Cast Components for High Temperature CSP Thermal Systems
Oak Ridge National Laboratory
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Gen 3 CSP Systems Demand High Performance Materials

- Components for Gen 3 systems are targeted for >700°C operation to achieve improved efficiencies
- Systems have to operate at high temperatures for long periods of time under relatively high stresses
  - Cross-cutting needs for multiple Gen 3 pathways
- Low-cost components are required to achieve to achieve the Sunshot goal of 6 ¢/ kWh
Candidate Ni-Based Alloys Are Expensive

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Ni</th>
<th>Co</th>
<th>Cr</th>
<th>Fe</th>
<th>W</th>
<th>Mn</th>
<th>Mo</th>
<th>Nb</th>
<th>Al</th>
<th>Ti</th>
<th>Si</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haynes®230</td>
<td>Bal</td>
<td>2.38</td>
<td>22.14</td>
<td>1.55</td>
<td>14.24</td>
<td>0.53</td>
<td>1.3</td>
<td>0.0</td>
<td>0.39</td>
<td>0</td>
<td>0.37</td>
<td>0.1</td>
</tr>
<tr>
<td>(Heat 830587876)</td>
<td>Spec</td>
<td>Bal</td>
<td>5 Max</td>
<td>22</td>
<td>3 max</td>
<td>14</td>
<td>0.5</td>
<td>2</td>
<td>0.5 Max</td>
<td>0.3</td>
<td>0.1 Max</td>
<td>0.4</td>
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<tr>
<td>Haynes®282</td>
<td>Bal</td>
<td>10.18</td>
<td>19.39</td>
<td>0.79</td>
<td>0.06</td>
<td>0.08</td>
<td>8.53</td>
<td>0.0</td>
<td>1.52</td>
<td>2.22</td>
<td>0.06</td>
<td>0.062</td>
</tr>
<tr>
<td>(Heat 208278368)</td>
<td>Spec</td>
<td>Bal</td>
<td>10</td>
<td>20</td>
<td>1.5 Max</td>
<td>-</td>
<td>0.3 Max</td>
<td>8.5</td>
<td>-</td>
<td>1.5</td>
<td>2.1</td>
<td>0.15 Max</td>
</tr>
<tr>
<td>IN740H</td>
<td>50.03</td>
<td>20.21</td>
<td>24.51</td>
<td>0.19</td>
<td>0</td>
<td>0.25</td>
<td>0.33</td>
<td>1.45</td>
<td>1.34</td>
<td>1.34</td>
<td>0.14</td>
<td>0.024</td>
</tr>
<tr>
<td>(HT3779J)</td>
<td>Spec</td>
<td>Bal</td>
<td>20</td>
<td>24.5</td>
<td>3 Max</td>
<td>-</td>
<td>1 Max</td>
<td>1 Max</td>
<td>1.5</td>
<td>1.35</td>
<td>1.35</td>
<td>0.15</td>
</tr>
</tbody>
</table>

- Alloys have high levels of Ni and in some cases Ni + Co
Casting Components Offers a Route for Cost Reduction

- Certain component geometries can be cast with cost savings
  - Example: Cylindrical objects (pipes) can be centrifugally cast
  - Complex valve bodies can be fabricated using the casting process
- Other benefits can be anticipated with castings
  - Customized material choice and component design, smaller order quantities, potentially lower lead-times
- ORNL has a history of successful development and collaborations on centrifugal cast components

ORNL Alumina Forming Austenitic tubes fabricated using centrifugal casting in air (ARPA- E OPEN 2015)

Furnace roll fabricated using centrifugal casting of ORNL alloy has been successfully operating in heat-treat furnace at 900°C for more than two years (ARPA- E OPEN 2015)
Centrifugal Casting of Smaller Vessels, Pipes, and Tubes Saves Manufacturing Cost Due to Reduced Steps

Cost savings and feasibility depends on size of tubing
Project Objectives

• Evaluate the feasibility of using a centrifugal casting process to lower manufacturing cost of piping fabricated using Ni-based alloys including Haynes®230, Haynes ® 282, or IN ® 740H

• Evaluate properties of cast and heat-treated alloys fabricated using this process
  • Investigate properties of alternate alloys with lower raw material costs

• Knowledge would be applicable to the design of piping, valve fittings, valve bodies along with those of turbo-machinery
Approach

• Fabricate laboratory scale castings, develop heat-treatment processes and measure high temperature mechanical properties
• Verify high temperature mechanical properties using small industrial scale castings and down-select alloys for centrifugal casting trials
• Fabricate pipes using centrifugal casting and verify that target properties are met
Summary of Various Castings Completed

Laboratory Scale

Industrial Scale

Centrifugal
Technical Accomplishments

• Centrifugal cast tube of Haynes ®230
Technical Accomplishments

• Centrifugal cast tube of Haynes ®282
Centrifugal Haynes® 282 Ingots Were Subject to Two-Step Aging Heat-Treatments

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Heat-treatment</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haynes® 282-HT3</td>
<td>Step #1: Homogenization: Ramp to 1093°C, hold for 8 hours, increase temperature to 1204°C, hold for 24 hours</td>
<td>Minimizes elemental segregation that occurred during solidification</td>
</tr>
<tr>
<td></td>
<td>Step #2: Solution anneal: 1149°C for 1 hour, water quench</td>
<td>Prepares material for aging treatment</td>
</tr>
<tr>
<td></td>
<td>Step #3: Aging: 1010°C for 2 hours in inert atmosphere, air cool</td>
<td>Two-step aging treatment for high strength</td>
</tr>
<tr>
<td></td>
<td>Step #4: Aging: 788°C for 8 hours, air cool</td>
<td></td>
</tr>
</tbody>
</table>
Microstructure of as-centrifugally cast Haynes® 282® Shows Dendritic Structure
Homogenization was Achieved in Centrifugally Cast Haynes®282

As-cast

As-cast + Homogenized+ Solution annealed + Two-Step aging
• Yield strength of centrifugal cast + heat-treated Haynes®282 > 80% of wrought

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Y. S. at 750°C (Ksi)</th>
<th>Y. S. at 800°C (Ksi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wrought Haynes®282</td>
<td>91.7</td>
<td>85.6</td>
</tr>
<tr>
<td>80% of Yield strength of wrought Haynes®282</td>
<td>73.3</td>
<td>68.5</td>
</tr>
</tbody>
</table>
LMP Plot Shows Creep Properties of Cast Haynes®282® Likely to Match or Exceed Wrought Haynes®282® at Expected Stress and Temperature Levels
Centrifugally cast material has been successfully welded.

- Tensile and creep properties are under evaluation