



Report No. 5004.9268 Rev. 1

September 11, 2013

**METALLURGICAL EVALUATION OF A SECTION FROM
L-147 MP 2.2 BRITTAN AVE. AND ROGERS AVE., SAN CARLOS**

Customer Authorization: CWA 2500876408
Agreement 4400000067

Report To: Pacific Gas & Electric Co.

Attn: Redacted

Redacted

1.0 INTRODUCTION

One section of 20 -inch diameter gas transmission pipe identified as L-147 Redacted Redacted was submitted by PG&E for metallurgical evaluation. The subject section had a PLIDCO weld cap permanent repair, and an A. O. Smith longitudinal seam weld. The section was cut out to perform a root cause investigation of a reported leak under the PLIDCO cap. It was reported the subject passed hydrotest as part of L-147 on October, 24, 2011, at a pressure of 600-psi, or 1.5 times the desired Maximum Allowable Operating Pressure (MAOP) of 400-psi, and the PLIDCO cap was located at the six o'clock position, on the bottom of the section. The purpose of this evaluation was to determine the metallurgical condition of the pipe wall under the PLIDCO cap, and perform Charpy impact testing of the A. O. Smith weld and unaffected base metal.

The sample was evaluated by the following laboratory procedures:

- 1) Visual and macroscopic examination
- 2) Metallography
- 3) Scanning electron microscopy and energy dispersive X-ray spectroscopy
- 4) Charpy V-notch impact testing

Based on the results of this evaluation, weld crater cracks and underlying weld heat affected zone liquation cracks likely formed a leak path under the PLIDCO cap. However, penetrant testing and 40-psig compressed air testing failed to detect a leak under the cap. Metallography revealed that the liquation cracks were filled with oxide. No evidence of crack growth during service or hydrotesting was detected.

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2.0 EVALUATION¹

2.1 Visual Examination

The subject sample of L-147 was received sectioned into two halves along the longitudinal axis, with the outside surface grit blasted, as shown in Figure 1 through Figure 5. The section half with the PLIDCO cap was arbitrarily labeled A and the other section was labeled B, in the laboratory. Based on the reported position of the cap, the longitudinal flame cuts were located at three o'clock and nine o'clock positions. Wall thickness measurements were made with a pointed anvil micrometer and the results are listed in Table 1. Small regions of weld metal and a few shallow hemispherical pits were present near the cap, as shown in Figure 2. Pits were also present just past the three o'clock position toward the cap, indicated in Figure 1. Pit depths were measured with a pit gage, and the results are listed in Table 2. No evidence of a leak location or repair was visible to the unaided eye on the inside surface of the pipe under the cap.

The appearance of the longitudinal seam was typical of A. O. Smith welds, a wide low-crowned cap on the outside surface and a narrow flash on the inside surface. A weld stop/start was visible on the outside surface.

The region containing the PLIDCO cap was sectioned from sample A and the cap was cut off to expose the outside surface of the pipe wall. The outside surface was covered with rust and had a slightly oily feel. Both surfaces were cleaned with dilute Oakite® 33 and a wire brush. The outside surface is shown before and after cleaning in Figure 6. Several regions of weld metal were visible on the outside surface. Examination using low-power optical microscopy revealed a pit consistent with corrosion on the outside surface, indicated in Figure 7. The inside surface is shown after cleaning in Figure 8. Indications of heat exposure were visible on the inside surface, corresponding to the weld metal on the outside surface. No evidence of weld burn through was detected, and fine grooves typical of wrought steel surfaces were continuous across the region, which indicated that repairs did not extend to the inside surface. Examination using low-power optical microscopy revealed a crack-like feature on the inside surface within the heat affected zone of a weld deposit, as shown in Figure 8b.

Both sides of the cap sample shown in Figure 6 were thoroughly cleaned with acetone and dried with compressed air. A liquid penetrant test was performed by applying developer to the inside surface, and penetrant was liberally applied to the outside surface in the area covered by the cap. After 1.5-hours, no indication of penetrant was visible on the inside surface.

The sample shown in Figure 6 was returned to PG&E for radiography. A digital radiograph of the sample is shown in Appendix A along with a photograph of the sample. A crack indication was found that corresponded to the crack-like feature detected visually on the inside surface, shown in Figure 8b.

A pressure test was performed by clamping a plate over the sectioned cap, sealed with a silicone gasket, and introducing 40-psig of compressed air. Snoop® liquid leak detector was applied to the inside surface. No leaks were detected. The compressed air was valved-off, and no pressure drop from 40-psig was detected after 45-minutes.

¹ The magnifications of the optical and scanning electron micrographs in this report are approximate and should not be used as a basis for dimensional analyses unless otherwise indicated.

2.2 Metallography

Specimens were prepared for metallography from section 1 and 2 indicated in Figure 8b. Weld crater cracks and heat affected zone liquation cracks were present in the sections. Serial grinding and polishing was performed on section 1, referred to as sections 1a, 1b, and 1c. As shown in Figure 10 through Figure 20, a weld crater crack extended from the outside surface into the weld heat affected zone in section 1a, but did not penetrate through the wall at this location. Shrinkage porosity was present near the outside surface, and intergranular cracks consistent with grain boundary liquation were present in the heat affected zone.

In section 1b, shown in Figure 13 through Figure 15, cracks were present from the outside surface to the inside surface. Only a few small ligaments prevented the demonstration of a through-wall leak path. However, it is likely that a leak path existed between section 1a and 1b. The weld metal crack morphology was consistent with shrinkage, and the heat affected zone crack morphology was indicative of grain boundary liquation.

In section 1c, shown in Figure 16 through Figure 18, one small ligament at the outside surface prevented demonstration of a through-wall leak path. Once again, the weld crack morphology was consistent with shrinkage and the heat affected zone crack morphology was consistent with grain boundary liquation. In all three sections of specimen 1, the weld fusion zone followed a smooth broad contour with no indications of external corrosion prior to welding.

Section 2 is shown in Figure 19. The fusion zone in this section had a profile that was more varied in depth than in sections 1a through 1c, which suggested the possibility that the weld metal was deposited to build-up locations where wall thickness had been reduced by external corrosion. Measurements of the minimum thickness of base metal beneath the weld metal are shown in Figure 10, Figure 13, Figure 16, and Figure 19.

2.3 Scanning Electron Microscopy and Energy Dispersive X-ray Spectroscopy

Scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy² (EDS) was performed on the section 3 polished and etched surface. A composite SEM micrograph of the crack is shown in Figure 20. Much of the crack was filled with oxide, indicated by the morphology and chemical composition of primarily iron and oxygen, with sulfur present, likely from mercaptan in the gas stream.

2.4 Charpy V-Notch Impact Testing

Charpy-V notch impact test specimens were machined from the longitudinal seam weld and base metal such that fracture propagation was in the longitudinal direction. Three 5.0 mm thick specimens from each area were tested at +32°F and +50°F. The results, listed in Table 3, were typical for line pipe carbon steel. No requirements were given.

² The EDS analysis method used here detects the presence of elements from boron (B) to uranium (U), atomic numbers from 5 to 92 in the periodic table. EDS data alone are, however, insufficient to differentiate chemical compounds such as oxides, hydroxides, or carbonates or to characterize organic materials that consist of carbon (C), hydrogen (H), and nitrogen (N) only.

3.0 CONCLUSIONS³

The following conclusions are based upon the submitted samples and the evidence gathered:

1. Metallography revealed a leak path was likely present under the PLIDCO cap between an external weld crater crack and liquation cracks in the underlying weld heat affected base metal.
2. No evidence of crack growth during service or hydrotesting was detected.
3. A dye penetrant test and a pressure test with 40-psig compressed air failed to detect a leak path in the region covered by the PLIDCO cap.
4. Radiography, performed by PG&E, revealed a crack indication under the PLIDCO cap, which was confirmed with metallography.
5. Several shallow hemispherical pits consistent with corrosion were present on the outside surface of the sample adjacent to surface welds.

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Reviewed by:

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Associate Director of Laboratories

Redacted

Director, Engineering and Laboratories

³ The conclusions in this report are based upon the available information and evidence provided by the client and gathered by Anamet, within the scope of work authorized by the client, and they are hereby presented by Anamet to a reasonable degree of engineering and scientific certainty. Anamet reserves the right to amend or supplement its conclusions or opinions presented in this report should additional data or information become available, or further work be approved by the client.

Table 1
 Wall Thickness Measurements

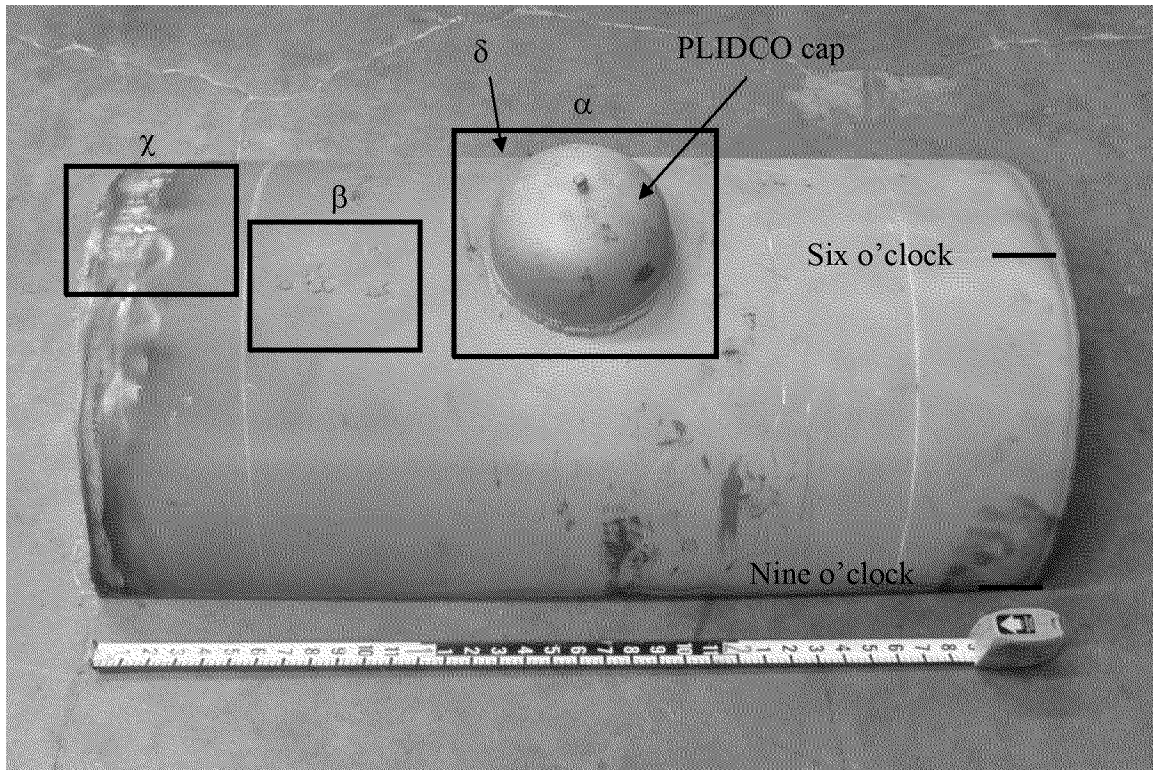
| Location | Thickness (inches) |
|----------------|--------------------|
| Twelve o'clock | 0.248 |
| Three o'clock | 0.253 |
| Six o'clock | 0.247 |
| Nine o'clock | 0.243 |

Table 2
 Pit Depths

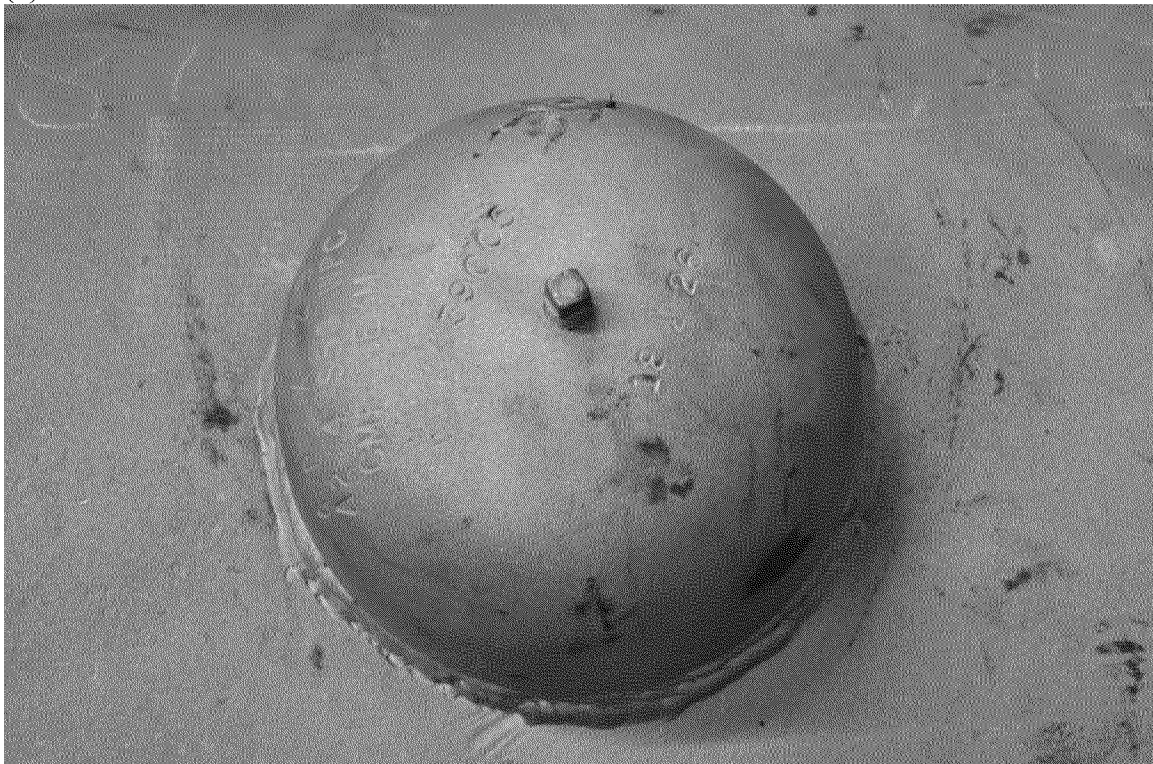
| Pit | Depth (inches) |
|-----|----------------|
| 1 | 0.062 |
| 2 | 0.078 |
| 3 | 0.062 |
| 4 | 0.062 |
| 5 | 0.047 |
| 6 | 0.063 |
| 7 | 0.047 |

Table 3
 Charpy V-Notch Impact Test Results

| Specimen and Test Temperature (°F) | Energy Absorbed (ft·lbs) | Lateral Expansion (mils) | Shear (%) |
|------------------------------------|--------------------------|--------------------------|-----------|
| Weld +32°F | 7 ½ | 21 | 18 |
| | 7 ½ | 19 | 23 |
| | 6 | 18 | 18 |
| Weld +50°F | 11 ½ | 33 | 18 |
| | 9 | 26 | 28 |
| | 10 | 28 | 28 |
| Base Metal +32°F | 4 | 7 | 9 |
| | 4 | 8 | 9 |
| | 6 | 8 | 9 |
| Base Metal +50°F | 4 ½ | 11 | 13 |
| | 6 | 13 | 18 |
| | 6 | 14 | 13 |

