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# MSi Investigative Summary

## Weld testing defect analysis of circumferential groove weld

### BACKGROUND

One (1) boiler tubing sample containing a GTAW (TIG) circumferential groove weld was submitted to our laboratory for a metallurgical investigation. Reportedly, the sample consisted of two, ~2" diameter "old" and "new" tube sections, joined together with ER 80S-B2 filler metal. It was also reported that an RT (radiographic) inspection of the weld joint revealed a porosity-like indication at the 7 o'clock position. We were requested to identify the likely cause of the defect.

### SAMPLE IDENTIFICATION

| **Tubing Sample** | **Size** | **Grade** | **Steel** |
|---|---|---|---|
| "Old" Section | 2" x .132" wall | ASME SA-178C | Low-carbon |
| "New" Section | 2" x .132" wall | ASME SA-213 T2 | Alloy |

### PERFORMED TESTING

Visual and Stereoscopic Examination
Metallographic (Microstructural) Examination
Hardness Testing
Chemical Analysis

### CONCLUSIONS

**1.** Based upon the performed tests and examinations, it is our opinion that the porosity defect in the circumferential weld was caused by welding technique deficiencies. The porosity was not caused by the filler metal or tubing material.

**2.** The defect was highly localized and contained a cluster of three (3) cavities. One cavity was spherical and measured ~.012" in diameter. The other two cavities were conjoined, elongated, and had an overall length of ~.06". The shapes of the observed cavities were characteristic of gas porosity (i.e., gas bubbles trapped inside the molten filler metal).

**3.** Stereoscopic and metallographic examination of four (4) additional, randomly-selected locations on the weld joint circumference revealed no evidence of porosity, cracking or detrimental inclusions, which confirmed that the localized porosity defect was welding technique-related, rather than material-related.

**4.** Welding-related porosity may result from the following causes:

- Slow gas flow
- A significant momentary change in the gas cup orientation
- The arc is too long

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- Too much electrode is extending beyond the gas cup end
- Intermittent drafts in the work area

**5.** The face and the root surfaces on the examined circumferential weld also revealed some irregularities, associated with uneven welding speed and excessive heat input. This produced excessive weld root penetration areas in the sample portion marked "top", along with some weld root concavity in the sample portion marked "bottom".

**6.** Metallographic examination of the "old" tube material revealed a microstructure consisting of ferrite and spheroidized pearlite, which is typical of low-carbon steel tubes exposed to boiler temperatures over a prolonged period of time. No evidence was observed of pre-existing steel defects, excessive nonmetallic inclusions, or any other detrimental material conditions.

**7.** Metallographic examination of the "new" tube material revealed a microstructure consisting of ferrite and very fine unresolved pearlite, which is typical of alloy steel boiler tubes. No evidence was observed of pre-existing steel defects, excessive nonmetallic inclusions, or any other detrimental material conditions.

**8.** Hardness testing showed values of 66 HRB in both base metal sections ("old" and "new"). This hardness is typical of low-carbon and alloy boiler tubing. Chemical analysis confirmed the "old" section as ASME SA-178C and the "new" section as ASME SA-213 T2 materials.

**9.** To alleviate excessive root penetration, root concavity and welding technique-related porosity defects in the weld joints, we respectfully recommend reviewing and adjusting the current welding procedures. Destructive examinations of weld test coupons will be helpful in improving the weld quality and eliminating the welding defects.

## SUMMARY of TEST RESULTS

### Visual and Stereoscopic Examination

Visual and stereoscopic examination of the sample revealed a single, uniform filler metal bead on the OD of the top portion of the tube, and evidence of excessive weld root penetration on the corresponding ID areas. (See Photos 1 and 3).
The bottom portion of the sample revealed two beads and evidence of surface grinding on the OD. The corresponding ID areas exhibited weld root concavity. (See Photos 2 and 4).
The observed weld joint features are indicative of some inconsistencies of the welding technique, primarily associated with an excessive heat input and speed variations.

