IN USE: HIGH CHROMIUM WELD METAL DEVELOPMENT AND CRACKING MECHANISMS

ISSUE STATEMENT

Alloys 52 and 52M are high-chromium, nickel-based weld metals developed specifically for their superior resistance to stress corrosion cracking in nuclear power applications. These weld metals are used extensively for repair and mitigation of primary water stress corrosion cracking (PWSCC) in dissimilar metal 82/182 welds. Experience shows that Alloys 52 and 52M are susceptible to weld cracking and have less than optimum weldability. Repair and rework of these weld metals has cost the nuclear power industry millions of dollars. Despite years of effort to optimize welding process parameters and develop specialized welding equipment, the problems with Alloys 52 and 52M continue to impact operating plants and influence new plant deployment. A new high-chromium welding alloy is needed that has the desired mechanical properties and corrosion resistance, but also has significantly improved weldability and superior resistance to weld cracking.

DRIVERS

Significant drivers include:

Outage Schedule and Cost Impact

Between 2006 and 2009, the use of Alloy 52/52M for PWSCC mitigation and repair resulted in extended refueling and maintenance outages, causing lost generation capacity and increased outage cost. Until a long term solution is realized, the continued use of Alloy 52/52M will likely continue to cause outage schedule extensions with the related lost plant availability and associated lost revenues.

Asset Management for Operating Pressurized Water Reactors

A number of PWR owners have elected to defer Alloy 82/182 PWSCC mitigation, choosing to inspect instead. This decision resulted from insurmountable Alloy 52/52M weld cracking problems encountered at one plant during installation of a weld overlay on reactor coolant system piping in the spring of 2009. Since that time, only one utility has successfully mitigated Alloy 82/182 PWSCC by Alloy 52/52M weld overlay. Therefore, lack of a high chromium nickel-base alloy welding solution not only impacts outage schedule and cost, but also is causing incremental inspection costs.

Regulatory Impact

Relief requests approved by the U.S. Nuclear Regulatory Commission (NRC) have specified a 24 wt% chromium minimum in deposited weld metal for PWSCC mitigation of 82/182 dissimilar metal welds. The American Society of Mechanical Engineers has approved Code Cases invoking this same minimum percentage. Alloy 52/52M, with 30 wt% nominal chromium, has been used to meet this minimum requirement and to ensure superior PWSCC resistance. Due to the weldability challenges and difficulties experienced with Alloy 52/52M, the NRC is supportive of a long-term solution, such as development of a new high-chromium alloy with improved weldability and superior crack resistance.

Lack of a Coordinated Approach

Historically Alloy 52/52M development has been problem driven and has occurred on an as-needed basis. Welding problems and cracking that occurred during refueling outages and or during manufacture and repair of critical PWR nuclear components have driven small modifications or 'tweaks' to the base Alloy 52/52M composition. These small modifications or changes to composition may or may not have actually corrected the problem since the fundamental cause of the problem was not thoroughly researched, understood, and corrected. This ineffective approach continues today.

RESULTS IMPLEMENTATION

New alloy development tools and a new high-chromium alloy with superior weldability will be the main products of this project. Computational computer modeling and analyses in concert with newly developed small laboratory weldability testing techniques will be used to guide the development of the new high chromium nickel-base welding alloy. In the past, weld alloy development was normally accomplished by starting with the matching base metal composition followed by systematic additions of minor alloying elements to achieve acceptable welding characteristics. For example, Alloy 52/52M is based on Inconel™ 690 with only minor element additions. Rather than starting with the base metal composition, the new and innovative computational modeling and laboratory weld-ability testing approach will be used to first formulate an alloy composition that 1) has superior welding performance, 2) is compatible with the base materials to be joined, and 3) maintains the mechanical and corrosion properties required for the reactor coolant system environment in a nuclear power plant.
PROJECT PLAN

This project will perform fundamental research to understand Alloy 52/52M weldability and cracking issues by literature research, operating experience, and laboratory weldability testing. Concurrently, the project will develop, test, and validate a new high-chromium weld alloy as an alternative to Alloy 52/52M. The project will include composition development, weld alloy manufacturing, welding process and parameter development, and evaluation studies to validate use for repair and fabrication of critical nuclear power components.

