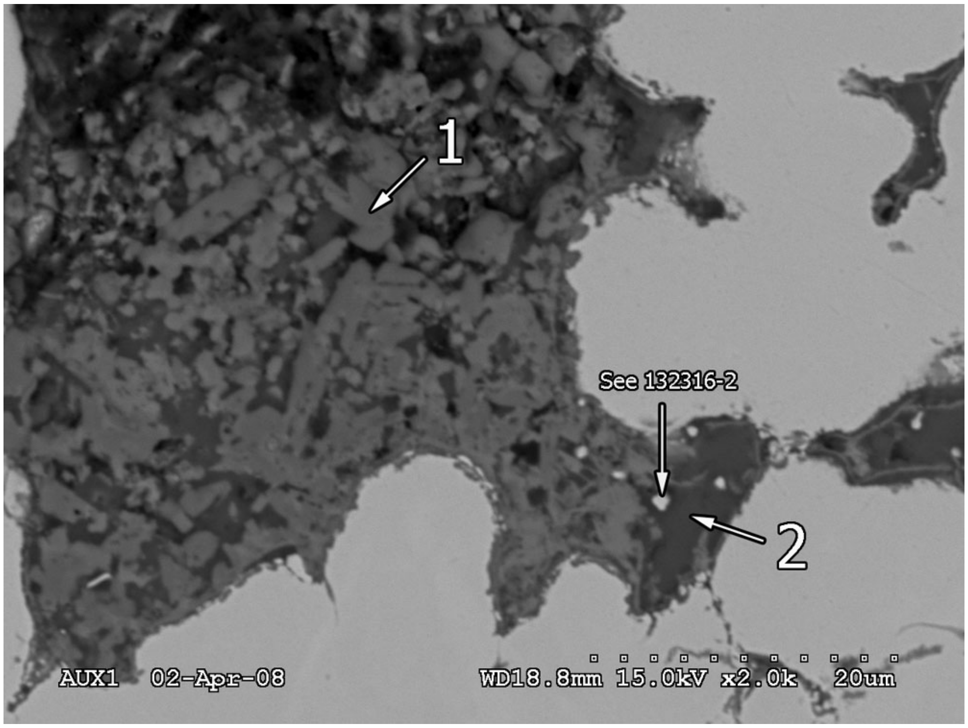


132316-1



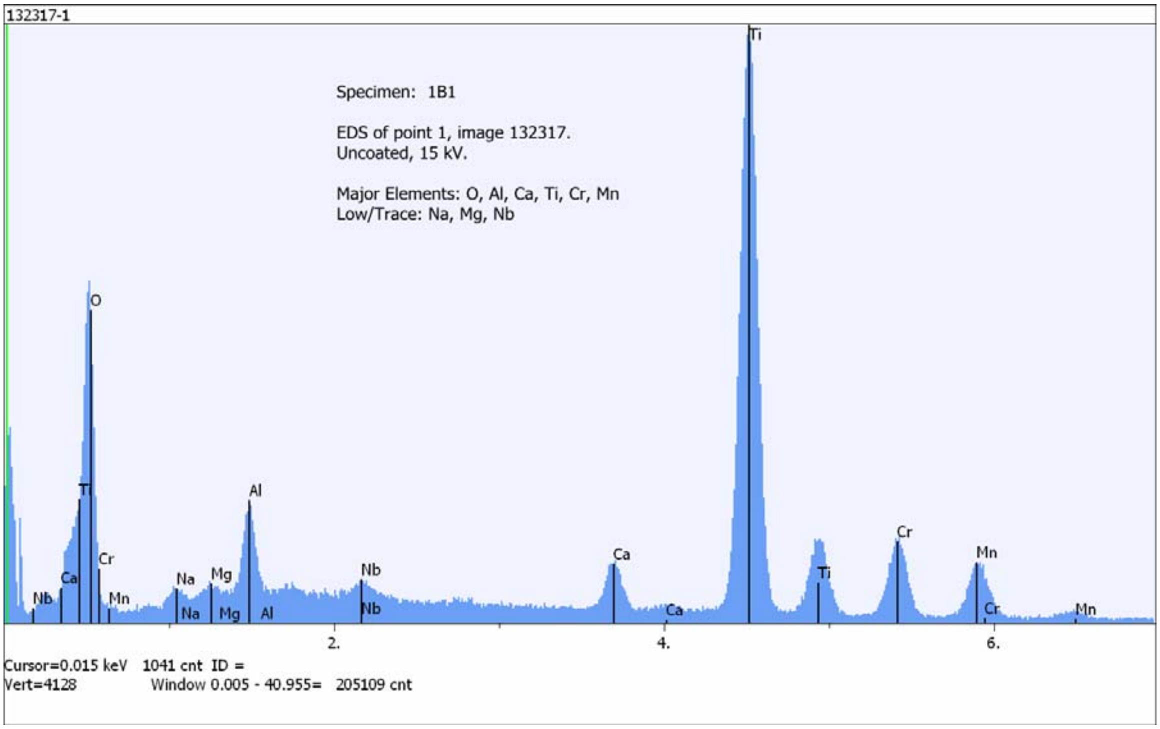
132316-2

Figure 22 (cont.): EDS results for previous micrograph. Point 1 contained primarily calcium and fluorine, while point 2 contained primarily nickel.

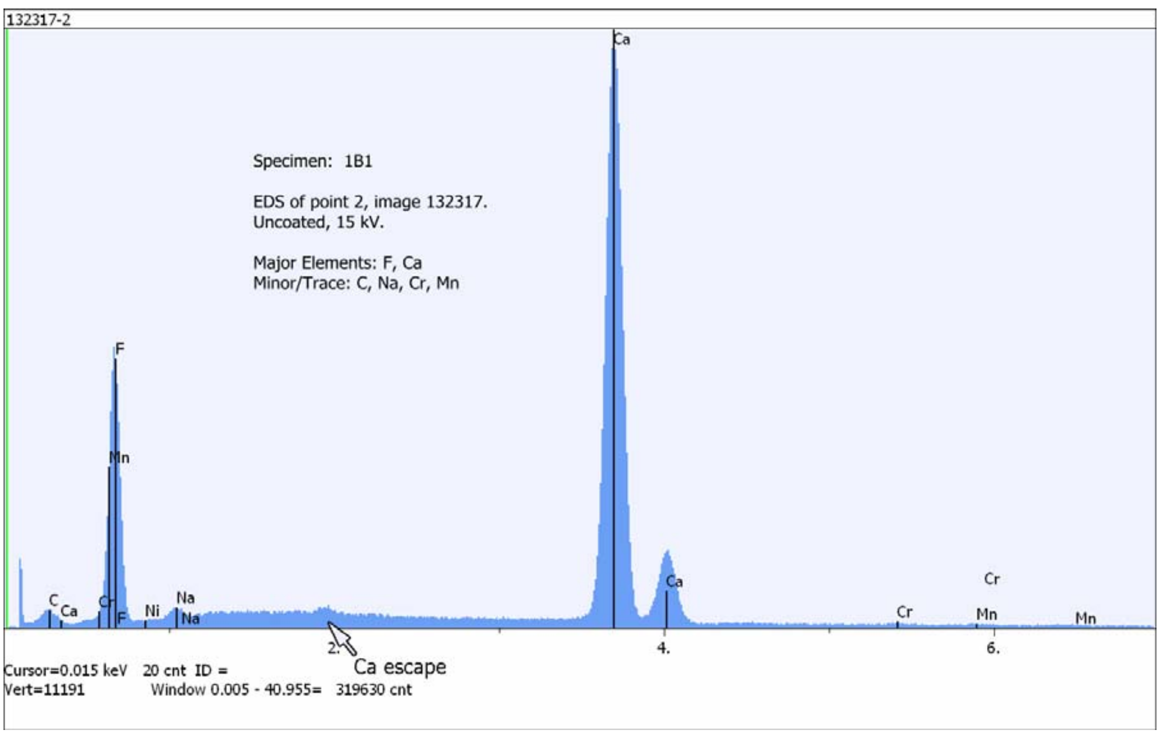


BSE 2,000X 132317_A

Figure 23: Higher magnification micrograph showing areas within the weld void selected for EDS analysis. The bright regions within the void contained primarily nickel, i.e. similar to 132316-2 (lower spectrum in previous figure).

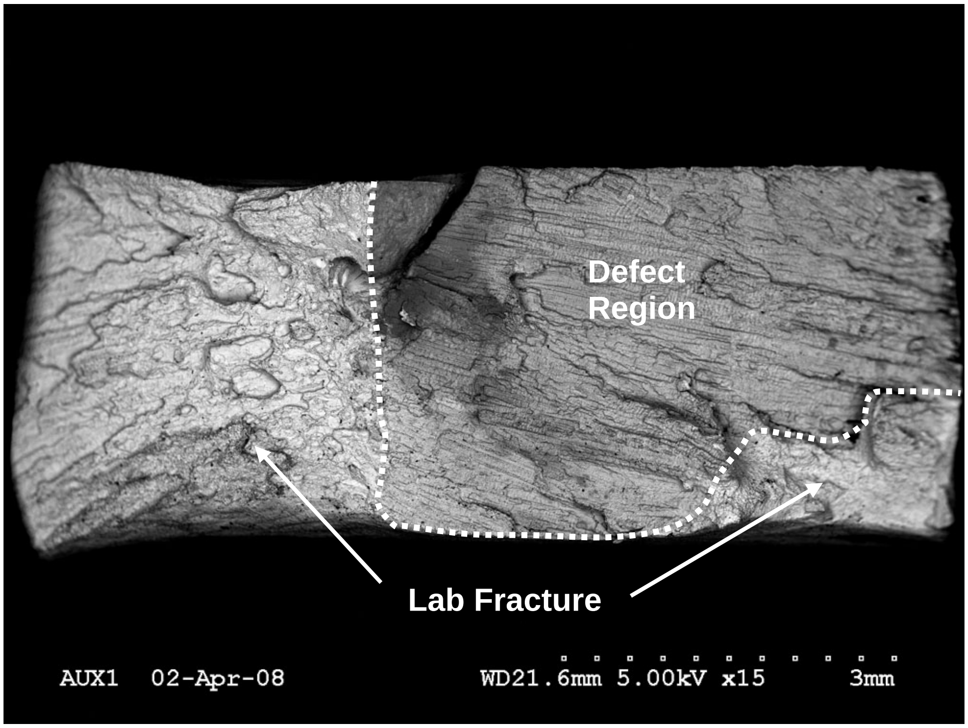


132317-1

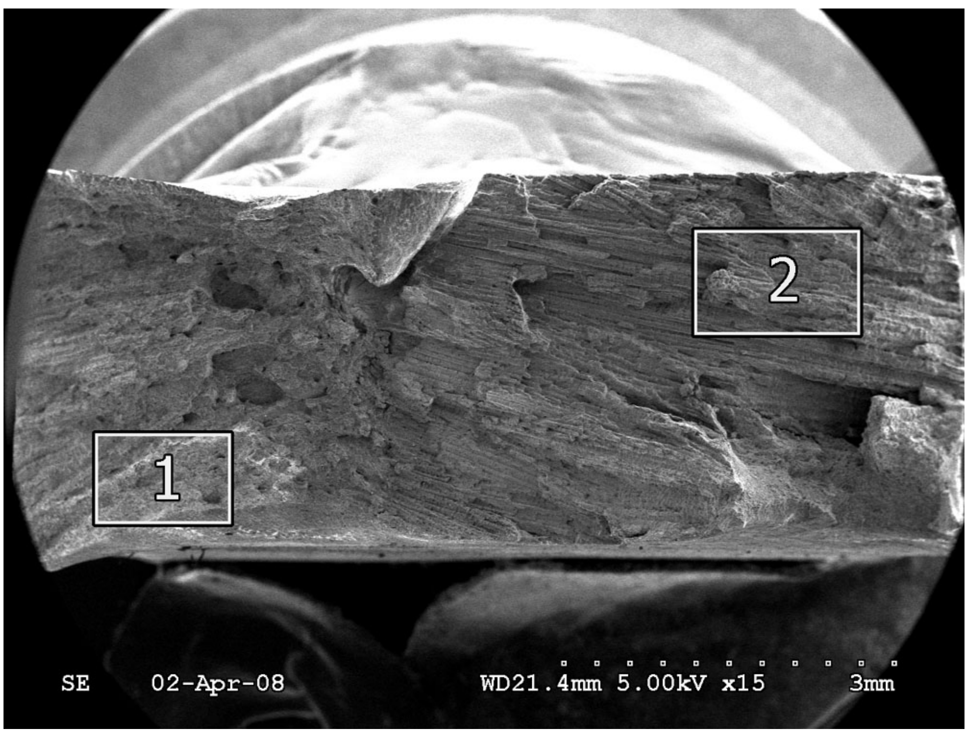


132317-2

Figure 23 (cont.): EDS results for previous micrograph. Point 1 contained primarily titanium and oxygen, while point 2 contained primarily calcium and fluorine.

