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

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2021 Crosscutting Research and Advanced Energy System Project Review Meeting
High Performance Materials Program
June 3, 2021

Acknowledgement

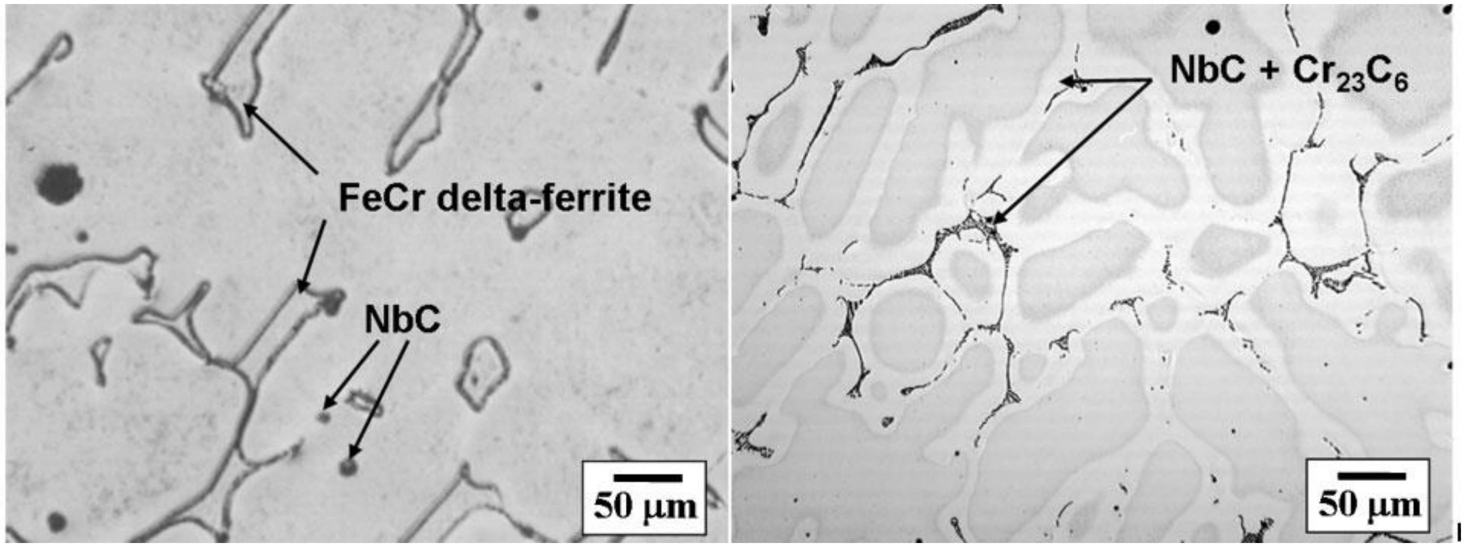
- This material is based upon work supported by the Department of Energy Award Number **DE-FEAA133**
- **NETL: Michael Fasouletos and Briggs White** for the programmatic support.
- **ORNL: Eric Manneschmidt, Jeremy Moser, Shane Hawkins, Kelsey Hedrick, Rick Lowden, Doug Kyle, and Doug Stringfield** for the technical assistance
- **EPRI: Scott Bailey** for the welding support

Background (1/3)

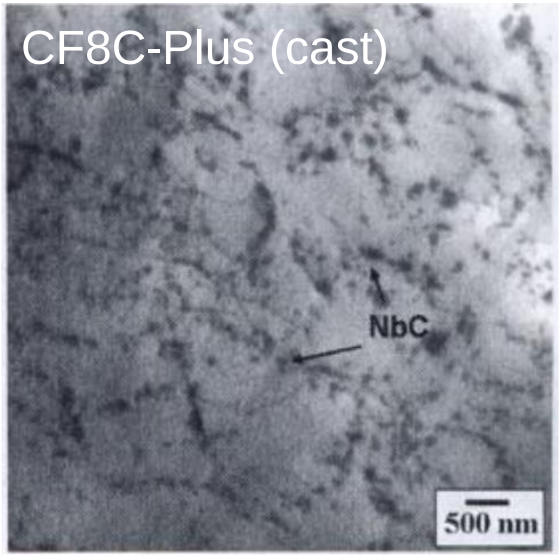
- **CF8C-Plus** is a heat- and corrosion-resistant cast austenitic stainless steel developed by the Oak Ridge National Laboratory and the Caterpillar Technical Center

Composition (wt%)

	C	Si	Mn	Cr	Mo	Ni	Nb	N	Fe
CF8C-Plus	**0.08**	**0.5**	**4.0**	**19.0**	**0.3**	**12.5**	**0.80**	**0.25**	**Bal**
CF8C	0.1	1.0	1.0 max	19.0	0.3	10	0.80	-	Bal



