A Comprehensive Overview of the United States Advanced Ultrasupercritical (USC) Materials Research Program

Robert Romanosky – Crosscutting Research Technology Manager

IEA Clean Coal Centre Workshop: Advanced USC Coal-Fired Power Plants Workshop

September 19-20, 2012 ,
Vienna, Austria

U.S. Program on Advanced Ultrasupercritical Power Plant Materials

U.S. DEPARTMENT OF ENERGY

Ohio Department of Development

NETL

Federal – State – National Laboratory
Non Profit – For Profit
Cost Sharing Consortium

Energy Industries Of Ohio

ALSTOM

B&W power generation group

EPRI ELECTRIC POWER RESEARCH INSTITUTE

FOSTER WHEELER

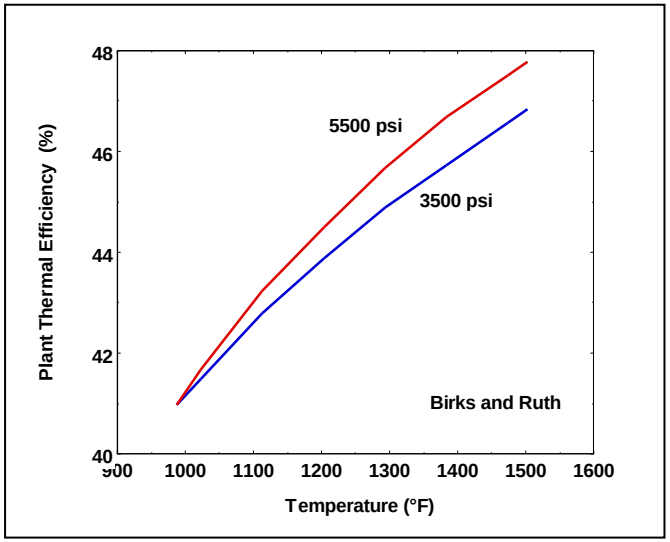
GE Energy

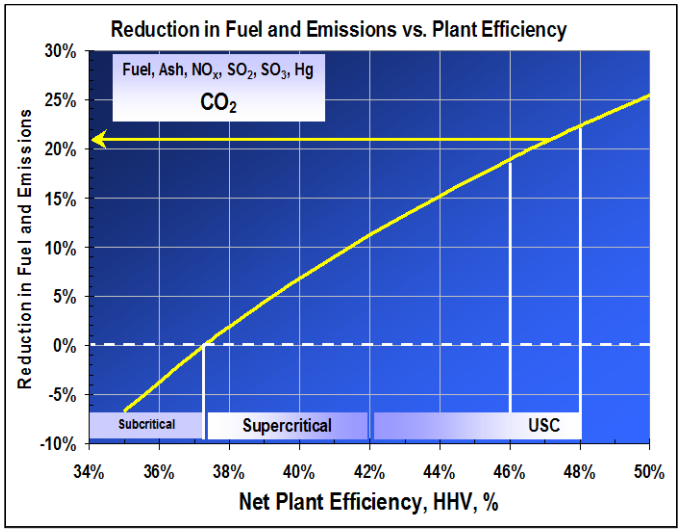