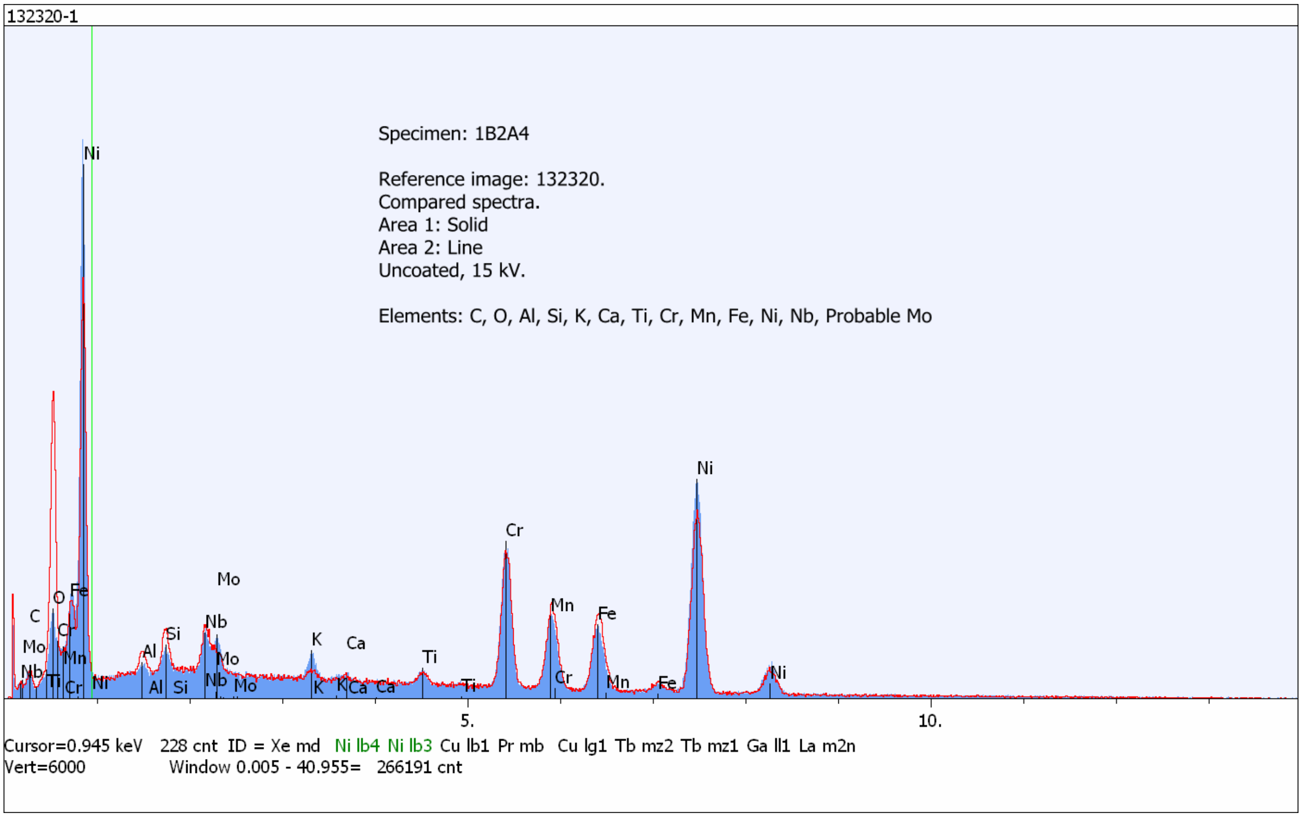


BSE 15X 132321



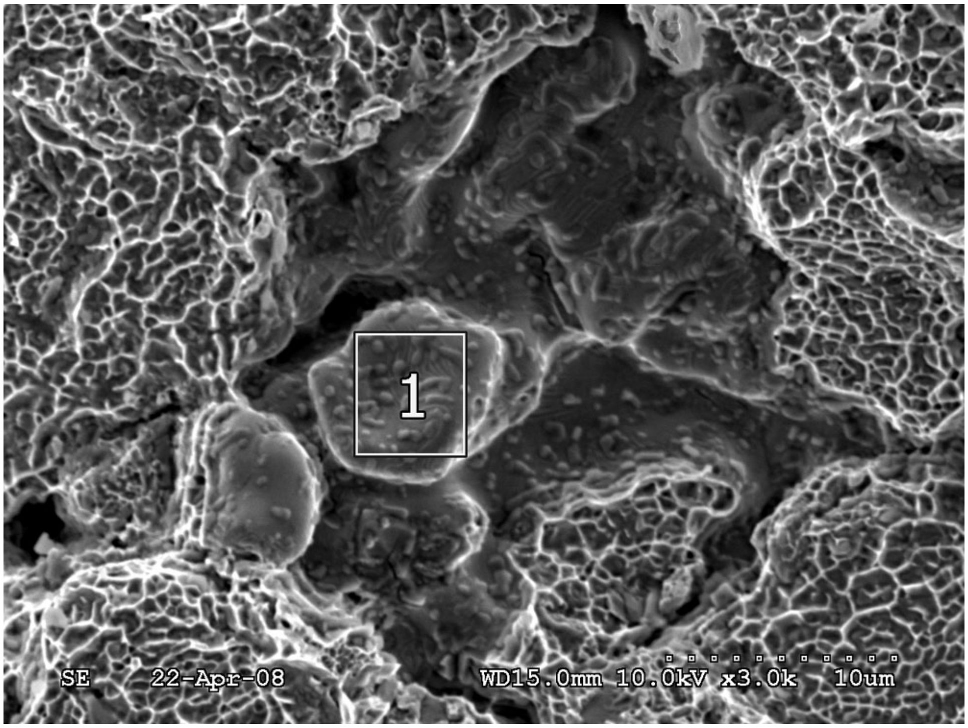
SE 15X 132320_A

Figure 24: Low magnification micrographs showing open crack specimen prepared from the 350° orientation. Lower micrograph shows two areas selected for EDS analysis. The ID surface is located to the right in both micrographs.

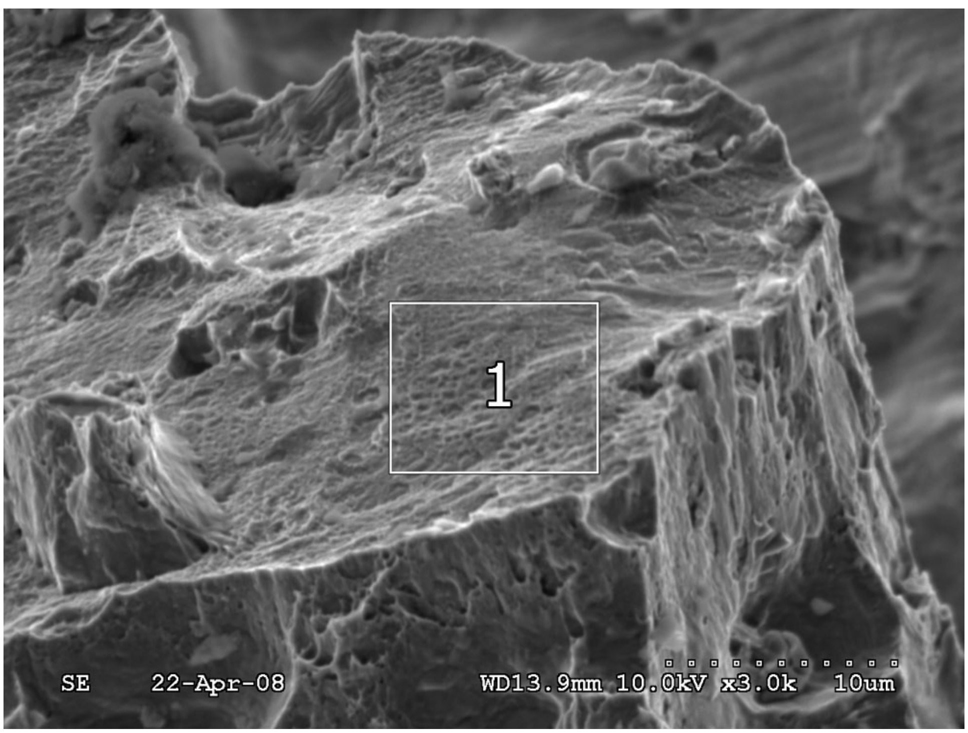


132320-1-2

Figure 24 (cont.): Comparative spectrum results for area 1 and area 2 shown in previous figure. Area 1 was located within the lab fracture and is shown in solid blue, while area 2 was within the existing defect and is shown as a red line. The primary differences between the two spectra were increased oxygen and decreased nickel in the pre-existing defect relative to the lab fracture.



SE 3,000X 132482_A



SE 3,000X 132485_A

Figure 25: Typical areas of the defect region (upper micrograph) and laboratory fracture (lower micrograph) at higher magnification showing the areas selected for EDS analysis.

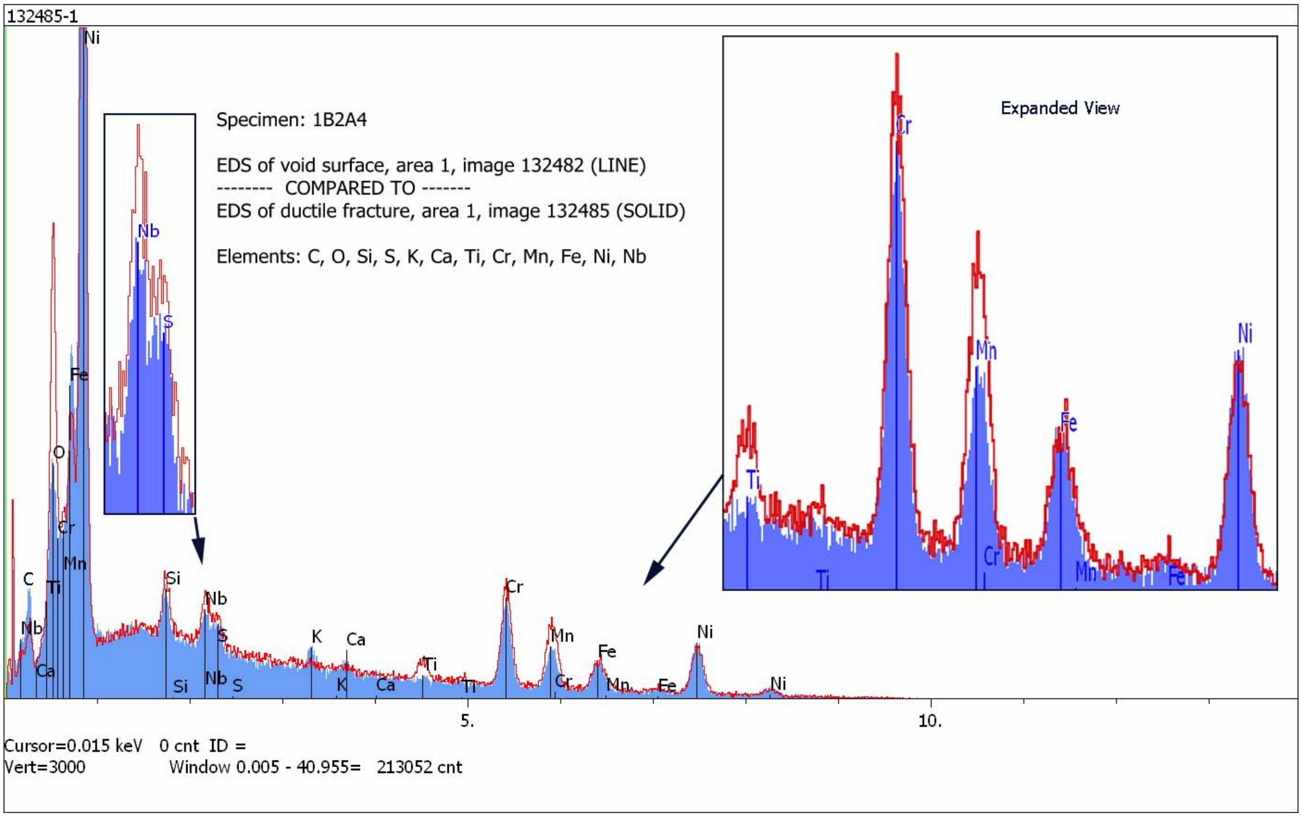
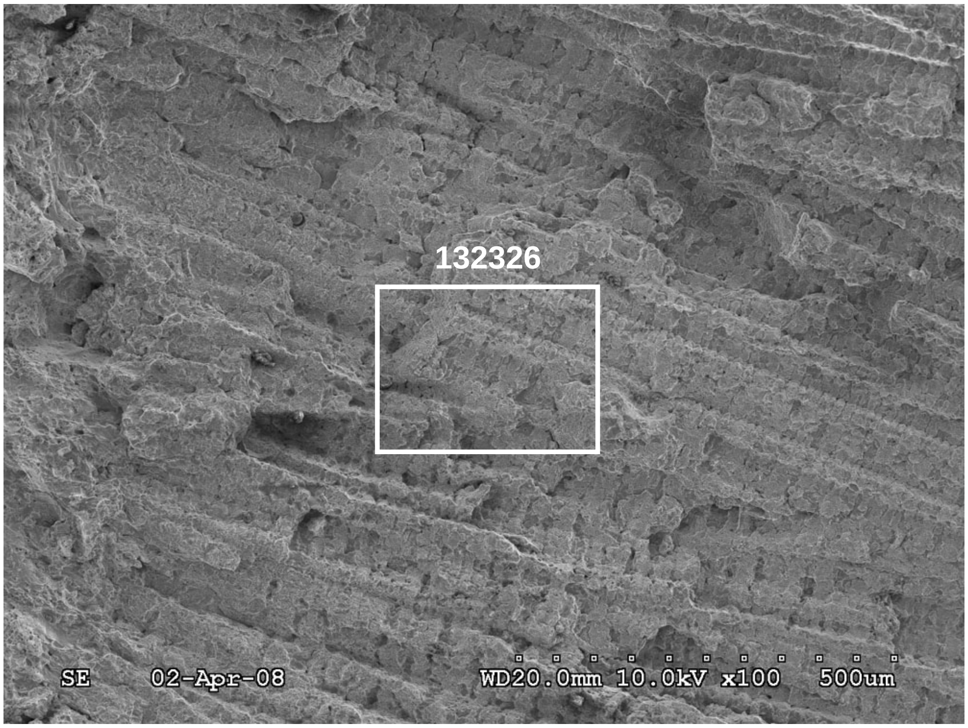
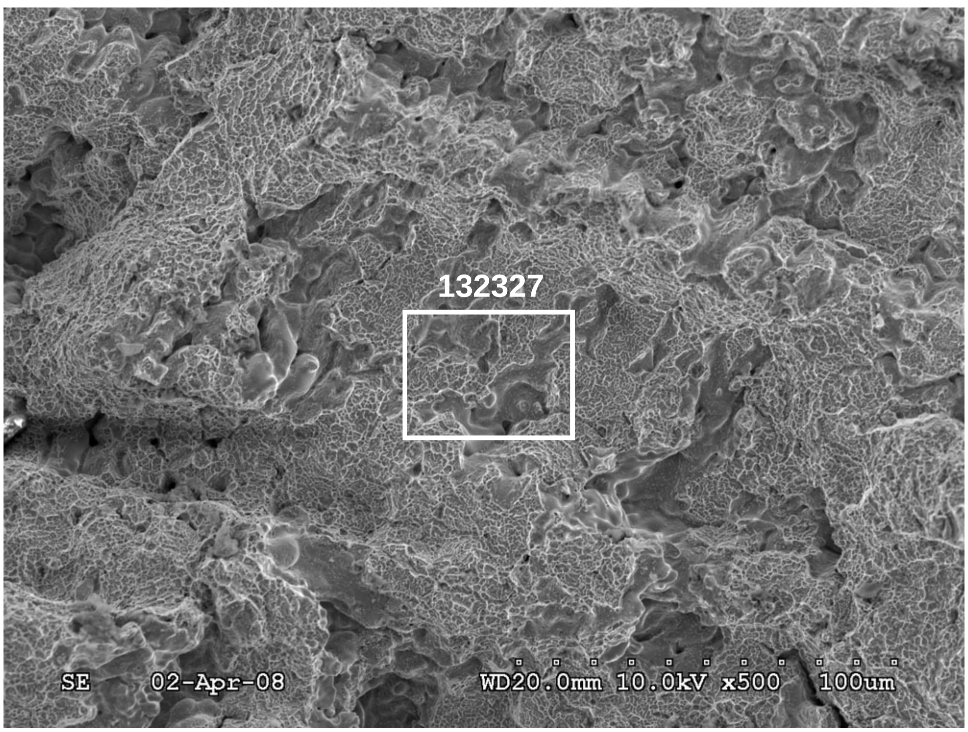


Figure 25 (cont.): Comparative EDS spectrum data for areas shown on previous page. The line spectrum represents the defect region, while the solid spectrum represents the laboratory fracture. The defect region contained higher levels of oxygen, niobium, titanium, and manganese compared to the laboratory fracture.