As-cast microstructure: ***CF8C (left) & CF8C-Plus (right)***

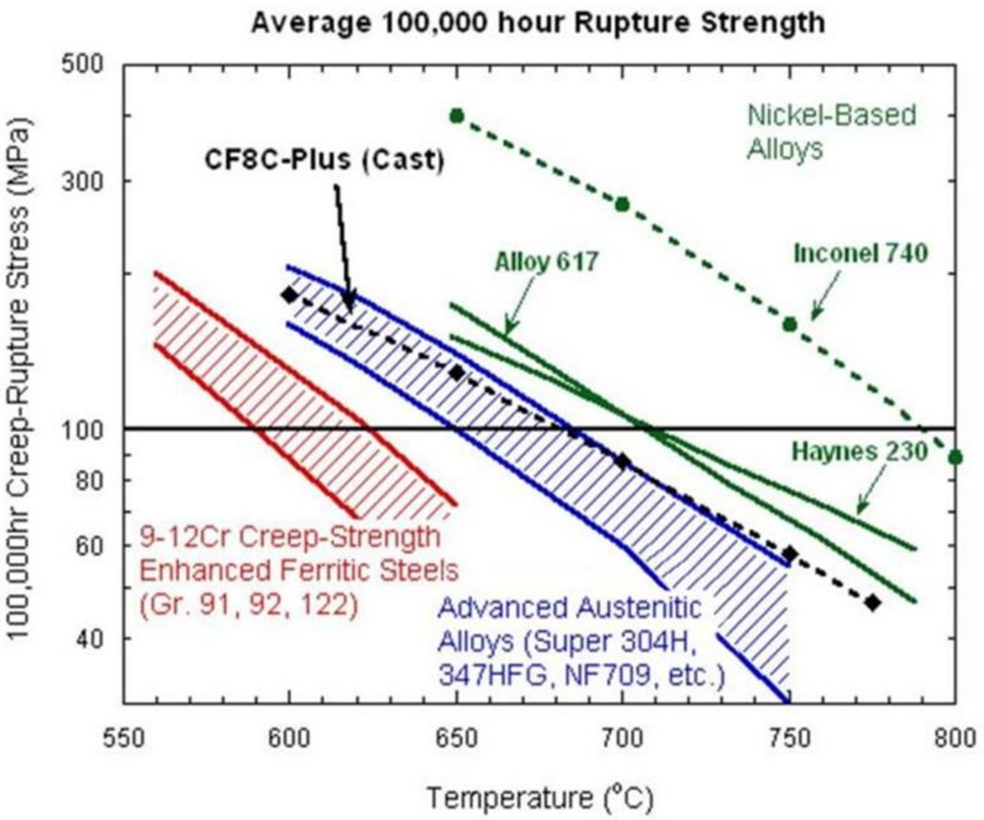


Nanoscale NbC precipitates in CF8C-Plus (courtesy of EPRI)

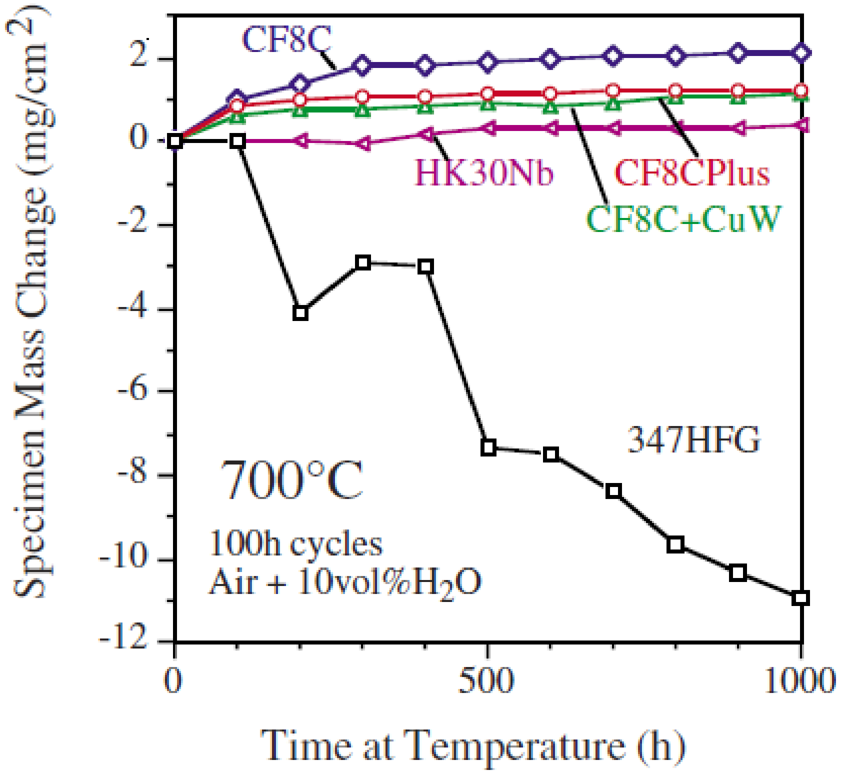
Shingledecker et al., Energy Materials 2006

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)

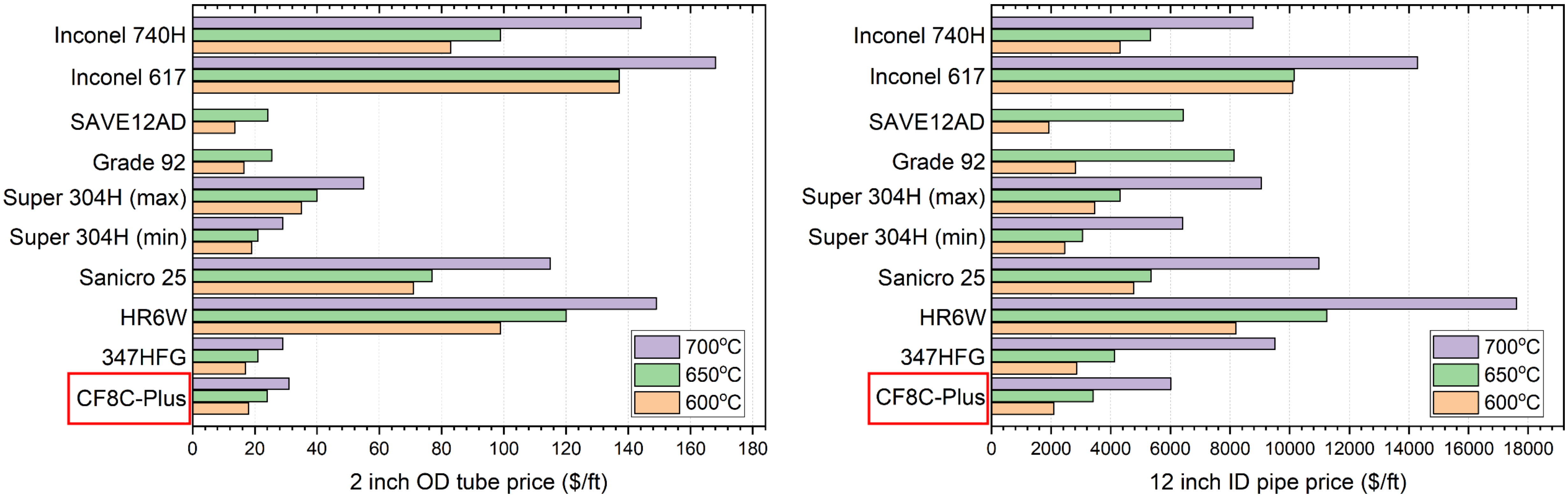


CF8C-Plus shows better corrosion resistance in 700°C humid air than 347HFG

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

X. Chen, E. Lara-Curzio, Reanalysis of Cost and Moist Air Oxidation Performance for CF8C-Plus and Other Alloys for AUSC Applications, ORNL/TM-2021/1943, https://www.osti.gov/biblio/1782110

