Materials for Advanced Ultra-Supercritical Steam Service - Turbines

Phil Maziasz
Materials Science and Technology Division
Oak Ridge National Laboratory

27th Ann. Conf. on Fossil Energy Materials, 18-20 June, 2013, Pittsburgh, PA

2 x 800 MW Lignite-Fired Power Plant Schwarze Pumpe, Germany

HMN-Series (High-, Intermediate- and Low-Pressure) Steam Turbine for Combined-Cycle and Steam Power Plants

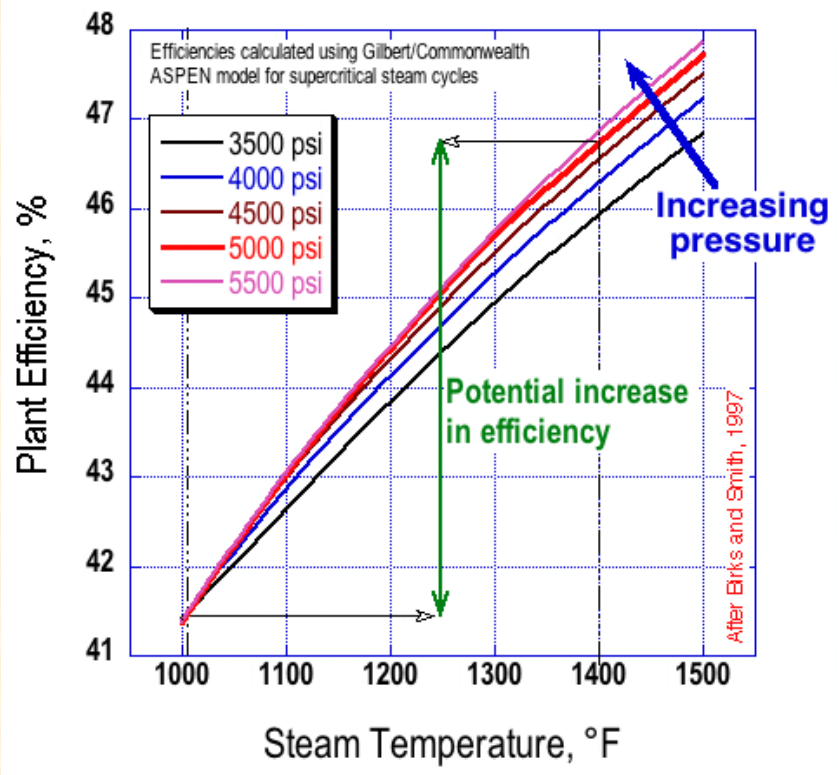
Acknowledgements – Funding, U.S. Department of Energy – Office of Fossil Energy

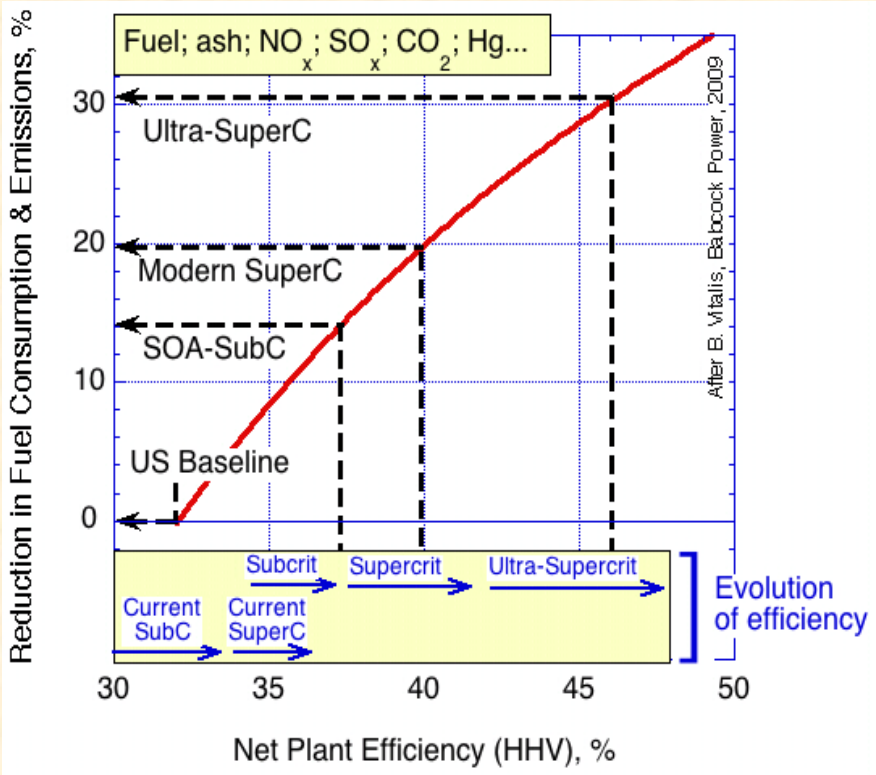
- DOE Headquarters/Germantown, MD – Regis Conrad
- DOE/NETL – Pittsburgh, PA – Patricia Rawls

Acknowledgements – Collaboration

- Bruce Pint, ORNL, Oxidation/Corrosion
- Amit Shyam, ORNL, Fatigue
- Paul Jablonski, NETL/Albany (OR) Casting and Processing

Increasing Steam Temperature and Pressure Increases Thermal Efficiency and Decreases Emissions for Advanced UltraSuperCritical (A-USC) Steam Technology