RileyPower

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

"Advanced" Ultra Supercritical Power Plant

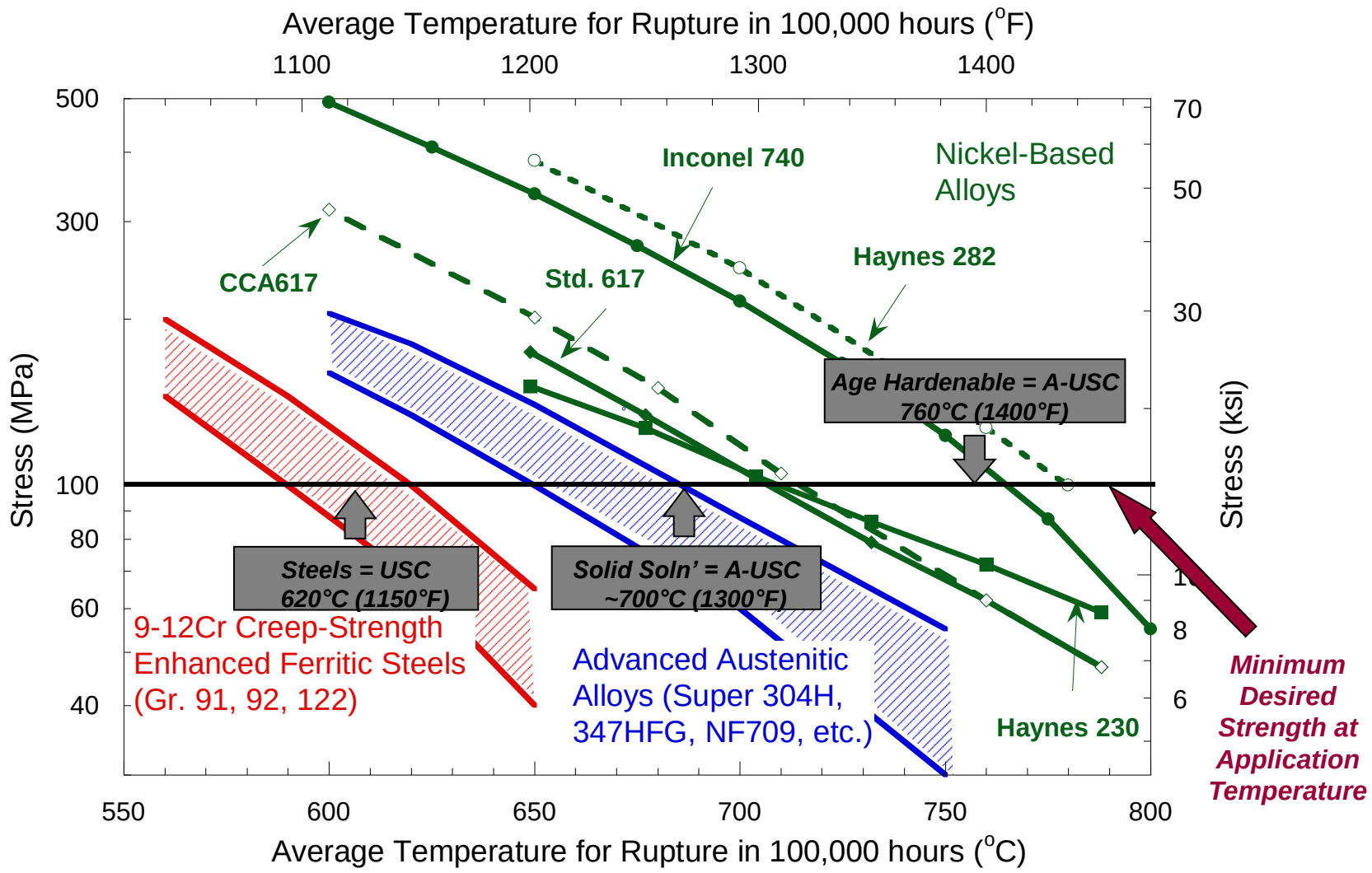
Operating up to 5,000 psi and 1,400 °F





- *Ultrasupercritical (USC) DOE goal for higher efficiency and much lower emissions, materials capable of:*
  - *760 °C (1400 °F)*
  - *5,000 psi*
  - *Oxygen firing*
- *Plant efficiency can be improved to 45-47 % Ultrasupercritical (USC)*
- *CO_2 Emissions are reduced by 15 to 22%*
- *Lower balance of plant cost means smaller coal handling and pollution controls for the same net plant output*
- *Meeting these targets requires:*
  - *The use of new materials*
  - *Novel uses of existing materials*

