High Temperature Oxidation Resistance of Welded Ferritic, Austenitic and Nickel Alloys for Balance of Plant (BOP) In Solid Oxide Fuel Cell (SOFC) Systems

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Outline

- Objective and Research Approach
- Materials
- GTAW Welding conditions
- Results and Analysis
- Conclusions
Objective

- Develop low cost 10 KW SOFC stationary power system.
  - Balance of plant Heat Exchangers (HE) cost reduction from $15,000 to $1,500.
    - Develop models to accurately predict the temperature in SOFC heat exchangers.
    - Select materials and manufacturing processes.
    - Use modeling to predict weld filler materials for the dissimilar metal joints.
    - Build and test heat exchangers to confirm model.
Research Approach

- Weld dissimilar metal materials without filler metal using GTAW.
- Heat the weld joints in air to 800°C for 100 hr, 500 hr, 1,000 hr and 2,000 hr.
- Determine cracking modes
- Hardness across the welds.
- Diffusion of alloy elements over time.
- Metallographic examination.
**Materials used in the welding experiments**

<table>
<thead>
<tr>
<th></th>
<th>Ni</th>
<th>Cr</th>
<th>Fe</th>
<th>C</th>
<th>Ti</th>
<th>Nb+Ta</th>
<th>Mo</th>
<th>Mn</th>
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<tbody>
<tr>
<td>IN 625</td>
<td>64</td>
<td>22</td>
<td>0</td>
<td>0.1</td>
<td>0.4</td>
<td>4</td>
<td>9</td>
<td>0.5</td>
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<tr>
<td>IN 600</td>
<td>75.4</td>
<td>15</td>
<td>7</td>
<td>0.1</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0.5</td>
</tr>
<tr>
<td>409 SS</td>
<td>0</td>
<td>11</td>
<td>87.4</td>
<td>0.04</td>
<td>0.75</td>
<td>0</td>
<td>0</td>
<td>0.75</td>
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<tr>
<td>321 SS</td>
<td>11</td>
<td>18</td>
<td>68.5</td>
<td>0.08</td>
<td>0.4</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>347 SS</td>
<td>12</td>
<td>18</td>
<td>68.9</td>
<td>0.08</td>
<td>0</td>
<td>0.8</td>
<td>0</td>
<td>2</td>
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</tbody>
</table>

compositions in weight percent
Welding Conditions

• GTAW using a horizontal welding track.
• Samples 1in. x 6 in. x 1/4 in.
• Welded side by side.
• One welding pass on top and bottom.
• 13 volts and 132 amps.
• Welding speed 0.4 in per minute.
Welding Results

- Solidification cracking and weld root cracking observed in all joints between all the stainless and the superalloys.
- Lack of full penetration was observed in all welds.
- No cracking was observed in the heat affected zone.
Weld Cracking

- 321 SS-INC625 centerline
- 321 SS-INC600 centerline
- INC625-409SS centerline, crater
- 409 SS-INC600 centerline
- INC600-INC625 centerline, crater
- 321SS-409SS no cracking
- 347SS-409SS no cracking
- INC600-347SS centerline, crater
- INC625-347SS centerline, crater
- 321SS-347SS no cracking
Chemical Analysis after 800°C Heat Treatment

• SEM chemical analysis was used to determine the composition across the welded joints for Cr, Ni, Fe, and Mn.

• Changes in the composition across the welds were not observed with SEM as a function of time up to 2000 hours.
# Hardness Results

<table>
<thead>
<tr>
<th>Material 1</th>
<th>Material 2</th>
<th>Hv</th>
<th>Hνσ</th>
</tr>
</thead>
<tbody>
<tr>
<td>321 SS-INC625</td>
<td>171-226</td>
<td>24</td>
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<tr>
<td>321 SS-INC600</td>
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<tr>
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<td>226-169</td>
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<td>174-169</td>
<td>23.0</td>
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<tr>
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<td>40.2</td>
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<tr>
<td>321SS-347SS</td>
<td>171-163</td>
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</table>
Conclusions

- Autogenous GTAW welds in several stainless steels did not crack even after heat treatment at 800ºC for 2000 hours.
- Weld cracking was observed in all the joints with superalloys.
- Elemental diffusion was not observed in the welds in samples heated to 800ºC for 2000 hours.
- Vickers hardness measurements across the welds did not change in samples heated to 800ºC for 2000 hours.