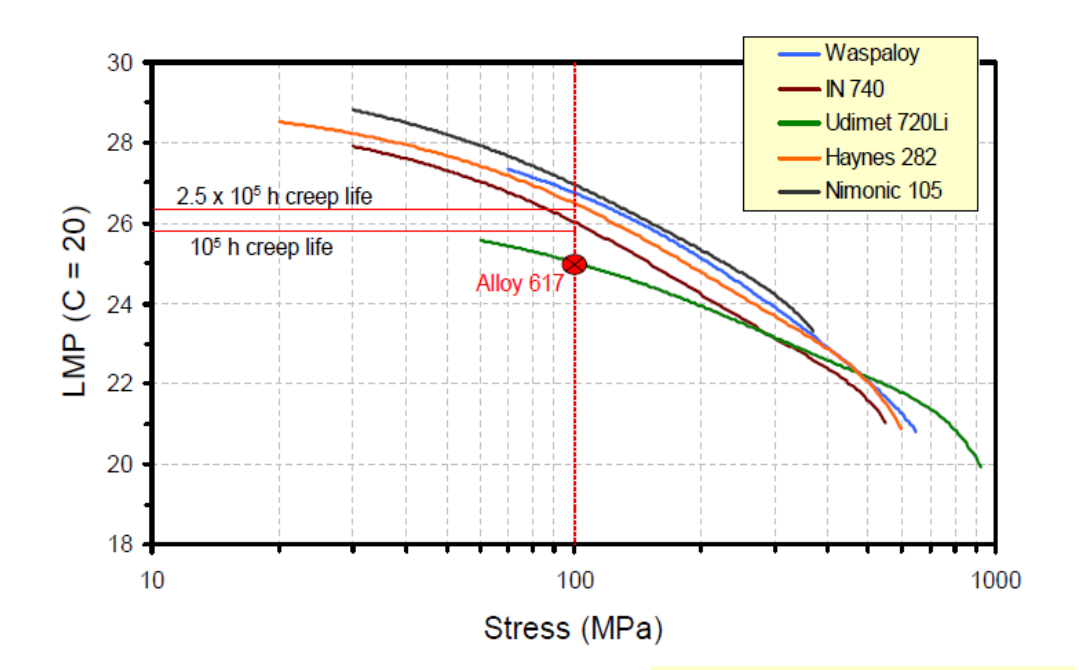




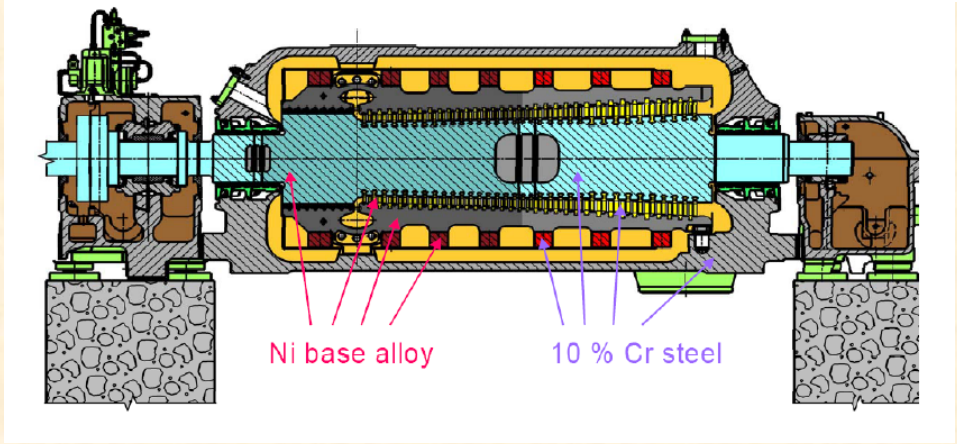
"Least Regret" Strategy for CO_2 Reduction (Viswanathan and Shingledecker, EPRI Conf., Santa Fe, NM, Aug. 2010)

A-USC Turbine Designs Need Ni-based Superalloys (rotors, blading, casing)

Wrought Ni-based superalloys (NI 105 and HR 282) have creep-strength needed for rotors and blading to last 250,000h



