Tritium Effects on Containment Alloys (U)

Hydrogen Isotopes and Helium in Materials
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Objectives

- Support tritium packaging safety & reliability
- Increase understanding of tritium & helium effects on materials.
- Define conditions that lead to tritium-induced crack growth in fielded reservoirs
- Measure mechanical properties, fracture toughness & crack growth rates of alloys as a function of hydrogen isotope and helium content
- Investigate role of forged and welded microstructures on tritium compatibility
Background and Tritium Testing Requirements

- Reservoir loading, unloading, reclamation, surveillance and life storage testing conducted at SRS.
- High-pressure hydrogen, tritium exposure and sample storage for aging data;
- Electric-discharge machining for unexposed and tritium-exposed components (online FY06) for sample preparation;
- Mechanical & fracture toughness testing and crack-growth rate monitoring for tritium-exposed samples;
- Contaminated metallography, scanning and transmission electron microscopy for investigating hydrogen and helium effects in metals
Effect of Tritium Exposure on Stainless Steels

Unexposed

Tritium-Exposed & Aged
Current Investigation: Weldment Test Matrix

- Types 304L and 21-6-9 stainless steels and their weldments;
- Automatic Gas Tungsten Arc Welding;
- Ferrite Contents: 4, 8, 12, 30% achieved by using different filler wires
- Hydrogen and tritium exposures up to 10000 psi, 350 C;
- Helium contents up to 1000 appm achieved by exposure to tritium and aging for decay to helium;
- EB welds also under investigation.
Accomplishments

- Weldment microstructures characterized and fracture toughness measured for unexposed, hydrogen and tritium-exposed-and-aged steels.
- Weldments toughness shown to be higher than the base metal toughness for normal weld ferrite contents.
- But, toughness depends on ferrite content & morphology.
- Hydrogen/Tritium charged weldments had lower toughness than base metals and the toughness decreased with increasing weld ferrite content.
- Weldment toughness did not decrease with aging because of reduced tritium contents from rapid off-gassing from weldment.
Experimental Procedure
## Compositions (Weight %)

<table>
<thead>
<tr>
<th>Element</th>
<th>304L</th>
<th>304L</th>
<th>304L</th>
<th>21-6-9</th>
<th>308L</th>
<th>309LM</th>
<th>312 M</th>
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<tbody>
<tr>
<td>Cr</td>
<td>18.0</td>
<td>19.9</td>
<td>17.8</td>
<td>19.3</td>
<td>20.5</td>
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<td>1.7</td>
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<td>9.9</td>
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<td>Mo</td>
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<td>0.04</td>
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<td>-</td>
<td>&lt;0.01</td>
<td>2.5</td>
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<td>-</td>
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<td>0.028</td>
<td>0.02</td>
<td>0.05</td>
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<tr>
<td>Si</td>
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<td>0.63</td>
<td>.544</td>
<td>.38</td>
<td>0.5</td>
<td>0.64</td>
<td>0.51</td>
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<td>Cu</td>
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<td>-</td>
<td>.123</td>
<td>-</td>
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<td>0.31</td>
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*304L composition from SRS ICPES analysis; all other heats are manufacturers’ supplied compositions.
## Weld Ferrite Contents

<table>
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<tr>
<th>Sample ID</th>
<th>Base</th>
<th>Filler</th>
<th>Vol % Ferrite</th>
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<tr>
<td>EB</td>
<td>304L Plate</td>
<td>EB Weld</td>
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<td>48</td>
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<td>9308</td>
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<td>49</td>
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<td>309L</td>
<td>33</td>
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<td>98</td>
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<tr>
<td>912</td>
<td>21-6-9</td>
<td>312</td>
<td>24</td>
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</tbody>
</table>

* Average ferrite at center of notch
Forced 304L & 21-6-9
- Welds of 304L/21-6-9 308L
- Fusion and EB welds
- Six Weld Ferrite Levels
- Exposed at 5000 psi and 350°C
- Goal is to Age to 1000 appm He
## Helium Contents

<table>
<thead>
<tr>
<th>Material Description</th>
<th>Measured Helium appm</th>
<th>Estimated Original T appm</th>
<th>Age J-Integral Test 1 days</th>
<th>Calculated Helium on Test Date 1 appm</th>
<th>Age J-Integral Test 2 days</th>
<th>Calculated Helium on Test Date 2 appm</th>
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*Note: Measured Helium appm, Estimated Original T appm, Age J-Integral Test 1 days, Calculated Helium on Test Date 1 appm, Age J-Integral Test 2 days, Calculated Helium on Test Date 2 appm.*
Typical Load-Displacement Records
Weldment Tensile Properties