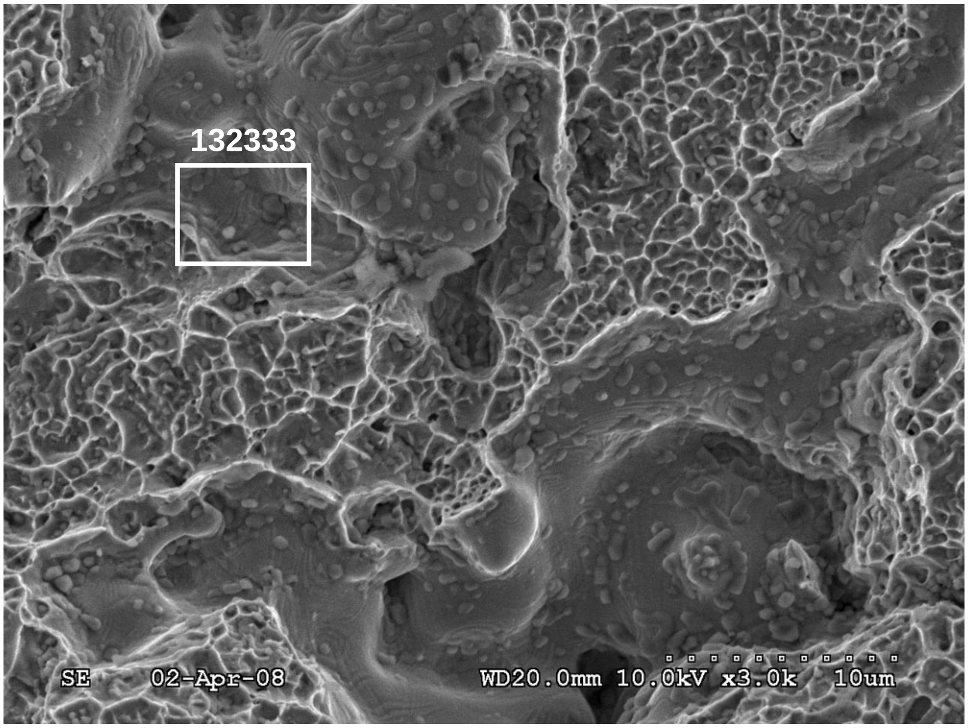


SE 100X 132325

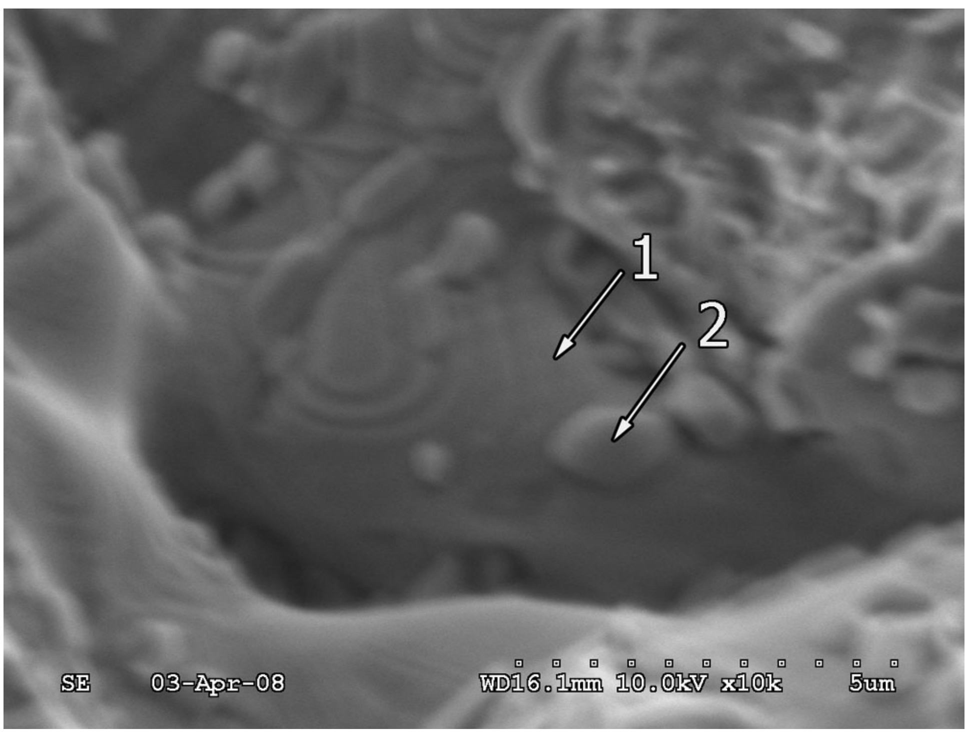


SE 500X 132326

Figure 26: Progressively higher magnification micrographs showing typical fracture surface morphology in weld defect region.

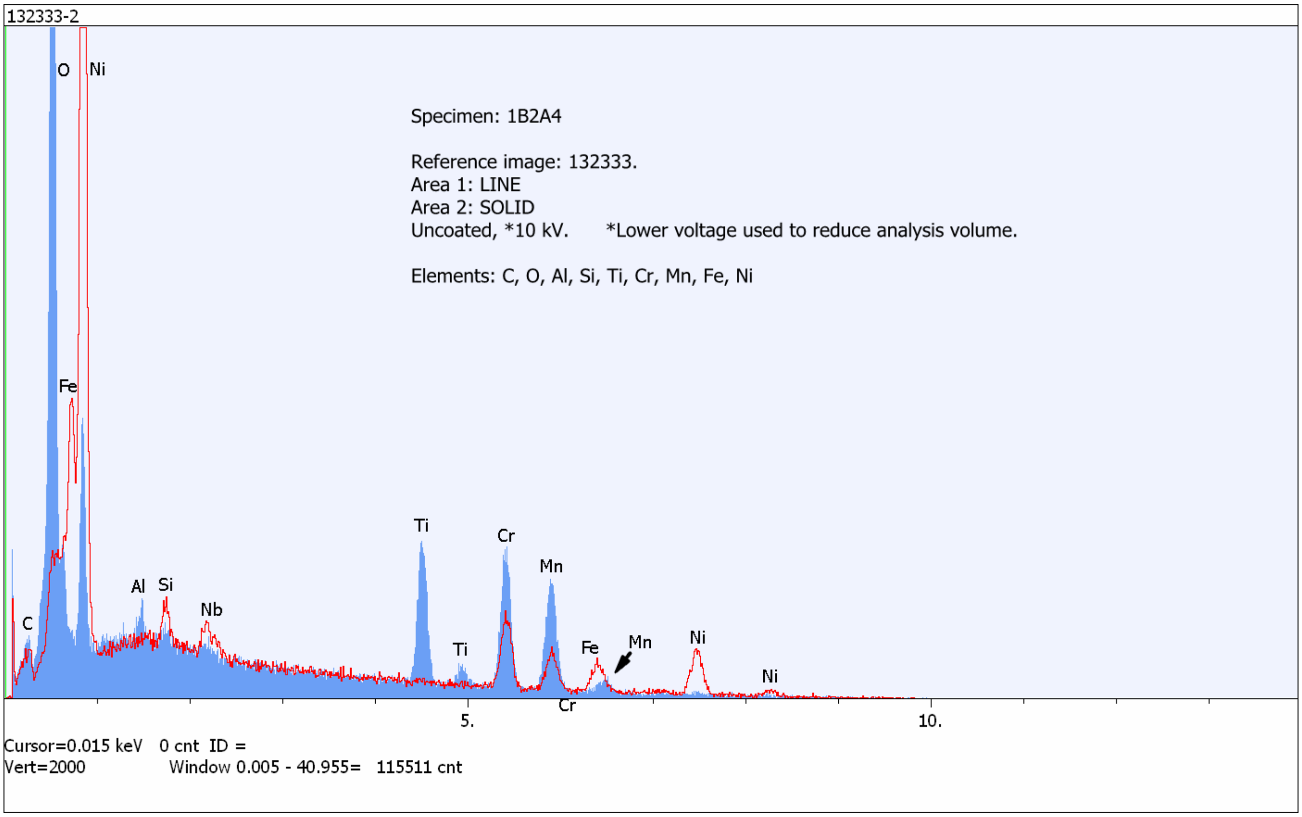


SE 3,000X 132327



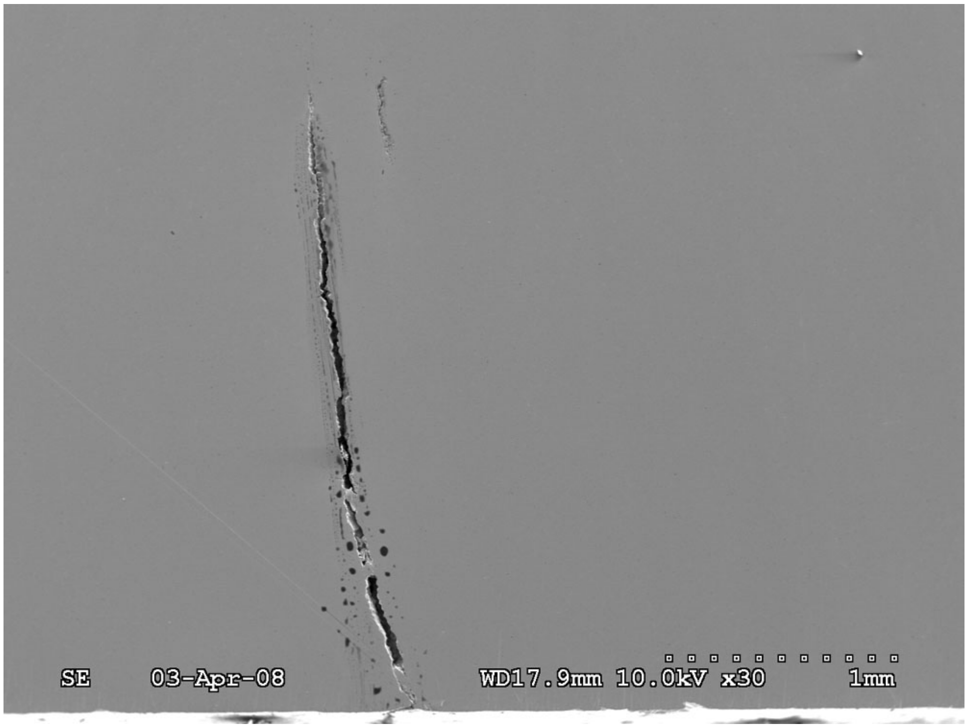
SE 10,000X 132333

Figure 26 (cont.): Progressively higher magnification micrographs showing typical mixed fracture morphology in weld defect region. The fracture surface contained both ductile microvoid coalescence and non-fused regions. Area 1 and area 2 were analyzed by EDS.



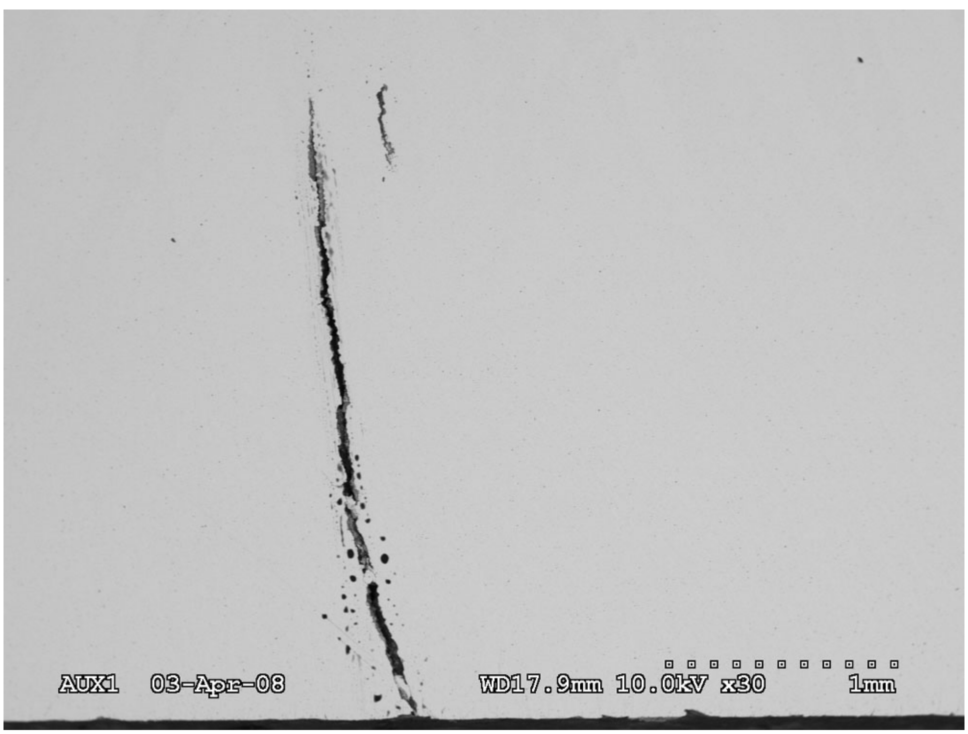
132333-1-2

Figure 26 (cont.): Comparative EDS spectrum results for area 1 and 2 in previous micrograph. Area 1 (smooth texture) contained higher levels of nickel, silicon, niobium, and iron as well as lower oxygen, titanium, chromium, manganese, and aluminum concentrations relative to area 2 (raised nodule). It appeared that there was some interaction between the flux and weld metal during solidification.



ID Surface

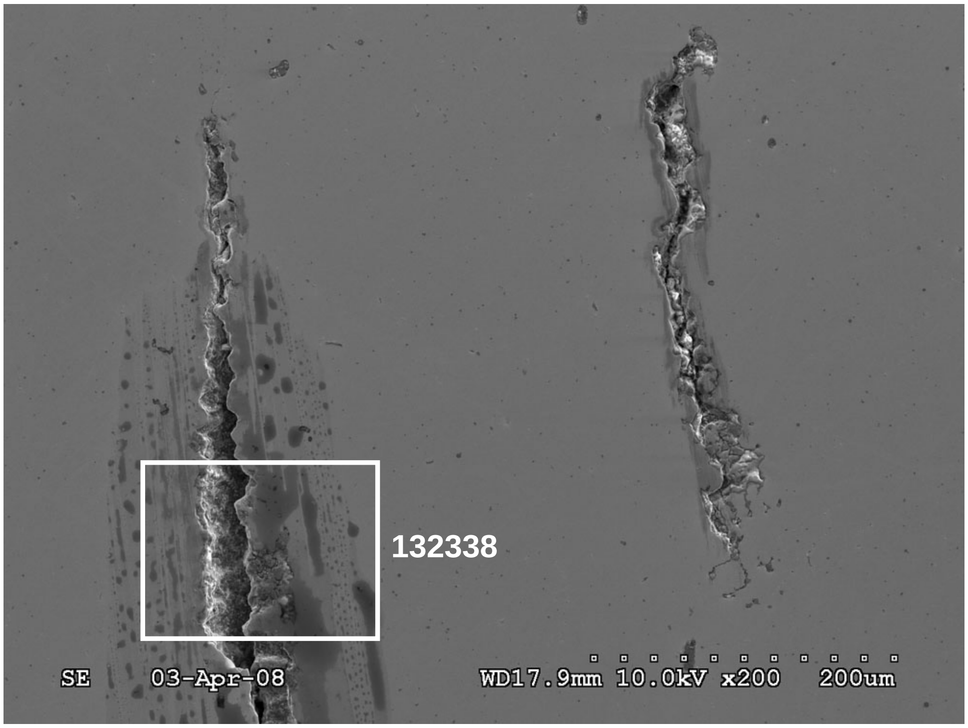
SE **30X** **132334**



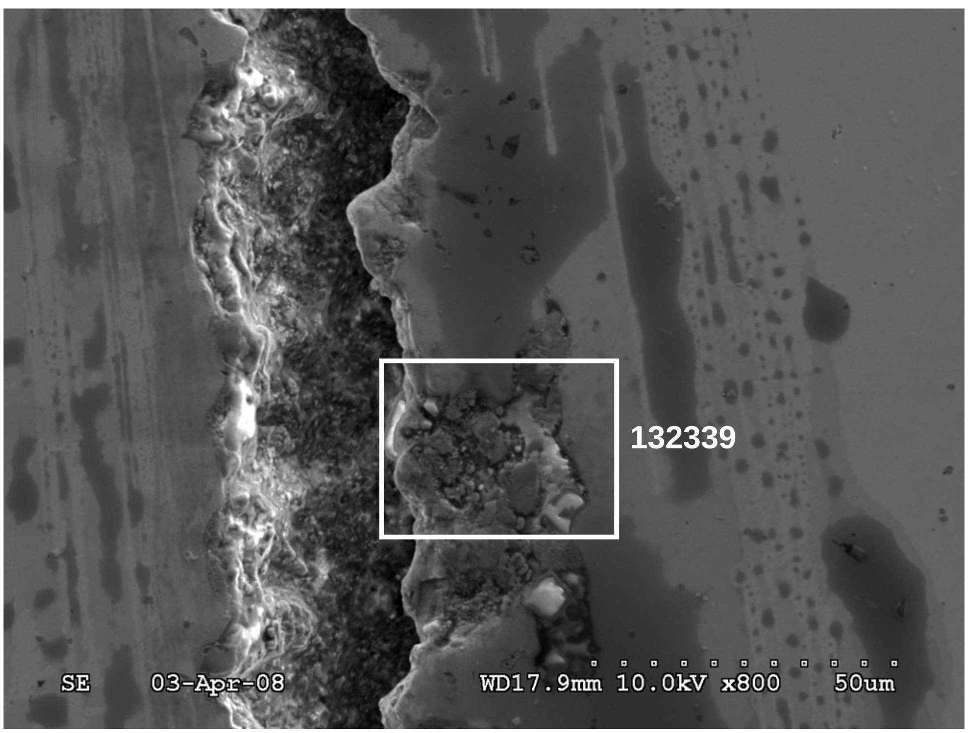
ID Surface

BSE **30X** **132335**

Figure 27: Low magnification micrographs of crack present in cross section prepared through 35°. Circular features toward the ID surface were caused by penetrant bleed-out from the defect. Note that the defect is tighter at the ID surface.