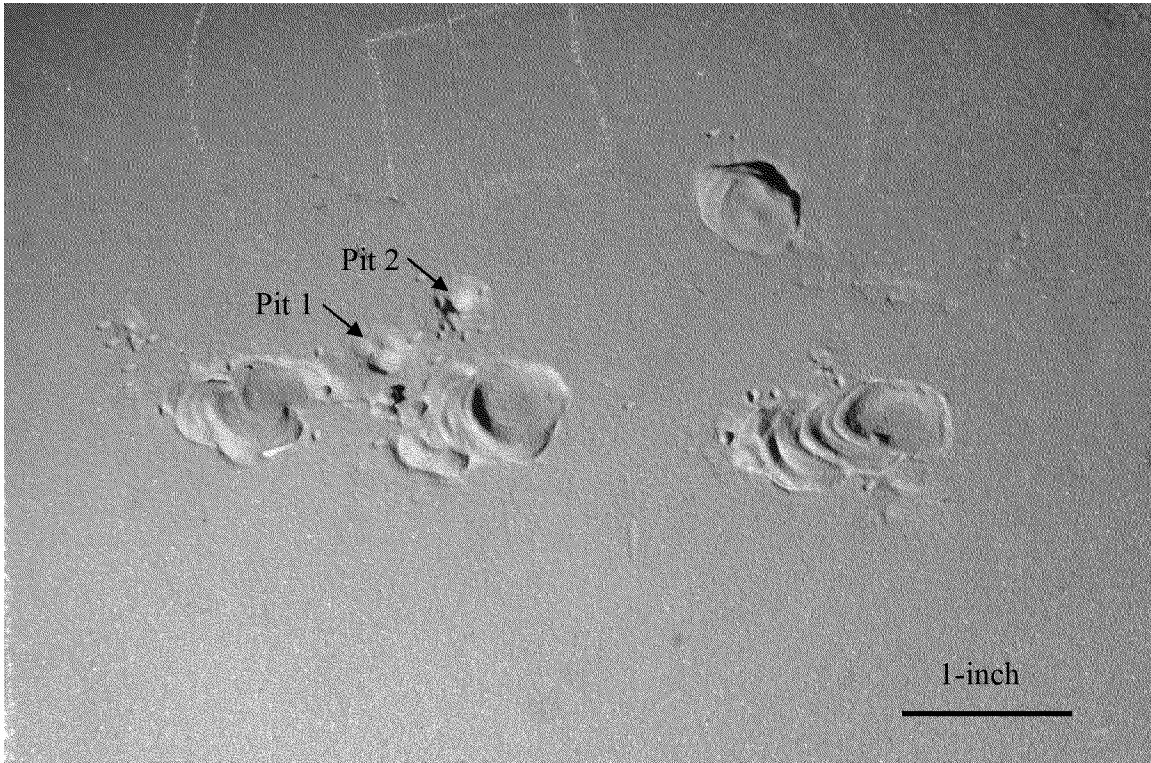


(a)

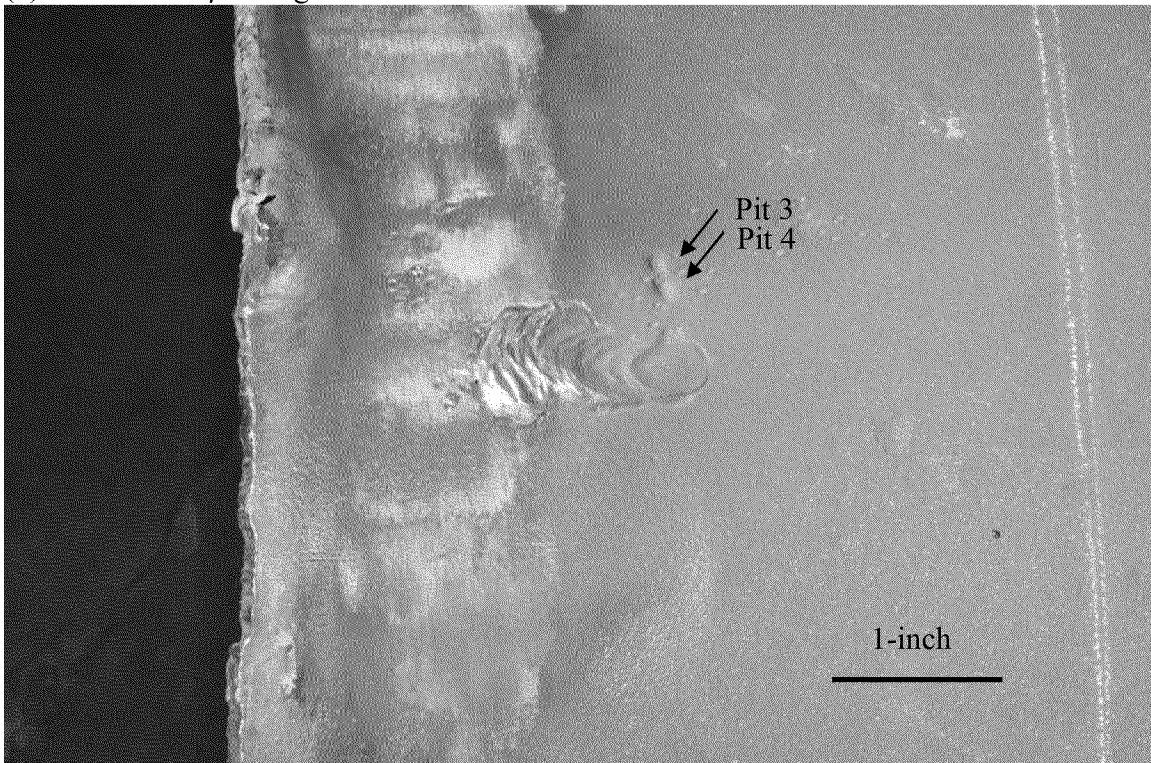


(b) Boxed area α in (a)

Figure 1 Photographs of the outside surface of sample half A as-received.

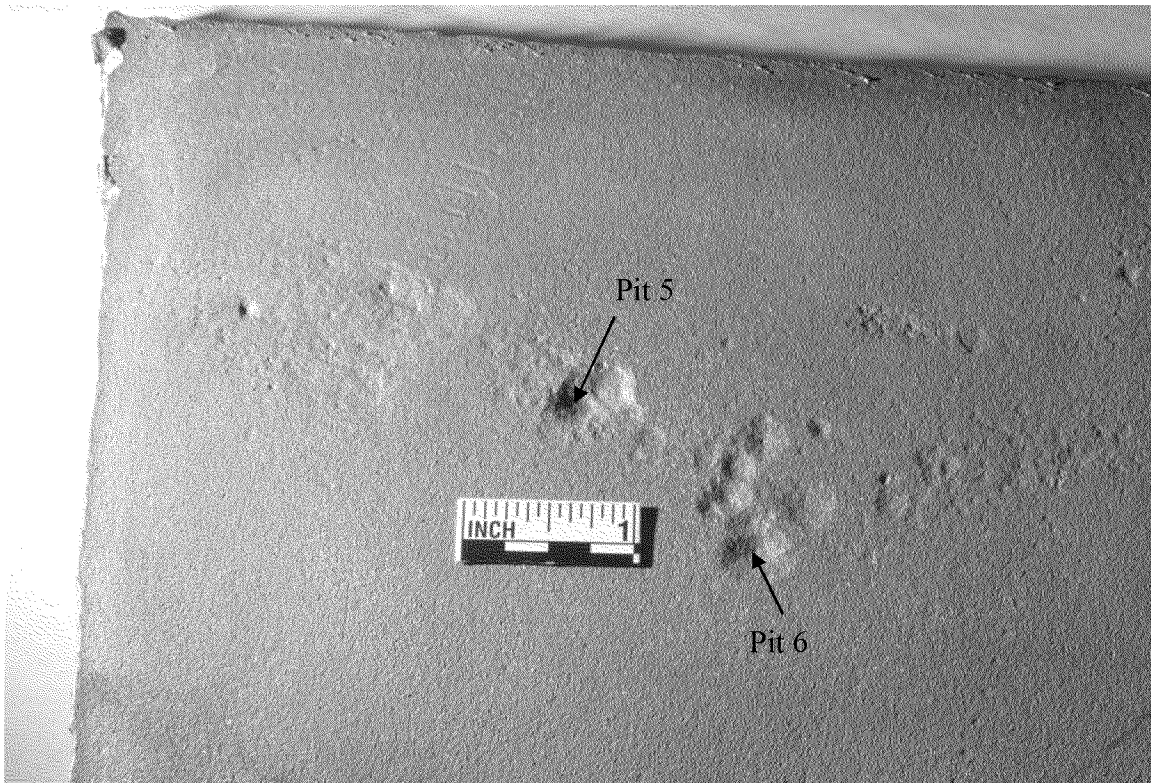


(a) Boxed area β in Figure 1a

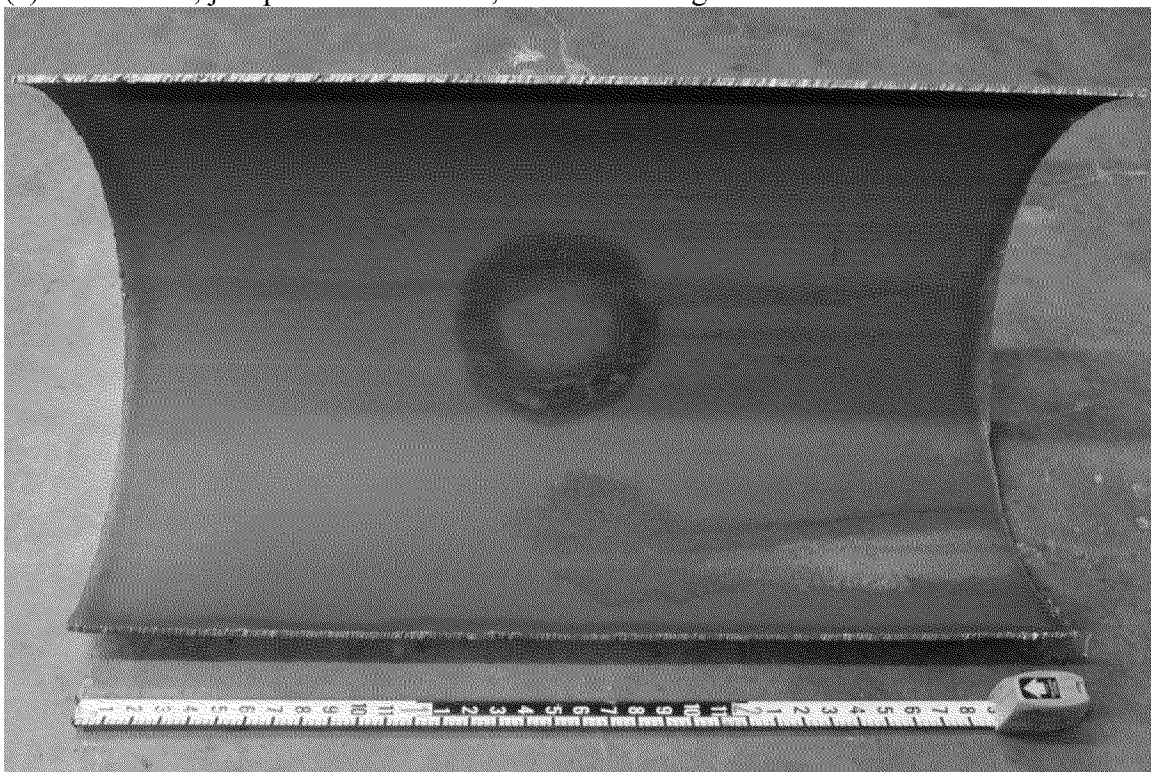


(a) Boxed area χ in Figure 1a

Figure 2 Photographs of the outside surface of sample half A as-received.