Alstom HP Turbine Concept

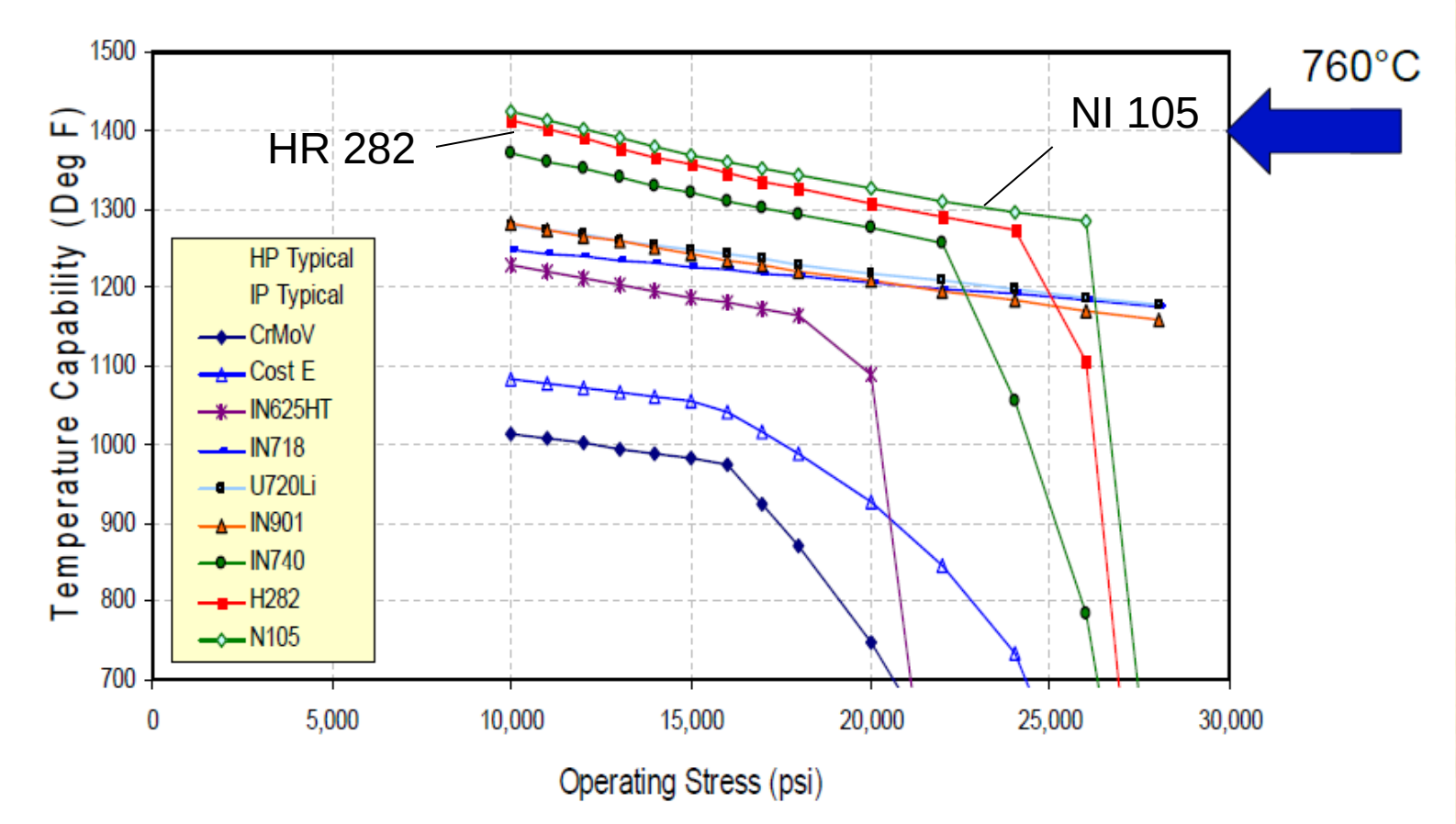


Consortium Phase 1 Result

Cast Ni-based superalloys were needed for turbine casing

UT-BATTELLE

Creep Properties Expressed for Designers as Temperature Capabilities and Operating Stress for HP/IP rotor application show NI 105 and HR 282 are best



ORNL and NETL/Albany Collaborated to Cast and Test the same wrought Ni-based superalloys

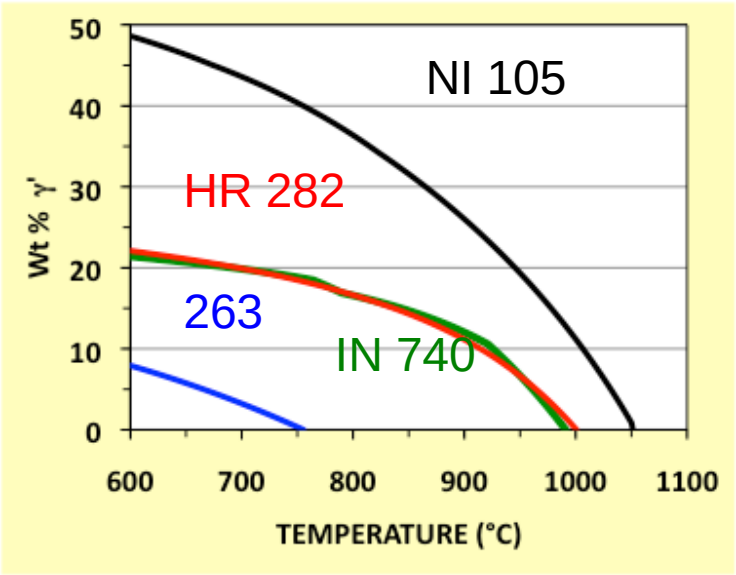
- Cast Ni-based alloys with sufficient creep-strength and temperature capability were also required for turbine casing application
- NETL/Albany cast ingots of Nimonic 105, HR 282, IN 740 and the other Ni-based superalloys of interest in late 2008.
- Homogenization was a critical step in getting good properties of cast Ni-based superalloys
- ORNL and NETL/Albany did the initial screening tests of cast Ni-based alloys at 800°C

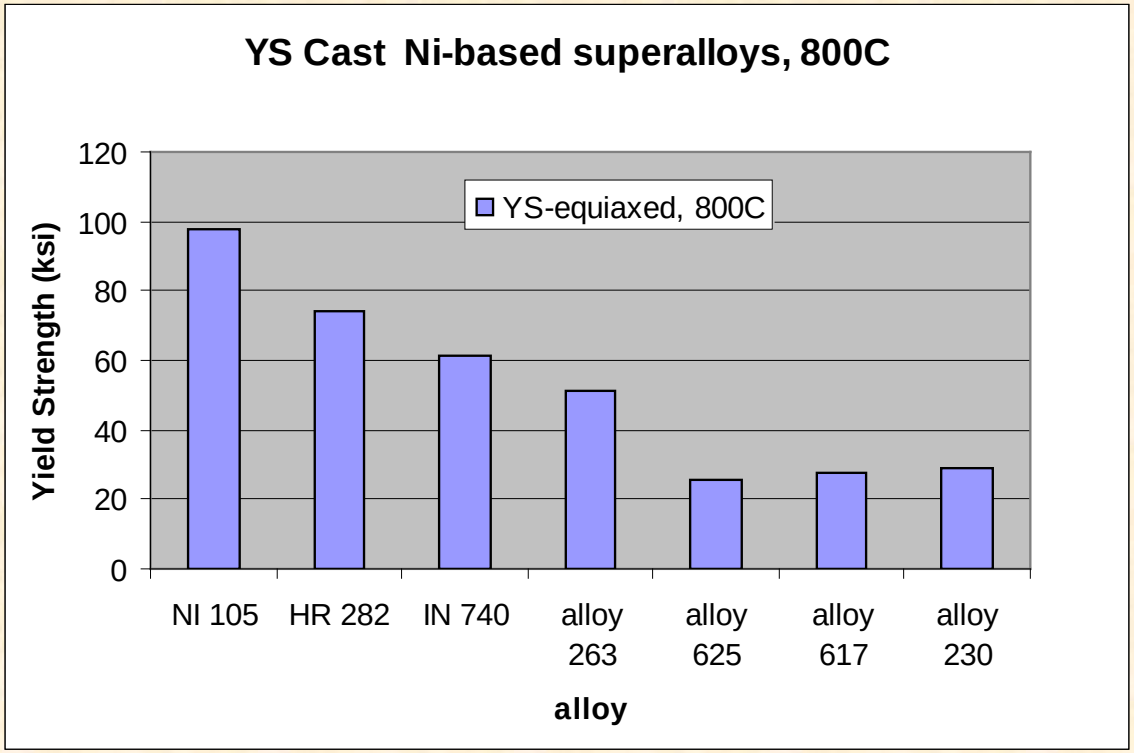
Compositions of Ni-based superalloys being considered for A-USC steam turbine application

