FEAA133-Low Cost High Performance Austenitic Stainless Steels for A-USC

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- **EPRI**: Scott Bailey for the welding support
Background (1/3)

- **CF8C-Plus** is a heat- and corrosion-resistant cast austenitic stainless steel developed by the Oak Ridge National Laboratory and the Caterpillar Technical Center.

### Composition (wt%)

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<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>Cr</th>
<th>Mo</th>
<th>Ni</th>
<th>Nb</th>
<th>N</th>
<th>Fe</th>
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<tr>
<td>CF8C-Plus</td>
<td>0.08</td>
<td>0.5</td>
<td>4.0</td>
<td>19.0</td>
<td>0.3</td>
<td>12.5</td>
<td>0.80</td>
<td>0.25</td>
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<tr>
<td>CF8C</td>
<td>0.1</td>
<td>1.0</td>
<td>1.0 max</td>
<td>19.0</td>
<td>0.3</td>
<td>10</td>
<td>0.80</td>
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As-cast microstructure: **CF8C (left) & CF8C-Plus (right)**

Nanoscale NbC precipitates in CF8C-Plus (courtesy of EPRI)

Shingledecker et al., Energy Materials 2006
Background (2/3)

- CF8C-Plus shows unique combination of high temperature mechanical properties, corrosion resistance, castability, and weldability

- Moreover, the strength advantages are found in the as-cast condition without additional heat-treatment

CF8C-Plus offers a bridge between 9-12Cr CSEF steels and nickel-based alloys (courtesy of EPRI)

CF8C-Plus shows better corrosion resistance in 700°C humid air than 347HFG

Maziasz and Pint, J ENG GAS TURB POWER, 2011
Background (3/3)

- CF8C-Plus offers impressive economic advantage over other AUSC candidate materials for the temperature range of 600-700°C

Material price per foot to withstand 24MPa steam pressure at designated temperatures

**Objective**: create *cast (ORNL lead)* and *wrought (EPRI lead)* CF8C-Plus data packages and pursue ASME code case approvals

- Perform welding of cast CF8C-Plus and obtain tensile and creep data from the weld
- Complete the ASME code case data package for the cast CF8C-Plus
- Produce a 5th heat of wrought CF8C-Plus; evaluate the microstructure induced by processing and how it affects the creep rupture strength; conduct tensile, creep rupture, and welding necessary to support a code case data package

Caterpillar regeneration system housing exhaust component using CF8C-Plus, 550 tons cast made from 2006 - 2011

A 6,700 lbs gas-turbine end-cover component made with cast CF8C-Plus (Maziasz et al., J PRESS VESS-T ASME, 2009)
<table>
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<tr>
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<th>2019</th>
<th>2020</th>
<th>2021</th>
<th>2022</th>
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Completed milestones
Ongoing milestones
Cast CF8C-Plus Code Case Application Update*

*95% of the code case data completed with funds from the American Recovery and Reinvestment Act
Tensile Strength

- 51 tensile tests have been performed from 22 to 871°C for three heats of materials
- ASME Sec. II Part D subpart 1 interim yield and tensile strength values have been determined
Conventional solution annealing temperature, i.e., 1100 and 1200 °C, did not result in any softening in cast CF8C-Plus
Creep Life

- 104 creep tests previously performed from 482 to 871°C for three heats of materials accumulating 457,403 hrs (~52 yrs)

- The ASME interim maximum allowable stress values have been calculated by ORNL and, more importantly, by appropriate members of ASME subcommittee
Additional Weld Testing in Support of Cast CF8C-Plus Code Case

- Completed weld fabrication (led by EPRI) and weld qualification (led by ORNL) of a new CF8C-Plus shield metal arc weld (SMAW) made with alloy 117 filler metal
- Specimens have been machined and will be tested to provide weld tensile and creep data

Cross-section view of SMAW of CF8C-Plus

Machining of cross-weld specimens

Machined tensile and bend bar specimens for weld qualification
Code Case Status (ASME Sec I Power Boilers)

