Candidate Alloys and Challenges for S-CO₂ Applications
DOE-EPRI S-CO₂ Workshop, October 15, 2015, San Diego
HAYNES® 230® and HAYNES® 282® Alloys

HAYNES® 230® alloy
- UNS N06230

HAYNES® 282® Alloy
- UNS N07208

<table>
<thead>
<tr>
<th></th>
<th>Ni</th>
<th>Cr</th>
<th>Co</th>
<th>Mo</th>
<th>W</th>
<th>Fe</th>
<th>Mn</th>
<th>Si</th>
<th>Al</th>
<th>C</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>230</td>
<td>57</td>
<td>22</td>
<td>5*</td>
<td>2</td>
<td>14</td>
<td>3*</td>
<td>0.5</td>
<td>0.4</td>
<td>0.3</td>
<td>0.10</td>
<td>La = 0.02; B=0.015</td>
</tr>
<tr>
<td>282</td>
<td>57</td>
<td>19</td>
<td>10</td>
<td>8.5</td>
<td>-</td>
<td>1.5*</td>
<td>0.5*</td>
<td>0.5*</td>
<td>1.5</td>
<td>0.06</td>
<td>Ti = 2.1; B=0.005</td>
</tr>
</tbody>
</table>

* Maximum content

HAYNES® 230® alloy:
- Is solid-solution strengthened
- Excellent creep strength among solid-solution alloys
- Excellent long-term thermal stability
- Have outstanding oxidation resistance to 980°C
- Excellent thermal fatigue resistance
- Lowest thermal expansion characteristics
- Is readily formed, fabricated and weldable

HAYNES® 282® alloy:
- Is γ’ - Ni₃(Al, Ti) strengthened alloy
- Excellent creep strength among age-hardenable alloys up to 900°C
- Resists strain-age cracking
- Excellent formability, fabricability, and castability
- Excellent long-term thermal stability
- Excellent low-cycle fatigue resistance
HAYNES 230 and 282 Alloys
Creep Rupture Data Comparison

Stress Rupture Data
Sheet, $T \leq 1700^\circ F (927^\circ C)$

Larson-Miller Plot – 1% Creep Life

Approx. Nimonic 90

263 alloy
WASPALOY alloy
R-41 alloy
282 alloy
HAYNES 282 Alloy
Resistance to Strain-Age Cracking

Prager & Shira plot (PS Plot) showing susceptibility of nickel based superalloys to strain age cracking / fabrication & weldability problems.

- The relatively low volume fraction (19%) of gamma-prime (γ') in 282® alloy, results in improved resistance to strain-age cracking
- 282® alloy approaches the strain-age cracking resistance of 263 alloy and possesses much higher resistance than Waspaloy and R-41 alloys
HAYNES 282 and 230 Alloys
Long-Term Thermal Stability

282 Alloy

<table>
<thead>
<tr>
<th>Exposure Time (hours)</th>
<th>Room Temperature Tensile Elongation (%)</th>
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</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4,000</td>
<td>20</td>
</tr>
<tr>
<td>8,000</td>
<td>25</td>
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<tr>
<td>12,000</td>
<td>30</td>
</tr>
<tr>
<td>16,000</td>
<td>35</td>
</tr>
</tbody>
</table>

Exposure Temperature:
- 1600°F (871°C)
- 1200°F (649°C)
- 1400°F (760°C)

230 Alloy

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</tr>
<tr>
<td>16,000</td>
<td>35</td>
</tr>
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</table>

Exposure Temperature:
- 649°C (1200°F)
- 760°C (1400°F)
- 871°C (1600°F)
Supercritical CO₂ Corrosion Resistance at 700°C/20 MPa

Pint and Keiser, ORNL; The 4th International Symposium - Supercritical CO₂ Power Cycles
Current Status of the Alloys and Challenges for S-CO₂ Tech.

- **Wrought Product Forms:** Standard commercial products are produced in billet, bar, plate, sheet, and welding wire.
- **Both Alloys** are fully commercialized. Currently being used in industrial applications.
- **230 Alloy** covered by ASME Section VIII Div. 1 up to 982°C.
- **282 Alloy Products** have been produced for evaluation in U.S., European and China A-USC programs.
  - ASME Code Case is currently being pursued in collaboration with ORNL for 282 alloy.
- **Cost:** - Sheet and Plate: Cut parts – Reduces scrap;
  - Work closely with alloy manufacturers during the heat exchanger designing stages to define sizes to lower costs early on;
  - “Standard” vs “non-standard” Product forms; “In-house” capability
  - Tubular product forms – Seamless vs welded tubulars
  - Qty for already defined product forms
- **Challenges:** - Offering product forms for the prototype testing, which are not “standard product forms”
  - Code Case and Standards Acceptance (Three Heats)
  - Commercialization of New Alloys
- **Information Needed:** - Design Parameters – Stress/Temp and Environmental conditions; Product Forms