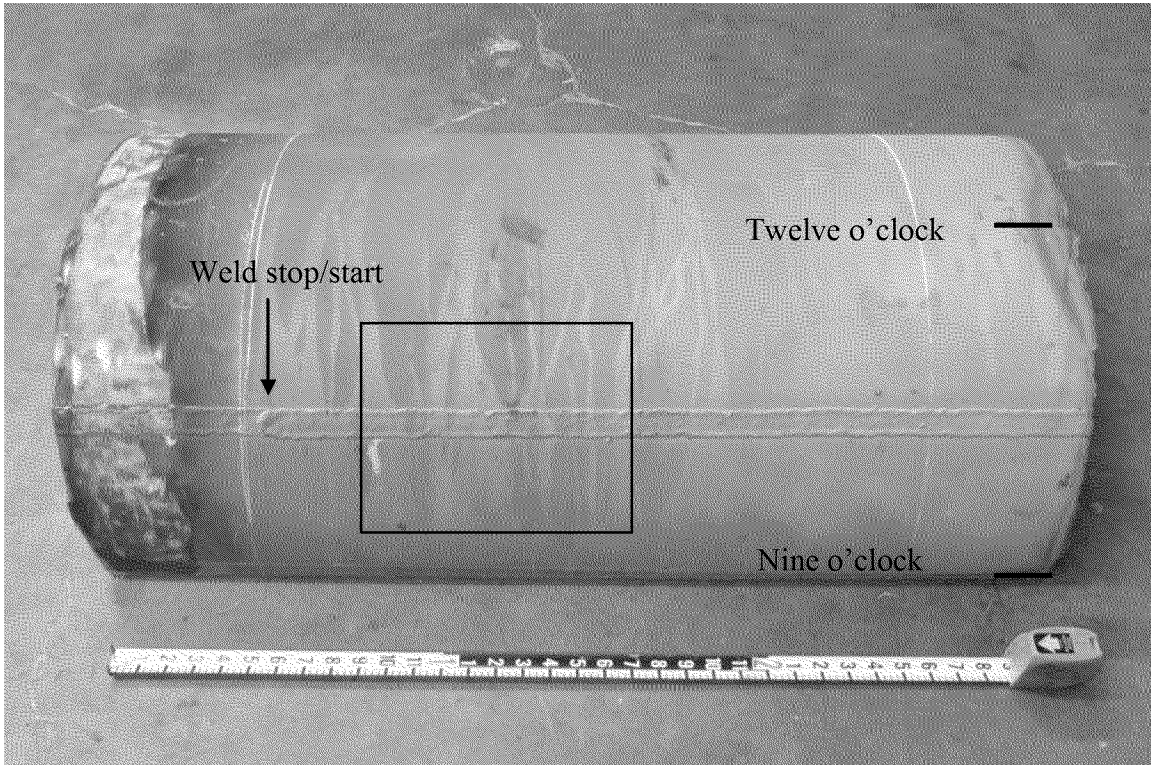


(a) Location δ , just past three o'clock, indicated in Figure 1a

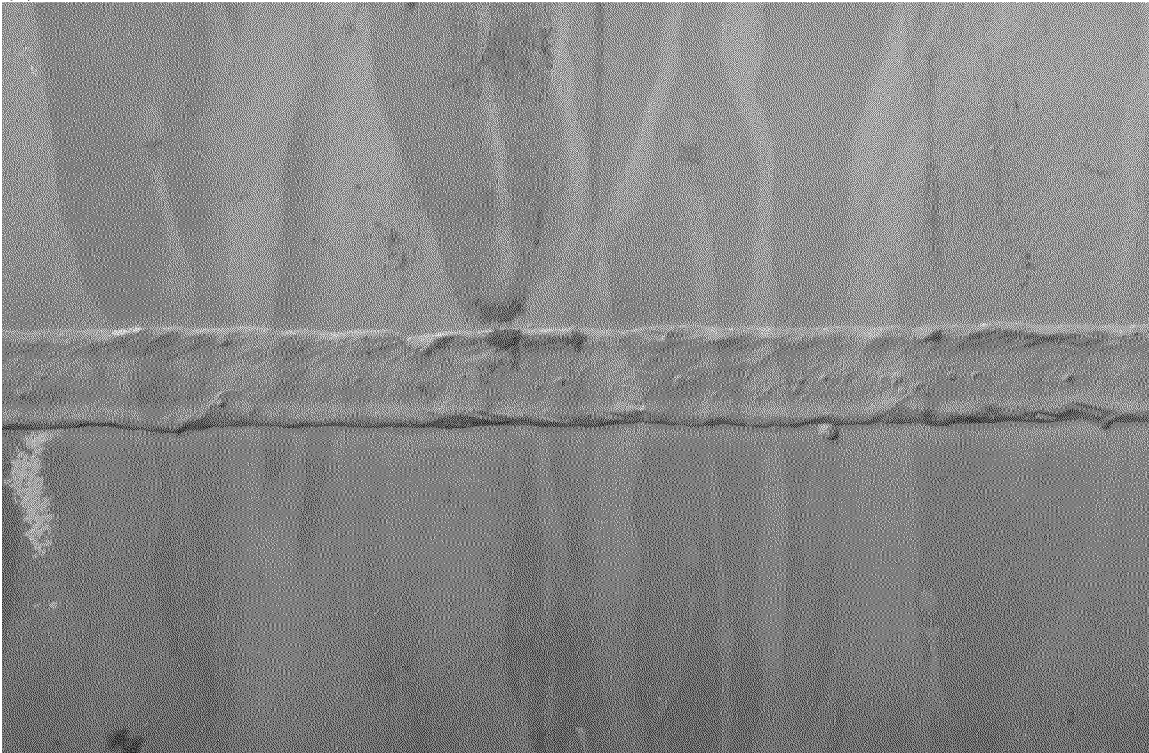


(b)

Figure 3 Photographs of pits on the outside surface and the inside surface of sample A.

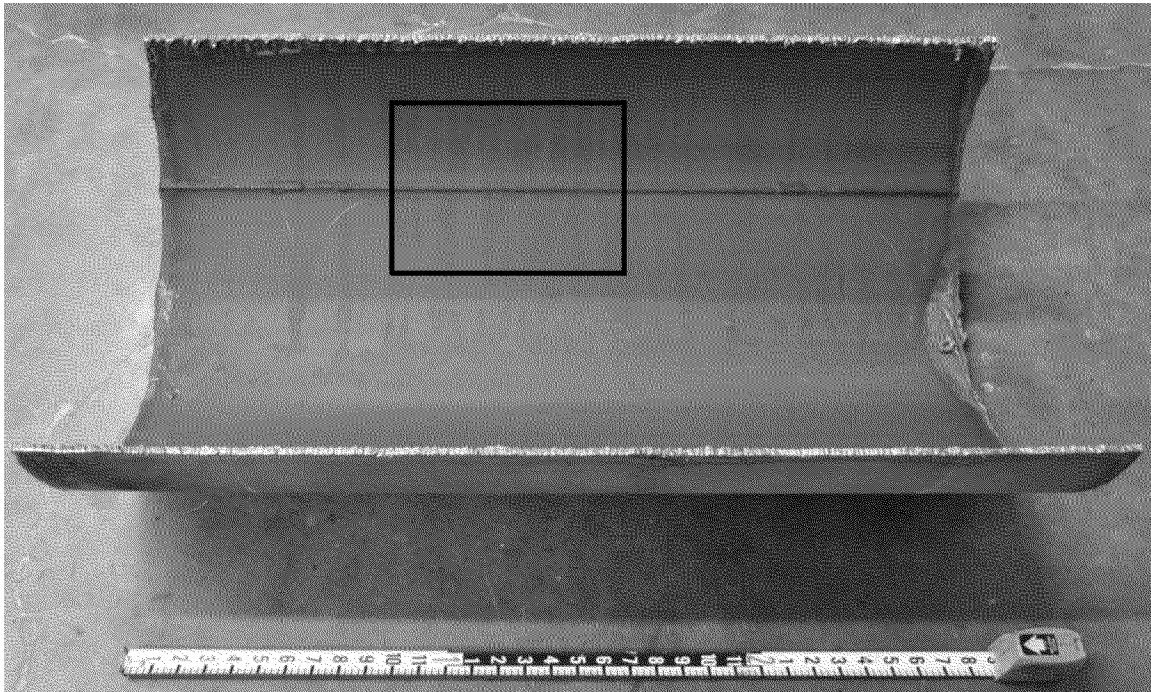


(a)

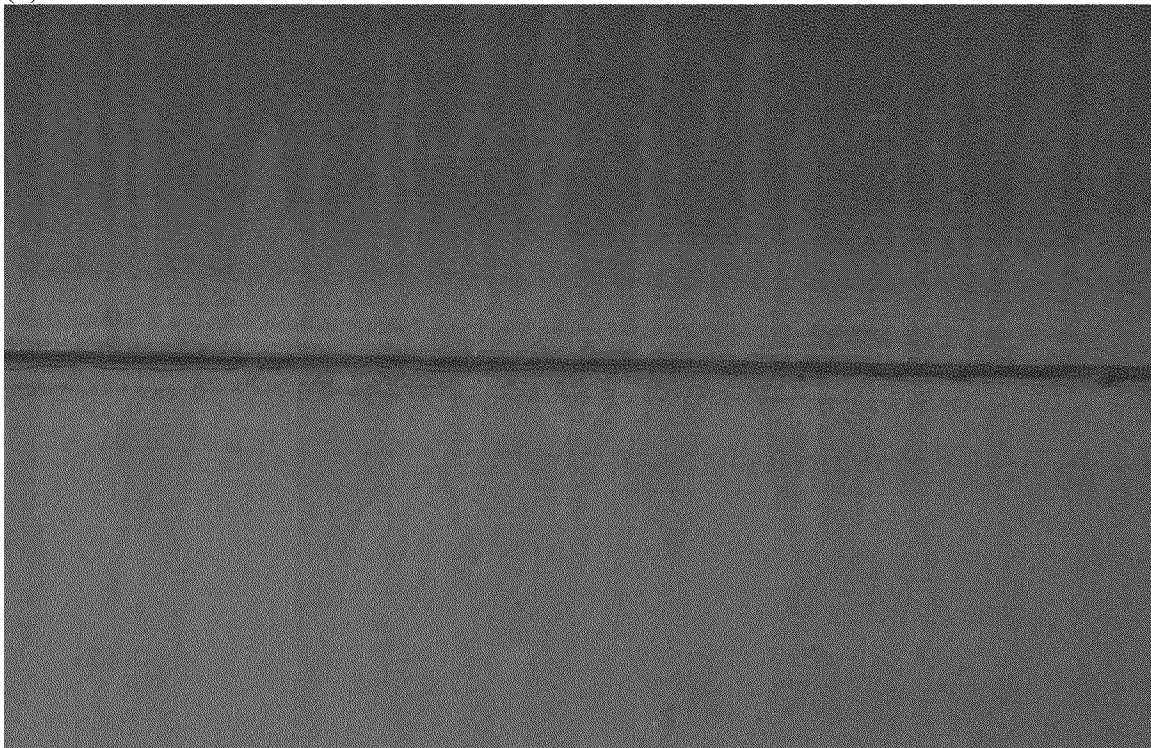


(b) Boxed area in (a)

Figure 4 Photographs of the outside surface of sample half B.

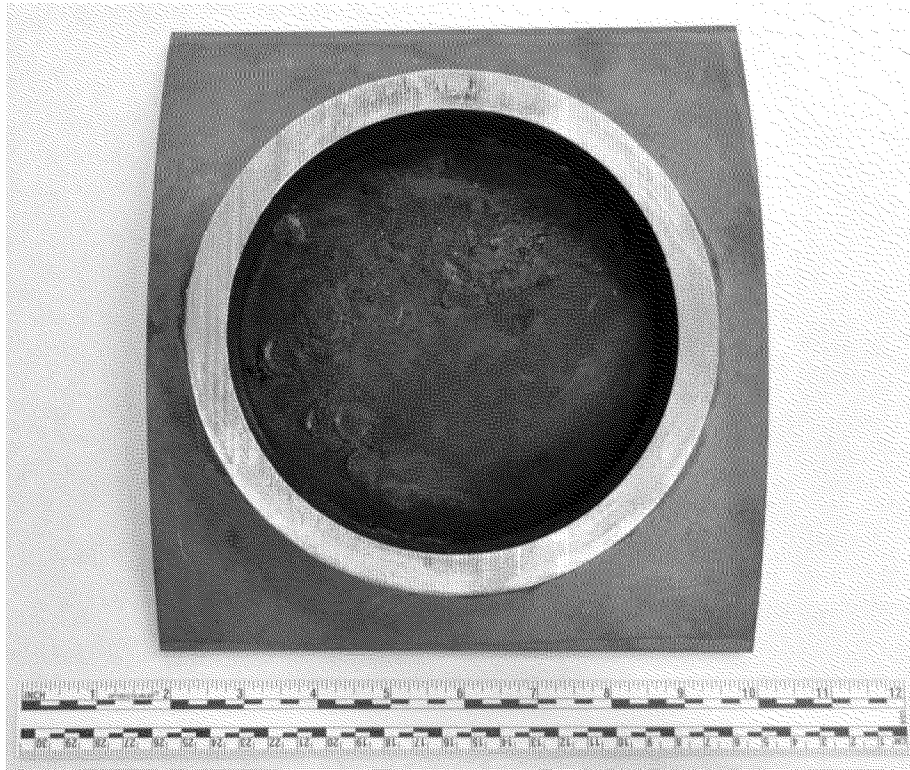


(a)

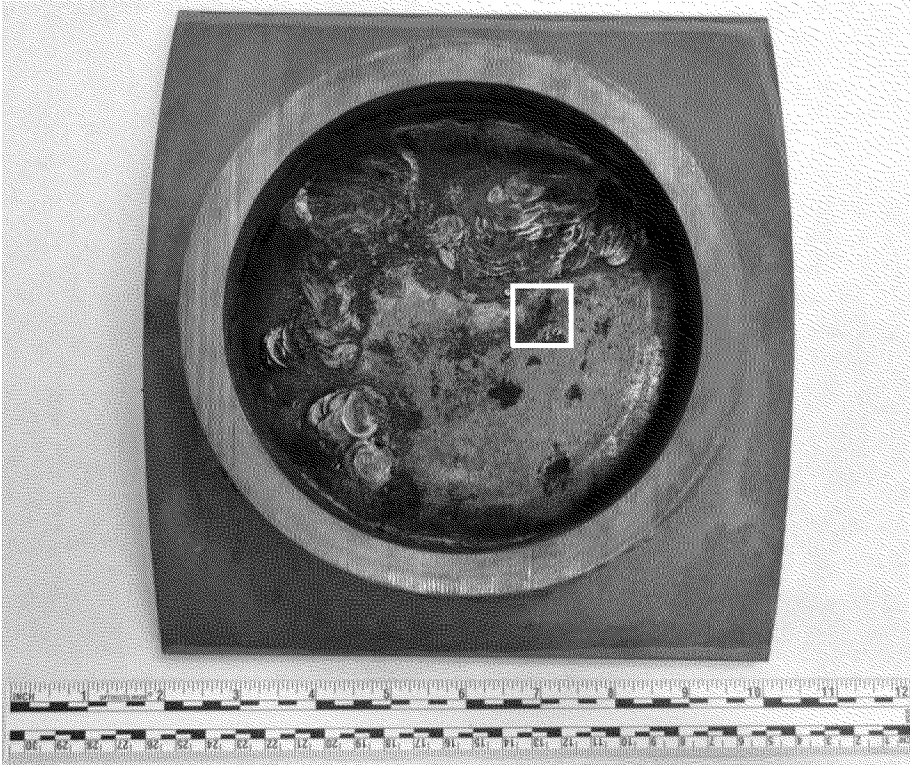


(b) Boxed area in (a)

Figure 5 Photographs of the inside surface of sample half B.



(a) Before cleaning



(b) After cleaning

Figure 6 Photographs of the PLIDCO cap area after sectioning.

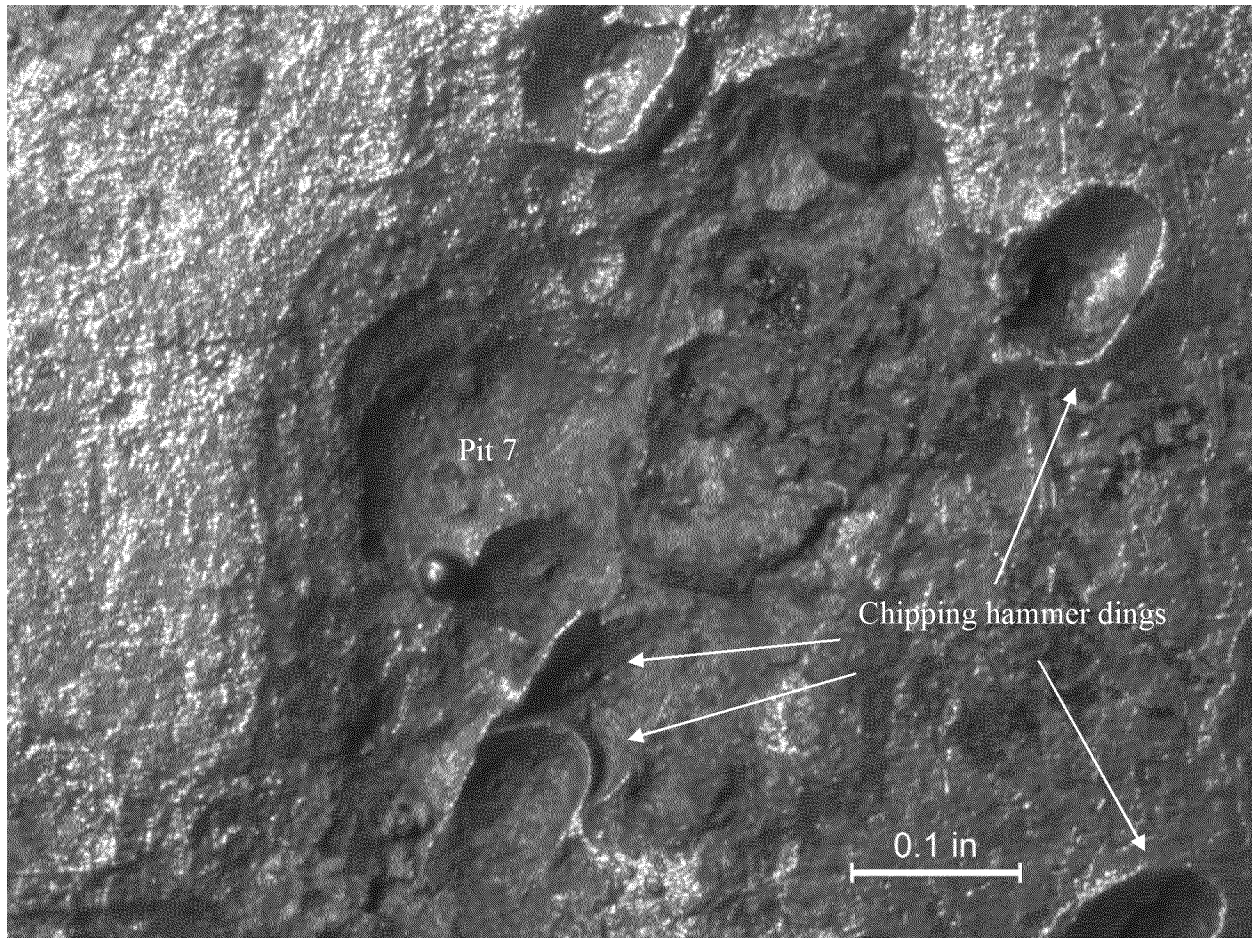


Figure 7 Macrograph of a pit under the PLIDCO cap, from the boxed area in Figure 6b.