Materials Limit the Current Technology



Why 1400°F (760°C)? Best Approach to Achieving Good Economics

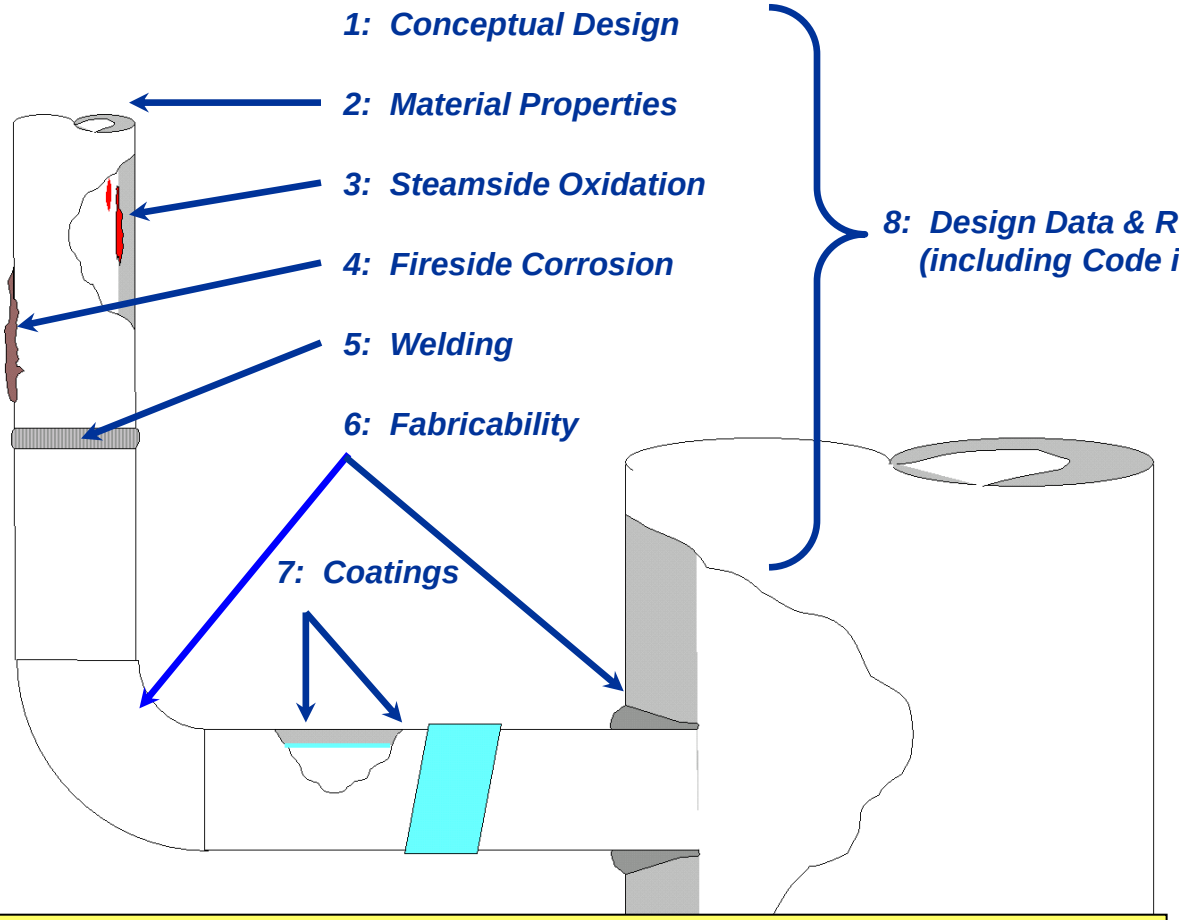
- Materials will limit the maximum achievable temperature
- Economics will dictate the optimum temperature
- For Example: a material suitable for 1400°F will have economic advantages at 1300°F over other materials because components will have *thinner walls*
  - Lower weight = lower material cost
  - Thinner sections = easier to weld/erect
  - Reduced thermal gradients = improved cycling

If you have to pay for nickel, make the most of it!