1. Obtain record number #
2. Develop proposal for a new code case in ASME BPV – Section I of the code
3. ASME SC I SubGroup Materials request approval
4. Submit proposal to SC II SubGroup Strength of Ferrous Alloy
5. SC II SubGroup Strength of Ferrous Alloy ballot
6. SC II & IX SubGroup Strength of Weldments ballot
7. SC II SubGroups Physical Properties and Ferrous Specification ballot
8. SC II & IX Subcommittee approval
9. SC I SubGroup Materials ballot
10. ASME SC I ballot and approval
11. ASME board level approval
12. Code case number issued
Wrought CF8C-Plus Development Status Update
Wrought CF8C-Plus for Power Piping

Materials technology drives higher temperature operation as well as more flexibility (through thin-walled components)

Supports piping upgrades in all extreme environments
  - Gen IV Nuclear, advanced HRSGs, AUSC conditions, sCO2 plants, concentrated solar, etc.

Develop wrought form of the cast advanced stainless steel, CF8C-Plus

Progress the demonstration from feasibility to commercial readiness
  - Provide data package for the ASME Code Case

Initial development and demonstration evaluated forged, extruded, and powder metallurgy components

Extensive microstructure characterization in 2016 led to recommended optimized chemistry for the wrought product
Timeline of Previous EPRI Work on Wrought CF8C-Plus

2009
Carpenter produced 188 kg VIM heat
Open-die forged 5:1 and 12:1

2011
Special Metals produced two 472 kg VIM heats
Extruded to pipes >130 mmØ

2016
Carpenter produced 4th 2800 kg powder metallurgy heat
Wyman-Gordon extruded 400 mmØ pipe

2017
Detailed SEM and TEM microscopy of precipitates following mechanical testing

2020
This project with ORNL kicks off to produce 5th heat and ASME code case

2021
Produce large ESR heat
Optimize Chemistry
Process mapping
Mechanical characterization

Manufacturing Studies of a High-Temperature Stainless Steel (2017)
EPRI Report 3002009212
Tasks and Timeline

- **2021 1st half**
  - Produce a new ingot using conventional manufacturing
    - Full-scale, commercial 10-ton ingot by Carpenter in March
    - Electroslag remelting completed in April
    - Extrusion of 6,000 lbs will follow in June, producing 400 mm OD x 38 mm wall thickness pipe

- **2021 2nd half**
  - Pipe heat treatment optimization
    - Includes demonstration via short-term mechanical testing
    - Emphasis on post-test microstructural analysis
    - Gleeble-based study to understand the influence of processing on microstructure

- **End of 2021**
  - Long-term mechanical testing
    - Provide input to ASME code case and ASTM spec. based on existing database
  - Remainder of pipe will undergo quality heat treatment

- **2022**
Gleeble-based Study for Thermomechanical Properties

- Gleeble used for optimal solutionizing heat treatment and modeling high temperature extrusion
  - Effect of increased solutionizing temperature on NbC precipitates
  - Impact of high temperature deformation (50% stretch)
  - Elevated temperature iso-stress test (“mock-creep test”)

- Key microstructural parameters to monitor across these tests
  a) All solutionizing (15 min) dissolved fine (<50 nm) NbC precipitates with no impact to larger precipitates
  b) The mock-creep test showed precipitation of fine precipitates in all samples
     • No significant differences across samples with different solutionizing temperature
  c) High temperature deformation appears to instigate nonuniform precipitation, or increases the driving force such that precipitation occurs on cool-down (<5 minutes)
Conclusions

- Advancing commercial readiness for cast and wrought advanced stainless steel CF8C-Plus
- Engaging U.S. supply chain to produce representative parts
- Significant progress in the preparation of ASME code case for cast CF8C-Plus
- Chemistry- and processing-optimized extruded material follows on-schedule
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