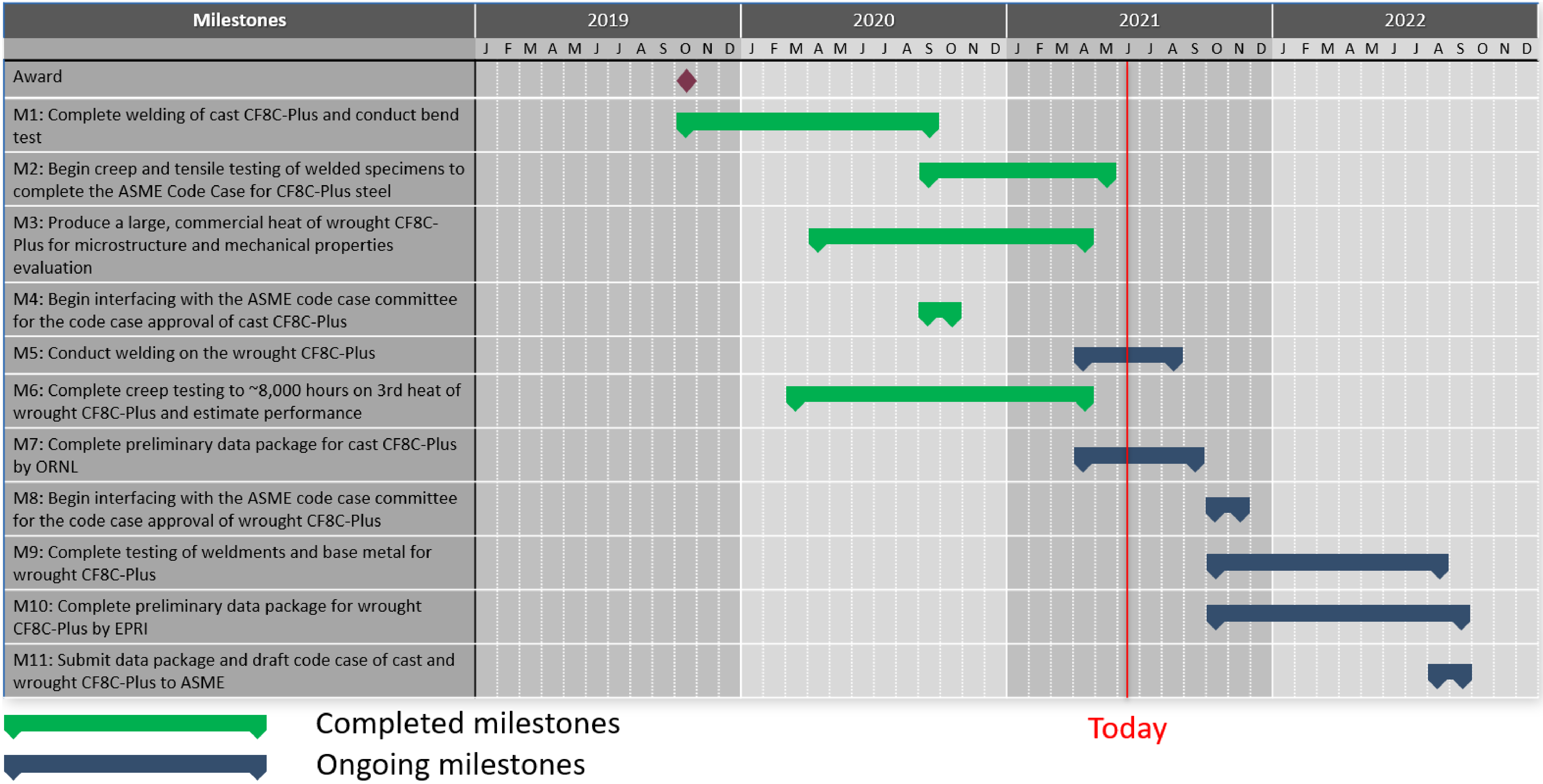
Objective: create cast (ORNL lead) and wrought (EPRI lead) CF8C-Plus data packages and pursue ASME code case approvals

- 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)