Primary Technical Goals of US A-USC Materials Programs

- **Materials Technology Evaluation**
  - Focus on **nickel-based alloys**
  - Development of fabrication and joining technology for new alloys
- **Unique Conditions for US Program Considerations**
  - Higher-temperatures than European Program (760°C versus 700°C) means **additional alloys** are being evaluated
  - Corrosion resistance for **US coals**
  - Data for **ASME code** acceptance of new materials
  - Phase II Boiler work includes **Oxycombustion**

U.S. DOE/OCDO: A-USC Steam Boiler Consortium



Develop the materials technology to fabricate and operate a A-USC Steam Boiler with Steam Parameter up to 1400°F (760°C)

U.S. DEPARTMENT OF ENERGY

MAKING OHIO COAL THE CLEAN CHOICE

Energy Industries Of Ohio

B&W

NETL

EPRI ELECTRIC POWER RESEARCH INSTITUTE

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

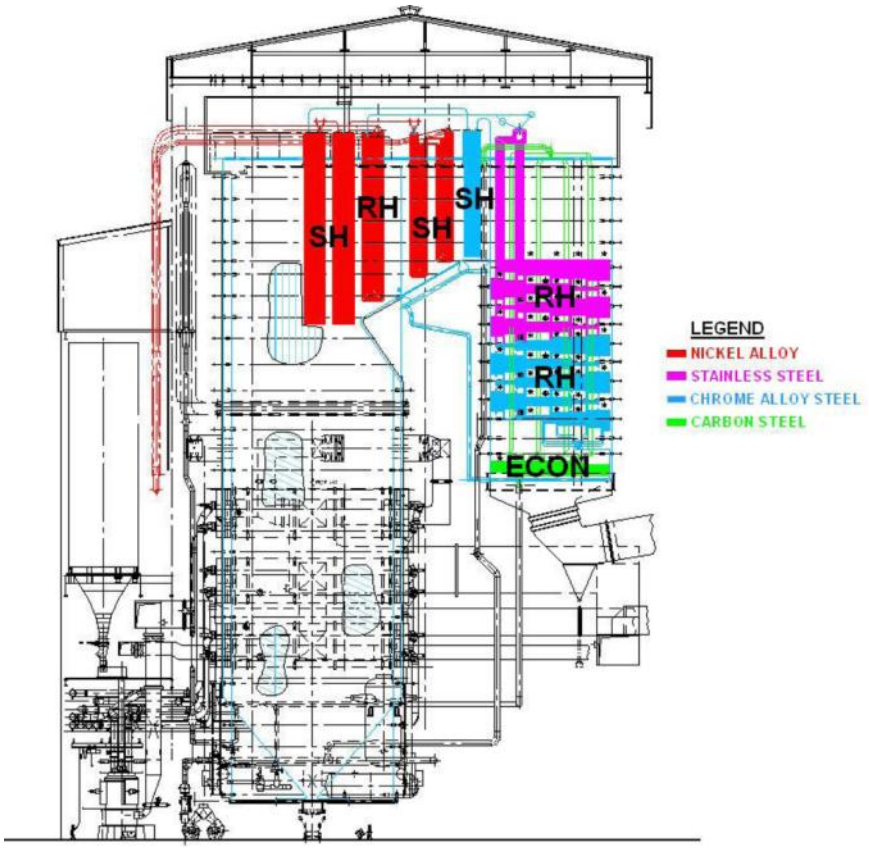
RILEYPower
A Babcock Power Inc. Company

ALSTOM

FOSTER WHEELER

A-USC Steam Boiler Highlight:
A-USC + Oxycombustion Design

- 1 OEM Design Completed
- Air vs. Oxy. Case Considered (no capture)
- Efficiency (HHV) drops by 9.3 points = ~21% relative drop
- No major change in materials selection for Air vs. Oxy.
- Future Work:
  - 2 other OEM designs in process

