Collaborative support for supply chain development

A-USC Experience & a Perspective on Supply-Chain

John Shingledecker, Ph.D., FASM, Sr. Technical Executive
Dan Purdy, Sr. Technical Leader
EPRI

Innovation Network for Fusion Energy Workshop
co-host: Electric Power Research Institute (EPRI)
Fusion Industry Association (FIA)
Virtual: 12-2-2020
Supply Chain for Power Generation (new power plants)

Material Manufacturers
- Alloy Producers
- Forging, casting, tubing, piping, etc. fabricators houses

OEMs
- Major Components (Boilers, Turbines, Generators, Environmental Controls,...)
- Balance of Plant (Valves, etc.)

EPCs
- Piping design, subsystem integration, construction
- Field Fabrication, start-up, early operation, warranty

Utility
- Plant specifications
- Oversight

Shape – Fabrication via Established Production Routes

Components/Sub-Systems – Shop Fabrication

Systems/Plant – Field Fabrication

Operation
Supply Chain for Power Generation (replacement/modifications)

Material Manufacturers
- Alloy Producers
- Forging, casting, tubing, piping, etc. fabricators houses

OEMs
- Major Components (Boilers, Turbines, Generators, Environmental Controls,...)
- Balance of Plant (Valves, etc.)

EPCs or 3rd Parties
- Piping design, subsystem integration, construction
- Field Fabrication, start-up, early operation, warranty

Utility
- Plant specifications
- Oversight

EPRI’s main members are utilities, but in order to meet its mission, EPRI is involved in all aspects of the electricity supply chain to enable technology innovation.

Project Goal: Develop the materials technology to build and operate an A-USC Boiler & Turbine with steam conditions up to 760°C and 35MPa
Key program attributes – 15 year effort +

- Precompetitive R&D to enable technology advancement
- Collaboration – all U.S. Boiler & Turbine Manufacturers + National Lab Support + EPRI/EIO Leadership
- Supply chain engagement
Materials Limit the Current Technology:

State-of-the-Art (USC) are defined by steel technology → New Alloys Required for A-USC

Stress (MPa)

Average Temperature for Rupture in 100,000 hours (°C)

- 229 9-12Cr Creep-Strength Enhanced Ferritic Steels (Gr. 91, 92, 122)
- Nickel-Based Alloys
  - Inconel 740/740H
  - Haynes 282
- Advanced Austenitic Alloys (Super 304H, 347HFG, NF709, etc.)
  - Haynes 230

Average Temperature for Rupture in 100,000 hours (°F)

- Steel = USC 620°C (1150°F)
- Solid Soln' = A-USC ~700°C (1300°F)
- Age Hardenable = A-USC 760°C (1400°F)

Minimum Desired Strength at Application Temperature
Example of Tasks Completed

- General design studies show favorable economics
- Welding Technology Developments
- Fabrication Processes
- Steam-Side Oxidation
- Fireside Corrosion (In-Plant Testing)
- Turbine Component Scale-up

- Materials for A-USC Turbines (DOE): [link], [link]
- Boiler materials for A-USC (DOE) (final report)
Example Key Results: In-Plant Testing at 760°C (1400°F)
Operating Steam Corrosion Test Loop

- Initial research:
  - Extensive laboratory testing & air-cooled probes in boiler
  - Steam-cooled loop (high S coal)

- 2nd Steam Loop
  - World’s first steam loop operating at 760°C (1400°F)
  - Removed from service after 33 months with >16,000 hrs in operation
  - Evaluations = little to no wastage

Southern Company – Plant Barry

Materials include:
740H, CCA617, HR6W, Super 304H, Coating, Overlays, and Others

Fabrication in Alstom Chattanooga TN shop
Example: Boiler Fabrication Successes - Performed at 4 different manufacturing centers

- No significant changes to fabrication techniques were required
- R&D was used to make changes to ASME Section I Table PG-19
- Full-size laboratory testing
- Initial tests on Inconel 740 led to additional phase 2 work on cold-work effects on creep which was needed for the code case
Welding Successes

Original Inconel 740 weld trials (Liquation cracking in heat affected zone)

Today: Repeatable 3” (75mm) thick Inconel 740 welds without cracking

- 7 alloys, multiple processes, thin & thick section
- Over 20 combinations qualified
- Some processes eliminated
- New learning: modified weld metal chemistries, different fluxes, process selection, etc.
Understanding performance of weldments is critical to design and life management of future A-USC plants