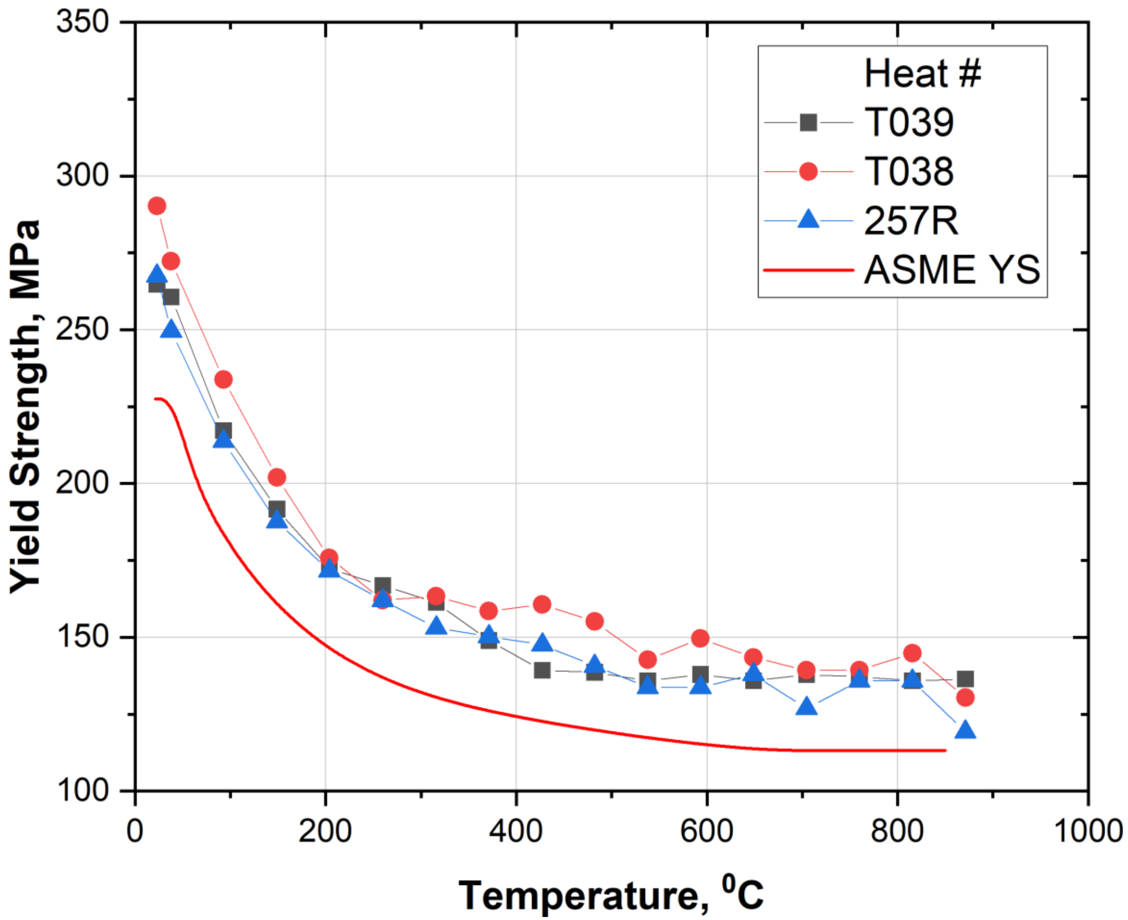
Milestone Status

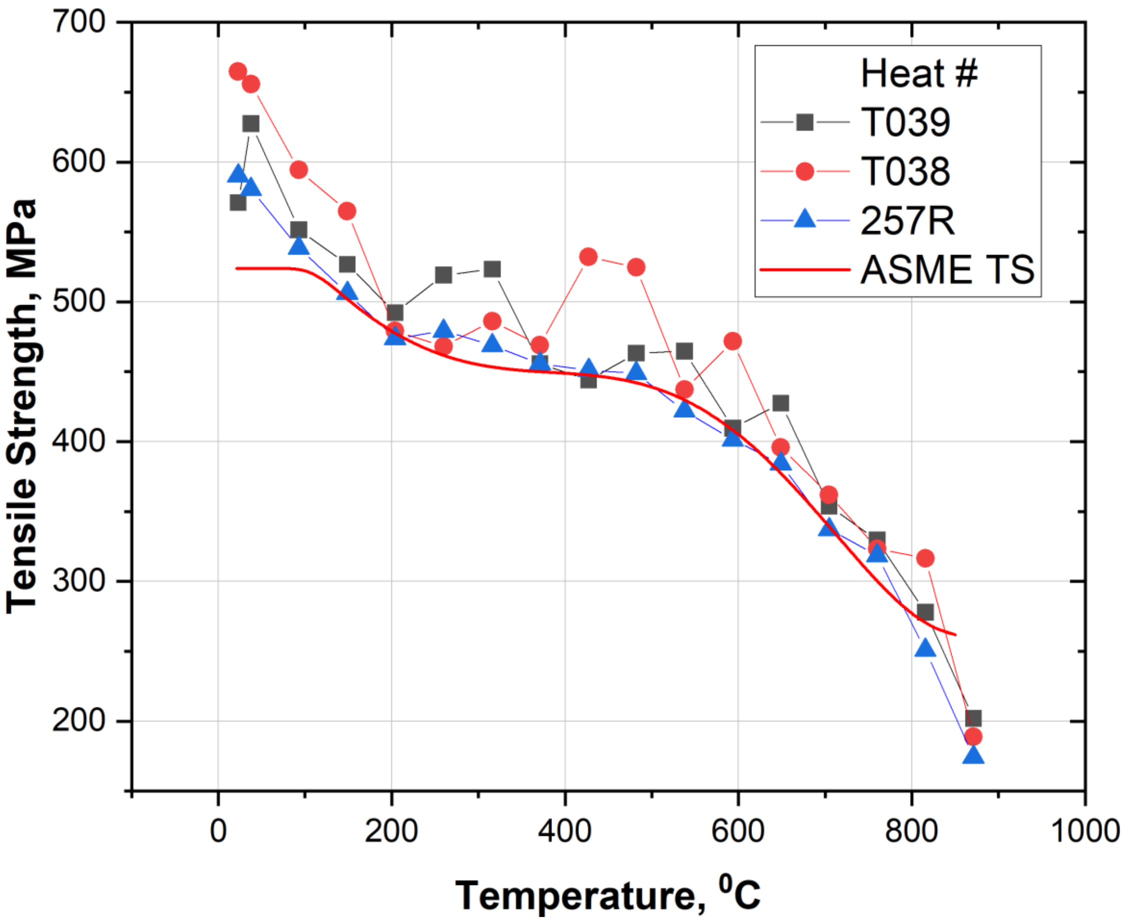


Cast CF8C-Plus Code Case Application Update*

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

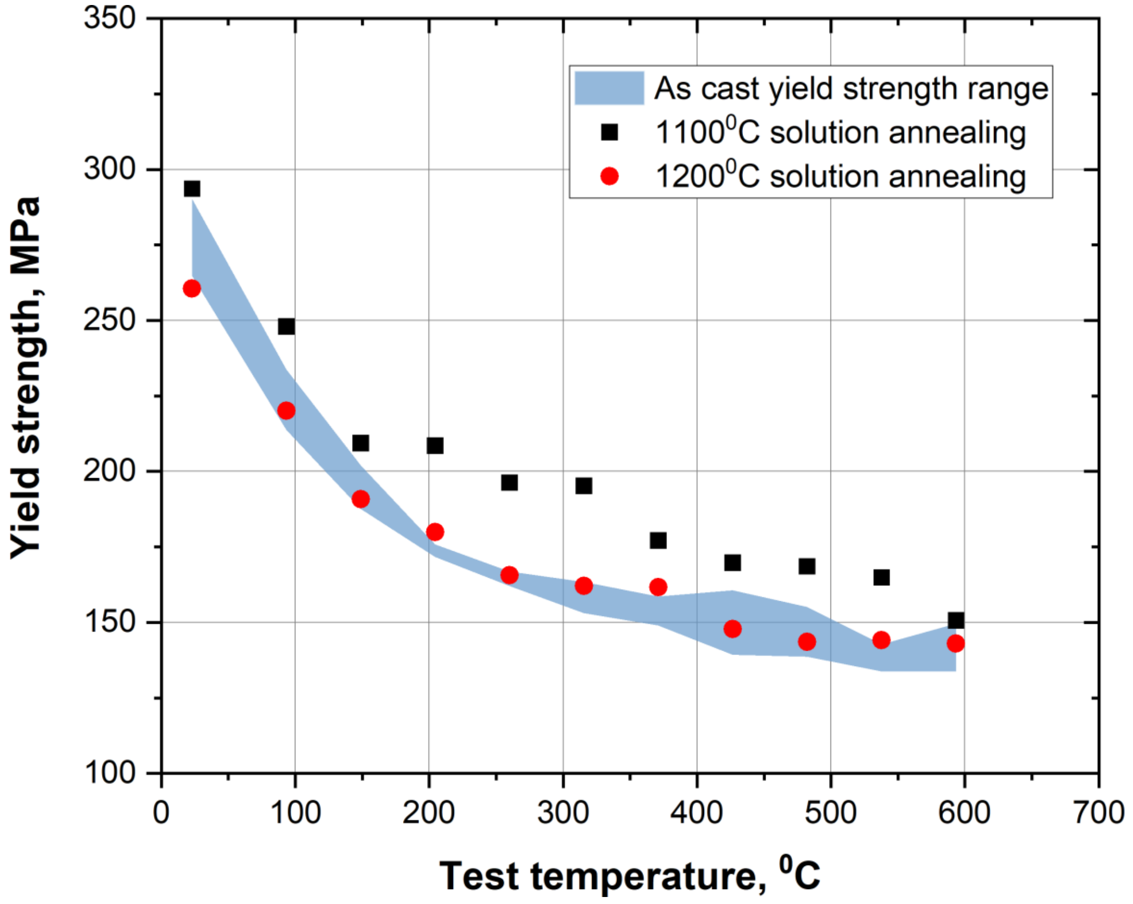