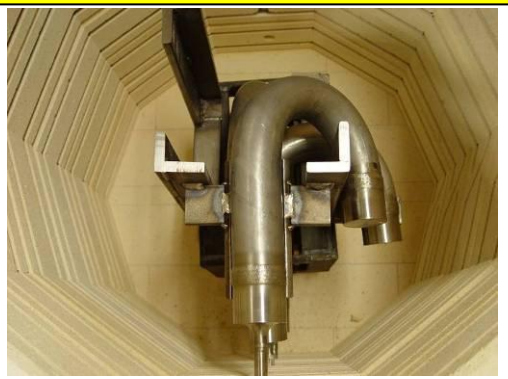


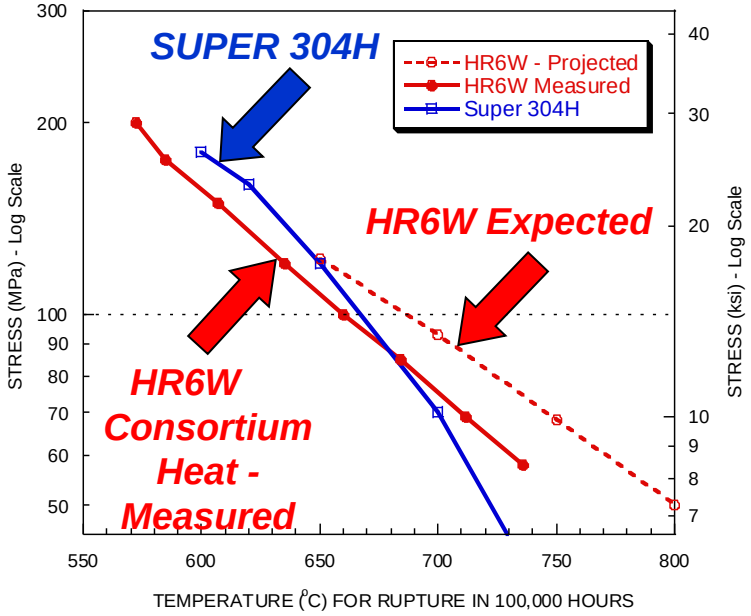
Conceptual Material Layout: 730C/760C/35MPa A-USC courtesy: ALSTOM Power

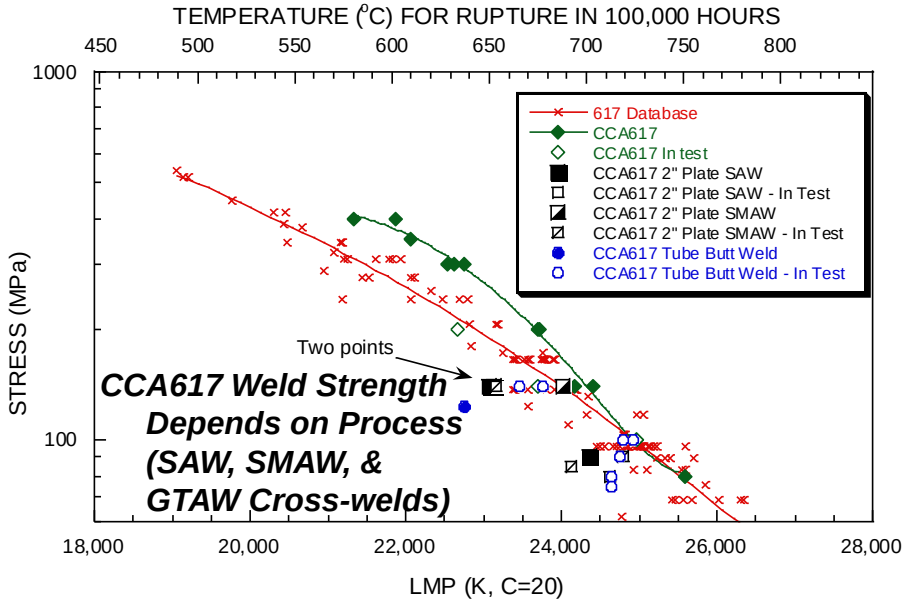
Task 2: Mechanical Properties

- Long-term creep-rupture strength
- Strength and behavior weldments
- Code approval activities for new alloys
- Fabrication effects on material reliability