Alloy	Ni	Cr	Co	Mo	Nb	Ti	Al	Mn	Si	C
NI 105	bal	14.85	20.0	5.0	-	1.1	4.7	0.5	0.5	0.15
HR 282	bal	19.5	10.0	8.5	-	2.1	1.5	0.15	0.15	0.07
IN 740	bal	25.0	20.0	0.5	1.5	1.5	1.3	0.3	0.3	0.03
Alloy 263	bal	20.0	20.0	5.8	-	2.1	0.35	0.5	0.35	0.07

High-Temperature Strength of Cast Ni-based Superalloys Depends on gamma-prime

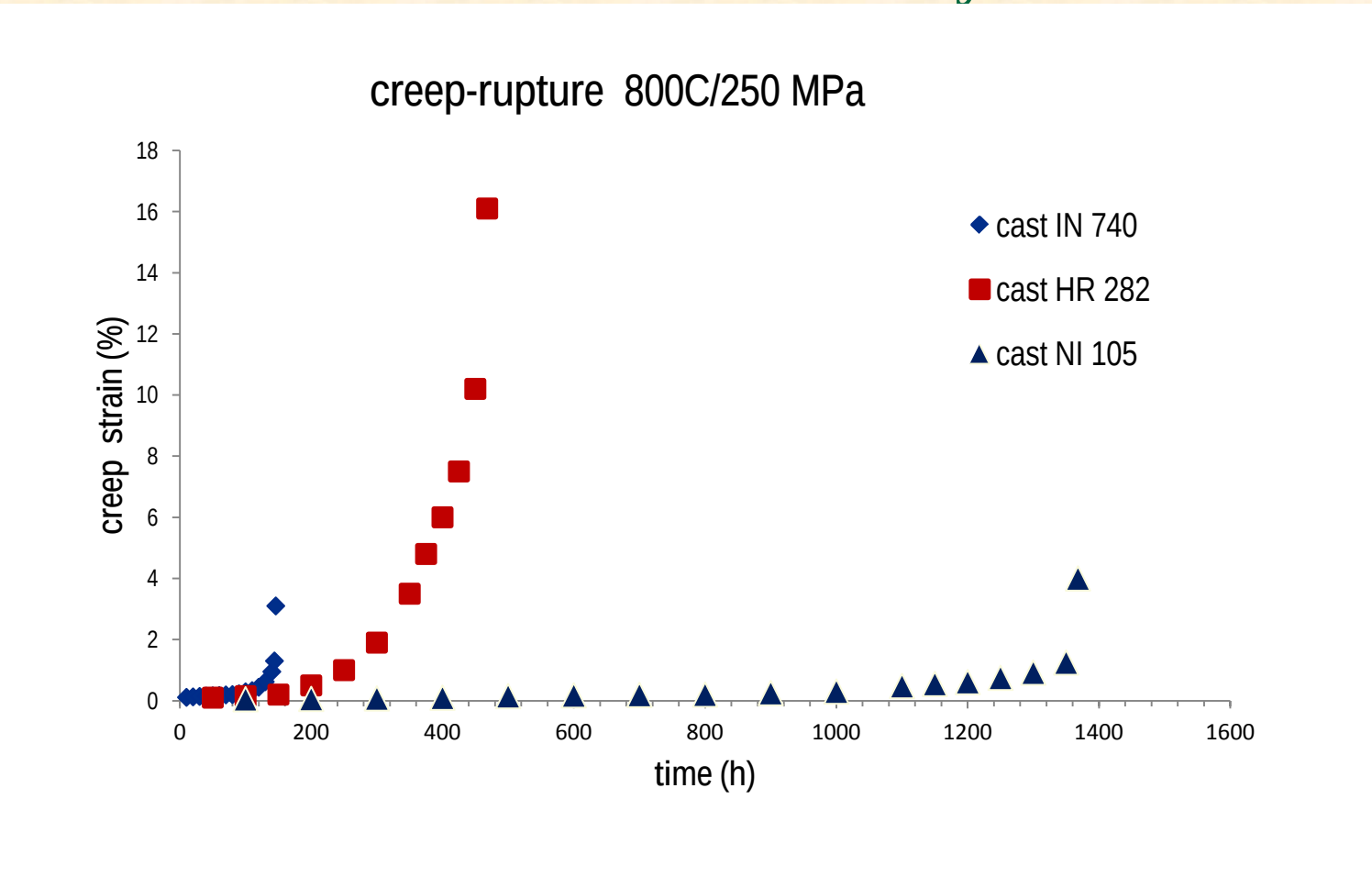
Alloy	(Ti+Al) Wt%
N105	5.8
282	3.6
740	3
263	2.45





JMatPro

Cast NI 105 has the best creep-resistance, but concerns about rupture ductility and weldability favor cast HR 282 alloy

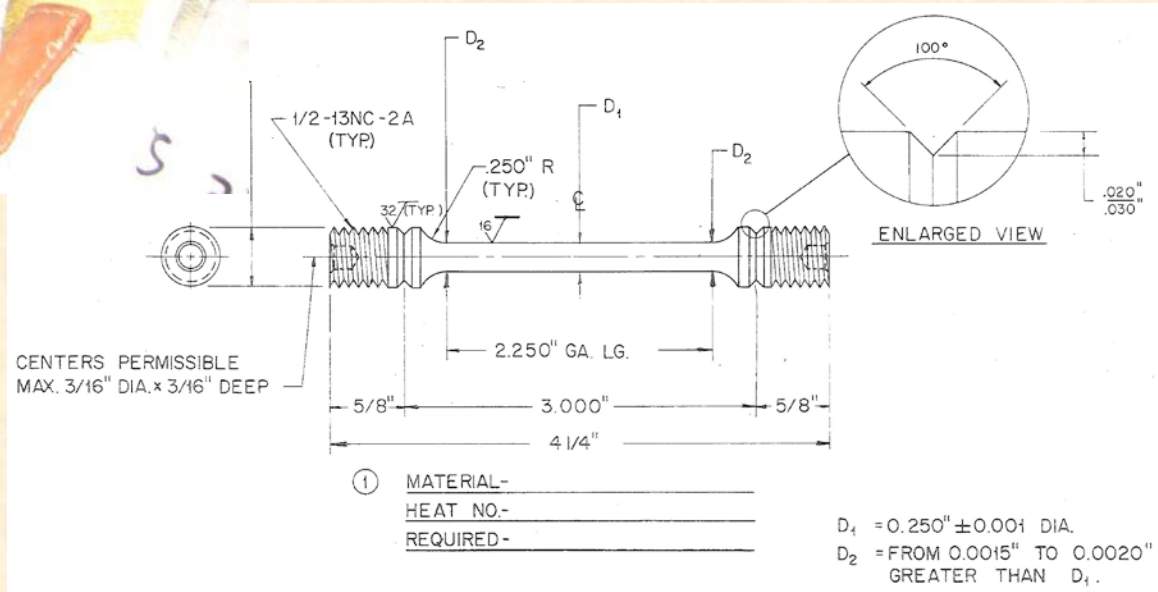


Completed Weld repair of homogenized casting using GTAW (TIG)