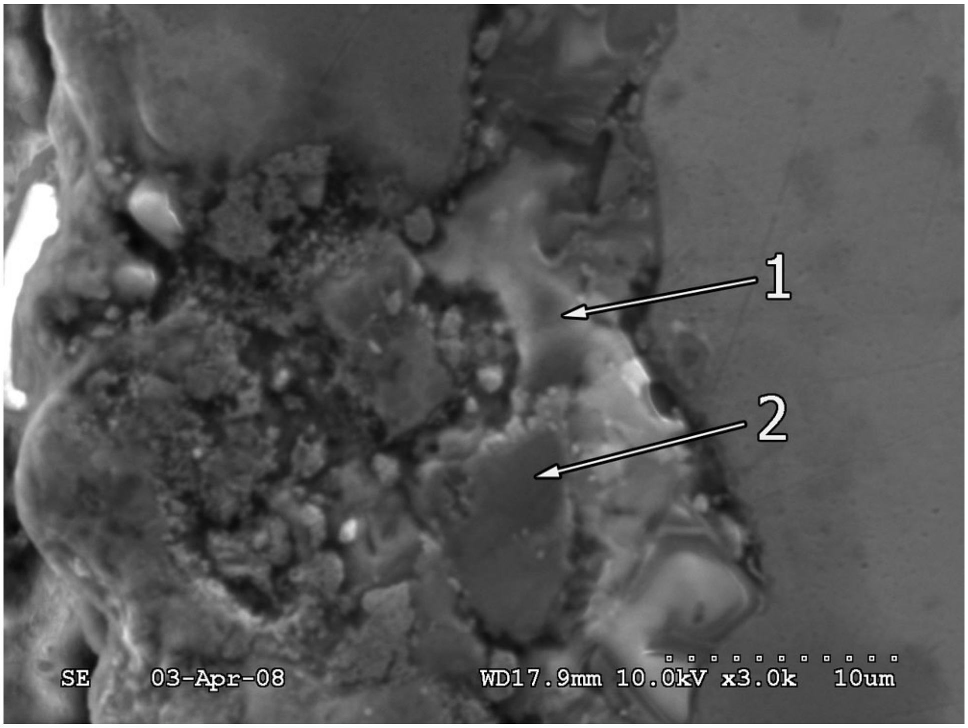


SE 200X 132337



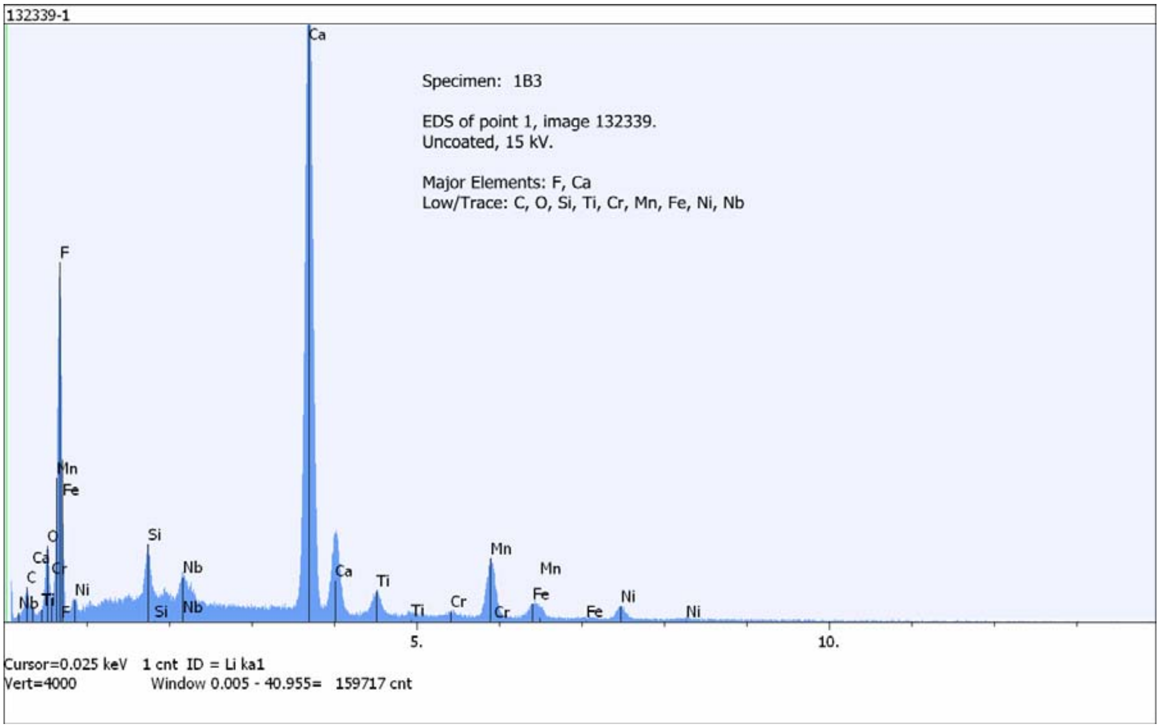
SE 800X 132338

Figure 28: Higher magnification micrographs of crack present at 35°. Staining adjacent to the crack was caused by bleed out from the defect.

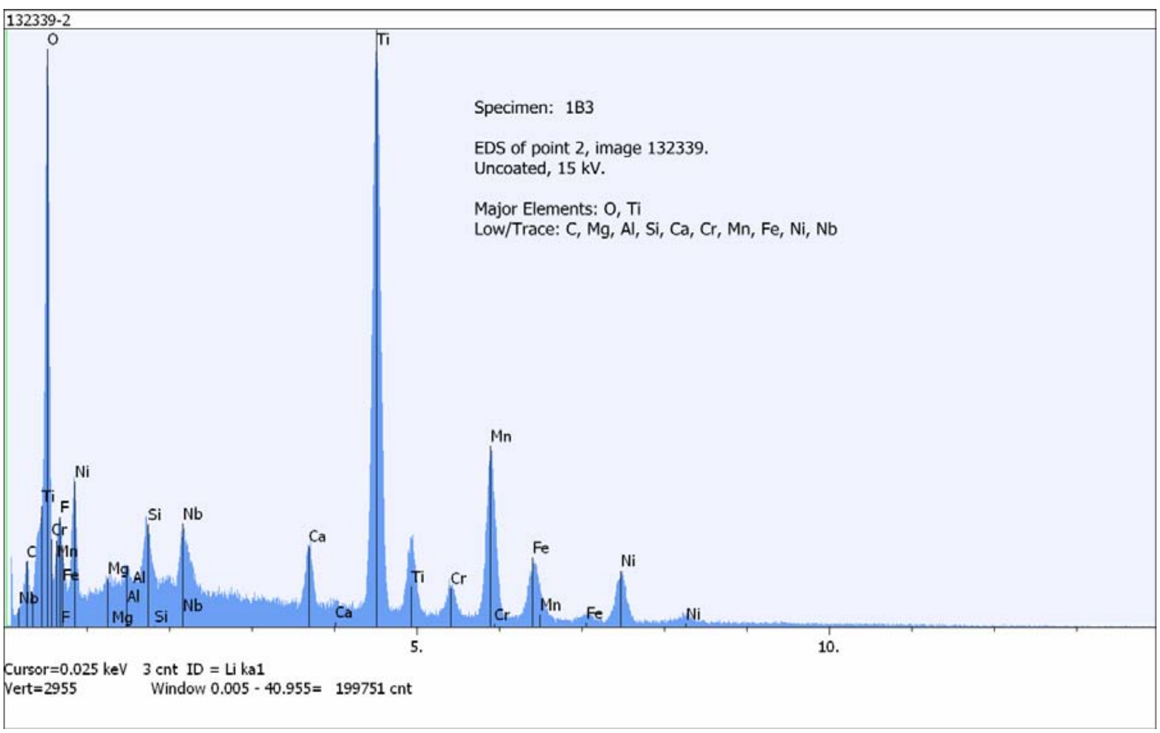


SE 3,000X 132339

Figure 28 (cont.): Higher magnification detail showing areas selected for EDS analysis.

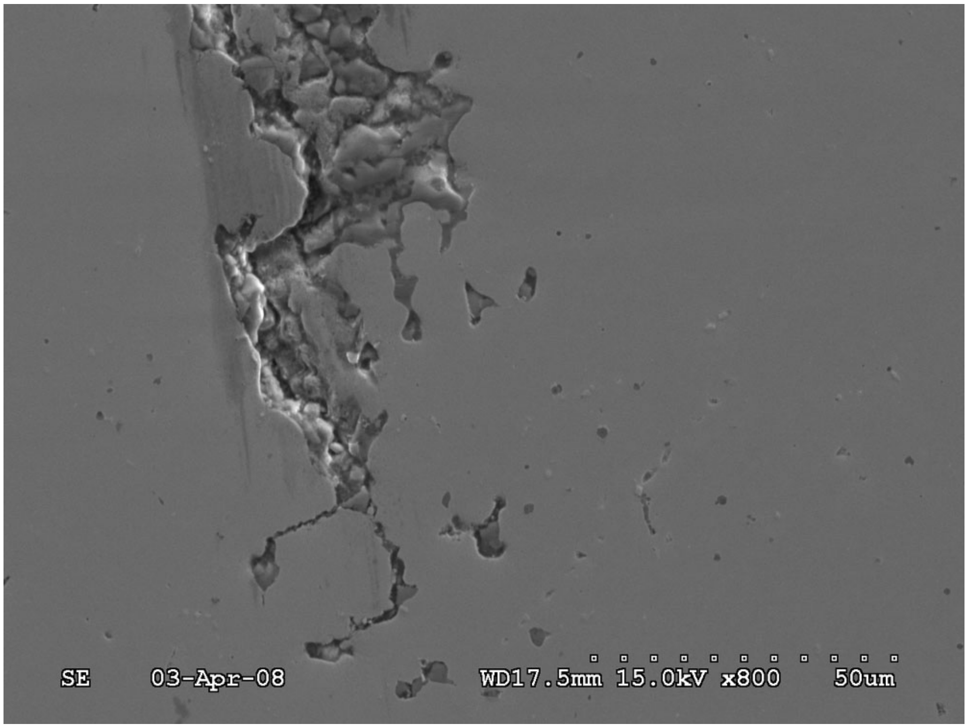


132339-1

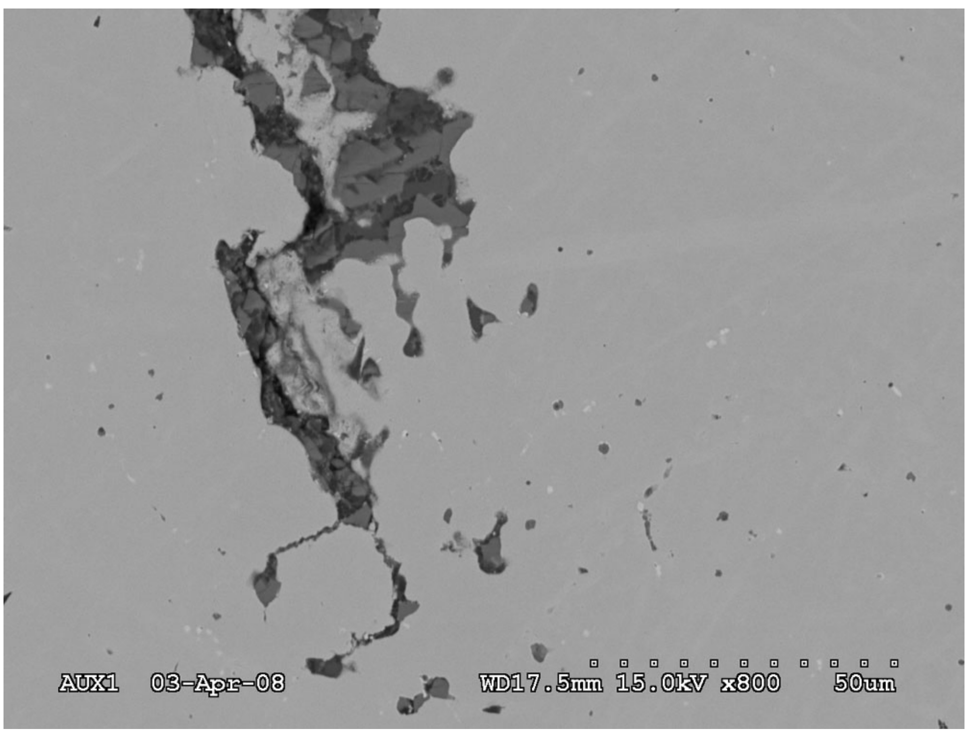


132339-2

Figure 28 (cont.): EDS results for two areas shown in previous figure. The first area contained primarily calcium and fluorine, while the second area contained primarily titanium and oxygen. These results were consistent with the results obtained from the crack located at 350°.

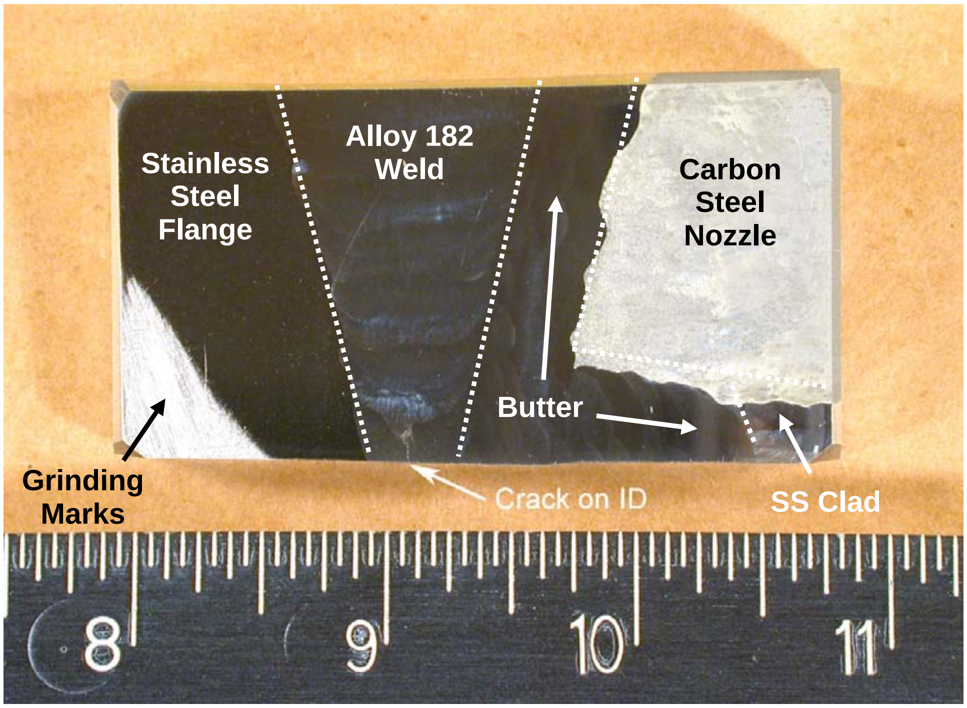


SE 800X 132340

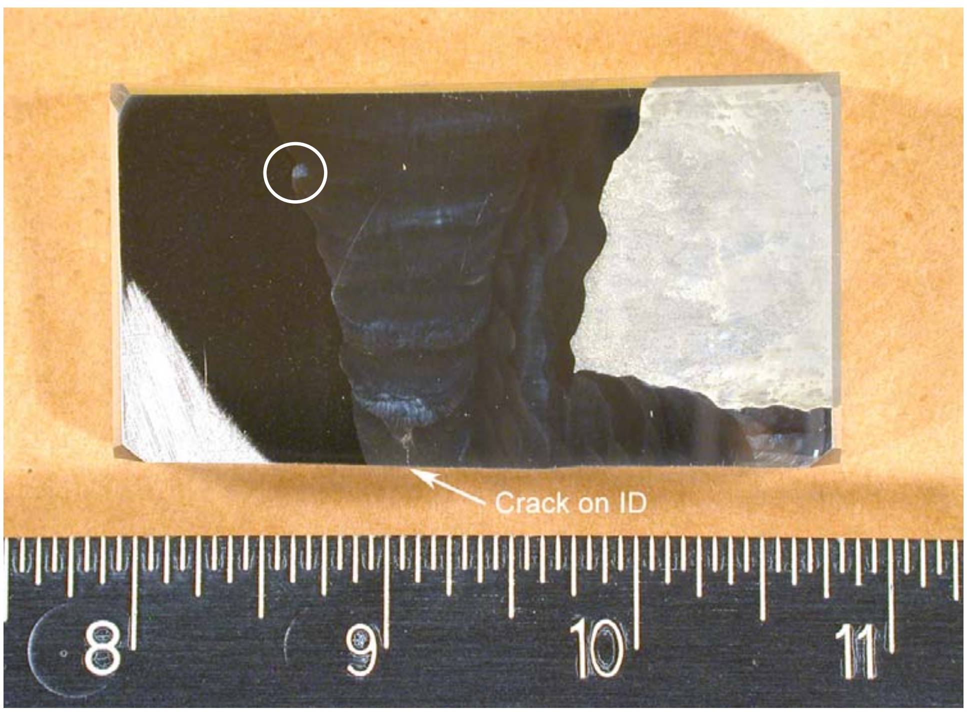


SE 800X 132314

Figure 29: Higher magnification micrographs details of crack showing dendritic structure. This morphology was similar to that seen previously at 350°.