*EPRI & ORNL Collaboration on data, metallurgy, etc.*

- Long-term creep testing of full-size weldments
- Development of Weld Strength Reduction Factors

Metallurgical failure analysis of 38mm (1.5”) thick CCA617 Weldment Creep Samples

Comparison of long-term creep test on CCA617 with various welding processes showing WSRFs
Code Case 2702 (Inconel®740H) now Approved for Use in Section I and B31.1
Case developed collaboratively

- Maximum Use Temperature: 800°C (1472°F)
- Rules for:
  - Chemistry
  - Heat-treatment
  - Welding
  - Post-weld heat-treatment
  - Cold-forming
  - Weld strength reduction factors

Larger forging window for Inconel 740H compared to CCA617 = longer pipes or larger possible diameters
Casting scale-up and turbine casing welding has progressed with supply chain development

**Supply Chain Engagement: 3 Foundries Qualified**

- **Haynes 282** centrifugal casting: 635kg (1,400lbs)
- Long-term creep of weldments & microstructural assessment

**Haynes 282** and **Alloy 263** Step Castings 135-450kg sizes (300 to 1,000 lbs)

Simulated casting weld defect repair

740H Pipe to 282 Casting Weld

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Modeling and Large-Scale Casting Development: Worlds Largest 282 Casting

- Casting simulation developed
- Cooling rate and secondary dendrite arm spacing predictions validated
- Modeling used to design valve body casting

~2700kg (6,000lb) ½ Valve body
(simulate full-size valve)
Casting successful Nov. 2014 (17,500lb pour)
What now? – ComTest Phase II (2019-2021)

- ‘Final Hurdle’ in supply chain readiness and demonstration
  - Full Size Components + Testing
  - New/alternative fabricators/suppliers → industry transition

- **Boiler SH/RH/Header Assembly**

- **Turbine Casing**: Nozzle Carrier (4X compared to valve body)

- **Turbine rotor forging** (largest possible ingot size)

- **Codes**: pressure relief valve
A-USC Materials Enables New sCO2 Power Cycles

Sunshot (SwRI) 1MWe 700C+ sCO2 Test Loop

<table>
<thead>
<tr>
<th></th>
<th>Recuperator Outlet/Heater Inlet</th>
<th>Heater Outlet/Turbine Inlet</th>
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<tbody>
<tr>
<td>Temperature</td>
<td>470°C</td>
<td>715°C</td>
</tr>
<tr>
<td>Pressure</td>
<td>251.9 bar</td>
<td>250.9 bar</td>
</tr>
<tr>
<td>Mass flow rate of CO₂</td>
<td>8.410 kg/s</td>
<td>8.410 kg/s</td>
</tr>
</tbody>
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Alloy 740H Piping & Components for sCO2 Application

Moore et al., sco2symposium.com

deBarbadillo et al., sco2symposium.com

A-USC Alloys (Alloy 740H) being used in heaters, piping, and components for sCO2 Demos
Lowering Costs: Collaborative Work on Concentrating Solar Power (CSP) – Gen3 Developments

Manufacturing & Supply Chain

Plate

Welded Tube

Re-drawn tube

Coil

Seam-welded pipe

Induction Bending

High-Temperature Testing & Analysis

- Relevant testing product forms (welded structures)
- New testing capabilities (multiaxial)
Convergence of technologies with complimentary needs

- Common conditions across multiple advanced power generation technologies:
  - Supercritical steam or CO2 power cycles
  - Molten salt heat-transfer and thermal energy storage
  - Temperatures >700°C
  - Introduction of innovative technologies (e.g. high efficiency heat exchangers, advanced manufacturing)

- Materials & Manufacturing are the enabling technology for all these new technologies
Summary

- Developing a supply chain for a new industry and technology will take collaboration and innovation

- Collaboration:
  - Projects which engage the entire supply chain which may include competitors (e.g. A-USC)
  - Leverage work across multiple technologies (e.g. synergies between solar-fossil-nuclear)

- Innovation:
  - New materials
  - New manufacturing

Investor and end-user acceptance and cost will only be achieved through pro-active and sustained supply chain engagement
Together...Shaping the Future of Electricity