Pressurized creep-rupture test of tube bends







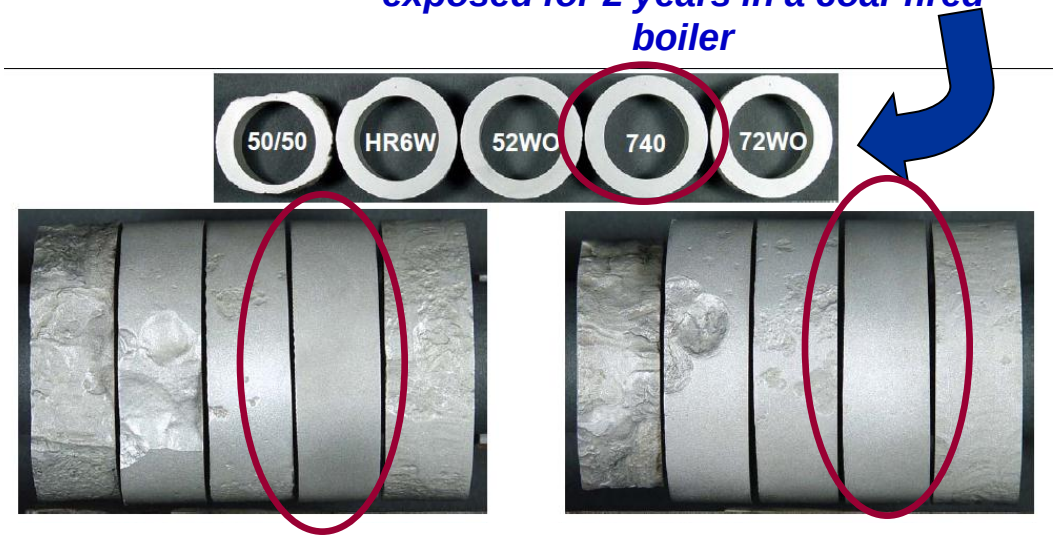
Task 3: Steamside Oxidation

- Laboratory steamside oxidation testing of various alloys and coatings
- Initial testing has been completed allowing relative ranking of materials
- Continued testing:
  - Long-term testing to verify kinetic data
  - Limiting behavior due to exfoliation of oxide scale as opposed to oxide growth rates

Task 4: Fireside Corrosion

- Fireside corrosion is a key concern (limiting factor for the first USC plant in the U.S. - Eddystone)
- Rank alloys, coatings, and overlays
  - Laboratory exposures
  - Field Trials
    - Steam Loop
    - Air-Cooled Probe
- Continuing work
  - Oxycombustion (lab)
  - Additional field work

Cleaned surface of an air-cooled probe exposed for 2 years in a coal-fired boiler



***Inconel 740** shows lower wastage than a high chromium claddings (50/50), a wrought alloy (HR6W), and weld overlays (WO)*

A-USC Steam Boiler Highlight: Fireside Corrosion – Steam Loop

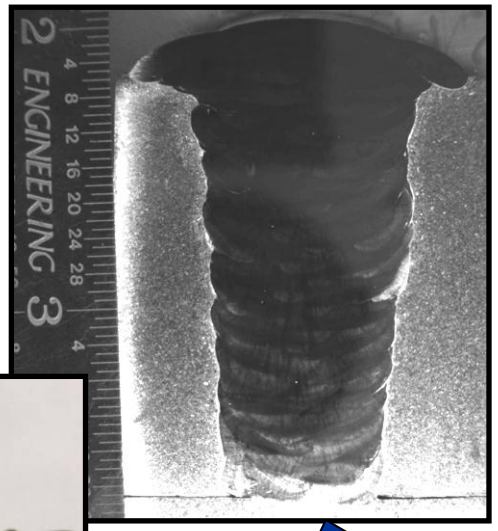
- **1st Steam Loop was completed in Phase 1**
  - Aggressive high Sulfur coal
  - Moderate A-USC temperatures (less than 760°C/1400°F)
- **2nd Steam Loop now installed and operating at design**
  - Goal: 12-18 months of operation
  - Maximum Temperature:
    - 760°C (1400°F)