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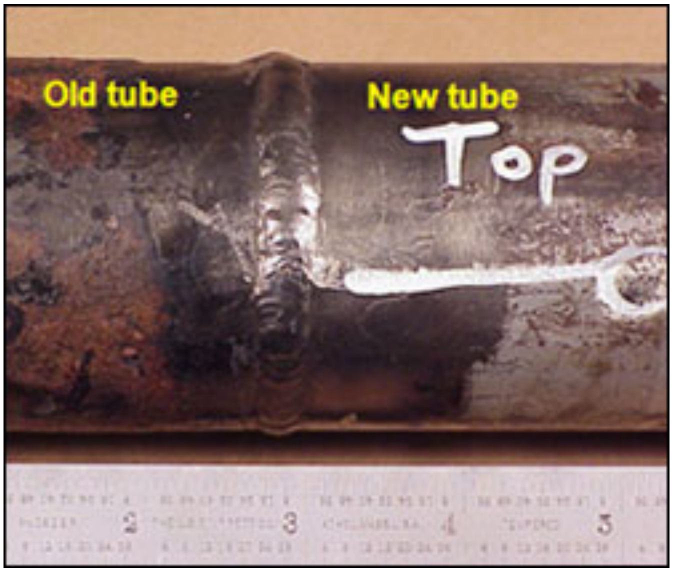