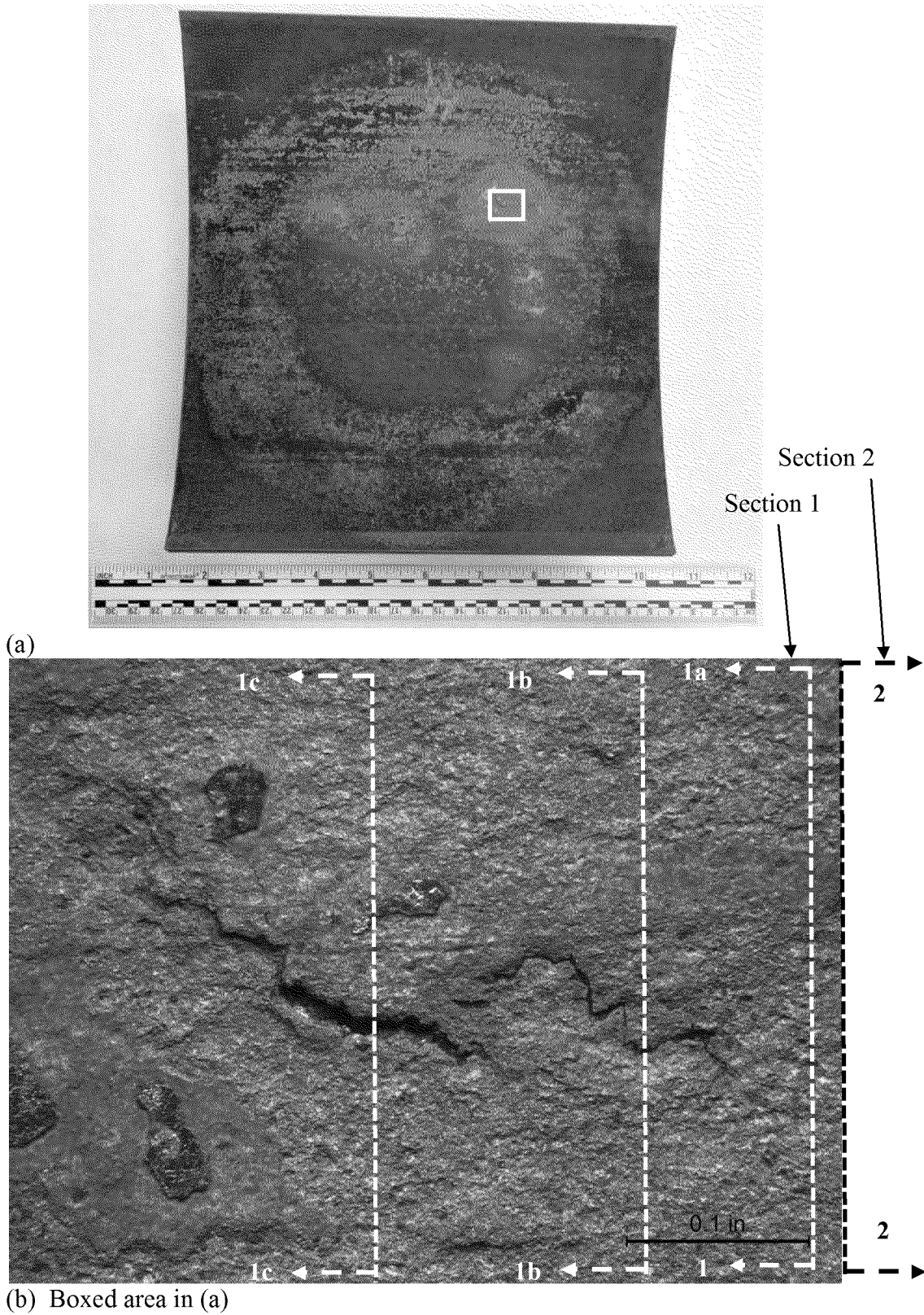


Figure 8 Photograph (a) and macrograph (b) of the inside surface of sample half A under the PLIDCO cap, after cleaning.

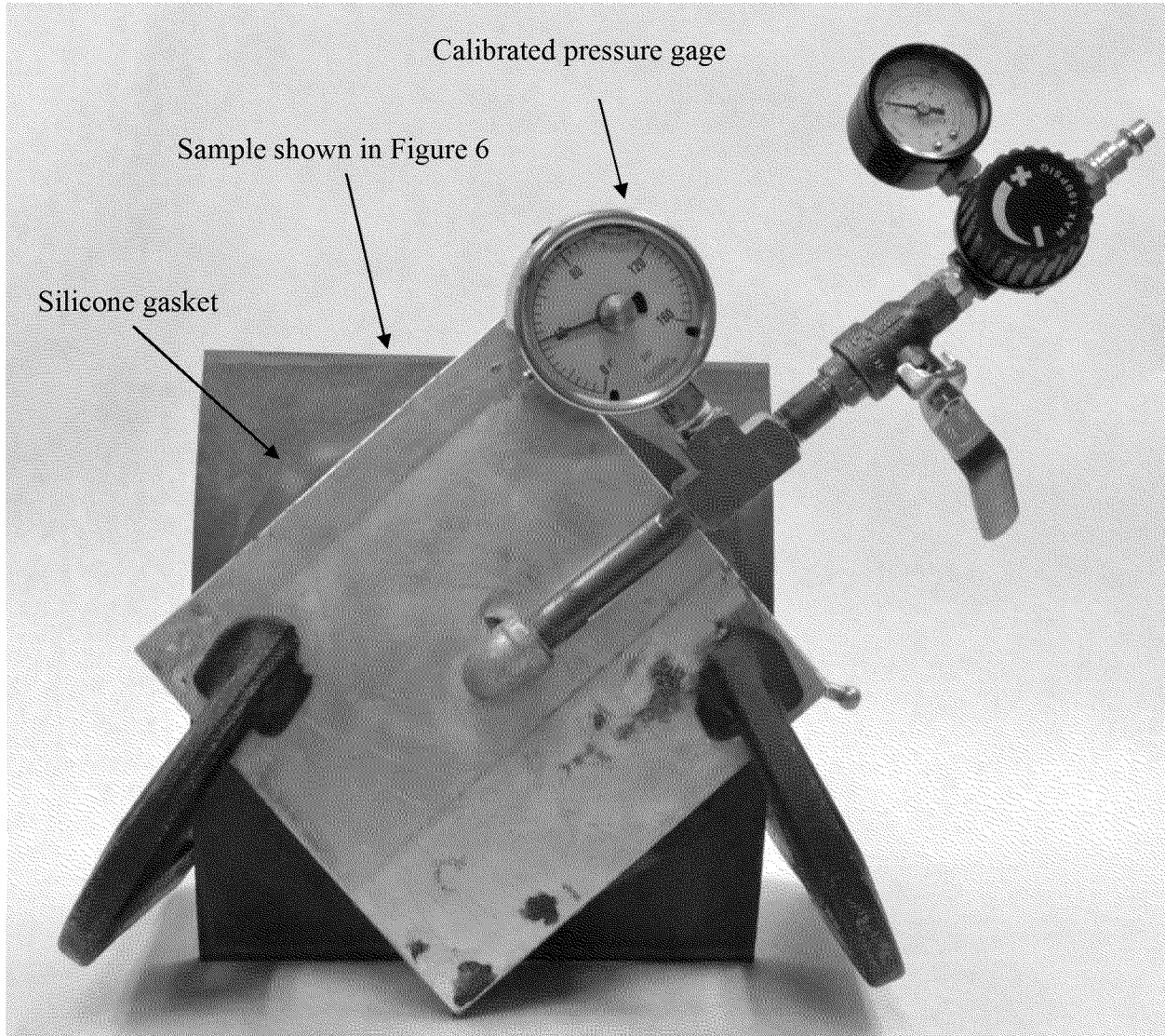
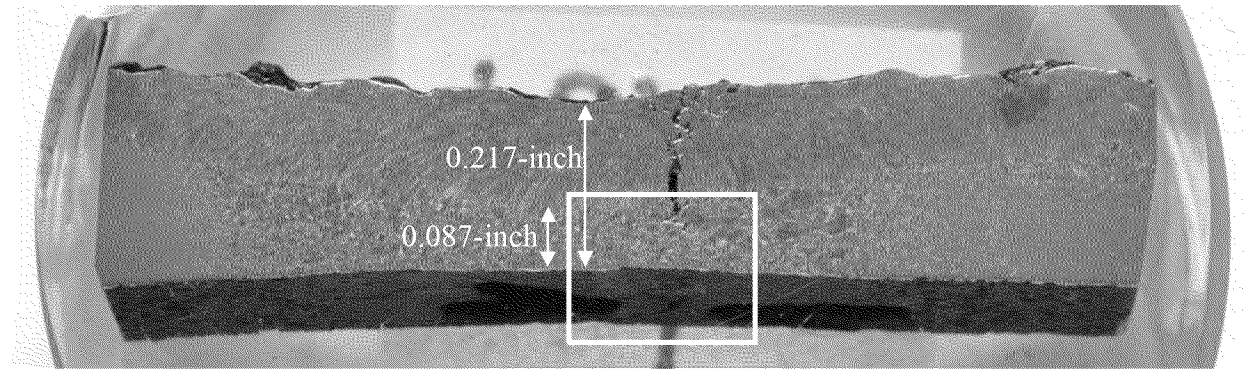
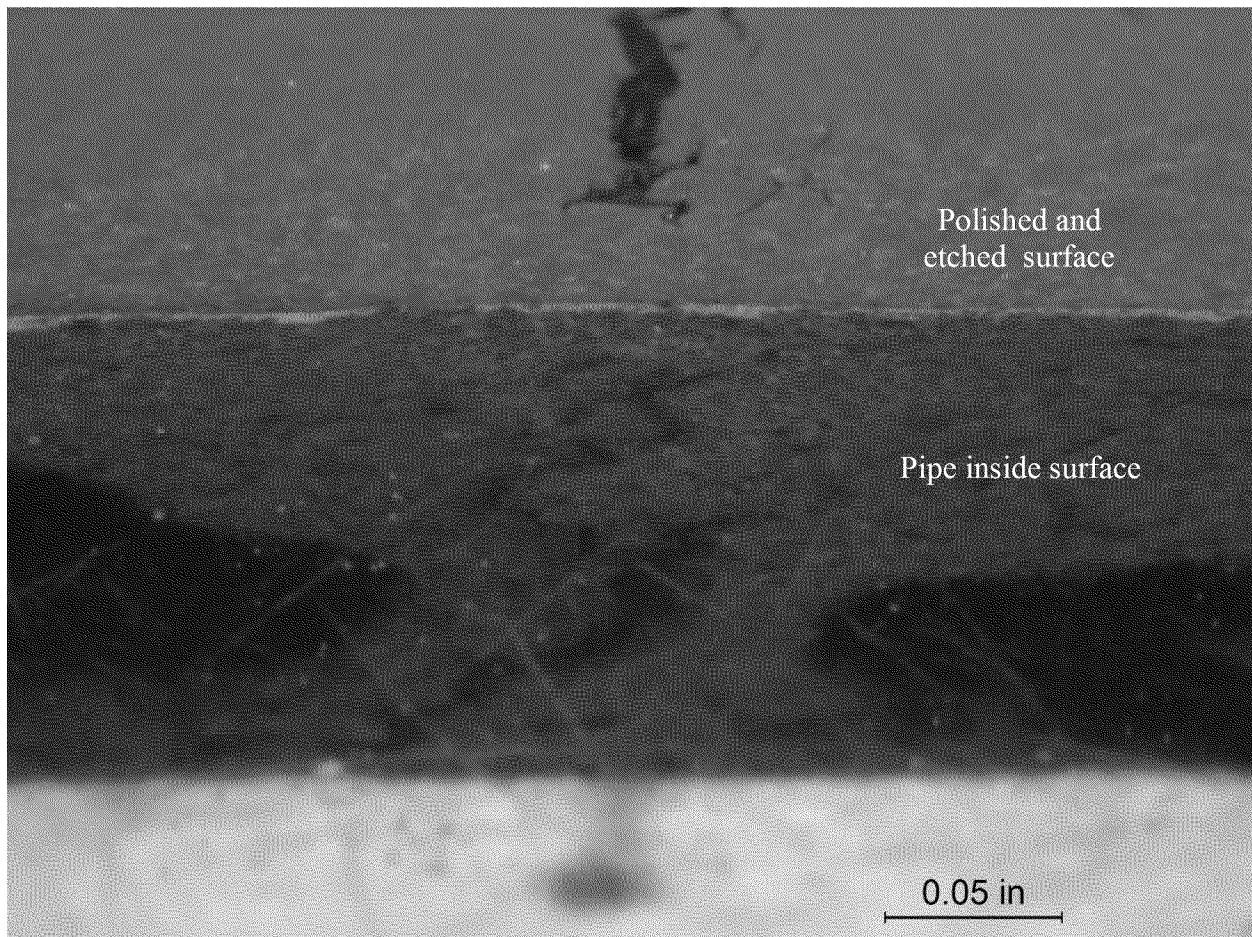


Figure 9 Pressure test setup.



(a)



(b) Boxed area in (a)

Figure 10 Images of the specimen prepared for metallography, section 1a. Etched with 2% nital.