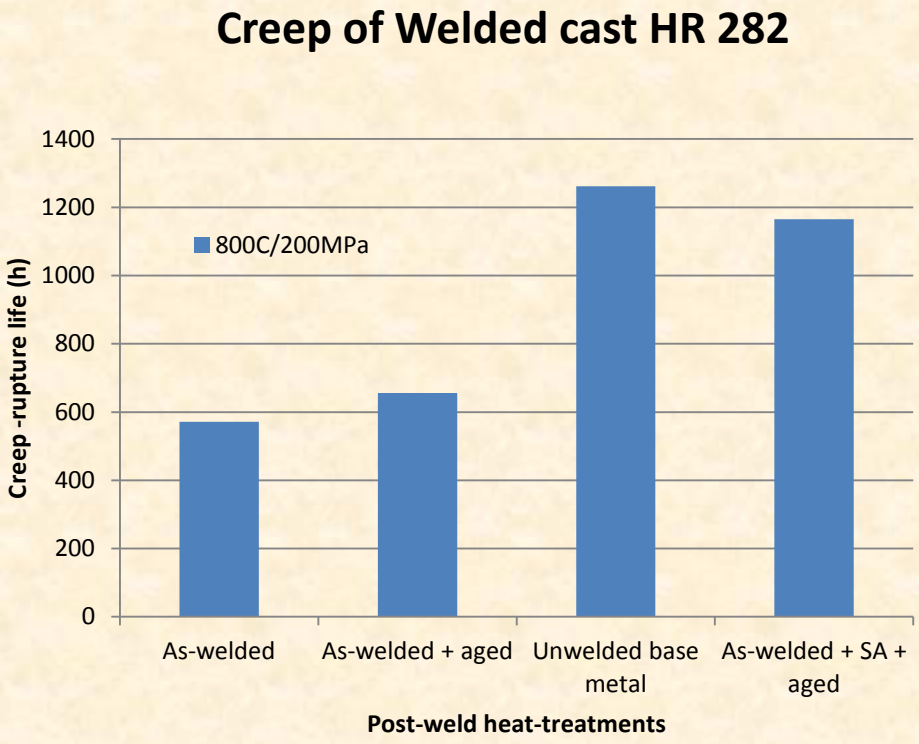
- Shrinkage cavity was ground to clean metal
- Cavity was filled with 282 by manual GTAW with Ar shielding
- Appearance was excellent

Testing of Narrow-gap GTAWs supplied by GE

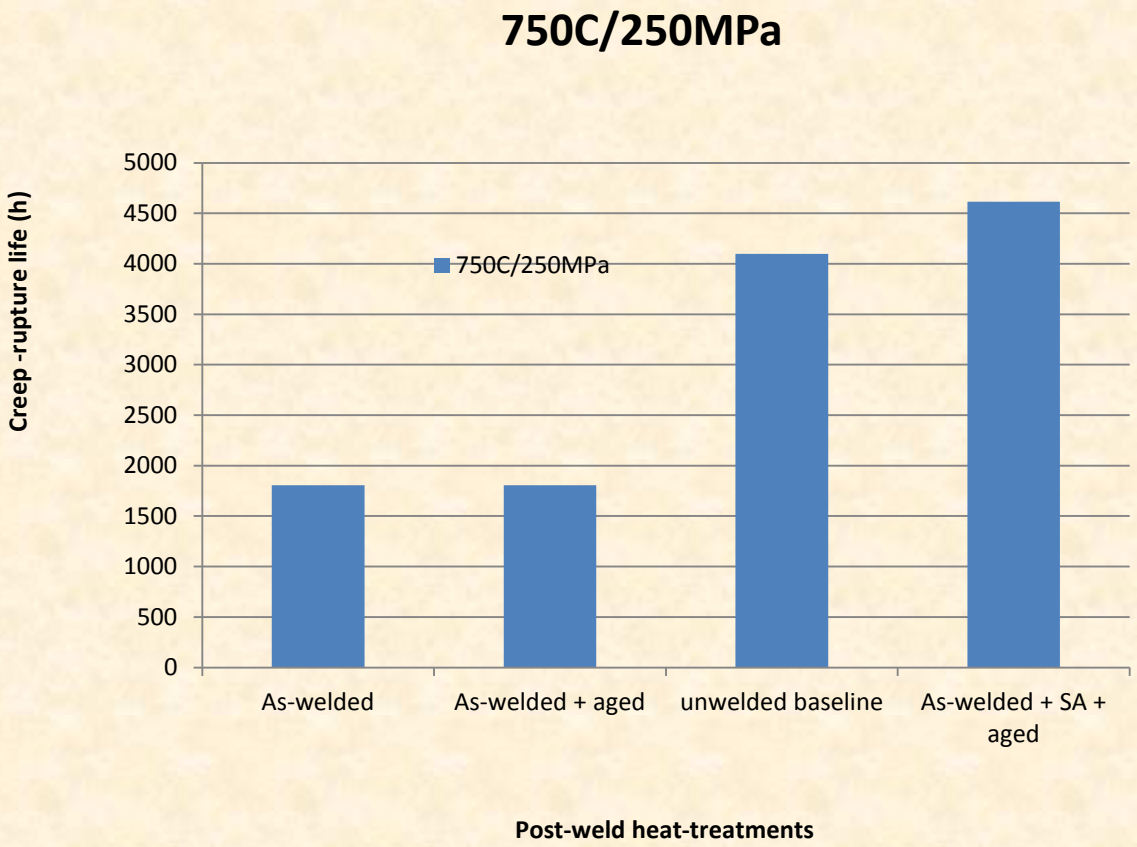
- 18 cross-weld specimens have been machined
- Stress-rupture creep testing is underway