Tensile Strength

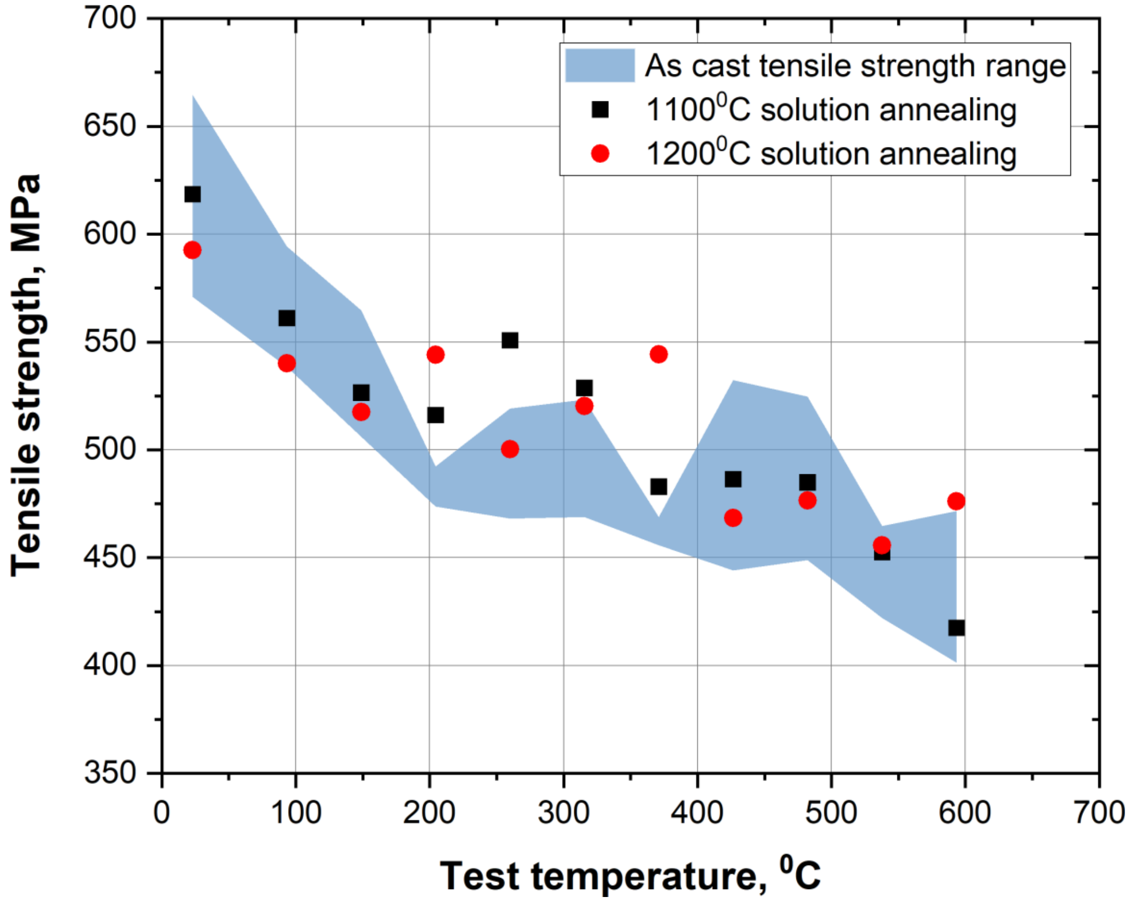




- 51 tensile tests have been performed from 22 to 871°C for three heats of materials
- ASME Sec. II Part D subpart 1 interim yield and tensile strength values have been determined