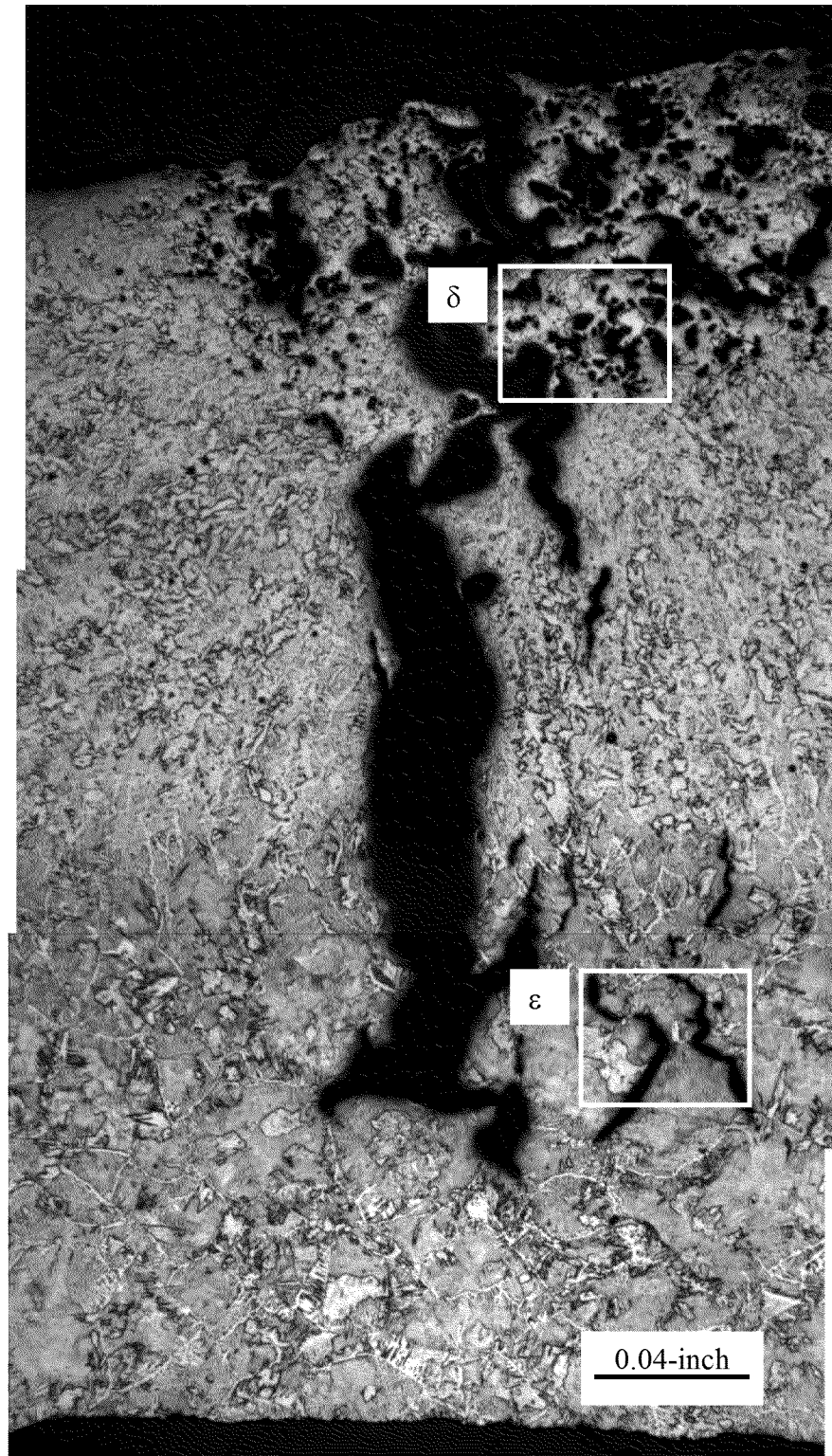
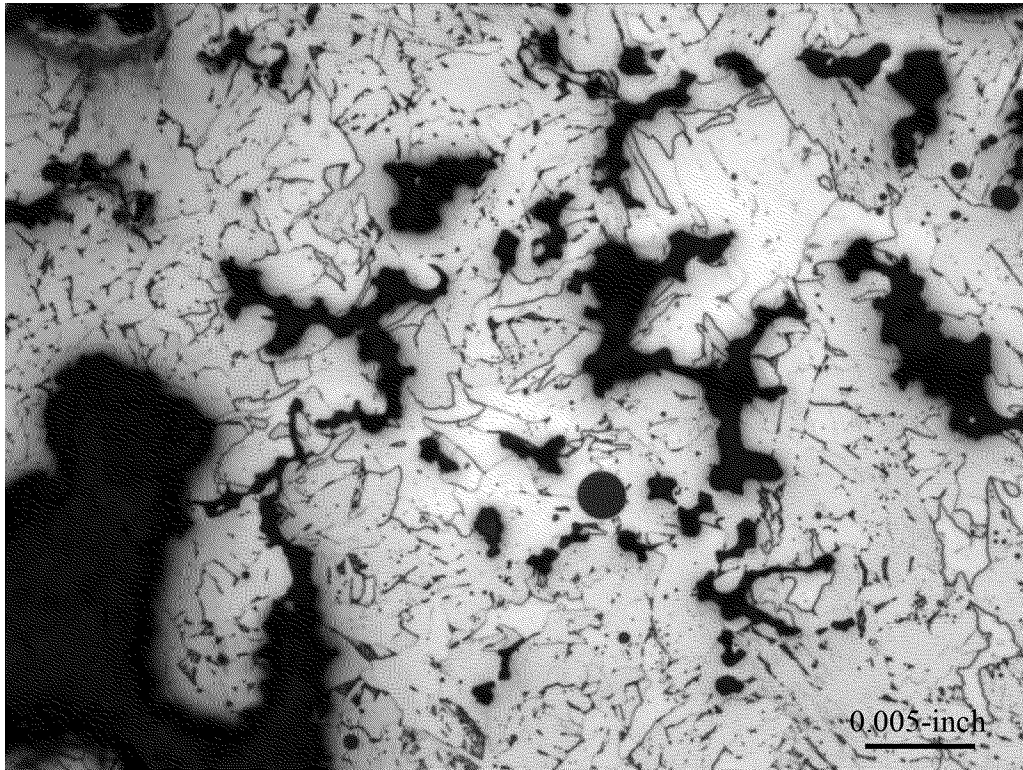
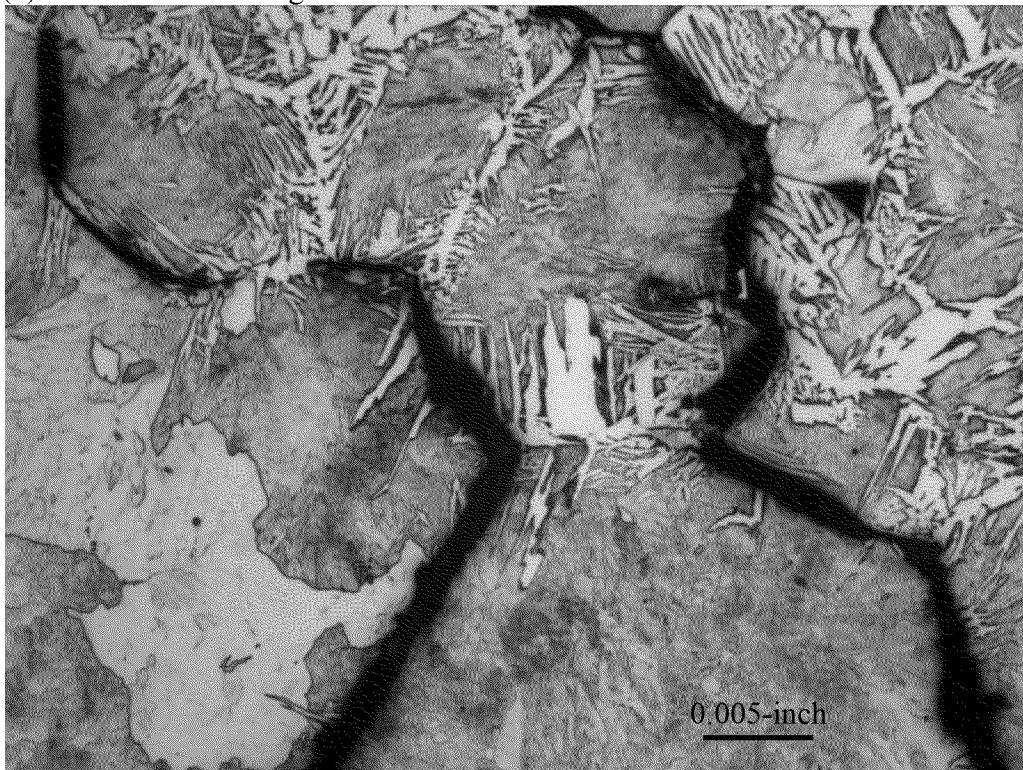


Figure 11 Composite optical micrograph of the specimen prepared for metallography, section 1a. Etched with 2% nital.

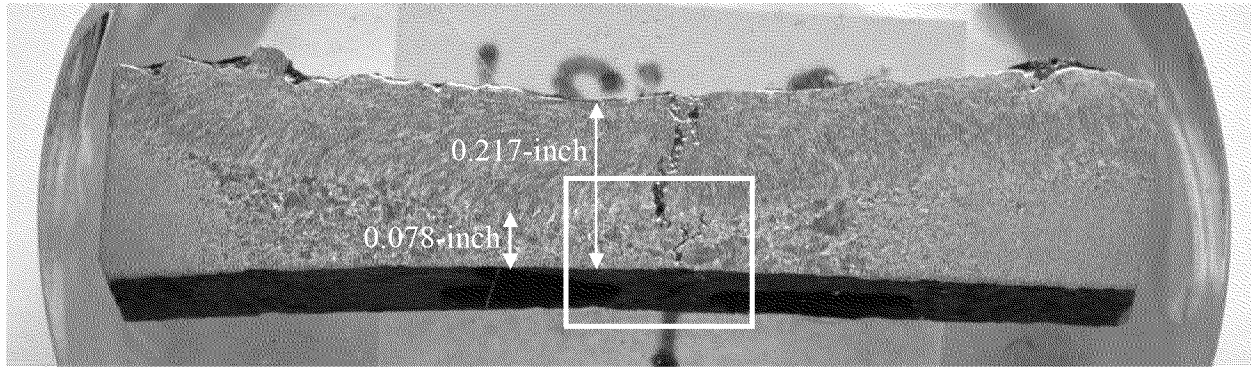


(a) Boxed area δ in Figure 11

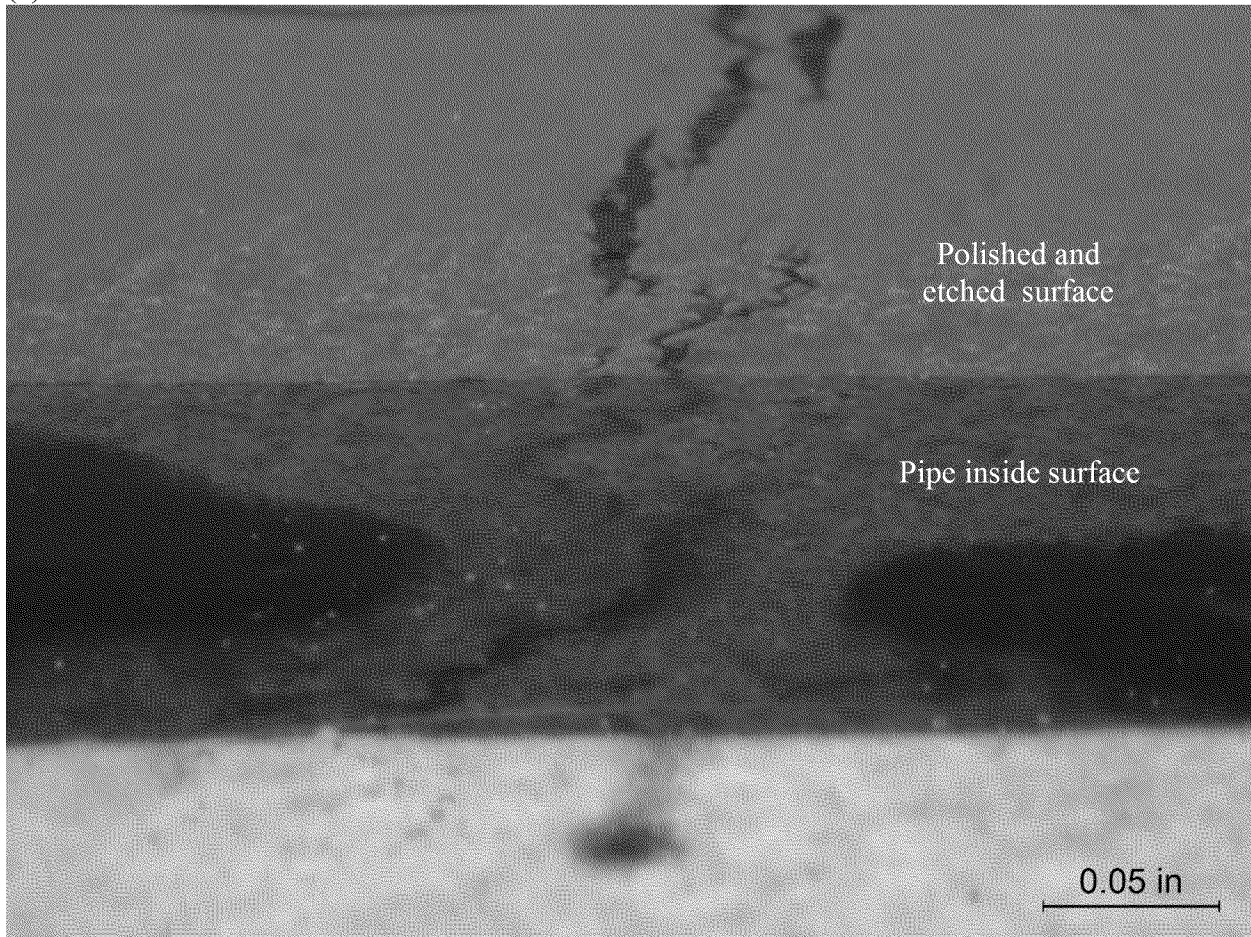


(b) Boxed area ϵ in Figure 11

Figure 12 Optical micrographs of the specimen prepared for metallography, section 1a. Etched with 2% nital.



(a)



(b) Boxed area in (a)

Figure 13 Images of the specimen prepared for metallography, section 1b. Etched with 2% nital.