Proposed plans and tasks include:

• Research and perform laboratory weldability testing to understand fundamental cracking mechanisms and weldability problems with high chromium nickel-base weld metals

• Develop alloy composition
  – Evaluate welding behavior and mechanical properties of target composition with modeling and analyses
  – Validate modeled behavior for target composition with small laboratory test samples
  – Manufacture experimental weld wire with target composition
  – Evaluate weldability of weld wire and perform mechanical, corrosion, and crack growth rate testing

• Assess welding and nondestructive evaluation of alloy composition
  – Assess and develop process parameters for gas tungsten arc and gas metal arc welding
  – Fabricate large scale mockups and assess impact on nondestructive evaluation
  – Assess feasibility and potential of advanced welding processes (laser welding, magnetic stir, hybrid, etc.)

• Application plan
  – Engage material manufacturer (Special Metals, Sandvik, etc.) to develop weld metal specification
  – Engage leading welding vendors (WSI, WEC, Areva, MHI, ENSA, Shaw, etc.) to evaluate new weld metal
  – Facilitate acceptance of new weld metal through AWS/ASTM/ASME Codes and Standards

RISKS

Development of a new PWSCC resistant high chromium weld alloy is a complicated effort with several uncertainties that could impact the project schedule and increase the cost. By its very nature, alloy development is an iterative process that requires in-process testing and validation of experimental compositions prior to moving to the next step. Experimental alloy compositions with less than the desirable weldability, lower than expected mechanical properties, or poor corrosion behavior may require reformulation of the alloy composition which then necessitates repeated testing. Use of newly developed laboratory weldability tests and development of computer modeling and computational analyses reduces this risk by identifying weld alloy issues early in the development process, before welding wire production and full scale mockup testing.

Use of a new high chromium weld alloy will necessitate new procedure development by welding vendors and component fabricators and also require acceptance by regulators and Code bodies. These efforts are included in the project plan, but by their very nature the outcomes and timing is not easily estimated.

RECORD OF REVISION

This record of revision will provide a high level summary of the major changes in the document and identify the Roadmap Owner.

<table>
<thead>
<tr>
<th>REVISION</th>
<th>DESCRIPTION OF CHANGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Original Issue: August 2011</td>
</tr>
<tr>
<td></td>
<td>Roadmap Owner: Greg Frederick</td>
</tr>
<tr>
<td>1</td>
<td>Revision Issued: August 2012</td>
</tr>
<tr>
<td></td>
<td>Roadmap Owner: Greg Frederick</td>
</tr>
<tr>
<td></td>
<td>Changes: Within the flowchart, extended Laboratory Weldability Studies: Fund Crack Studies until the middle of 2013. Added Alternative Commercial Wires from mid 2012 until the end of 2014. Added milestones for topical reports. One milestone completed.</td>
</tr>
<tr>
<td>2</td>
<td>Revision Issued: August 2013</td>
</tr>
<tr>
<td></td>
<td>Roadmap Owner: Greg Frederick</td>
</tr>
<tr>
<td></td>
<td>Changes: Updated flow chart.</td>
</tr>
<tr>
<td>3</td>
<td>Revision Issued: January 2014</td>
</tr>
<tr>
<td></td>
<td>Roadmap Owner: Greg Frederick</td>
</tr>
<tr>
<td></td>
<td>Changes: Added milestones legend and 3 milestones completed.</td>
</tr>
<tr>
<td>4</td>
<td>Revision Issued: December 2014</td>
</tr>
<tr>
<td></td>
<td>Roadmap Owner: Greg Frederick</td>
</tr>
<tr>
<td></td>
<td>Changes: Added milestones 4 and 5. We extended Manufacture Weld Wire and Develop code case to list new wire.</td>
</tr>
</tbody>
</table>
High Chromium Weld Metal Development and Cracking Mechanisms

Welding & Repair Technology Center (WRTC)
- Program Development
- Laboratory Weldability Studies: Fund Crack Studies
- Full Scale Weldability and Mechanical Testing
- New Studies: Mock-ups Narrow V Groove Overlay
- Primary System Corrosion Research (PSCR) Studies Crack Growth Rate

Nondestructive Evaluation
- Milestones
  1. CPTT Report
  2. Weldability Test
  3. Initial Heat Designs
  4. Fabrication of Initial Heat
  5. Weldability and Testing of Experimental Heats
- NDE Mock-up for New and Advanced Alloys
- NRC Review Data Issue SER

Government
- Legend
  - Key Milestone
  - Complete Milestone
  - Funded Work
  - Unfunded Work
- University Computational Modeling
- Manufacture Weld Wire
- Alternative Commercial Wires
- Weld Vendor Evaluating

Vendor

ASME
- Develop Code Case to List New Wire

UC_MAT_09_R4 High Chromium Weld.vsd  December 2014