Welded HR 282 – Creep at 800C/200 MPa

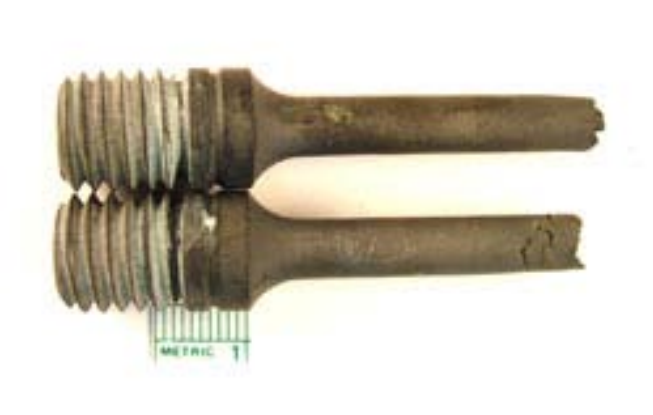


Welded HR 282 – Creep at 750C/250 MPa



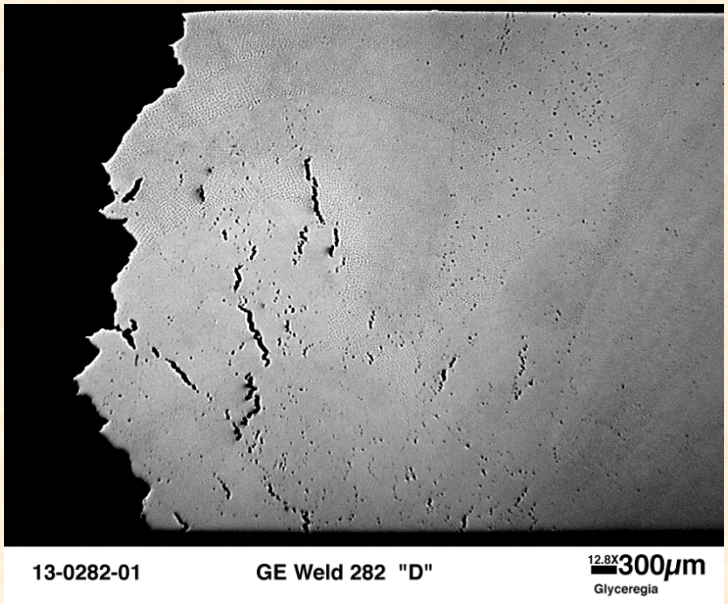
Welded HR 282 – Creep at 800C/200 MPa

As-welded

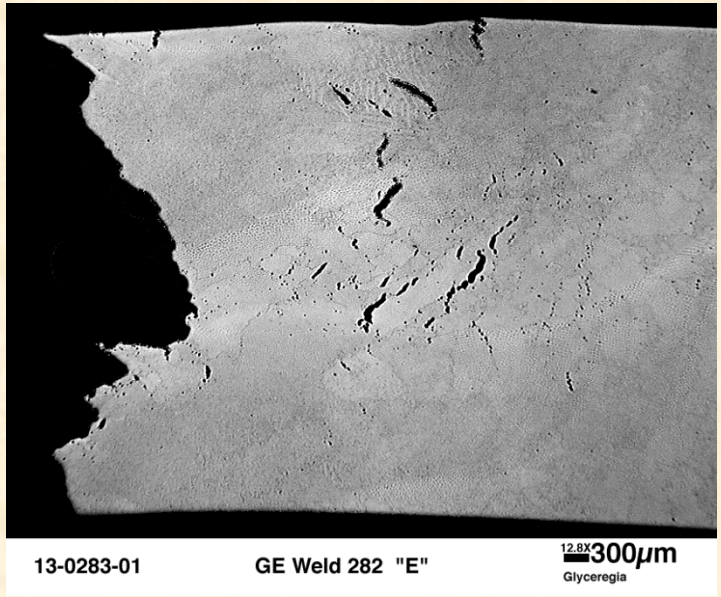


Welded + SA + aged

Welded HR 282 – Creep at 800C/200 MPa

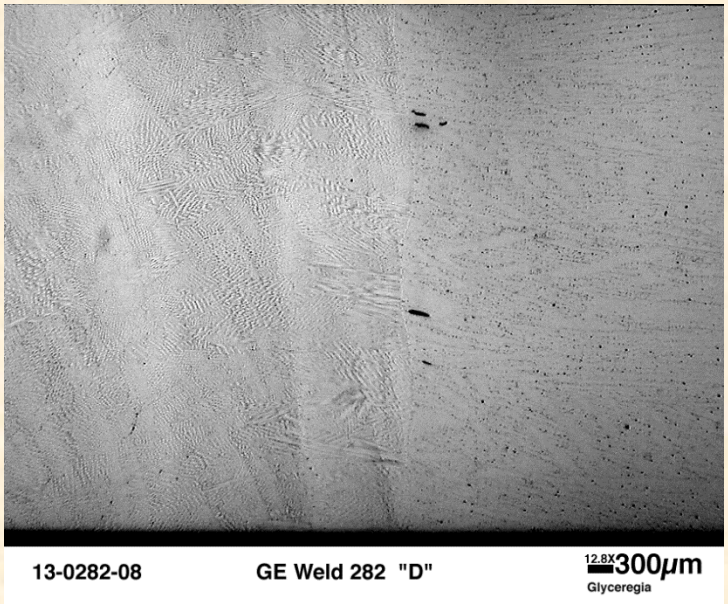


As-welded
(580 h)