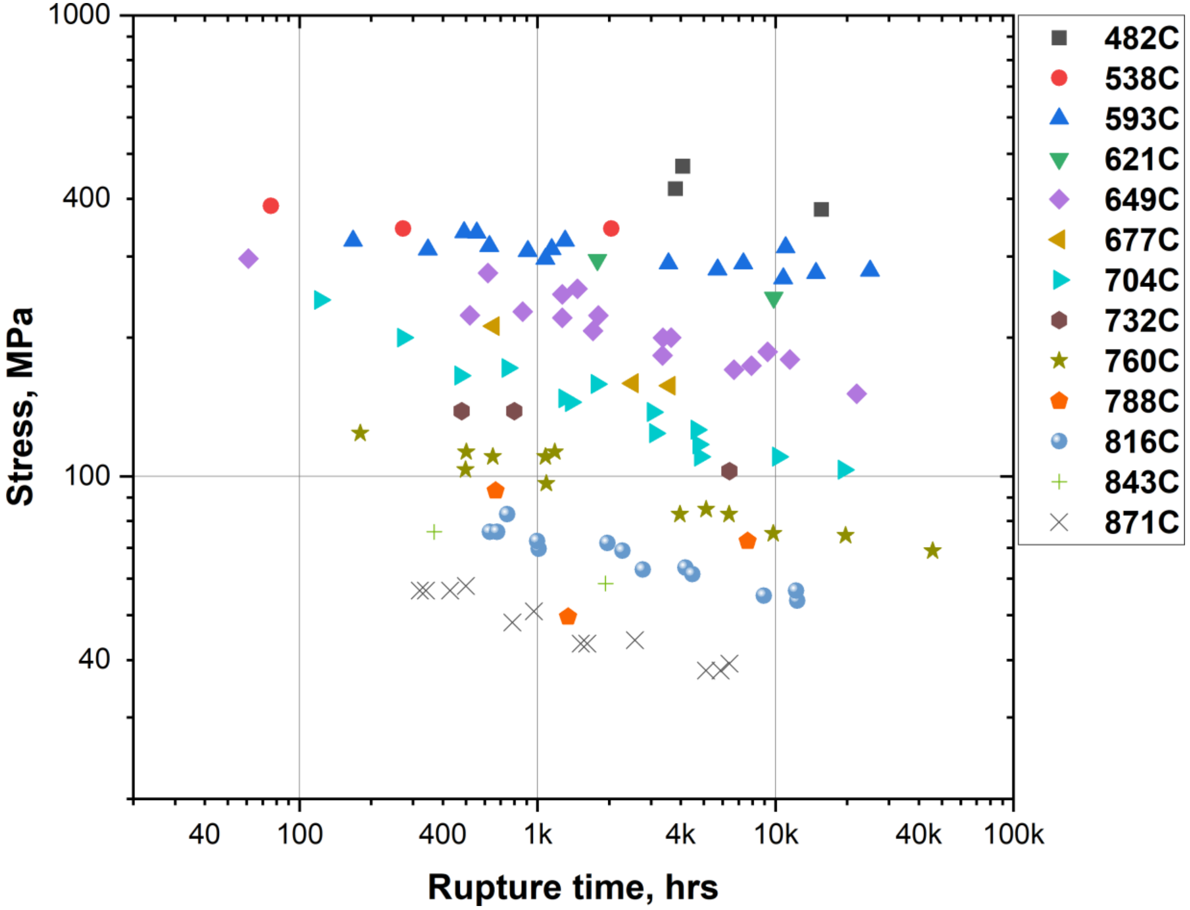
Effect of Solution Annealing on Tensile Strength