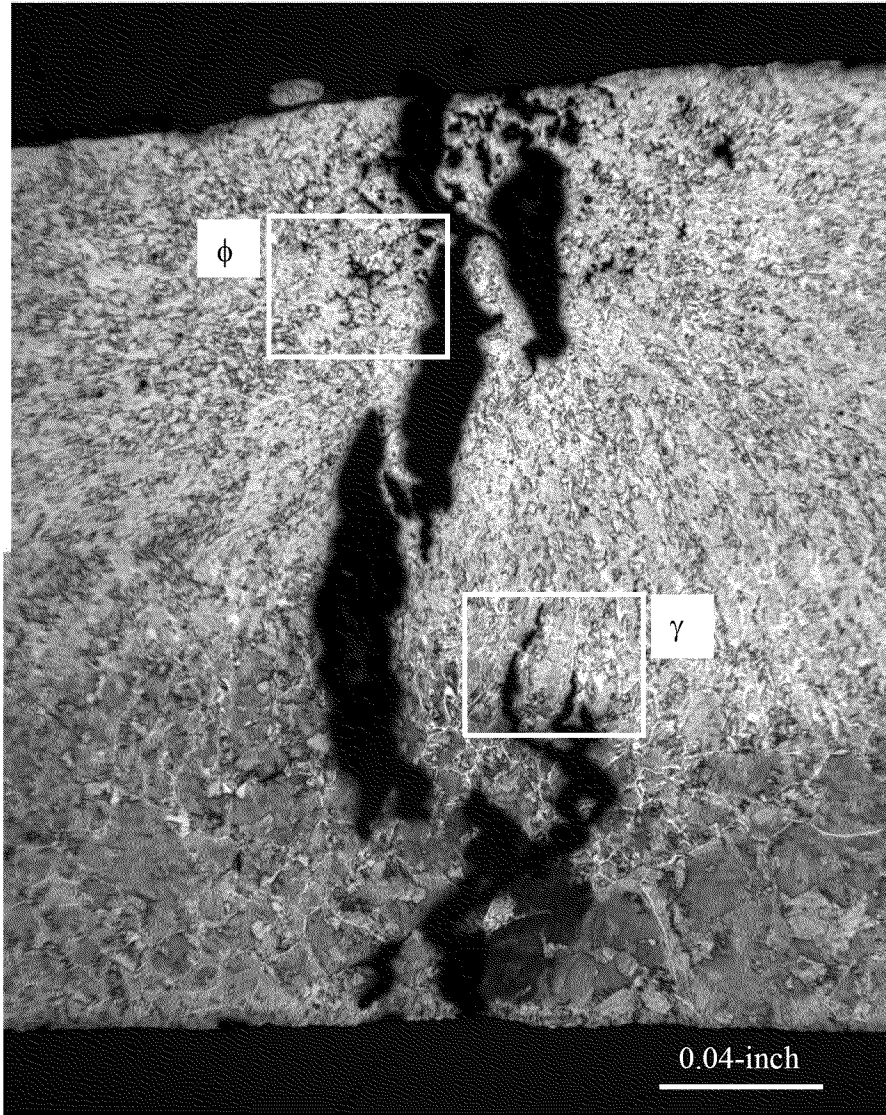
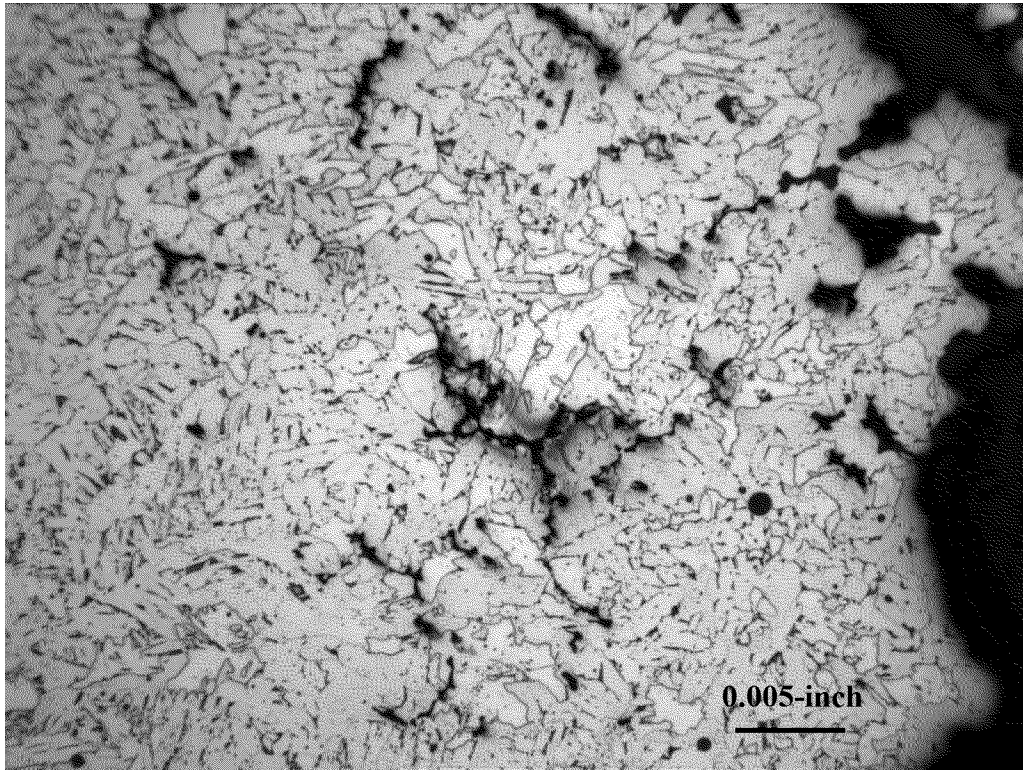
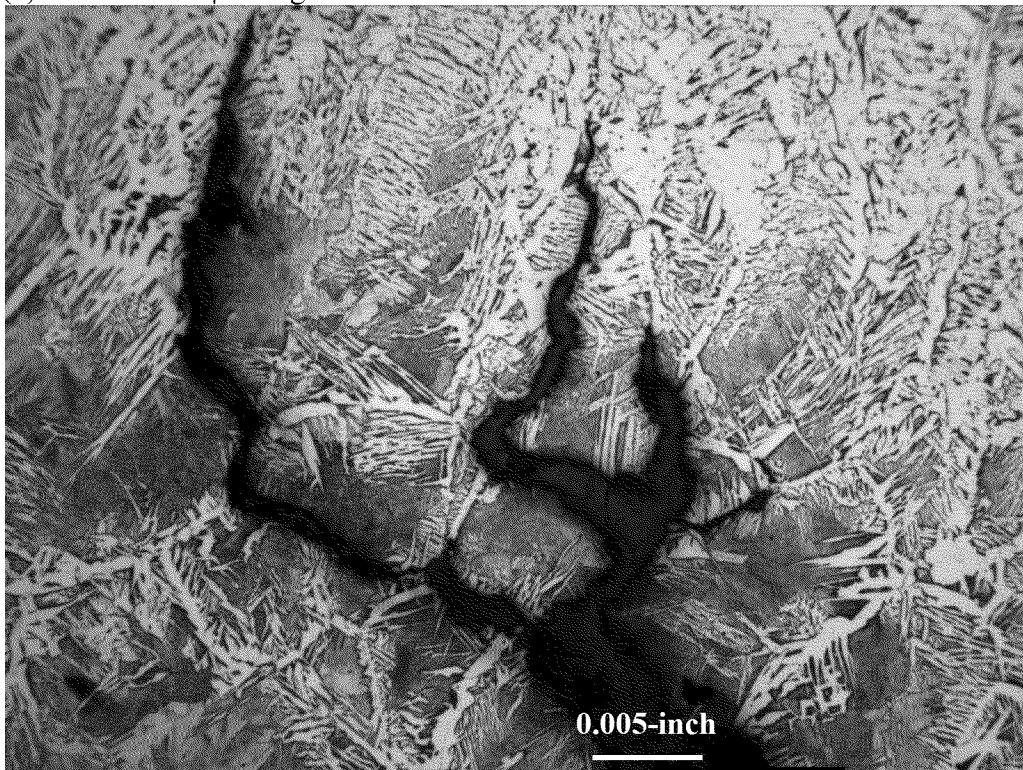


Figure 14 Composite optical micrograph of the specimen prepared for metallography, section 1b. Etched with 2% nital.

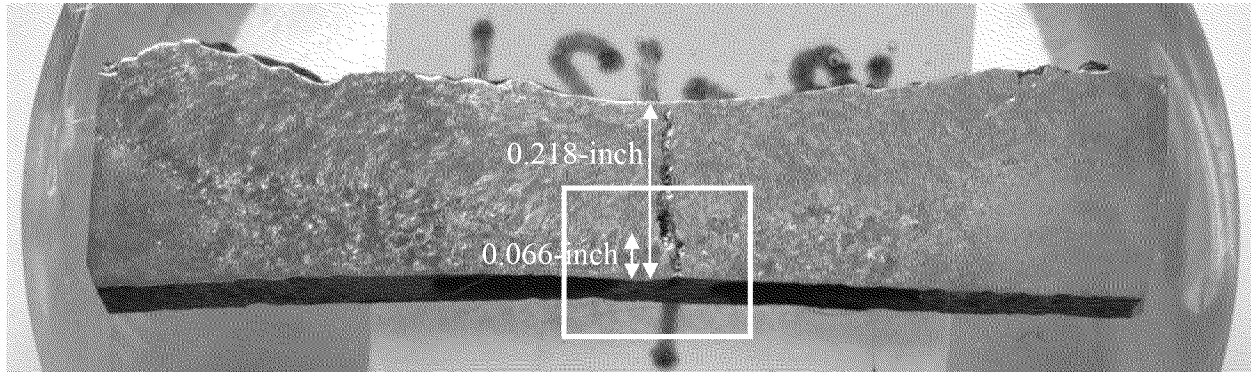


(a) Boxed area ϕ in Figure 14

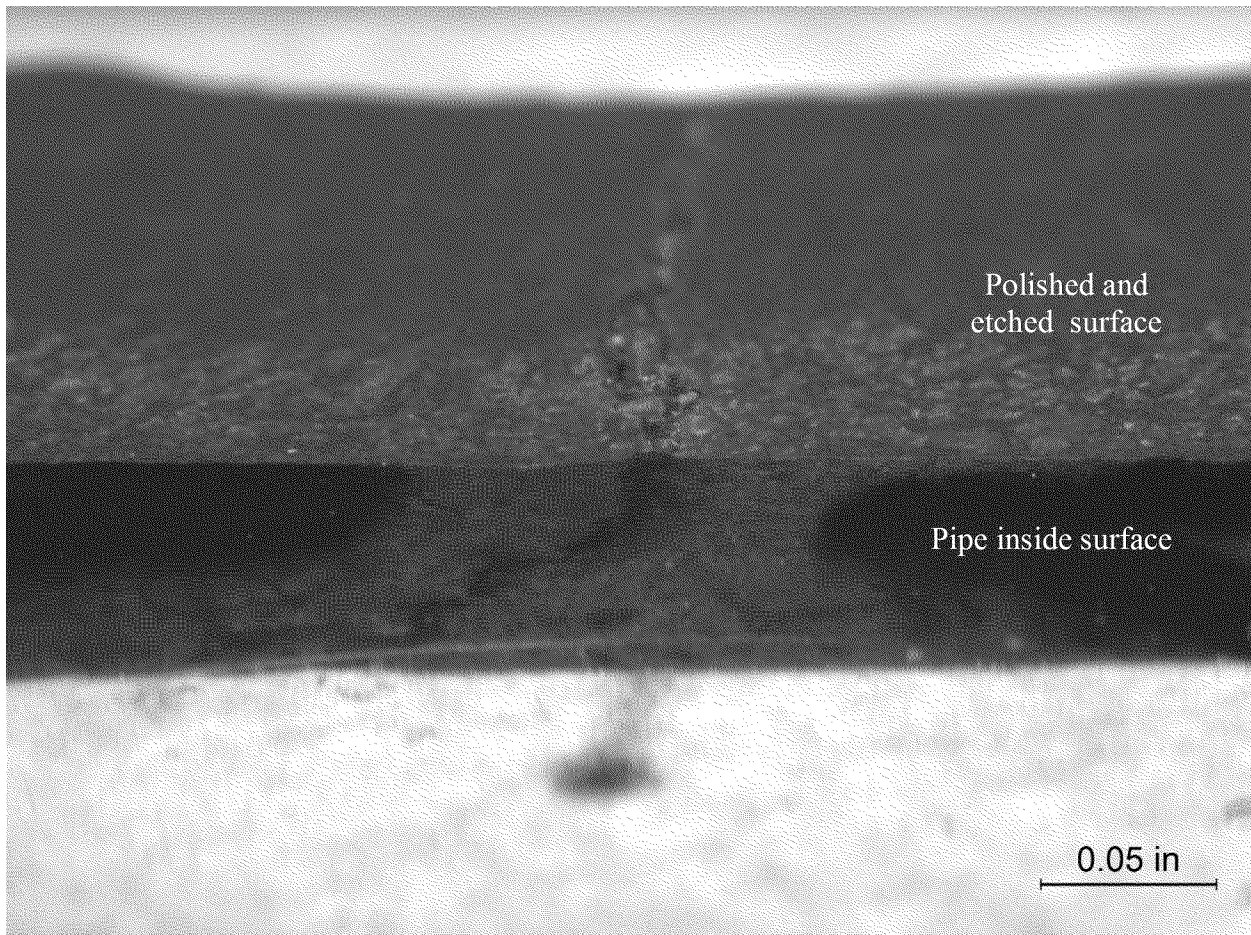


(b) Boxed area γ in Figure 14

Figure 15 Optical micrographs of the specimen prepared for metallography, section 1b. Etched with 2% nital.



(a)



(b)

Figure 16 Images of the specimen prepared for metallography, section 1c. Etched with 2% nital.

