Novel Dissimilar Joints Between Alloy 800H and 2.25%Cr & 1%Mo Steel

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Problem
Progressive degradation of creep resistance due to carbon depletion from the weld zone
Large difference in Cr concentration → large C potential difference since Cr reduces the chemical potential of C
Carbon diffusion → joint contains lower carbon levels → must proceed every other year of service

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Advisor: S. A. David, Oak Ridge National Laboratory

Approach
Solution: Reduce carbon diffusion by reducing carbon potential gradient
(a) Thermodynamically, model carbon potential gradient for various compositionally graded transition joints
(b) Fabricate selected transition joints by additive manufacturing
(c) Test fabricated joints

What is a carbon potential gradient?

\[ \log a_C = \log f_C = E_G \left( \frac{C_{00}}{C} \right) \]

Negative \( a_C \) for carbon transition → Chromium lowers carbon activity

Relating activity and chemical potential:

\[ \Delta G = \mu_C - \mu_C^{00} = R T \ln a_C \]

Fick's First Law of Diffusion (1-D):

\[ J = -D \frac{dC}{dx} \]

Under adiabatic conditions, can be rewritten as

\[ \frac{dC}{dx} = \frac{J}{D} \]

Exactly how is chemical composition adjusted?

Varying composition for two base alloys is essential

Compositional grading by additive manufacturing

How to minimize driving force for diffusion?

Thermodynamically model a transition joint by adjusting chemical composition to minimize C-potential gradient

Solution:

- Carbon potential gradient = Driving force for carbon diffusion
- At constant T, driving force depends on length
- Plot: Dependance of carbon potential gradient on length of transition joint for 4 temperatures
- Find:
  - Marginal benefits for joints over 5 cm

Understanding of additive manufacturing process and related processing conditions based on scientific principles

Numerical modeling with transient and adiabatic analysis

Fabricating transition joints

- Fabricate selected transition joints by additive manufacturing

Development of high quality transition joints based on numerical modeling

- Application of numerical analysis to comprehend the effects of process parameters
- Estimation of melting pool shape and size using 3D heat transfer and fluid flow analysis
- Numerical results validated with data from experiments
- Optimization of process parameters for homogeneous and defect free joints

Comparison between 2.25Cr-1Mo steel and 800H

- Carbon potential gradient across dissimilar joints depends on the temperature and alloy composition
- To set the desired condition to produce compositionally varying dissimilar joint, comparison of these three process parameters for two base alloys is essential
- 800H alloy exhibit bigger molten pool for the same process parameters

<table>
<thead>
<tr>
<th>Material</th>
<th>Laser Power (W)</th>
<th>Beam diameter (mm)</th>
<th>Scanning speed (mm/sec)</th>
<th>Layer thickness (mm)</th>
<th>Substrate thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>800H</td>
<td>100</td>
<td>0.5</td>
<td>12.5</td>
<td>0.10</td>
<td>4</td>
</tr>
<tr>
<td>2.25Cr-1Mo Steel</td>
<td>100</td>
<td>0.5</td>
<td>12.5</td>
<td>0.10</td>
<td>4</td>
</tr>
</tbody>
</table>

Creep tests

High-temperature testing at Oak Ridge National Laboratory