350° (10% oxalic etch)



350° (10% oxalic etch)

Figure 30: 1B1 macro photograph after etching. A crack extending 0.16" deep from the ID surface and a weld void measuring ~0.06" in diameter (inside circle) were present. The weld void was located at the edge of the Alloy 182 weld, adjacent to the stainless steel flange. ***(NOTE: The same photo appears twice above; the upper photo was annotated with the various constituents for clarity.)***

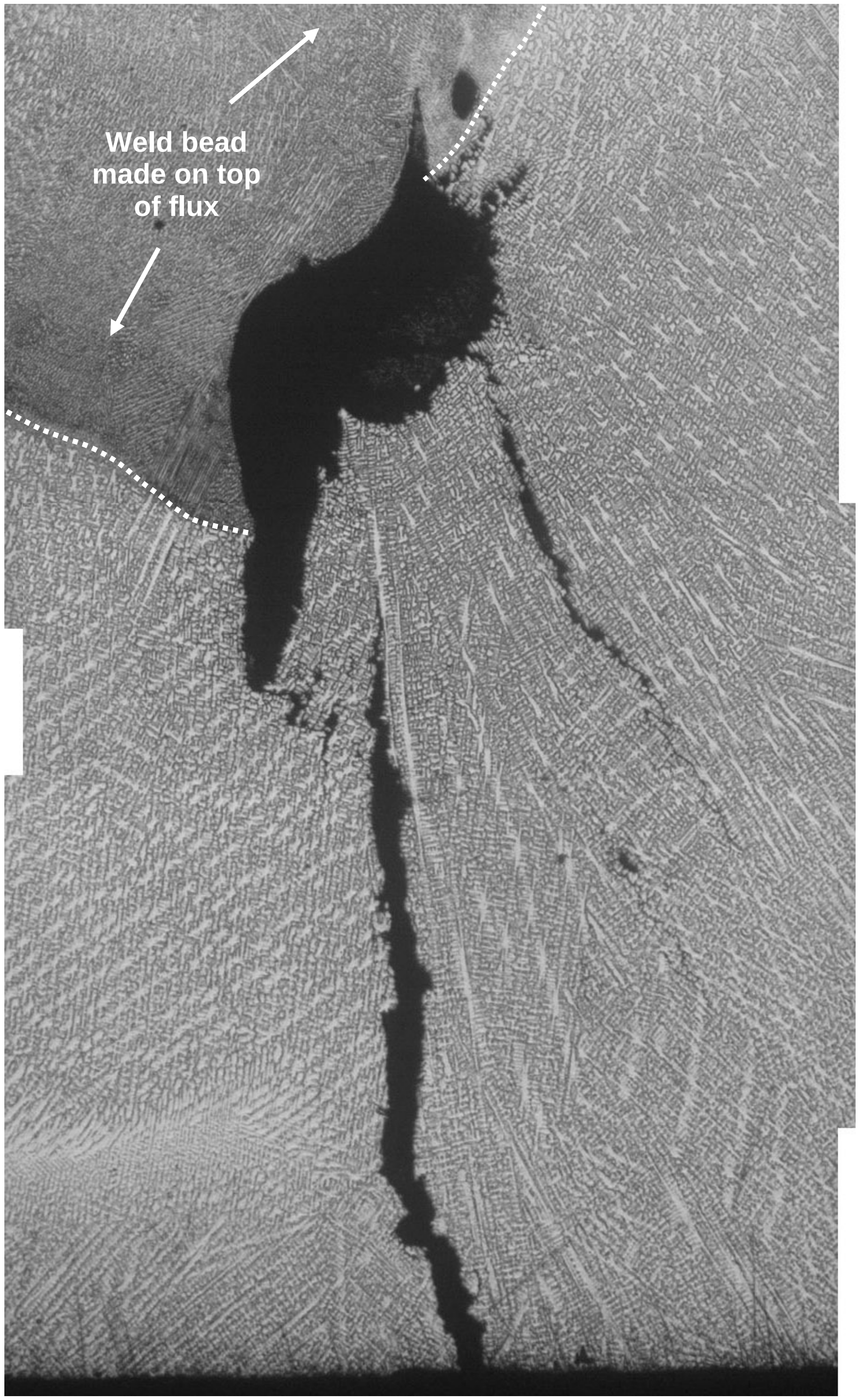
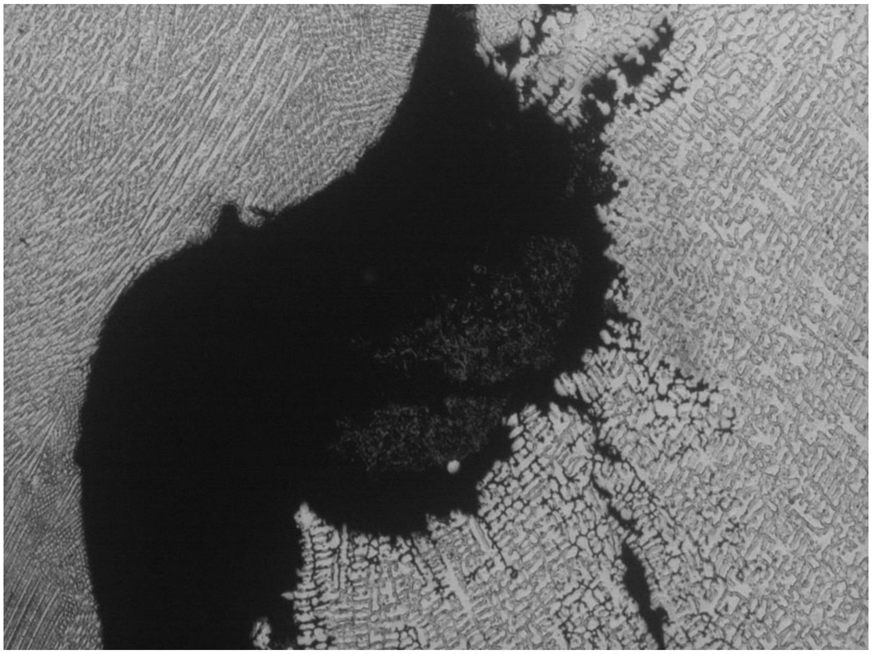
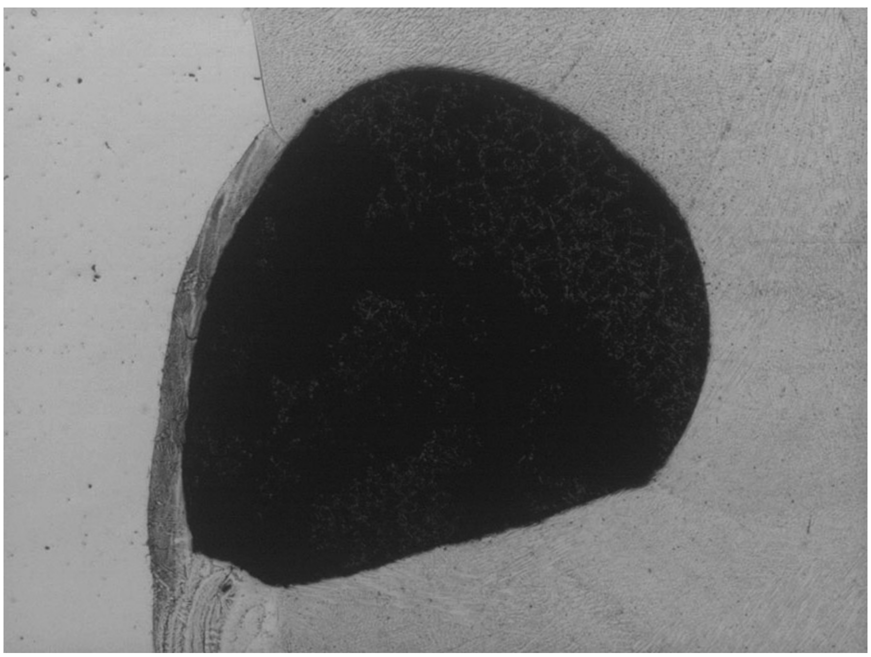


Figure 31: Micrograph montage showing the crack extending from ID surface to a weld void at the 350° orientation. Cracking was interdendritic, straight, and unbranched. The weld bead deposited over the flux likely contributed to the cracking.

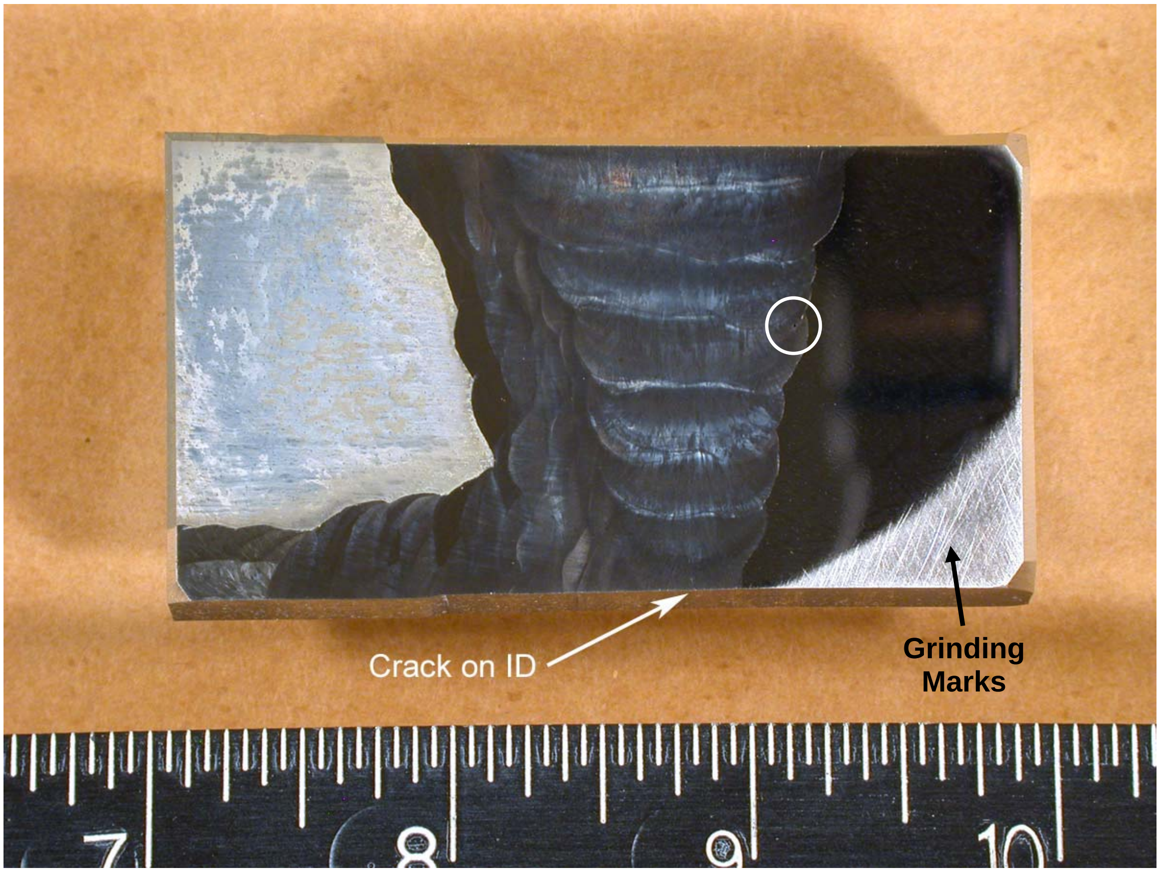


1B1 Etched 100X



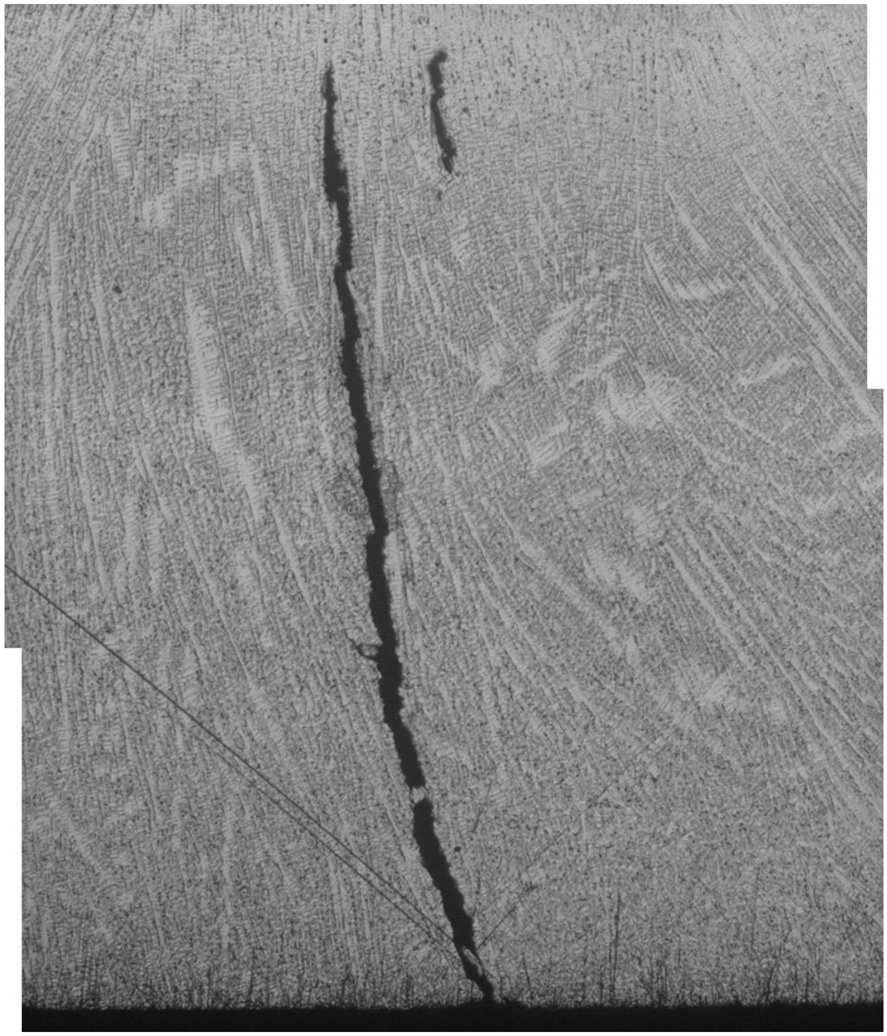
1B1 Etched 48X

Figure 32: Micrographs showing the crack tip (top) at higher magnification and the weld void (bottom). Non-fused areas are evident adjacent to the void in the upper micrograph. The weld void in the lower micrograph measured 0.06" in diameter; there was no cracking associated with this void.