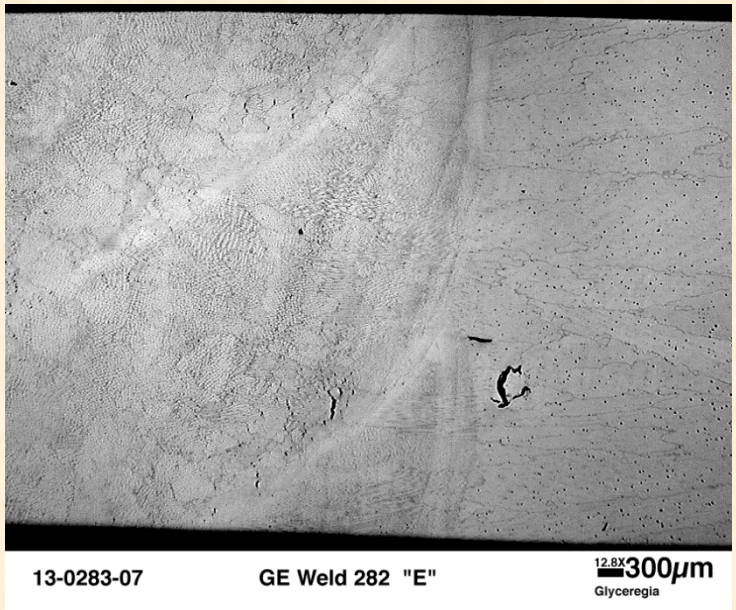


Welded + SA
+ aged (1180 h)

Welded HR 282 – Creep at 800C/200 MPa

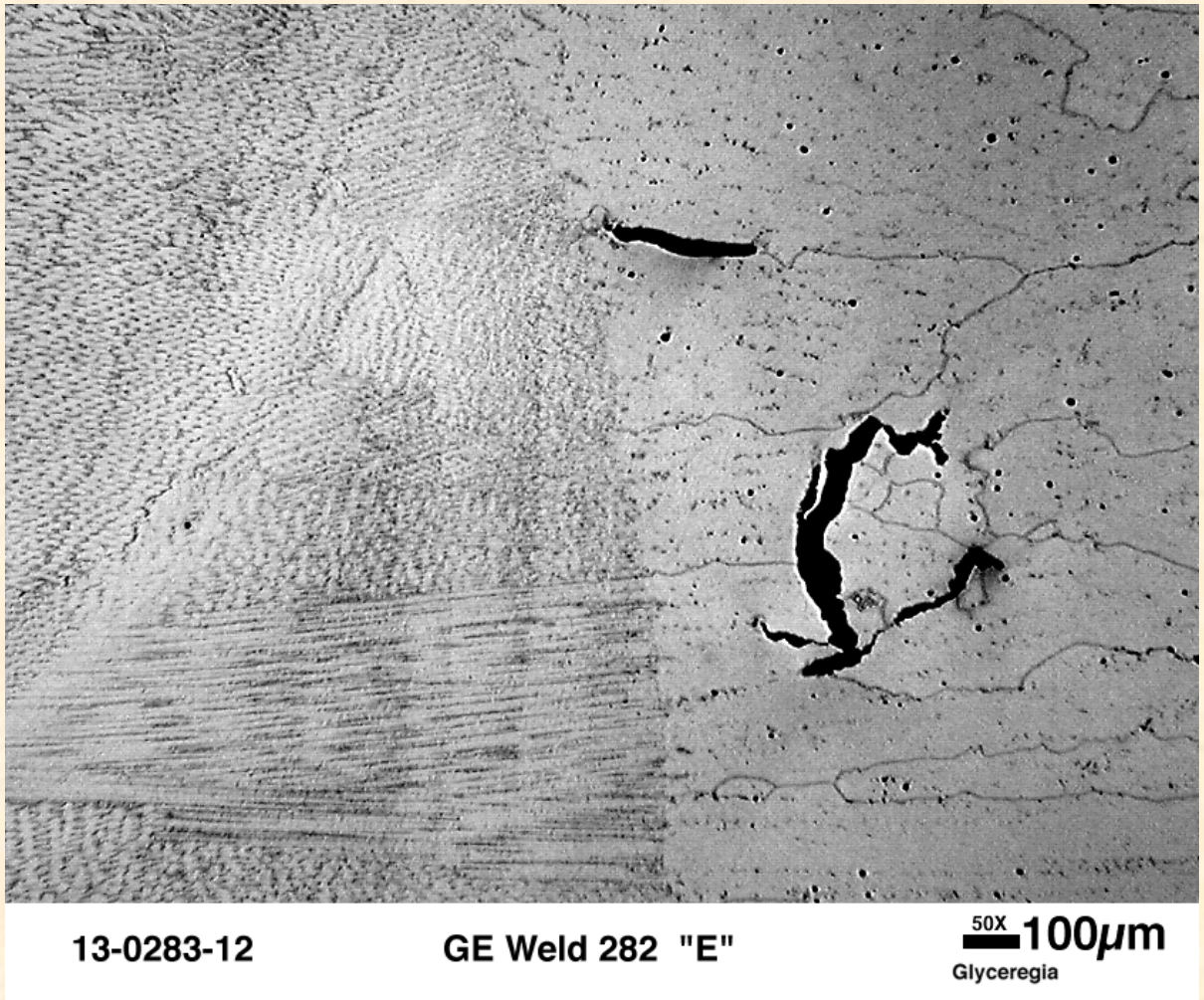


As-welded
(580 h)