2nd Steam Loop Installation

Task 5: Welding

- Key accomplishment for program has been the development of successful & repeatable weld procedures for thick-section (75mm – 3” thick) age-hardenable alloys
- Numerous material combinations, sizes, and configurations have been qualified
- Continuing work:
  - Dissimilar metal welds (DMWs)
  - Weld metal chemistry & effects on weld strength reduction factors

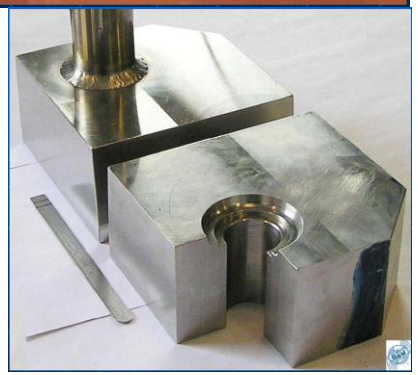
Inconel 740 Passed Bend Tests



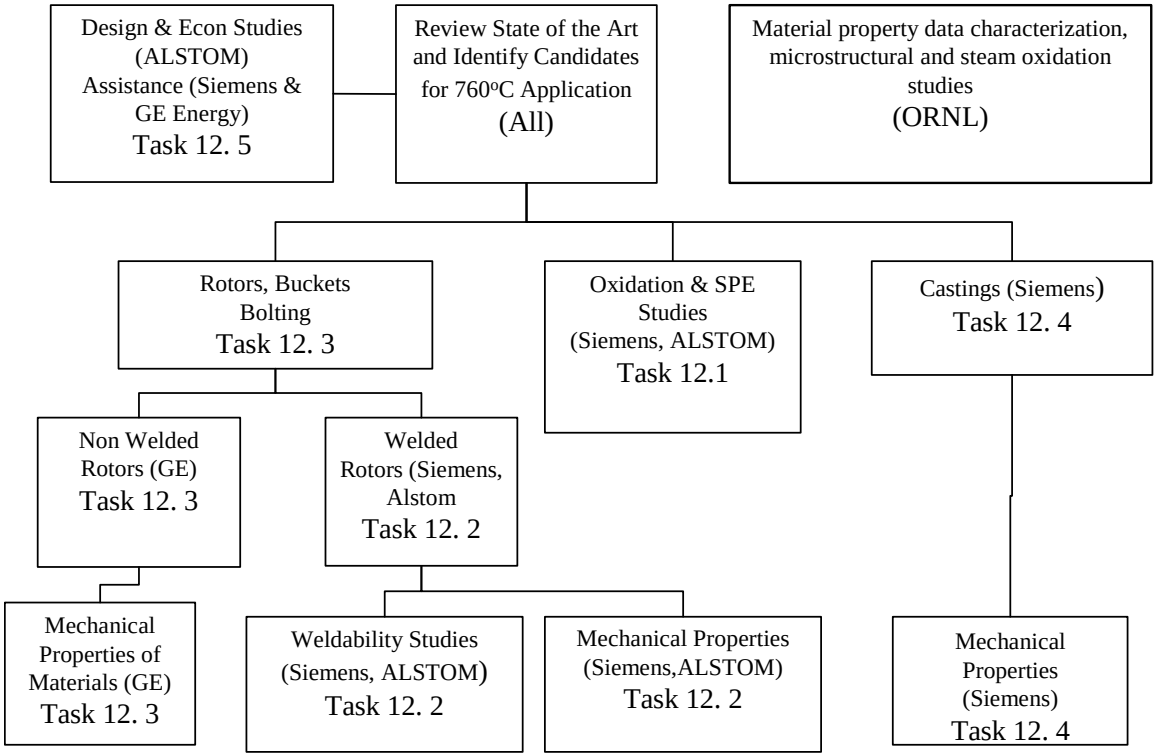
38mm (1.5”) Narrow Groove Inconel 740 Weldment