Effect of Weld Ferrite on Yield Strength

Effect of Weld Ferrite on Tensile Strength

Effect of Weld Ferrite on Elongation

Stress-Strain Diagrams Fusion Welds

- Annealed Plate
- Low Ferrite
- Fusion Welds - Forgings
  - High Ferrite
J-R Records 304L Welds

The graph shows the J-integral (J) in pounds per inch (lbs/in.) as a function of crack length increase in inches (in.). The graph compares different materials:

- 308L/FN8
- 312/FN 25
- 309/FN33
- As-Received 304L

The X-axis represents the crack length increase in inches (0 to 0.14 in.), while the Y-axis shows the J-integral (0 to 8000 lbs/in.).
J-R Records: Effect of H₂

![Graph showing the effect of H₂ on crack length increase for different materials.

- **308L**
- **304L**
- **304L-H₂**
- **308L-H₂**

Variables:
- **J**, lbs / in.
- **Crack Length Increase**, in.

Grid and scale for J and Crack Length Increase are provided.
## Fracture Toughness Values

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
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<td>304L/309LM</td>
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<td>108</td>
<td>711</td>
<td>71</td>
<td>54</td>
<td>275</td>
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</table>
Helium Effect on Toughness of Base Metals

J-Integral Fracture Toughness, lbs / in.

Helium Content (appm)

- Forged 304L
- HERF 21-6-9
- Forged 21-6-9
Helium Effect on Toughness of Weldments

J-Integral Fracture Toughness, lbs / in.

Ferrite Content (%)

- Weldments Control
- Tritium Charged (50-100 appm He)
- 100-200 appm HE
304L Weld Fracture Appearance

308L Filler Normal Weld Ferrite Content

- As-Welded
- H₂-Charged
304L Weld Fracture Appearance

308L Filler Normal Weld Ferrite Content

- T2-Charged
- H₂-Charged
Fracture Appearance 304L

309L Filler Very High Ferrite Weld

- T2-Exposed-Aged
- H2-Charged
A TEM Study of Helium-Bearing Fusion Welds (U)

- Characterize weld microstructures
- Identify Phases
  - Ferrite/austenite, martensite, others
  - Morphology of ferrite austenite
  - Precipitate distribution
- Characterize Deformation behavior
- Characterize Helium bubble distribution
Summary of Findings

- Helium bubbles were observed in the austenite
  - Grain interiors and on dislocations
- Helium bubbles were not observed in the delta ferrite.
  - Small bubble size, and/or
  - Increased tritium diffusivity/decreased solubility in ferrite and losses from outgassing
- Some BFZs (denuded zones) were observed some austenite/ferrite interfaces – no bubbles on interfaces
- Fewer bubbles were observed in regions of the weld that contained more ferrite. Related to solubility/diffusivity differences between austenite and ferrite.
A TEM Study of Helium-Bearing Fusion Welds (U)

21-6-9 Conventional Forging/ 308L Filler Wire

~ 5 vol.% δ ferrite
A TEM Study of Helium-Bearing Fusion Welds (U)

304L Weld Critical Plate - 308L/309 MOD Mix

~12 vol.% δ ferrite
TEM 304L Typical Weld

308L Filler Wire - Low Ferrite Weld

312M Filler Wire - High Ferrite Weld
Typical Defect Structure: Tritium-Exposed-Weld

Type 304L Tritium Low Ferrite

Ferrite/Austenite Interface

Helium Bubbles in Austenite
21-6-9 Conventional Forging – 308L Wire
21-6-9 Conventional Forging – 308L Wire
Summary

- Fracture toughness of weldments was higher than the base metal toughness for weldments with normal weld ferrite contents. Values decreased to about half the base metal value as ferrite content was increased from 8% to 33%.
- Weld microstructure and morphology affected fracture toughness: For discontinuous ferrite, fracture toughness was higher than base metal values; for continuous ferrite, fracture toughness values were lower than base metal values.
- Hydrogen-charged weldments had lower toughness than hydrogen-charged base metals and the toughness decreased with increasing weld ferrite content. Similarly, tritium-exposed-and-aged base metals and weldments had lower toughness than unexposed alloys.
- Base metal toughness decreased with aging time because of increased helium content from tritium decay. Weldment toughness did not decrease with aging time because of tritium off-gassing.
- Fracture modes were dominated by the dimpled rupture process in unexposed steels and welds. In hydrogen and tritium-exposed welds, the fracture modes depended on the weld ferrite content. At high ferrite contents, fracture occurred predominantly by transgranular cleavage through the weld ferrite phase.
Future Work

Properties of Components (Location and Orientation)

Heat Affected Zones

Testing in High Pressure Hydrogen

Inputs for simulation and verification

SRNL