**Photo 1:** Single weld bead on the OD of the top portion of the tube sample).

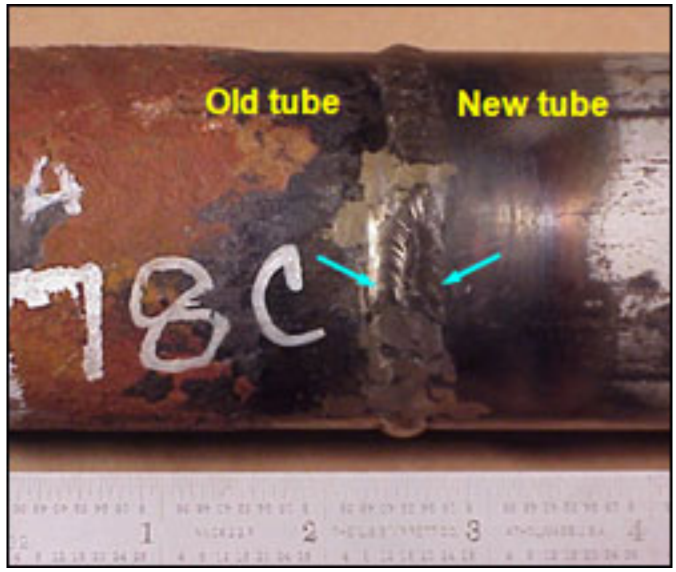


**Photo 2:** Two weld beads (arrows) on the OD of the bottom portion of the tube sample.

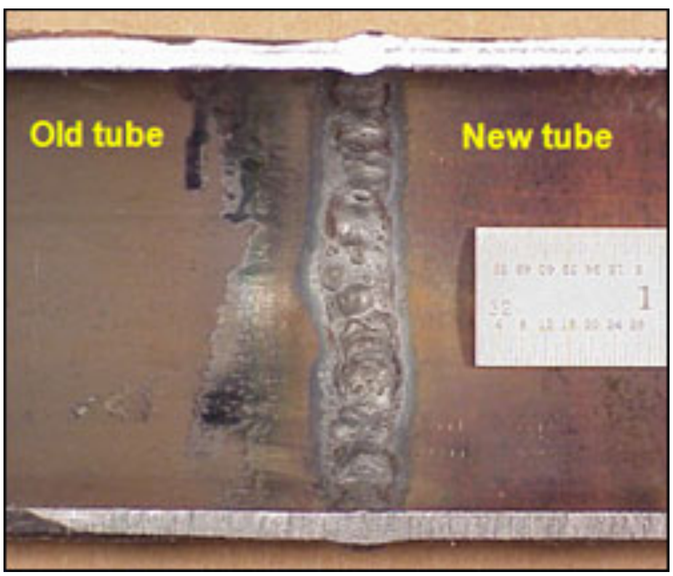


**Photo 3:** Excessive root penetration on the ID of the top portion of the tube sample).

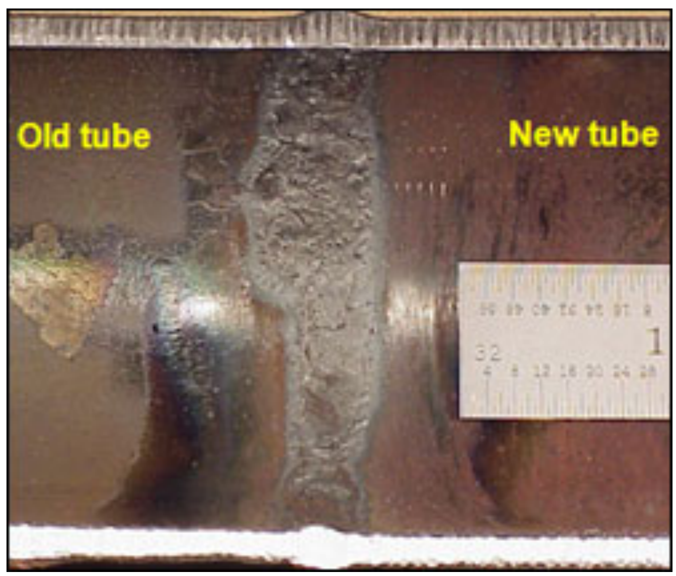


**Photo 4:** Concavity of the root on the ID of the bottom portion of the tube sample)

## Metallographic Examination

**1.** The sample was sectioned longitudinally at the 7 o'clock position, through the weld defect indication. In addition, four randomly-selected, reference weld sections were removed from the top and bottom portions of the sample.

**2.** Low-magnification metallographic examination of the weld defect area revealed a cluster of three

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cavities. One cavity was spherical and measured ~.012" in diameter. The other two cavities were conjoined, elongated, and had an overall length of ~.06". The shapes of all observed cavities were characteristic of gas porosity defects (see Photo 5).

**3.** Examination of the four additional, reference weld sections revealed no evidence of porosity, cracking or detrimental inclusions. However, excessive weld root penetration and weld root concavity were observed at the top and bottom tube locations, respectively (see Photos 6 – 8).