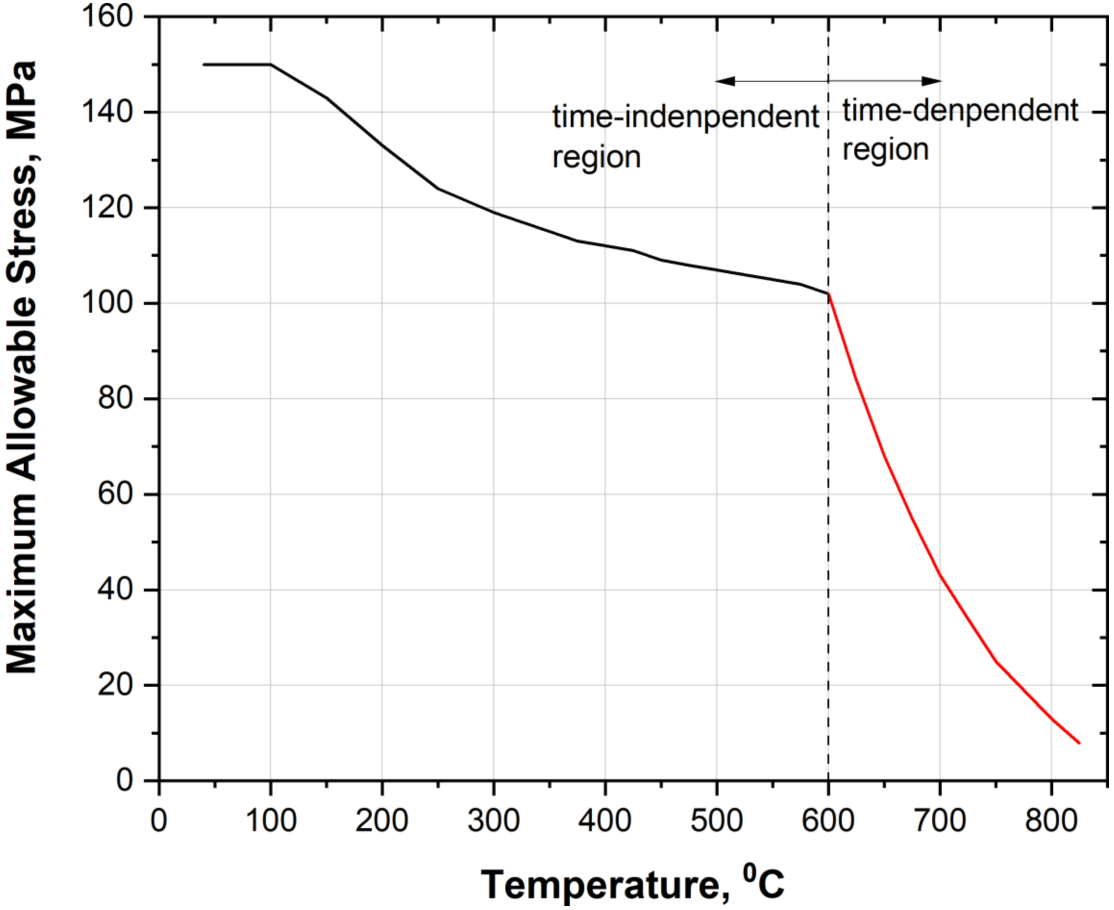




- Conventional solution annealing temperature, i.e., 1100 and 1200 °C, did not result in any softening in cast CF8C-Plus

Creep Life



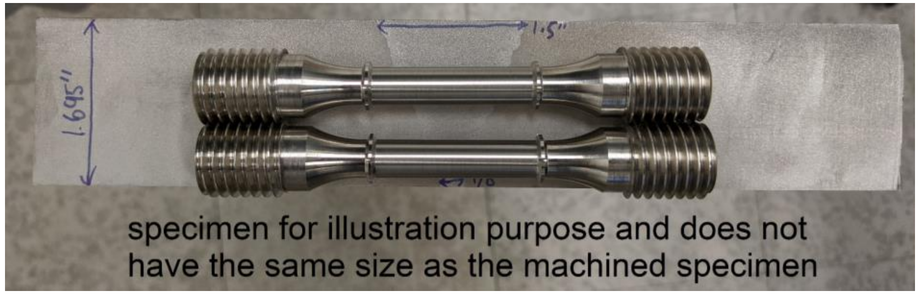


- 104 creep tests previously performed from 482 to 871°C for three heats of materials accumulating 457,403 hrs (**~52 yrs**)
- The ASME interim maximum allowable stress values have been calculated by ORNL and, more importantly, by appropriate members of ASME subcommittee

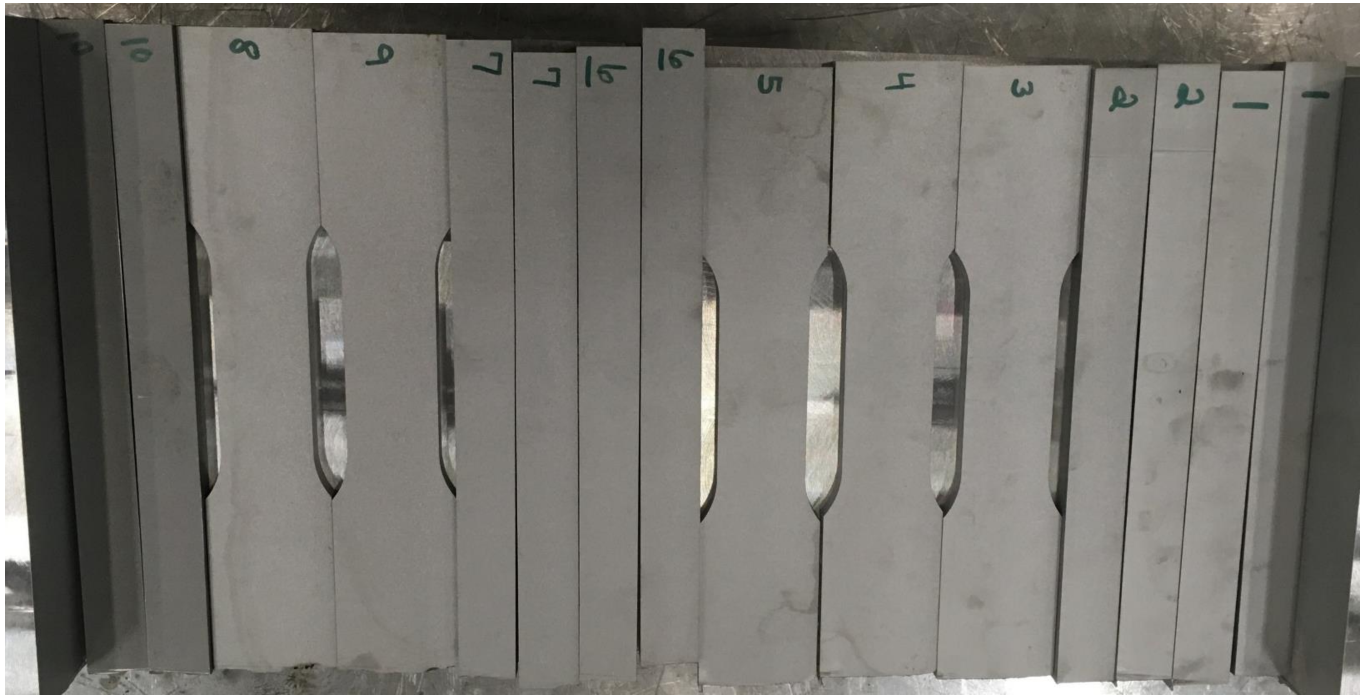
Additional Weld Testing in Support of Cast CF8C-Plus Code Case

- 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)

Start

- Obtain record number #
- Develop proposal for a new code case in ASME BPV – Section I of the code
- ASME SC I SubGroup Materials request approval
- Submit proposal to SC II SubGroup Strength of Ferrous Alloy
- SC II SubGroup Strength of Ferrous Alloy ballot
- SC II & IX SubGroup Strength of Weldments ballot
- SC II SubGroups Physical Properties and Ferrous Specification ballot
- SC II & IX Subcommittee approval
- SC I SubGroup Materials ballot
- ASME SC I ballot and approval
- ASME board level approval
- Code case number issued

Finish

Current state (SC II SubGroup Strength of Ferrous Alloy ballot; SC II & IX SubGroup Strength of Weldments ballot; SC II SubGroups Physical Properties and Ferrous Specification ballot)