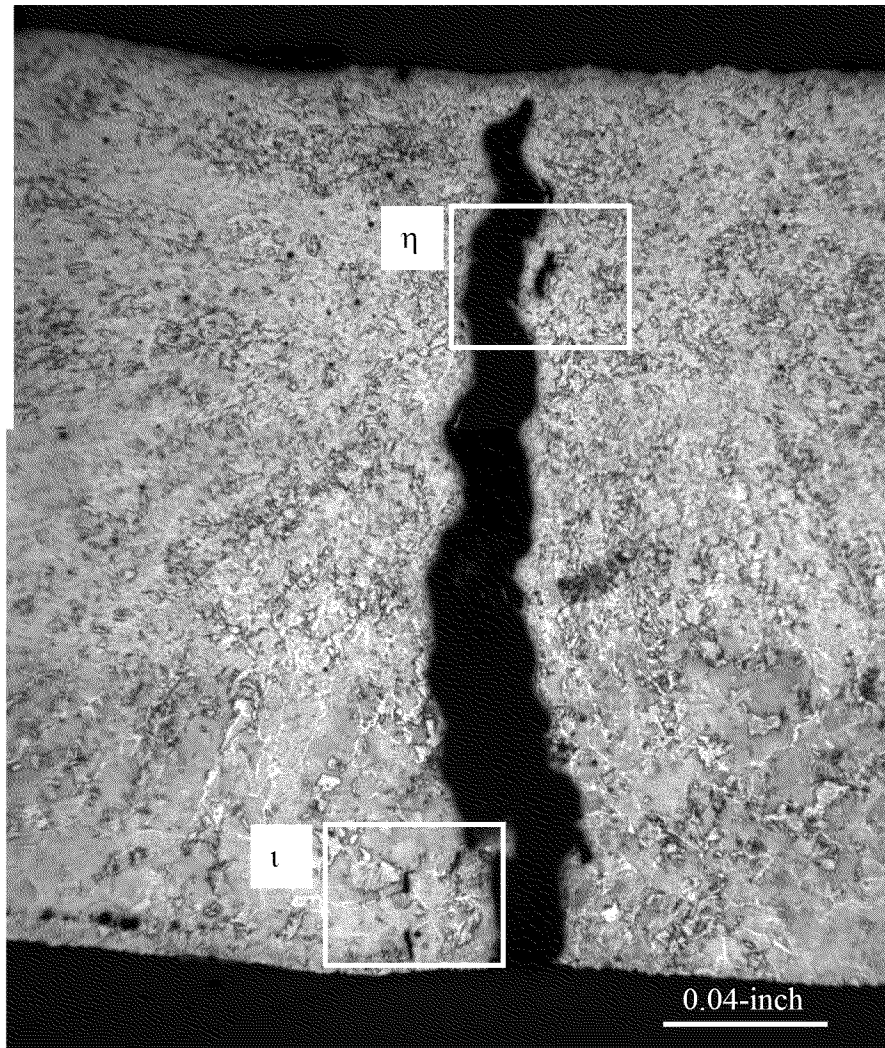
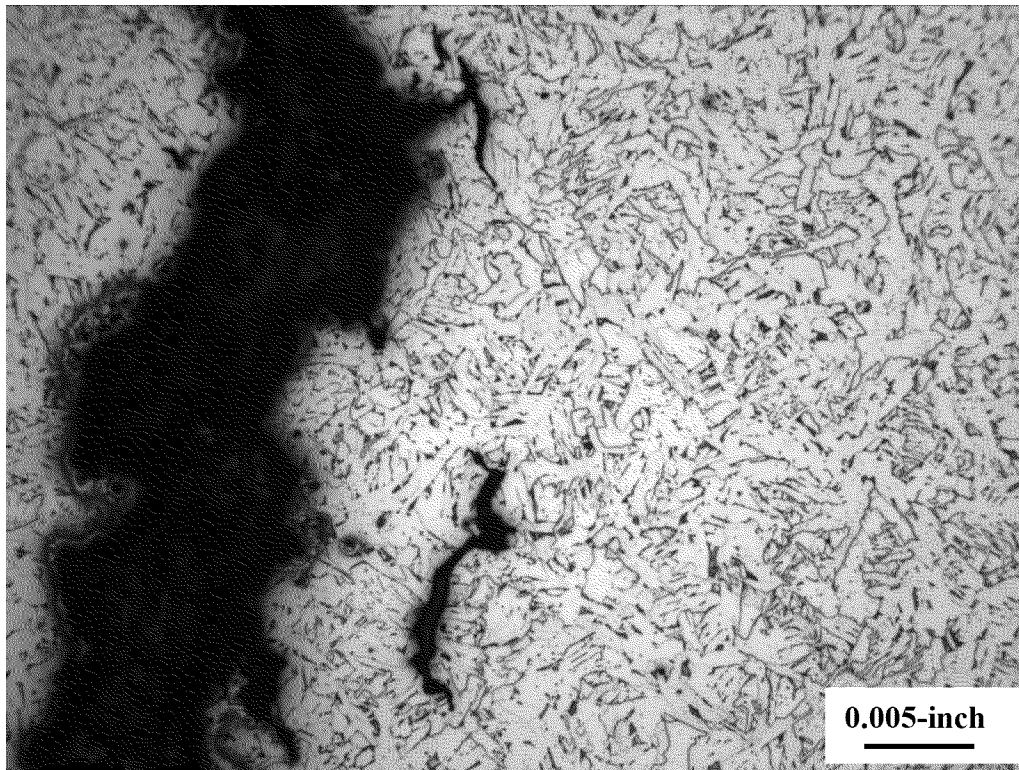
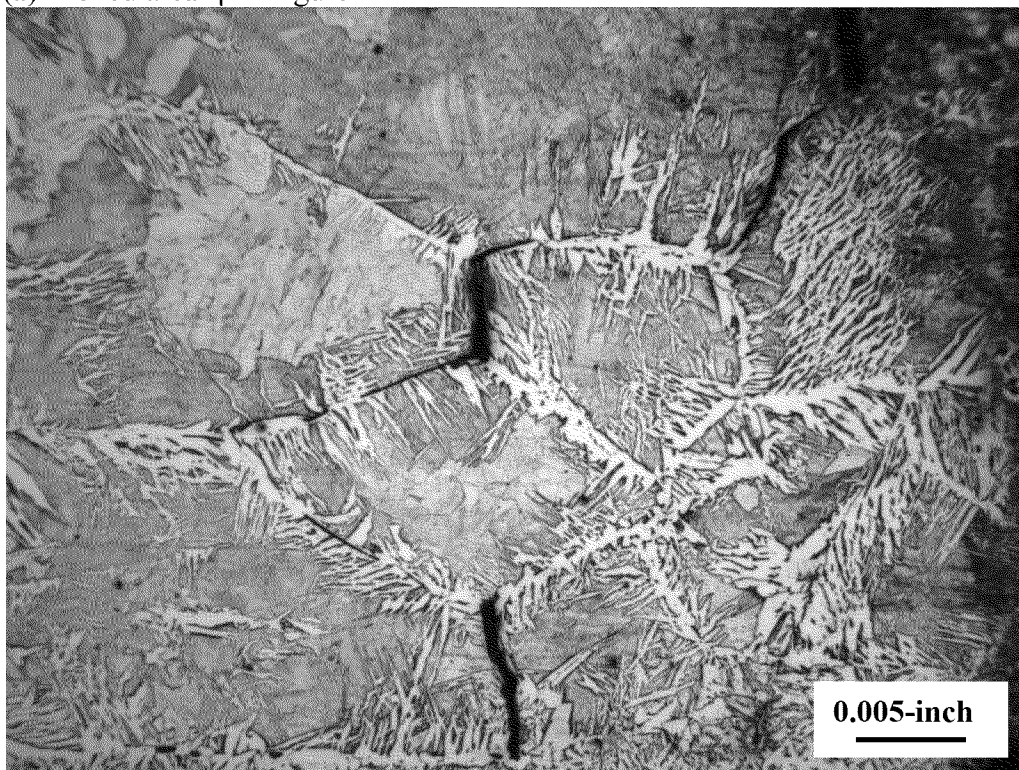


Figure 17 Composite optical micrograph of the specimen prepared for metallography, section 1c. Etched with 2% nital.

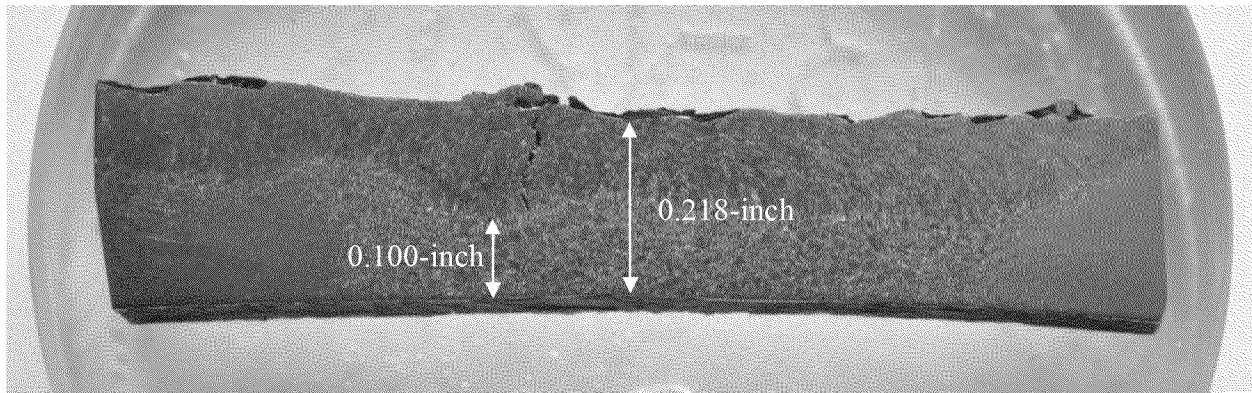


(a) Boxed area η in Figure 17



(b) Boxed area τ in Figure 17

Figure 18 Optical micrographs of the specimen prepared for metallography, section 1c. Etched with 2% nital.



(a) Photograph



(b) Composite optical micrograph

Figure 19 Photograph and composite micrograph of section 2. Etched with 2% nital.

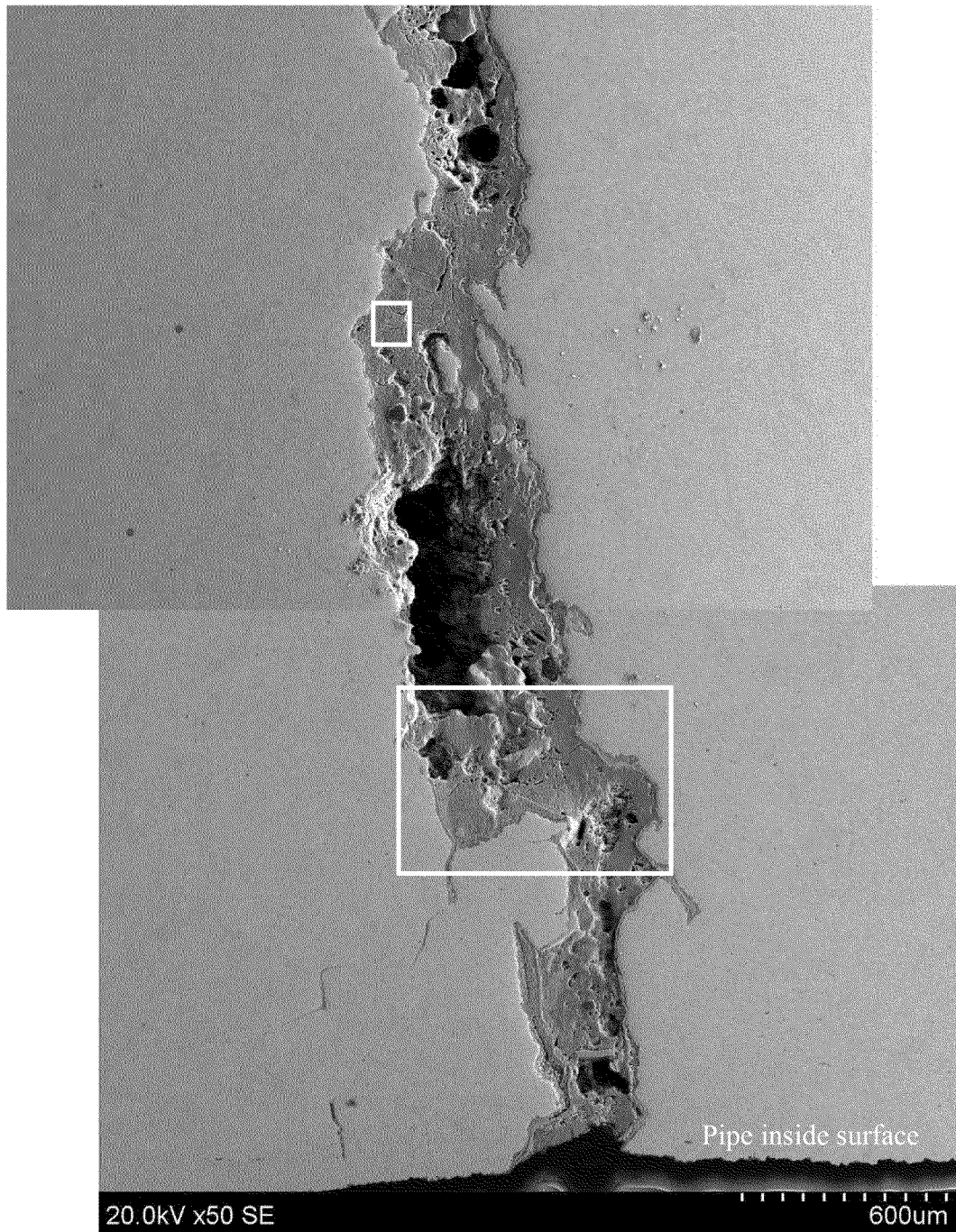
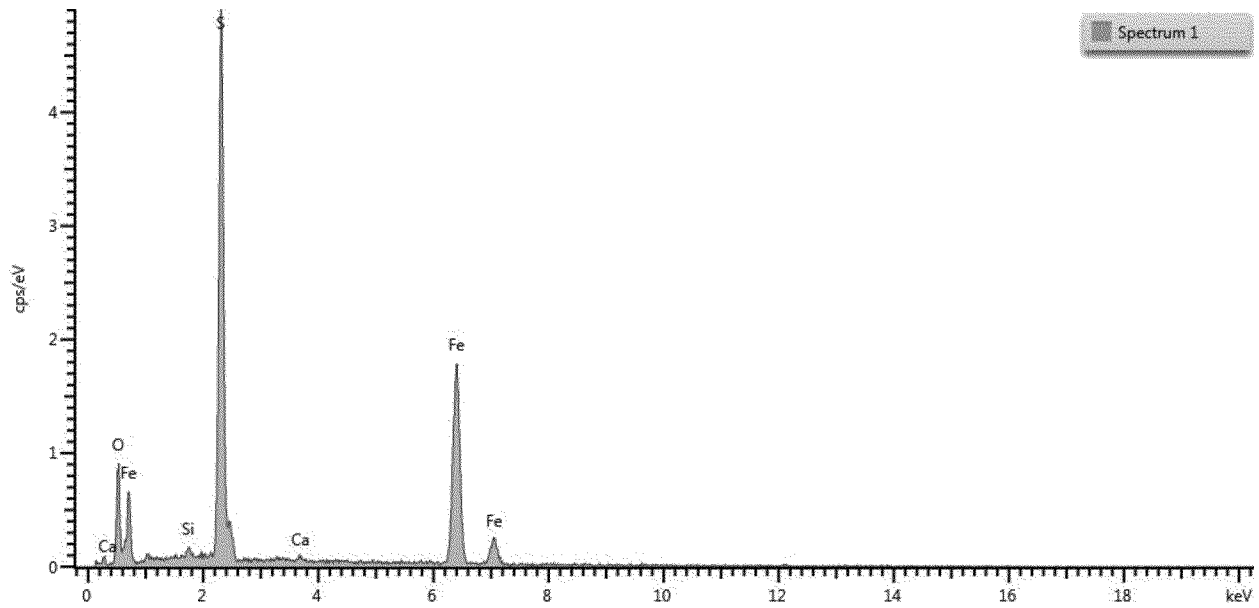
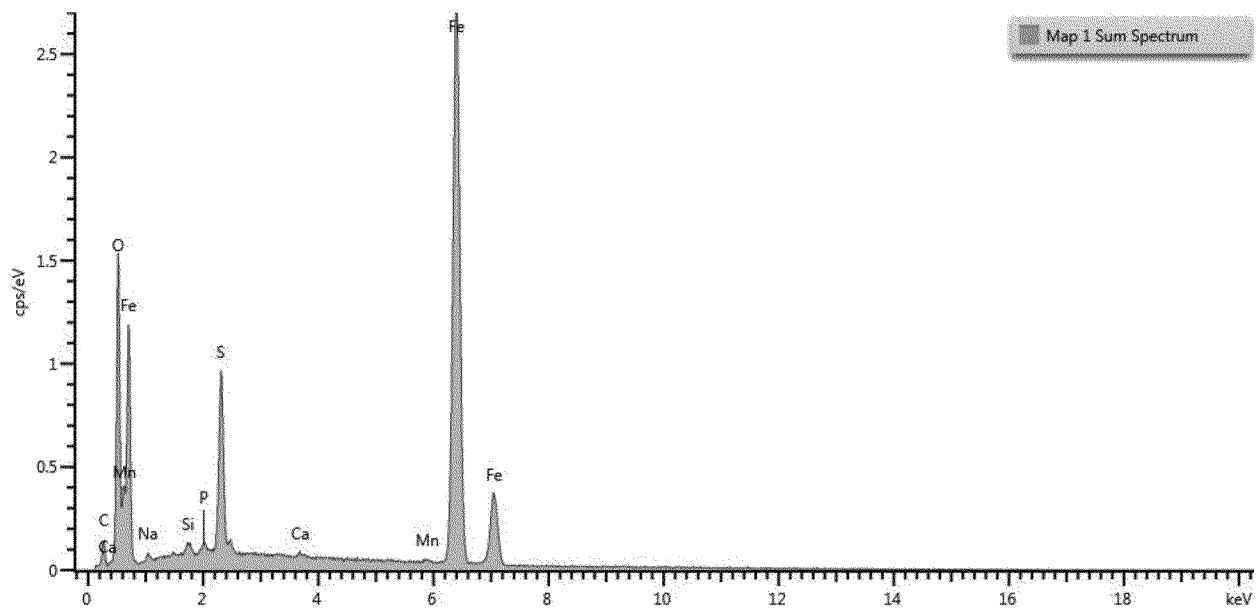


Figure 20 Composite SEM micrograph of the specimen prepared for metallography, section 1c.