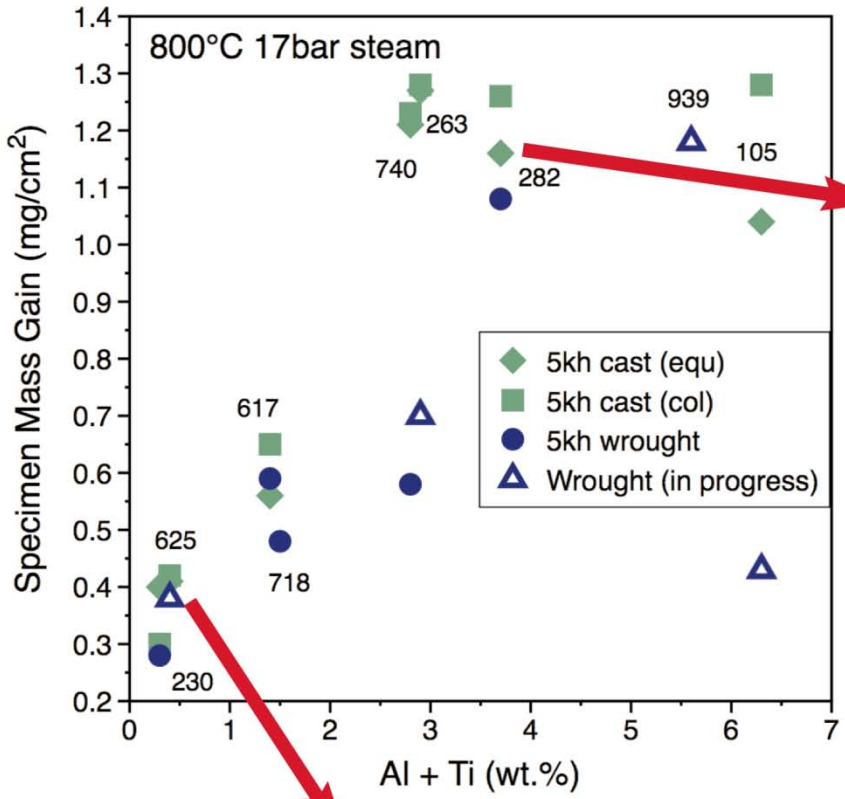
Welded + SA
+ aged (1180 h)

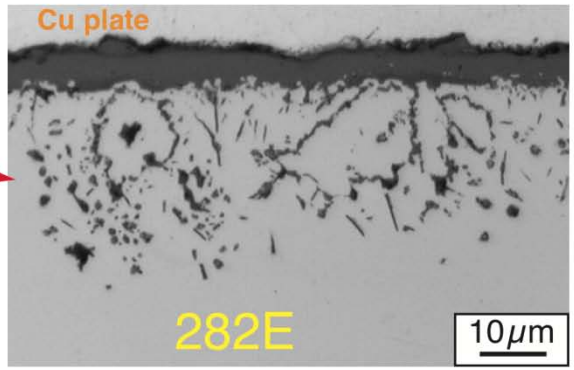
Welded HR 282 – Creep at 800C/200 MPa

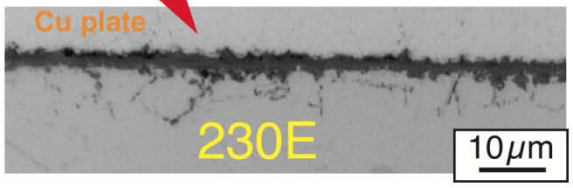


Welded + SA + aged

Stronger cast Ni-based superalloys also have more oxidation after 5000h in 17bar Steam at 800°C







Only mass gain data, need to complete with penetration depth

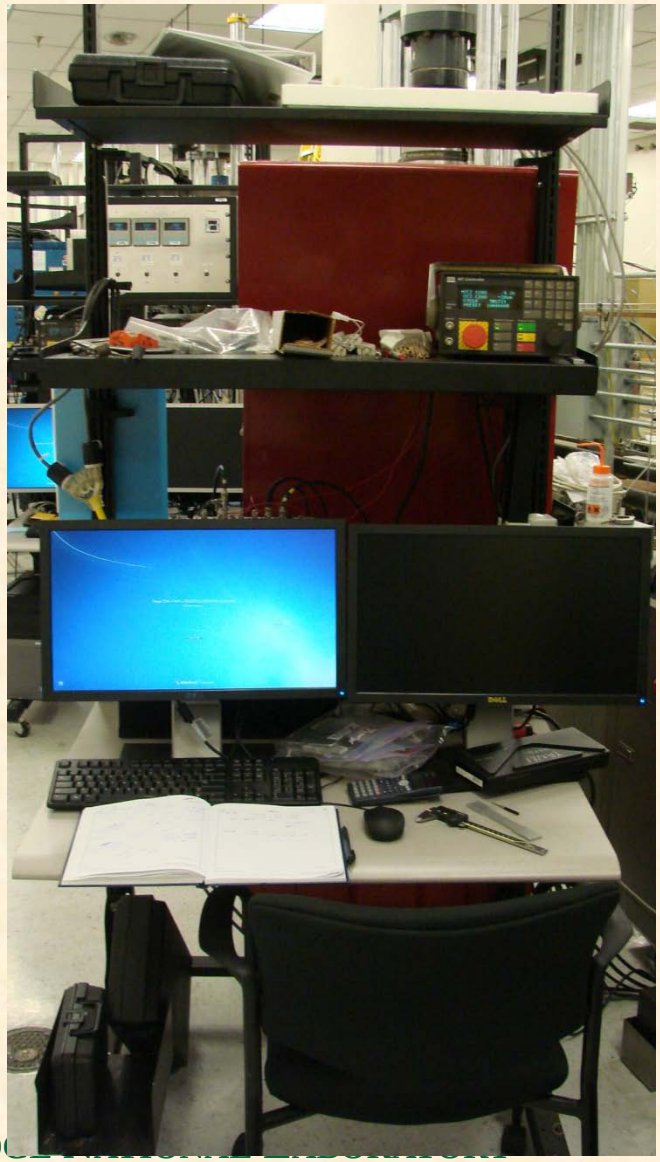
Steam Fatigue Testing Setup – Furnace and Controller

Steam Fatigue Testing Setup – Furnace Accesories

Bellows

Inconel Retort with cooling for bellows and extensometer port

Steam Fatigue Testing Setup – Test Machine



Summary

- Wrought NI 105 and HR 282 Ni-based superalloys have acceptable high-temperature properties for A-USC steam turbine rotor, blade, and bolting component applications
- Cast HR 282 has good combination of creep-strength and ductility for A-USC steam turbine casing application
- Current effort is focused on weldability and weldment properties of cast HR 282 to support the turbine casing and other cast component applications

DOE/FE 2013 Project Review – FY13 Milestones

- 2013 project milestone - Complete steam oxidation testing of cast Ni-based superalloys (June, 2013) - complete
- 2013 project milestone – Complete initial LCF testing of HR 282 in steam (July, 2013) – in progress
- 2013 project milestone – Complete initial creep-rupture tests of cross-weld specimens (Sept. 2013) – in progress