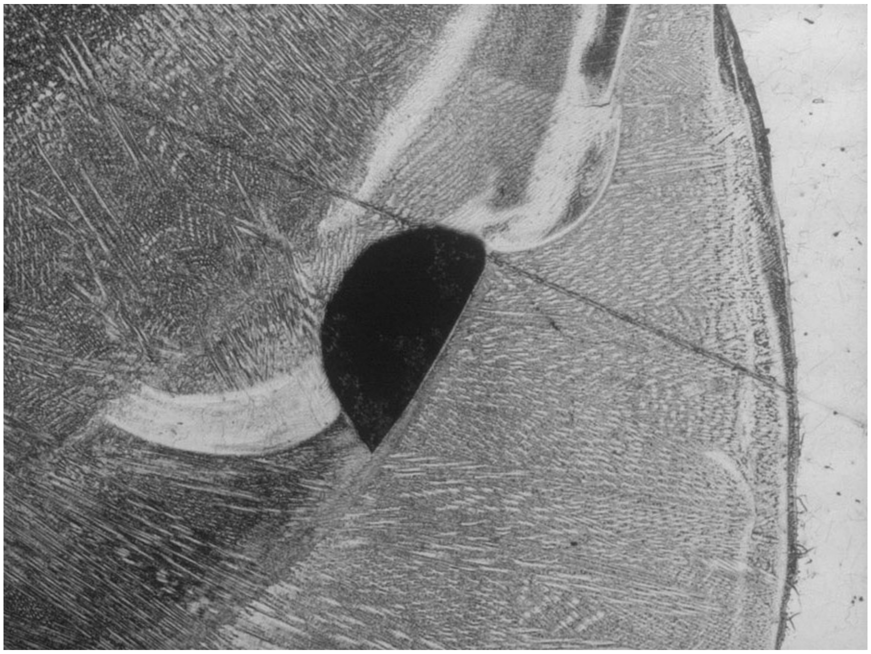
35°

Figure 33: 1B3 macro photograph after electrolytically etching with 10% oxalic acid. A crack extending 0.1" deep from the ID surface and a weld void measuring less than 0.03" in diameter were present. This void was located adjacent to the stainless steel flange.



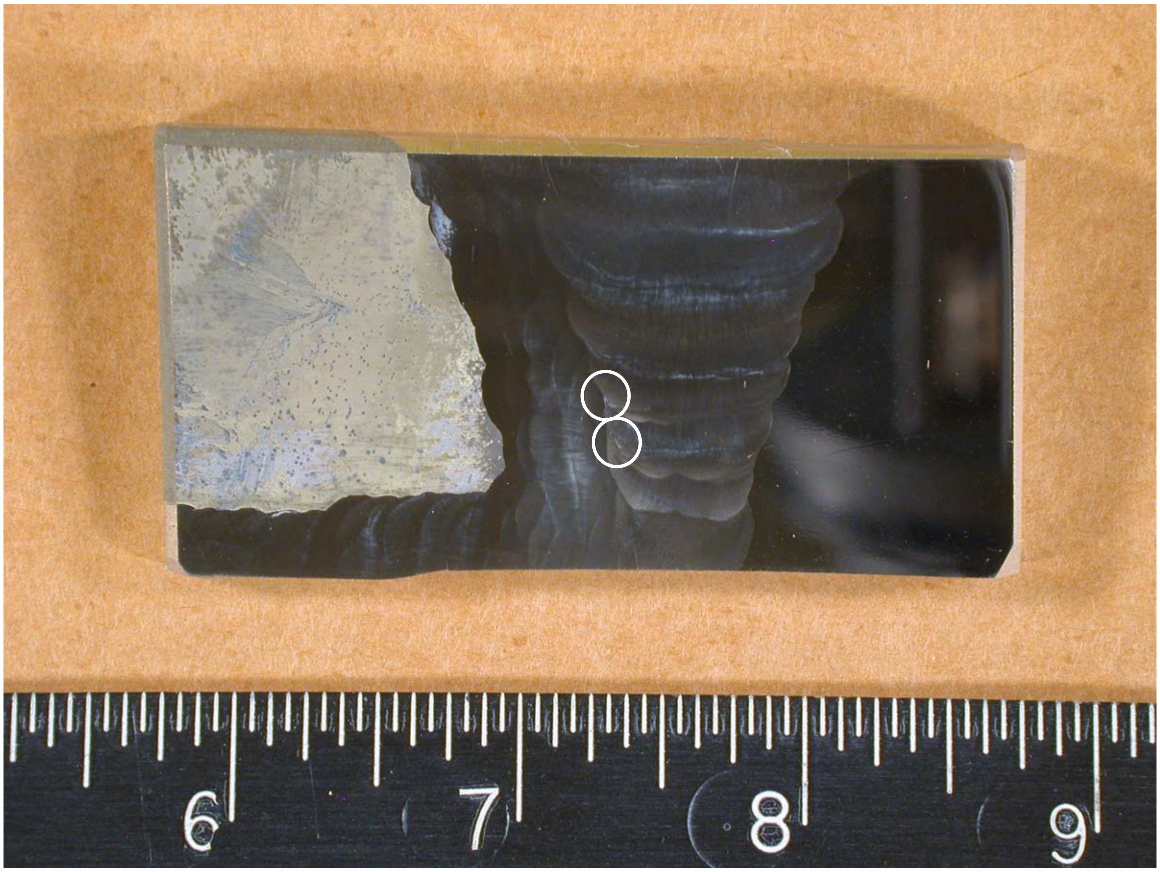
1B3 Etched 48X

Figure 34: Micrograph montage showing the crack extending from ID surface to a weld void at the 35° orientation. The cracking was interdendritic, straight, and unbranched.



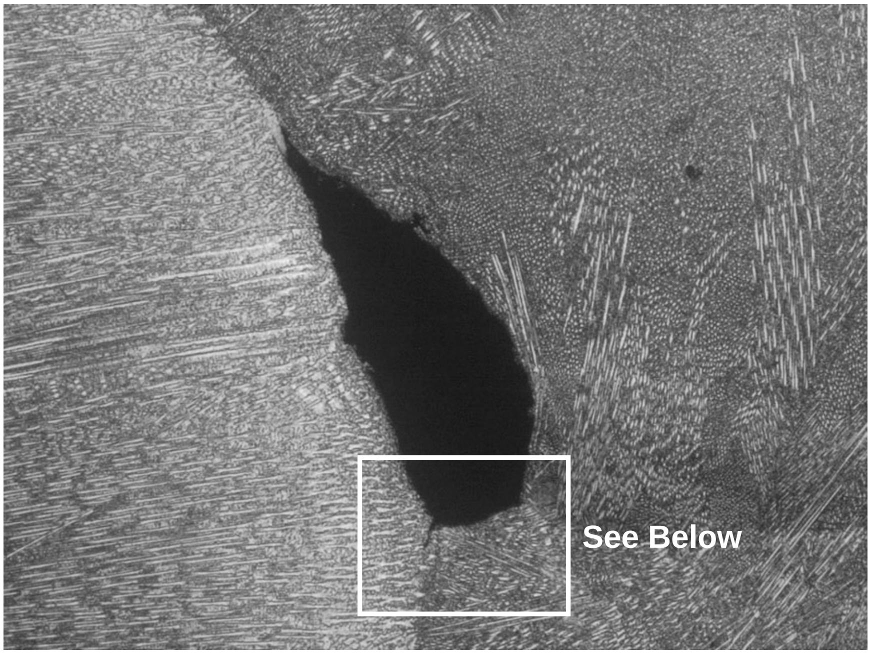
1B3 100X

Figure 35: Weld void measuring less than 0.03" in diameter at the 35° orientation. There was no cracking associated with this void.

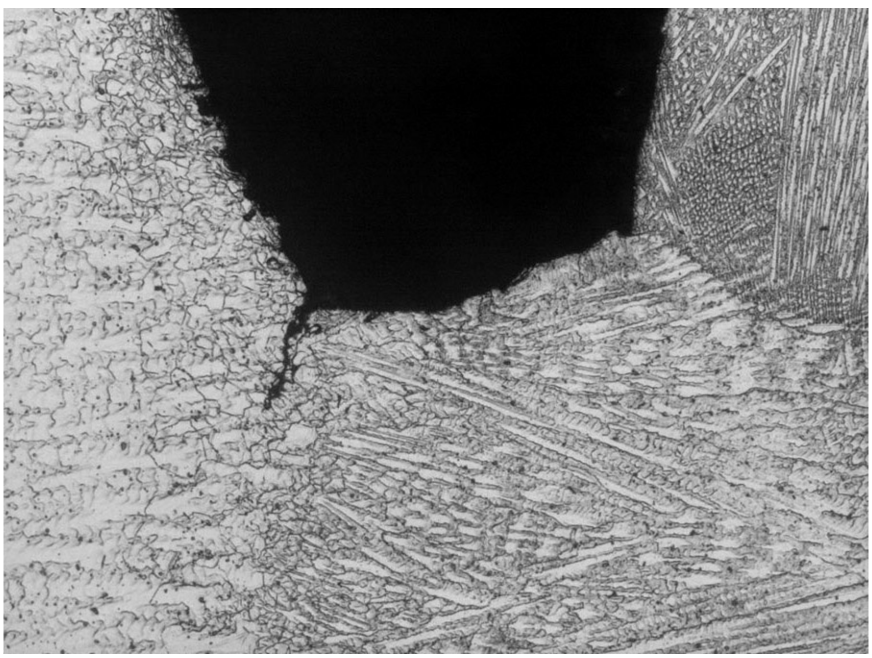


140°

Figure 36: 1B5 macro photograph after electrolytically etching with 10% oxalic acid. No cracking was present at this orientation. Two small voids, each measuring less than 0.03", were detected within the weld adjacent to the butter region.

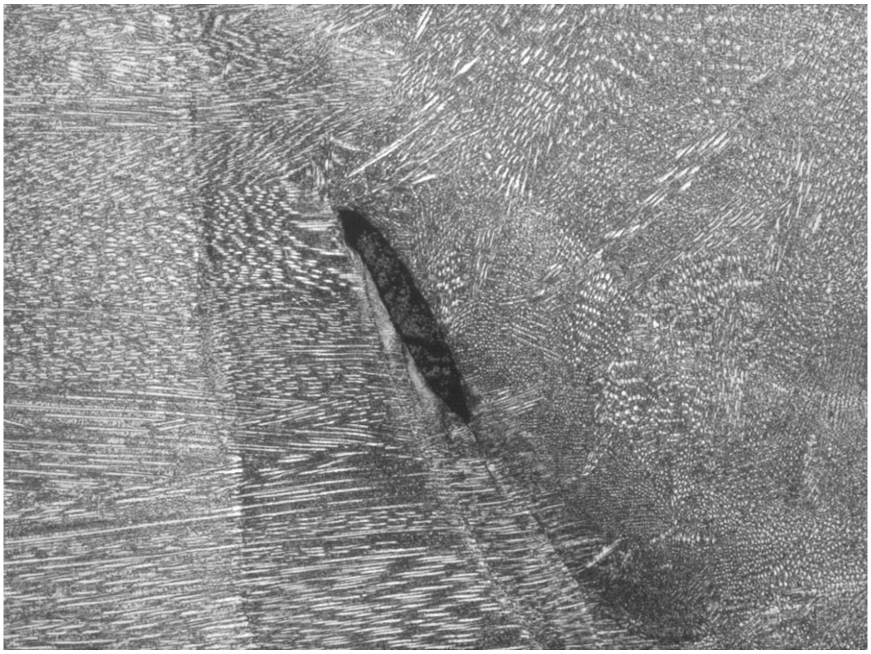


1B5 Etched 48X



1B5 Etched 190X

Figure 37: Micrographs showing a weld void measuring 0.050" by 0.015" present at the 140° orientation. A small crack measuring 0.003" long was noted adjacent to the void. This crack was likely a small hot crack.



1B5 Etched 48X

Figure 38: Second weld void present at the 140° orientation. This void measured 0.030" by 0.005". There was no cracking in this area.

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Project File (1)	B. Grambau (1)

KEY WORDS: PRESSURIZER SAFETY NOZZLE, FLUORESCENT PENETRANT TESTING, VISIBLE DYE PENETRANT TESTING, HOT CRACKING, WELD DEFECTS, ALLOY 182, DISSIMILAR METAL WELD

Destructive Examination Plan

For Saint Lucie Unit 1 Safety Nozzle “A” Alloy 82/182 Weld

Attachment 2

MRP 2008-053

Destructive Examination Plan
For Saint Lucie Unit 1 Safety Nozzle "A" Alloy 82/182 Weld

Purpose

The plan outlined below is intended to provide information relative to the extent and nature of the NDE indications found in the "A" safety nozzle to pipe dissimilar metal weld (DMW) from the retired St. Lucie Unit 1 pressurizer. The focus of the destructive examination (DE) will be to characterize metallurgical features giving rise to the NDE indications in the "A" safety nozzle DMW. This DE will be performed in a manner that investigates areas of interest identified by ultrasonic (UT), radiographic (RT), penetrant (PT) and eddy current (ECT) examinations as appropriate. The overall goal is to better correlate NDE results with actual weld conditions.

Discussion

The DE summarized above is a timely approach to developing information that will provide the following:

1. Characterization of potential flaws giving rise to NDE indications.
2. Confirmation of the NDE indications
3. Evaluation of NDE's capability to accurately characterize flaws
4. Determination of whether any microstructural abnormalities exist which might have adversely affected the UT or PT methods

The DMW was removed by machining with a transverse nozzle cut as close to the head as feasible (See Figure 1) on March 14th, 2008. The minimum reported distance from the toe of the DMW to the cut line is 2.563". This approach allowed for shipping part of the nozzle, the entire weld, and the remaining attached pipe section to a lab where conditions and procedures can be more carefully controlled.

Plan Details

Each step of the above process shall be thoroughly documented including macro- and micro-photography.

Work at RACE Facility:

1. Verify permanent NDE orientation markings and convention (UT and ET) on sample prior to severing from pressurizer (Hold Point). Identify sample orientation markings relative to pressurizer head uphill and downhill.
2. Sever nozzle from pressurizer head (Figure 1).
3. Package sample and ship to lab.

   The above three RACE Facility steps are complete.

Work at Lab Facility: (Tentative)

1. Perform receipt inspection at laboratory
   a. As-received photographs - complete
   b. Validate marking/orientation - complete

2. Perform replica (Microset) of ID of DMW
3. Cut locations have been determined in accordance with the logic established in Figure 2 and the field UT, RT, ET results. Cut locations will:
   a. Investigate at least two UT/RT indications of interest
   b. Investigate original/lab PT indications on ID
   c. Investigate results of ET exam
4. Measure DMW OD diameter at 45° increments before first cut.
5. Perform first axial cut at ~150º (196 mm OD) (Figures 3 – 5)
6. Measure DMW OD diameter at 45° increments after first cut for possible inference to residual stress level in weld joint.
7. Complete second axial cut to section sample into half-sections at ~330º (456 mm OD) (Figures 3 – 5).
8. Perform florescent PT of the DMW ID on each half-section with time-stamped photo-documentation.
9. Place the 150º to 330º (clockwise) section in reserve (Figures 3 – 5).
10. Perform transverse trim cuts ~3/4" above and below the DMW as needed to make the 330º to 150º (clockwise) sample more manageable from a handling and fixturing standpoint (Figures 3 – 5).
11. Remove an appropriately sized sample from the three locations identified below
12. Mark remaining sample adjacent to removed samples for traceability should an additional sample be required from the same area.
13. Mount, polish and etch the samples for metallographic evaluation. Perform optical and SEM/EDS investigation of sample microstructure.