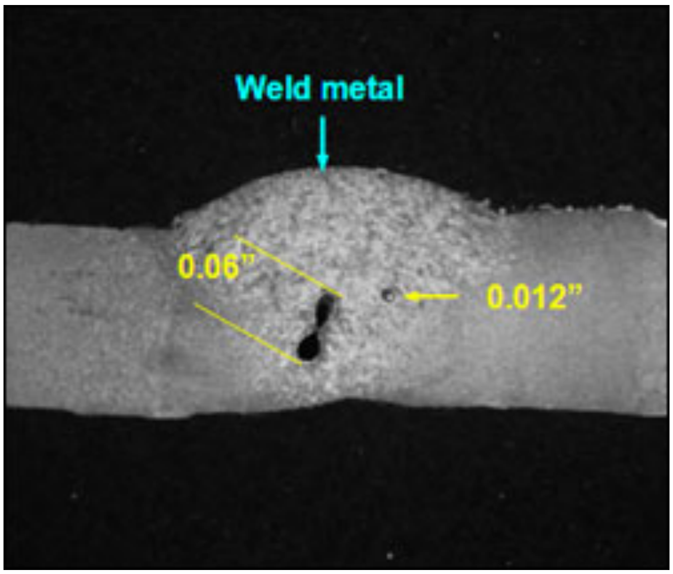



**Photo 5:** Porosity cluster in the weld metal (7 o'clock location on the tube circumference). Etchant: 3% Nital

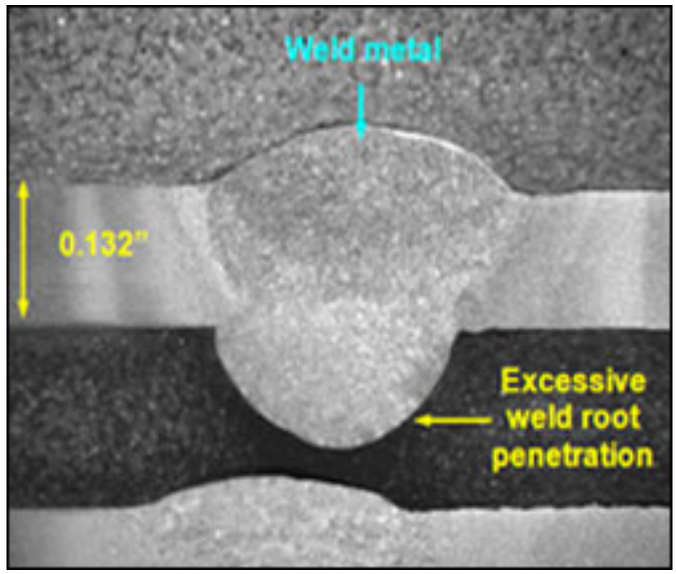
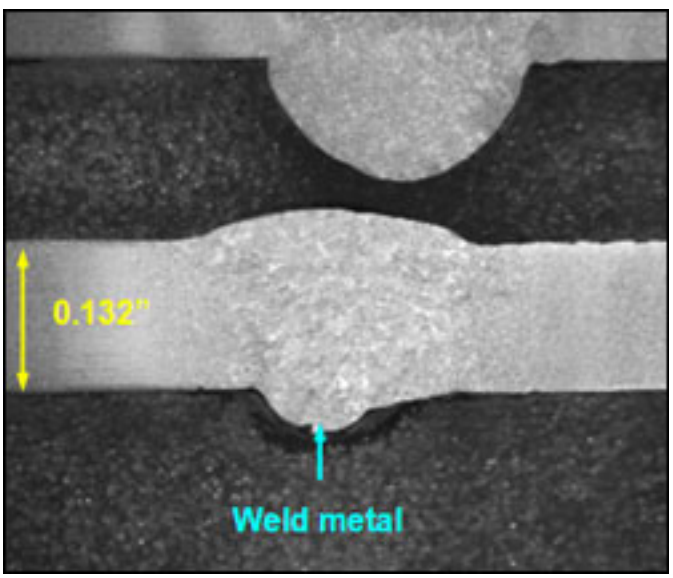



**Photo 6:** Reference section 1 from the top portion of the tube sample. No porosity detected. Etchant: 3% Nital



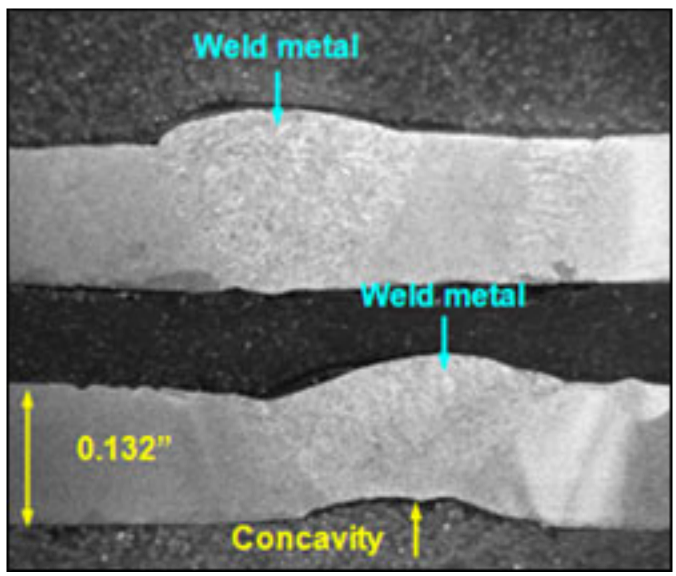




**Photo 8:** 2 reference sections from the bottom portion of

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**Photo 7:** Reference section 2 from the top portion of the tube sample. No porosity detected. Etchant: 3% Nital

the tube sample. No porosity detected. Etchant: 3% Nital

### Metallographic Examination (cont.)

The observed weld joint features indicated that the porosity cluster was welding technique-related, rather than material-related, and that the welding technique showed some irregularities in the form of excessive heat input and uneven welding speed.

Metallographic examination of the "old" tube material revealed a microstructure consisting of ferrite and spheroidized pearlite, which is typical of low-carbon steel tubes exposed to boiler temperatures over a prolonged period of time. No evidence was observed of pre-existing steel defects, excessive nonmetallic inclusions, or any other detrimental material conditions (see Photo 9).

Metallographic examination of the "new" tube material revealed a microstructure consisting of ferrite and very fine unresolved pearlite, which is typical of alloy steel boiler tubes. No evidence was observed of pre-existing steel defects, excessive nonmetallic inclusions, or any other detrimental material conditions (see Photo 10).