Tasks 6, 7, and 8

- **Fabrication:** Subjected alloys to common fabrication processes and produced prototype assemblies.
- **Coatings:** Identified external and internal coatings and methods, prepared samples for oxidation and corrosion testing, and evaluated the results.
- **Design:**
  - Proposed a more accurate and less conservative **design formula** which was adopted into the ASME B&PV Code Section I
  - Proposed and passed **new cold-work rules** for nickel-based alloy in ASME B&PV Code Section I (previously not addressed)



A-USC Steam Turbine Program: Phase I (complete)



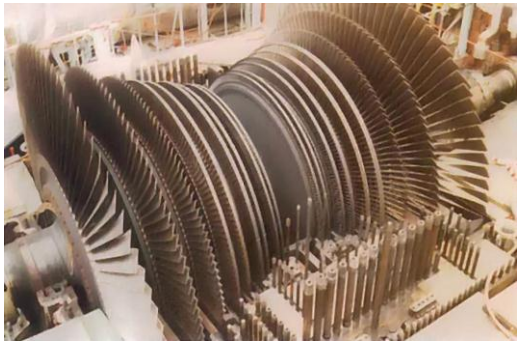
- Scoping Studies – Downselect Materials
- Key Issues
  - Welded rotors materials
  - Non-welded rotor materials
  - Air Casting
  - Erosion resistance
  - Oxidation resistance

Steam Turbine Phase II Work

- Using Selected Materials from Phase I
- Tasks
  - Rotor/Disc Testing (near full-size forgings)
  - Blade/Airfoil Alloy Testing
  - Valve Internals Alloy Testing
  - Rotor Alloy Welding and Characterization
  - Cast Casing Alloy Testing
  - Casing Welding and Repair

NETL

EPRI ELECTRIC POWER RESEARCH INSTITUTE



MAKING OHIO COAL THE CLEAN CHOICE

Energy Industries Of Ohio

U.S. DEPARTMENT OF ENERGY

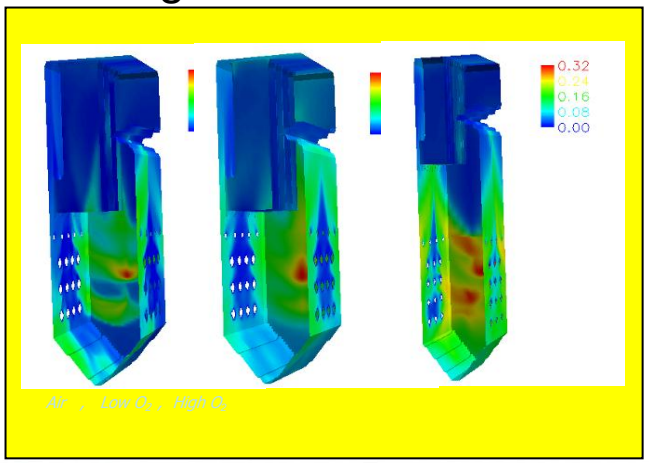
imagination at work

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Summary

- Phase 1 efforts successful
  - Demonstrated materials capability operating at AUSC conditions.
  - Technical economic studies indicate significant CO_2 reduction
  - Code approval of Inconel 740H

- Current Boiler & Turbine Materials R&D
  - Effect of oxycombustion on materials
  - Improved weld/weldment performance
  - Code approval of new alloys
  - Long-term high-temperature material property databases
  - Production of larger forgings
  - Casting R&D for nickel-based alloys



- Path Forward
  - Supplier Development for full-size forgings, extrusions, and castings
  - Test facility → Demo Plant

Contact Information

Robert R. Romanosky
304-285-4721
robert.romanosky@netl.doe.gov

NETL
www.netl.doe.gov

Office of Fossil Energy
www.fe.doe.gov

Patricia Rawls
412-386-5882
patricia.rawls@netl.doe.gov