    Features of interest in the metallographic cross section would include:
    - Grain size and morphology
    - Microstructural material processing inclusion types (carbides, sulfides, etc), size, density, distribution, morphology
    - Location of weld passes, heat affected zone(s), and base materials
    - Welding fabrication (likely macroscopic and microscopic) inclusion types (slag, tungsten, ??)
    - Other welding induced anomalies like lack of fusion, porosity, hot cracking, etc.
    - Evidence of service induced flaws

    These features would be investigated with various techniques as appropriate and available such as:

    - Various differentiating etchants and optical techniques
    - Microhardness testing
    - SEM and EDS examination of the transverse cross section(s)

    Any significant evidence of service induced flaws (cracking) or the need to differentiate service induced from fabrication induced flaws may dictate exposing the face of the flaw(s) for more detailed examination with SEM, EDS, etc. as deemed appropriate and available.

The decision to employ these various techniques will be dictated by the progress of the work and the results at each stage of the effort in accordance with the protocol outlined below in "**Direction of Work"**

Sample Locations (Figures 3 – 5)**:**

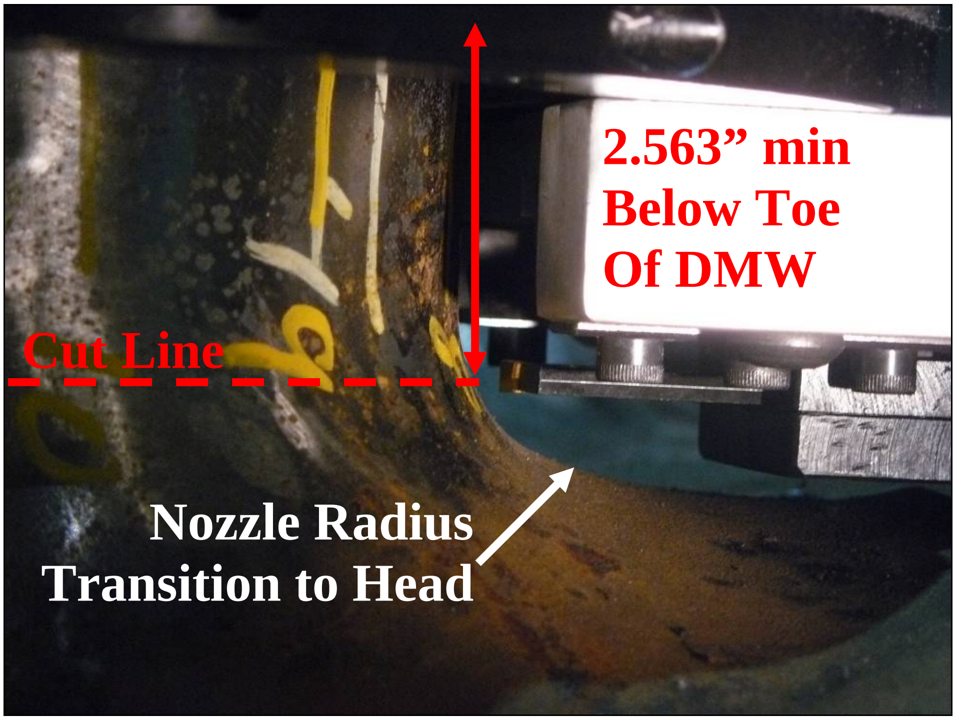
Note: Sectioning cuts and sample azimuthal locations given are approximate and should be applied with appropriate judgment and the data from Figure 6 to establish the final cut layout on the specimen to meet the intent for each cut or sample location as stated below.

1. Make first cut at ~150º to allow investigation of:
   a. An area that was reported as containing a deep reflector in the original manual exam but not via automated UT
   b. Surface indications ET3 & PT3
   c. The degree of continuity exhibited by embedded indication UT8
2. Remove a sample adjacent to the cut face at ~330º to allow investigation of:
   a. Embedded indication UT7 as one area without clear correlation between UT and RT results
   b. Surface indications PT1 and ET1
   c. The degree of continuity exhibited by embedded indication UT8
3. Remove a sample from a zone centered at ~36º (49 mm OD) to allow investigation of:
   a. Embedded indications UT2 and RT2 as one area with good UT / RT correlation
   b. Surface indications PT5 and ET5
   c. The degree of continuity exhibited by embedded indication UT8

Direction of Work:

This DE shall be guided in the following manner:

- The overall objective and general direction is defined by this plan
- B&W is responsible for the examination and for drawing independent conclusions regarding the origin and condition of metallurgical features in the sample that are relevant to the stated Plan objectives
- Industry and NRC representatives on-site will, in consultation with B&W lab staff, interpret and apply the general guidance of this plan as necessary to determine specific actions over the course of the exam
- Consultation with the entire DE team will be arranged if:
  - Evidence of service-induced degradation is identified
  - Definitive agreement cannot be reached between the NRC & Industry representatives on-site and B&W lab staff regarding methods, sequence, priority, etc.
  - Scope expansion beyond the initial sample set appears warranted



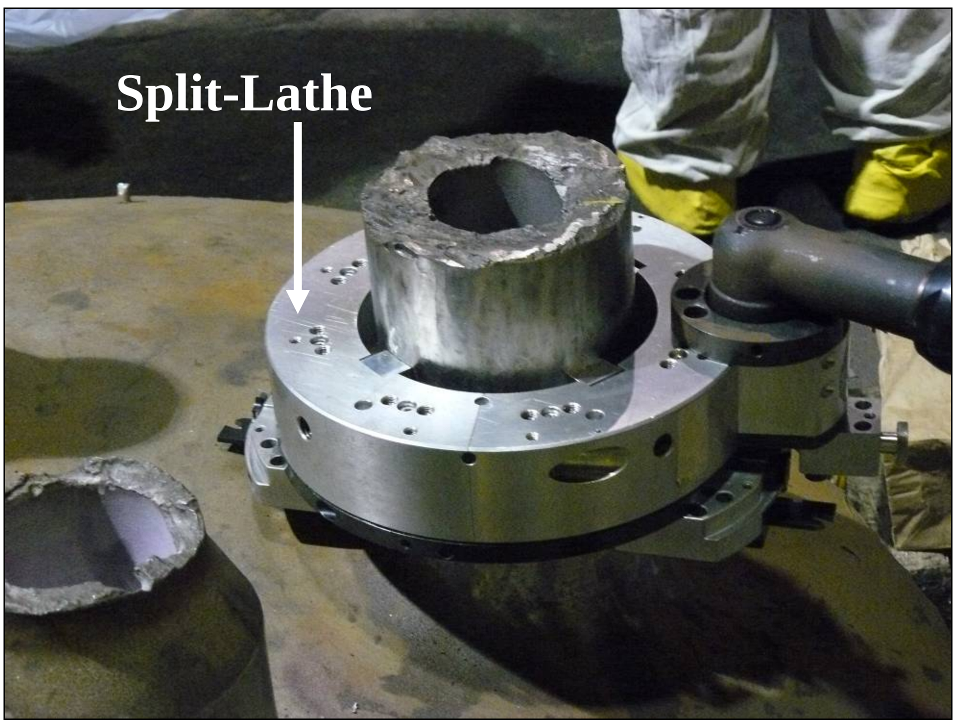


Figure 1: DMW Removal of Safety Nozzle "A"

Destructive Examination Plan
For Saint Lucie Unit 1 Safety Nozzle "A" Alloy 82/182 Weld

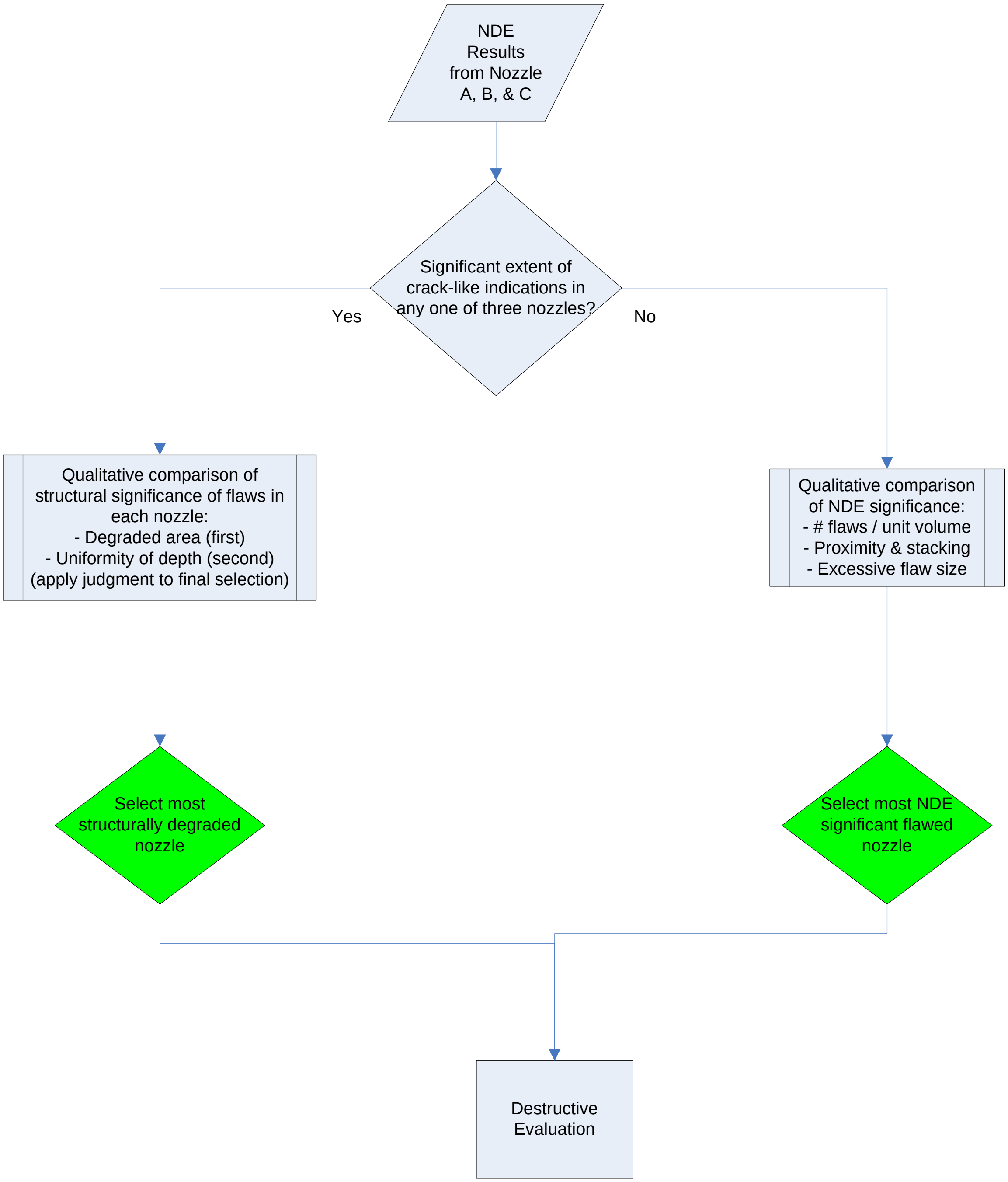


Figure 2 – Nozzle Selection Decision Logic

Destructive Examination Plan
For Saint Lucie Unit 1 Safety Nozzle “A” Alloy 82/182 Weld