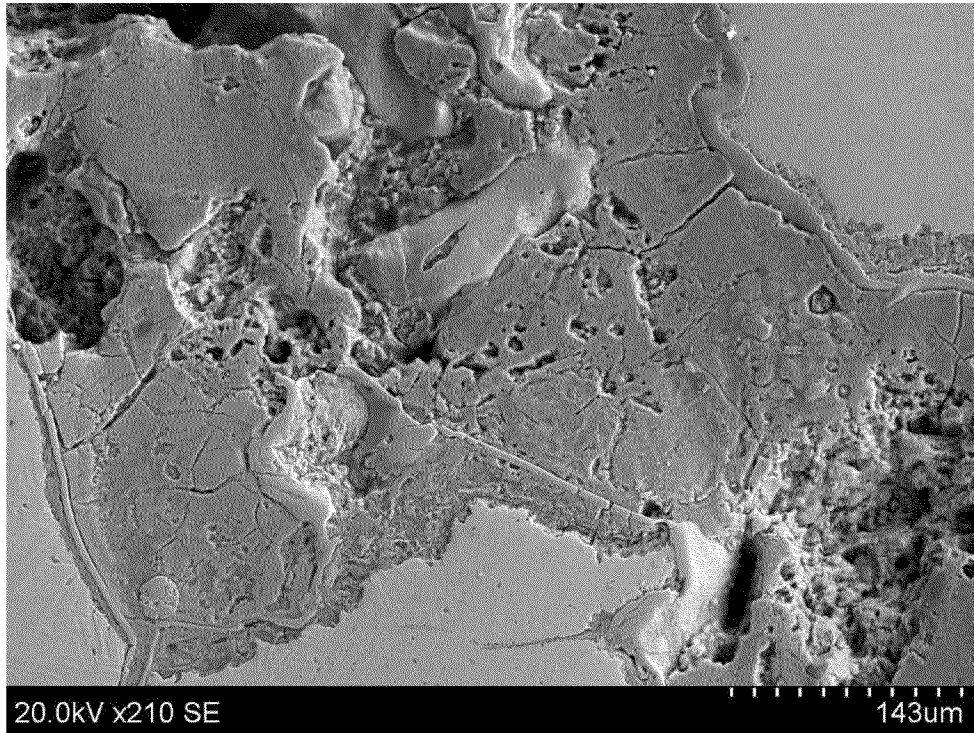


(a) EDS spectrum from the small boxed area in Figure 20

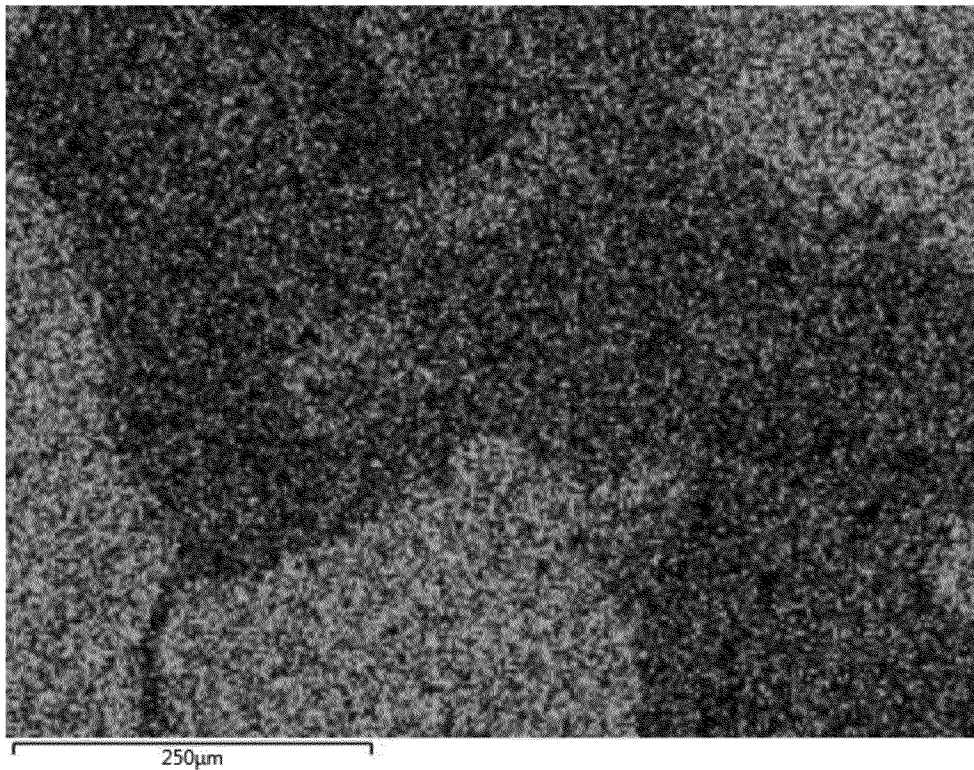


(b) EDS spectrum from the large boxed area in Figure 20

Figure 21 EDS spectra from the specimen prepared for metallography, section 1c.

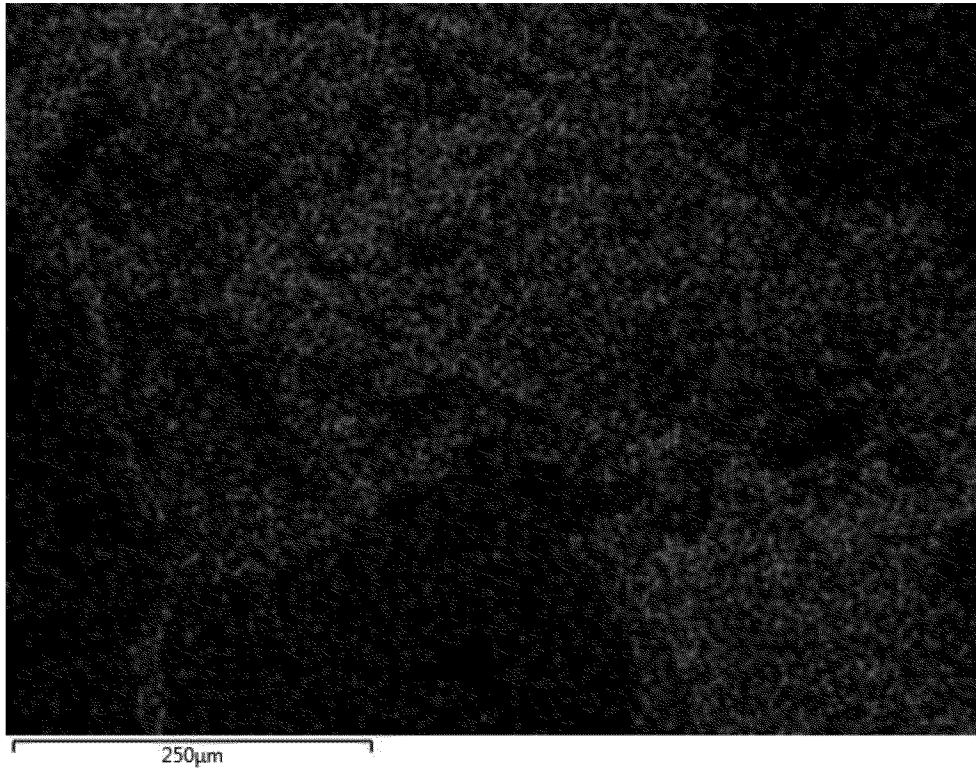


(a) SEM micrograph

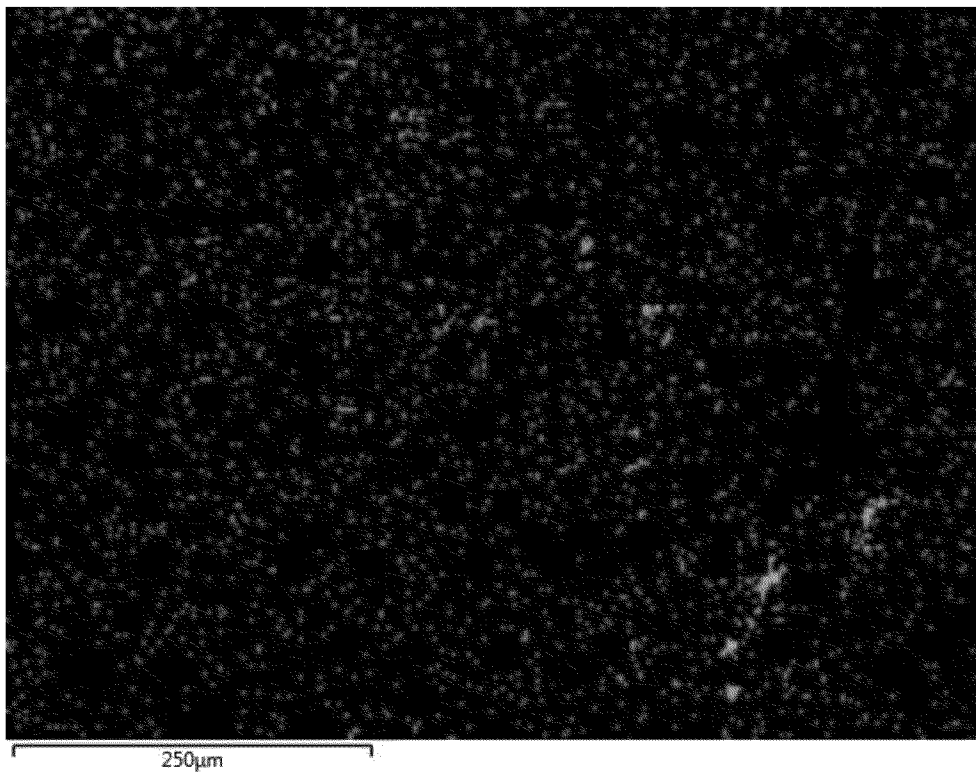


(b) EDS dot map for iron from the area indicated in (a)

Figure 22 SEM image and EDS dot map for iron from the specimen prepared for metallography, section 1c.



(a) EDS dot map for oxygen



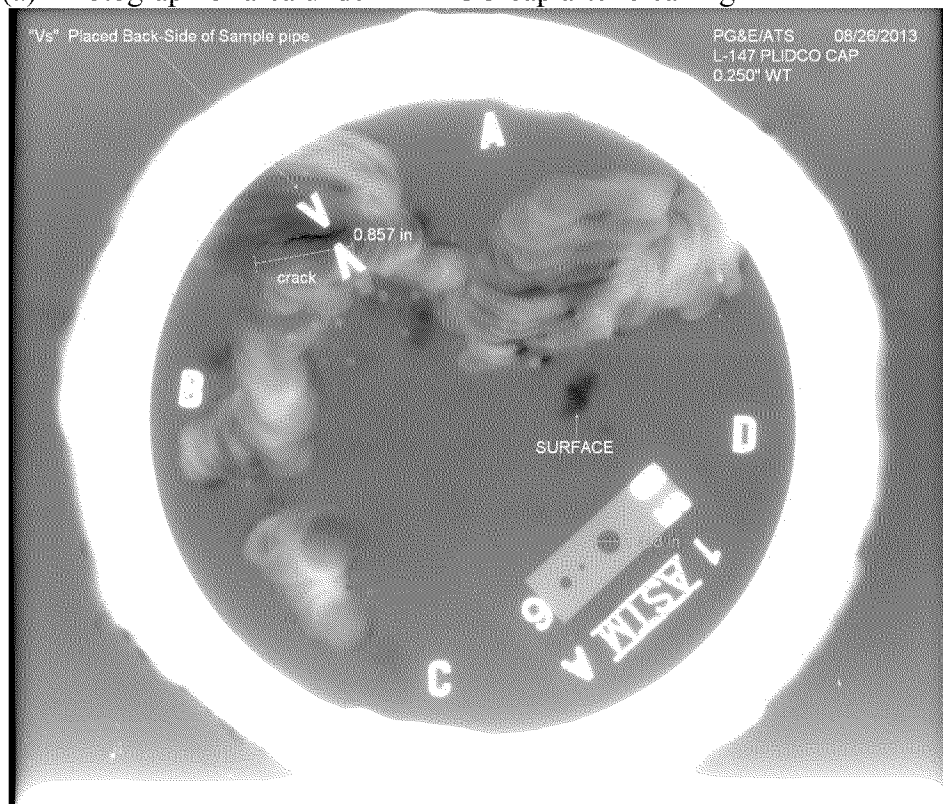
(b) EDS dot map for silicon

Figure 23 EDS dot maps for oxygen and silicon from the area indicated in Figure 22a.

Appendix A
(Radiograph courtesy of PG&E)



(a) Photograph of area under PLIDCO cap after cleaning



(b) Radiograph of area shown in (a)

Appendix B
 Parts List L-147 MP 2.2 Brittan Ave. And Rogers Ave., San Carlos

| Identification | Description |
|----------------|-------------------------------------|
| A-1-1-1 | Under PLIDCO cap remnant |
| A-1-1-2 | Under PLIDCO cap remnant |
| A-1-1-3 | Under PLIDCO cap remnant |
| A-1-1-4 | Under PLIDCO cap remnant |
| A-1-1-5 | Under PLIDCO cap remnant |
| A-1-1-6 | Under PLIDCO cap remnant |
| A-1-1-7 | Metallographic specimen |
| A-1-1-8 | Metallographic specimen |
| A-1-1-9 | PLIDCO cap |
| A-1-2 | Remnant |
| A-1-3 | Remnant |
| A-2 | Remnant |
| A-3 | Remnant |
| A-4 | Remnant |
| B-1-1 | Remnant |
| B-1-2 | Remnant |
| B-1-3 | Remnant |
| B-1-4 | Remnant |
| B-1-5 | Remnant |
| B-1-6 | Remnant |
| B-1-7 | Remnant |
| B-1-8 | Base metal Charpy V-notch specimens |
| B-1-9 | Weld metal Charpy V-notch specimens |
| B-2 | Remnant |

Appendix C
Photographs of sample remnants