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)

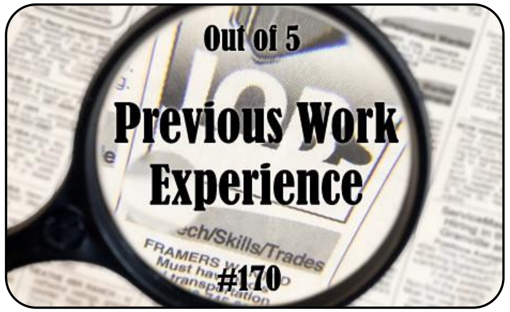
Supports piping upgrades in all extreme environments

- 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



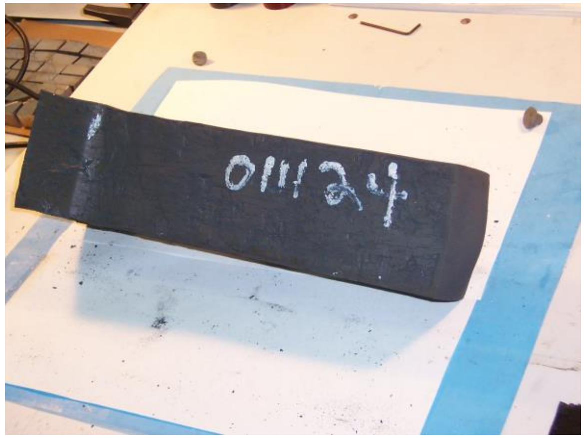
Initial development and demonstration evaluated forged, extruded, and powder metallurgy components

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

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

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

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

Remainder of pipe will undergo quality heat treatment

2022

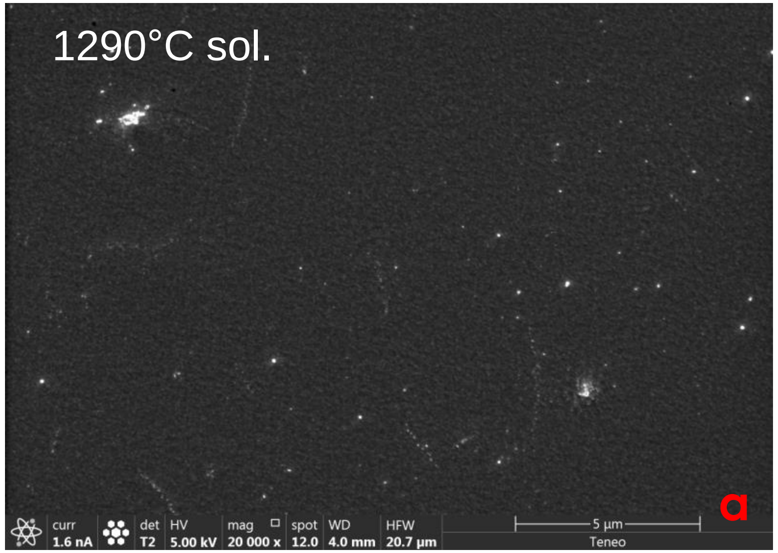
Long-term mechanical testing

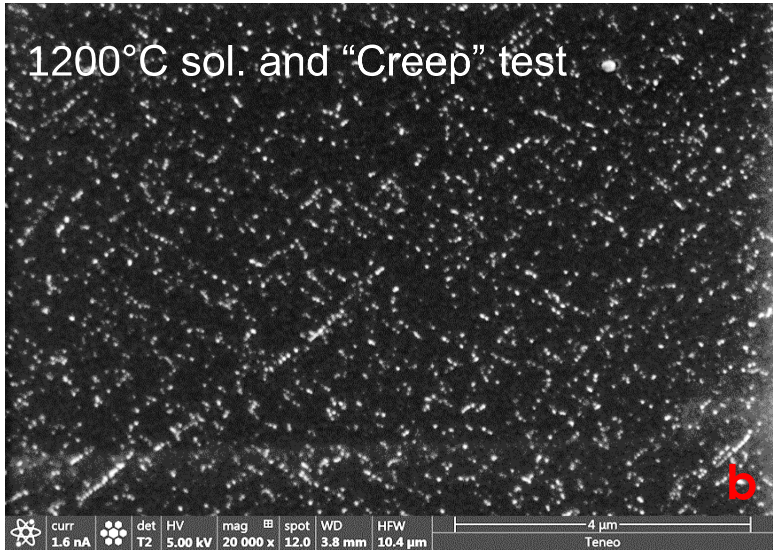
- Provide input to ASME code case and ASTM spec. based on existing database

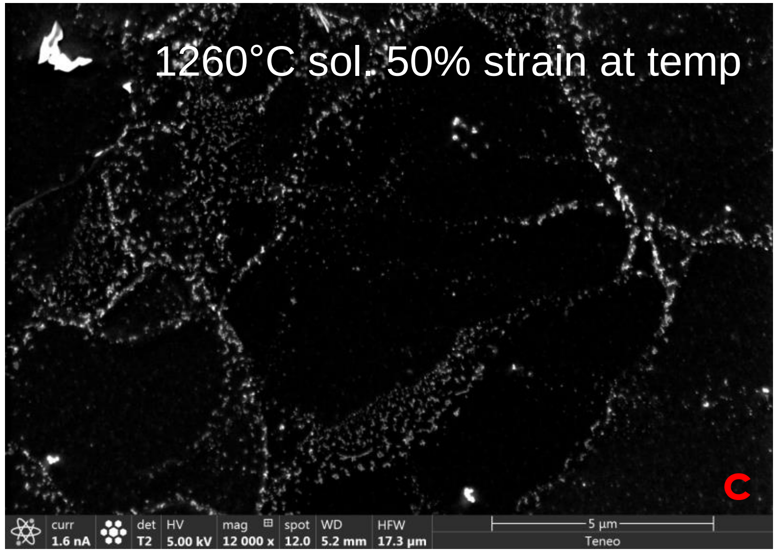
Gleeble-based Study for Thermomechanical Properties

- 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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