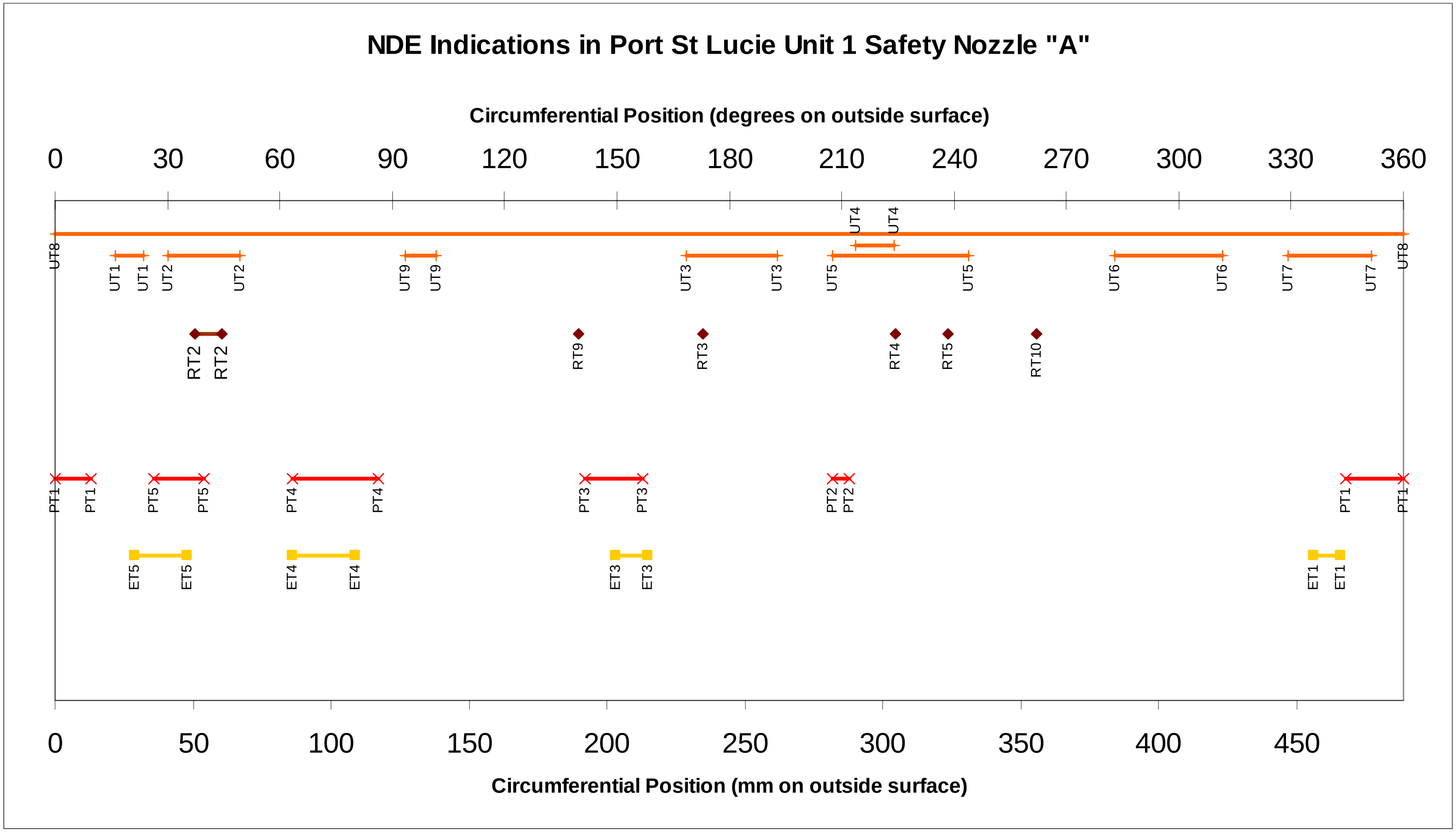


Figure 3 – Azimuthal Location Correlation of Indications by NDE Method

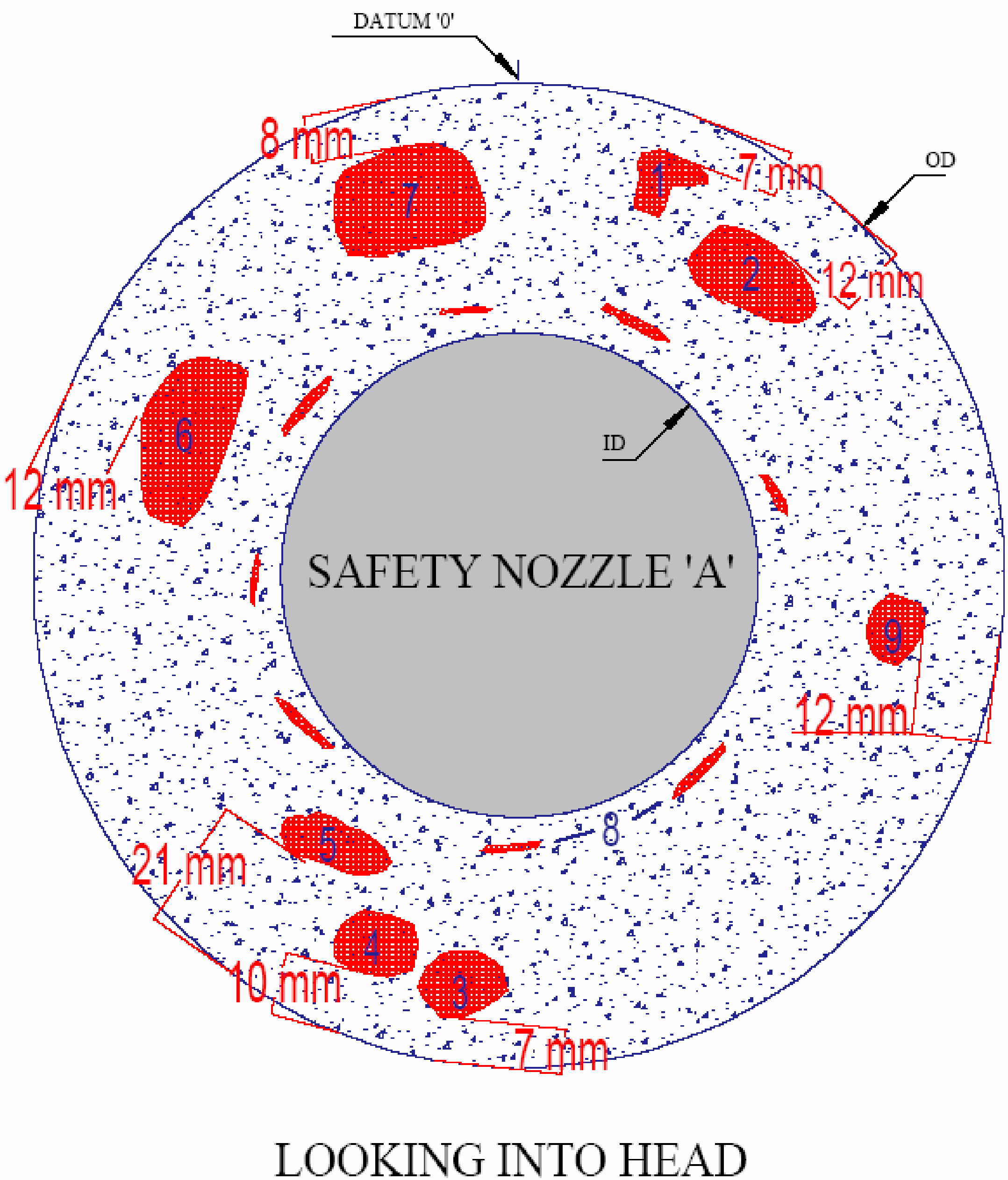


Figure 4 – Automated UT Reflectors Mapped onto Weld Cross-Section
(Positive angular progression is clockwise)

Destructive Examination Plan
For Saint Lucie Unit 1 Safety Nozzle "A" Alloy 82/182 Weld

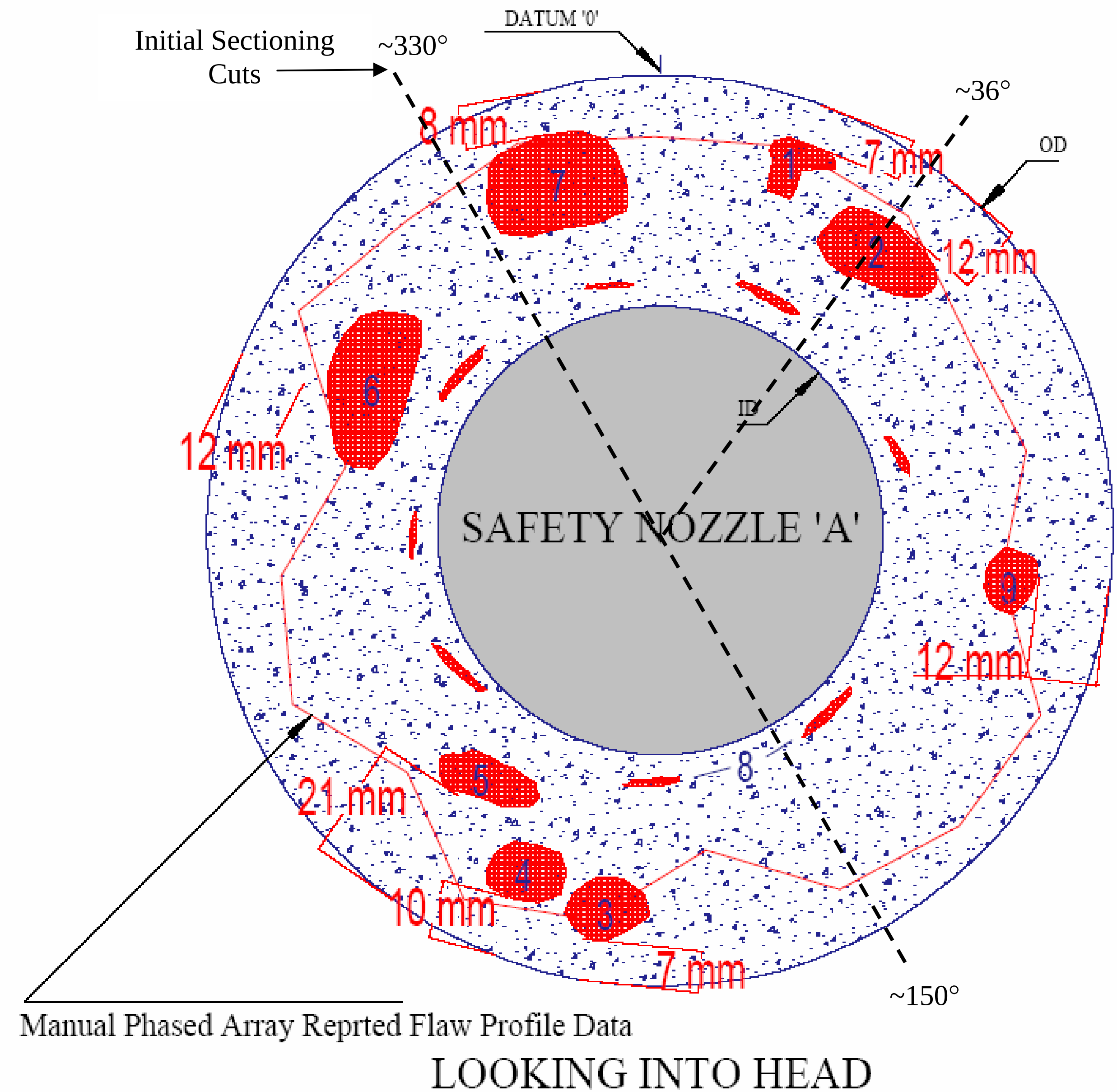


Figure 5 – Automated UT Reflectors Mapped onto Weld Cross-Section w/ Manual UT-Derived Profile Superimposed

(Positive angular progression is clockwise)

Destructive Examination Plan
For Saint Lucie Unit 1 Safety Nozzle "A" Alloy 82/182 Weld

PSL FIELD REMOVED PZR SAFETY NOZZLES

SURFACE EXAMINATION METHOD COMPARISON

EXAMINATION METHODS														
NOZZLE IDENTIFICATION	INDICATION	DYE PENETRANT			DYE PENETRANT			EDDY CURRENT			EDDY CURRENT			COMMENTS
		ID START	ID STOP	LENGTH	OD START	OD STOP	LENGTH	ID START	ID STOP	LENGTH	OD START	OD STOP	LENGTH	
PSL SAFETY 'A'	1	-10	6	16	-21	13	33	218	223	5	456	466	10	ID SURFACE INDICATION (1)
	2	135	138	3	282	288	6							ID SURFACE INDICATION
	3	92	102	10	192	213	21	97	103	6	203	215	13	ID SURFACE INDICATION
	4	41	56	15	86	117	31	41	52	11	86	109	23	ID SURFACE INDICATION
	5	17	26	9	36	54	19	14	23	9	29	48	19	ID SURFACE INDICATION

NOTES: *(1) SINGLE WALL EXPOSURE RADIOGRAPHIC EXAMINATION REPORTED 2 LINEAR INDICATIONS LOCATED CIRCUMFERENTIALLY AT 0 to 8 mm AND -3 to 6 mm LOCATIONS WICH CORRESPOND TO INDICATION # 1.*
(2) INDICATION # 5 CORRESPONDS TO 2 SEPARATE EDDY CURRENT INDICATIONS.

VOLUMETRIC EXAMINATION METHODS						
NOZZLE IDENTIFICATION	INDICATION	ENCODED PA			RADIOGRAPHY	COMMENTS
		START	STOP	LENGTH	LOCATION	
PSL SAFETY 'A'	1	22	32	10		EMBEDDED FABRICATION FLAWS RECORDED WITH ENCODED PHASED ARRAY ONLY
	2	41	67	26	50.8 / 60.3	EMBEDDED FABRICATION FLAWS RECORDED WITH ENCODED PHASED ARRAY AND RADIOGRAPHY
	3	229	262	33	234.9	EMBEDDED FABRICATION FLAWS RECORDED WITH ENCODED PHASED ARRAY AND RADIOGRAPHY
	4	290	304	14	304.8	EMBEDDED FABRICATION FLAWS RECORDED WITH ENCODED PHASED ARRAY AND RADIOGRAPHY
	5	282	331	49	323.8	EMBEDDED FABRICATION FLAWS RECORDED WITH ENCODED PHASED ARRAY AND RADIOGRAPHY
	6	384	423	39		EMBEDDED FABRICATION FLAWS RECORDED WITH ENCODED PHASED ARRAY ONLY
	7	447	477	30		EMBEDDED FABRICATION FLAWS RECORDED WITH ENCODED PHASED ARRAY ONLY
	8	360° INTERMITTENT				EMBEDDED FABRICATION FLAWS RECORDED WITH ENCODED PHASED ARRAY ONLY
	9	127	138	11	139.7	EMBEDDED FABRICATION FLAWS RECORDED WITH ENCODED PHASED ARRAY AND RADIOGRAPHY
					355.6	EMBEDDED FABRICATION FLAWS RECORDED WITH RADIOGRAPHY ONLY

NOTES:
1. *RADIOGRAPHY EXAMINATION RESULTS ONLY GIVE FLAW LOCATION IN THE CIRCUMFERENTIAL PLANE. NO THRU-WALL OR LENGTH DIMENSION DATA PROVIDED. ALL INDICATIONS RECORDED WITH RADIOGRAPHY ARE WITHIN THE APPLICABLE ASME CODE ACCEPTANCE CRITERIA.MAXIMUM ALLOWABLE FLAW LENGTH = 0.53"*

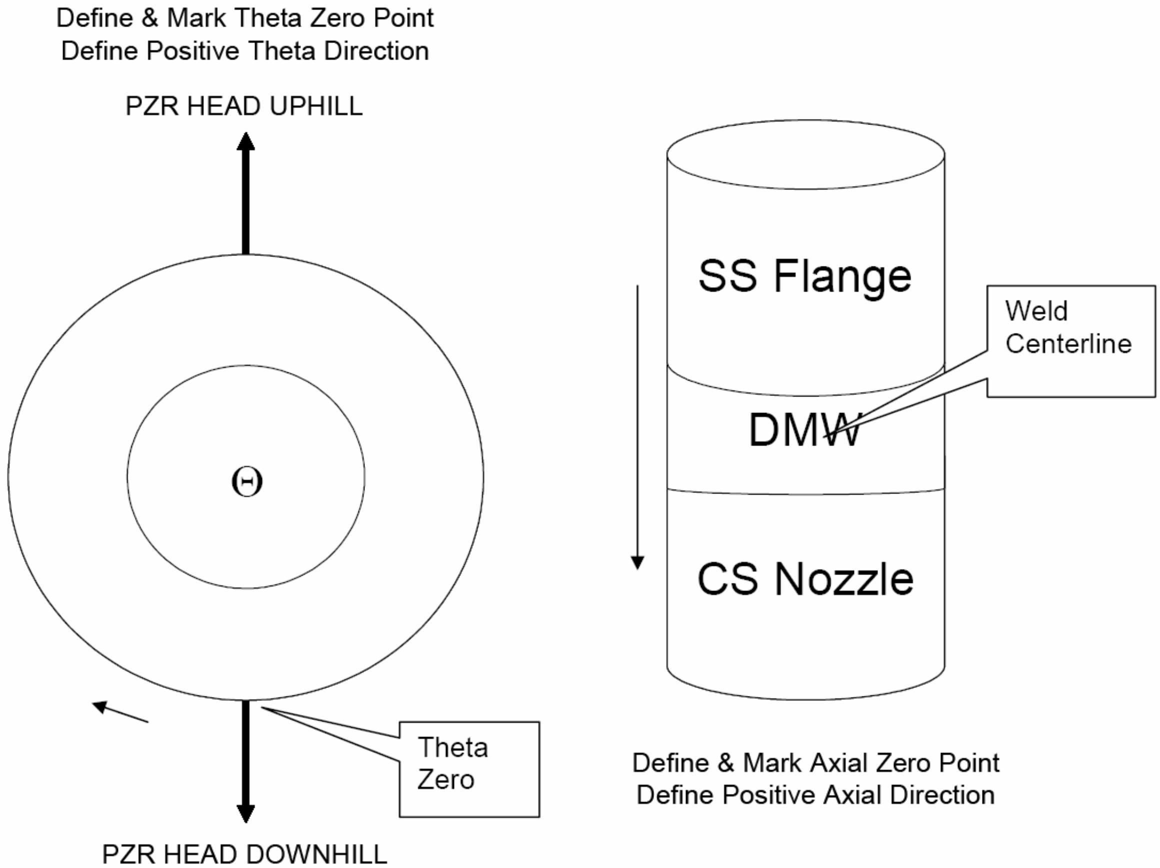
Figure 6 – NDE Indication Location Data

Destructive Examination Plan
For Saint Lucie Unit 1 Safety Nozzle "A" Alloy 82/182 Weld

St. Lucie Unit 1 Safety Nozzle "A" Markings

Instructions:

Prior to severing the Alloy 82/182 dissimilar metal weld from the nozzle, permanently mark the NDE theta and axial zero locations using low stress die stamp or vibra-tool. Define theta zero point relative to pressurizer head uphill/downhill direction. Define axial zero point and distance relative to top end of flame-cut stainless steel flange. Sketch the locations on the figures below. Completion of permanent marking and this form complete the HOLD POINT defined in RACE facility step #1 in the DE plan.



PREPARED BY: ______________________ **DATE:** ___3/14/2008___

Positive angular progression is clockwise looking into head
Positive axial progression is toward head with zero at the weld centerline

Figure 7 – NDE Orientation Marking