The filler metal exhibited a cast, dendritic microstructure consisting of acicular ferrite and unresolved pearlite, typical of carbon steel welds.

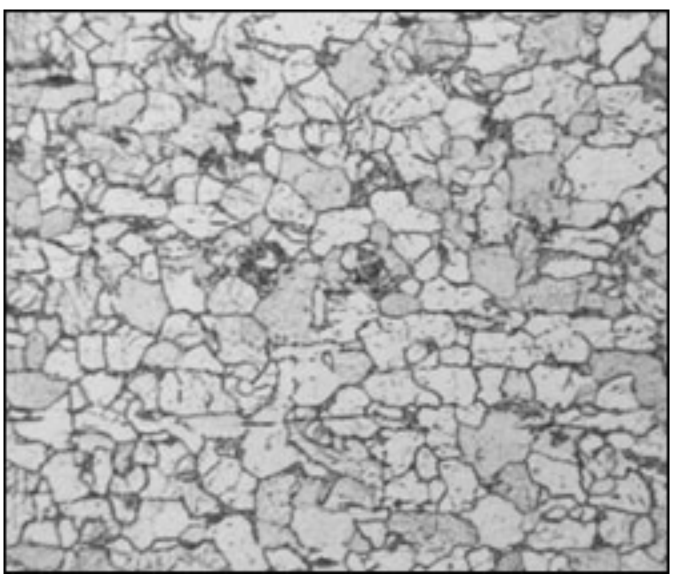

**Photo 9:** Magnification: 400X
"Old" tube microstructure. Etchant: 3% Nital

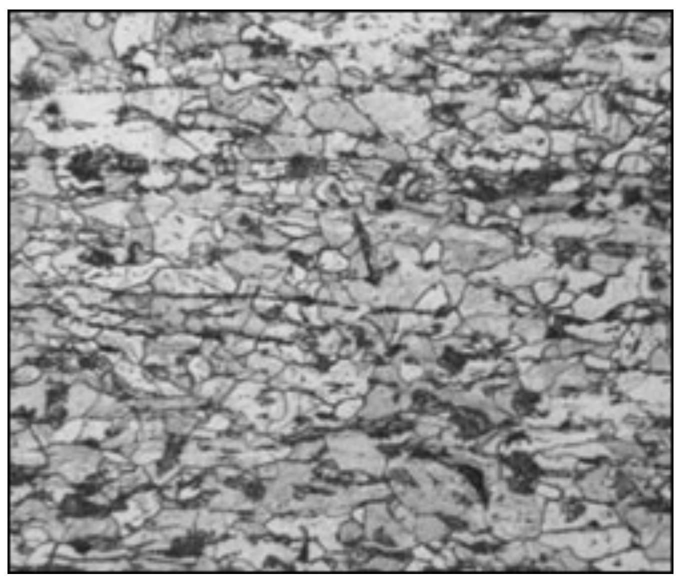

**Photo 10:** Magnification: 400X
"New" tube microstructure. Etchant: 3% Nital

### Hardness Testing

**1.** Hardness testing revealed values of 66 HRB in both base metal sections ("old" and "new"). This hardness is typical of low-carbon and alloy boiler tubing.

**2.** The results are shown in Table 1 on the following page.

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## Chemical Testing

**1.** Chemical analysis confirmed the "old" section as ASME SA-178C and the "new" section as ASME SA-213 T2 materials.

**2.** The results are shown in Table 2 below.

### Table 1 - Hardness Testing*

| Sample | Hardness, HRB |
|---|---|
| "Old" Tube | 66 66 66 |
| "New" Tube | 66 66 66 |

* Testing performed in accordance with ASTM E18.

### Table 2 - Chemical Testing*

| Element | "Old" Tube | "New" Tube |
|---|---|---|
| Carbon | .15% | .15% |
| Manganese | .74 | .50 |
| Phosphorus | .008 | .007 |
| Sulfur | .015 | .023 |
| Silicon | .16 | .15 |
| Nickel | .07 | .09 |
| Chromium | .13 | .62 |
| Molybdenum | .01 | .55 |
| Copper | .06 | .17 |
| Aluminum | .03 | .02 |

* Testing performed in accordance with ASTM E415.