Materials for Advanced Ultra-Supercritical Steam Service - Turbines

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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

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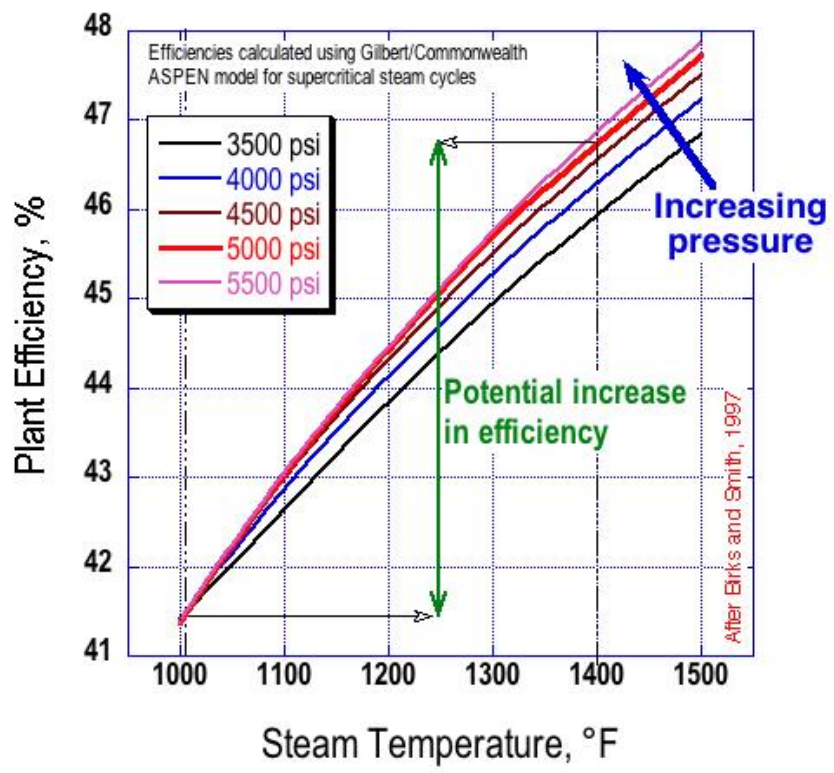
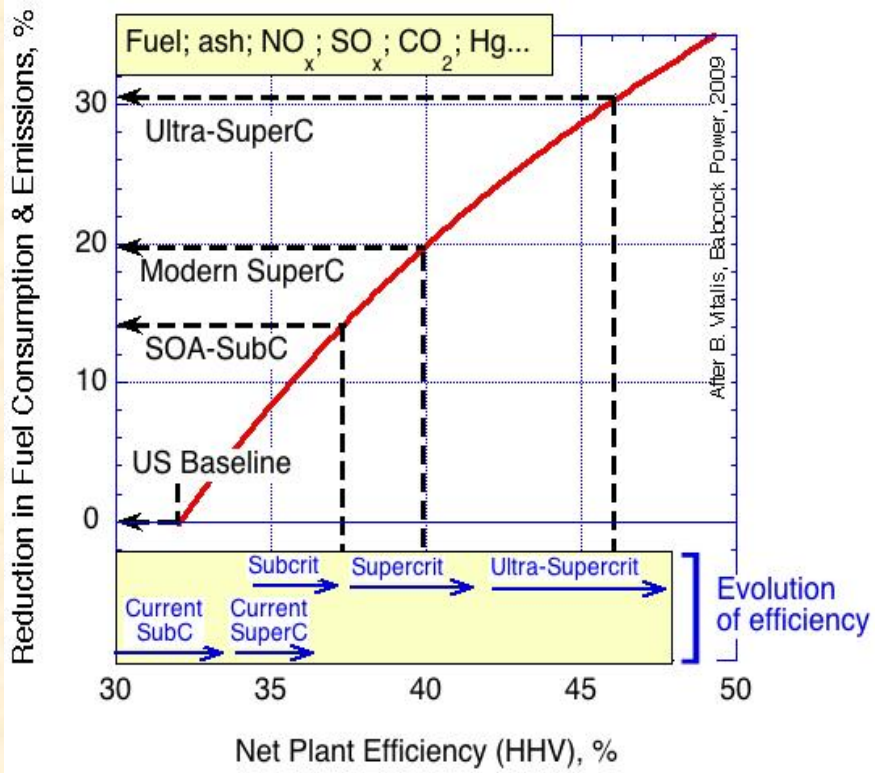
Acknowledgements – Collaboration

- Bruce Pint, ORNL, Oxidation/Corrosion

- 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

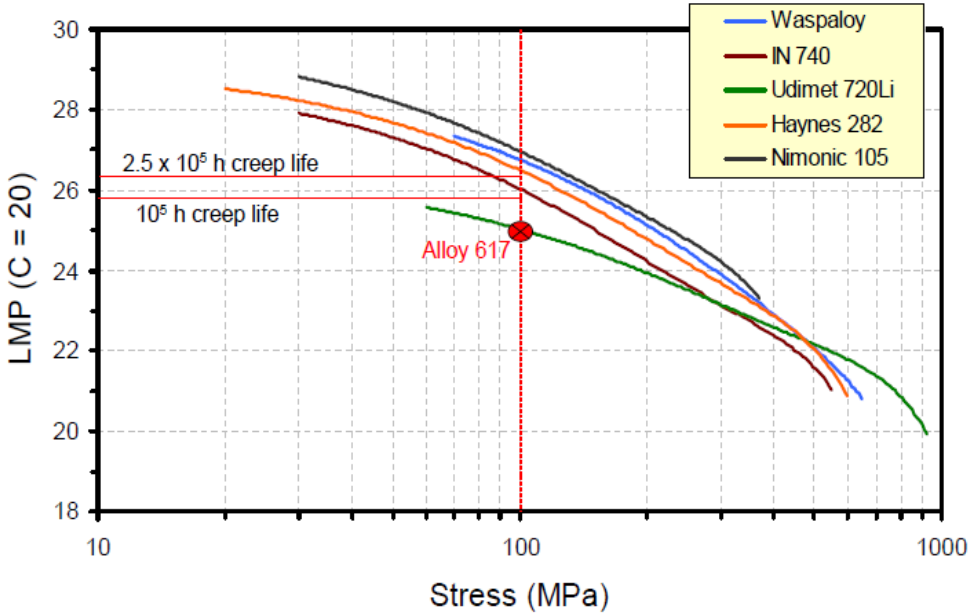




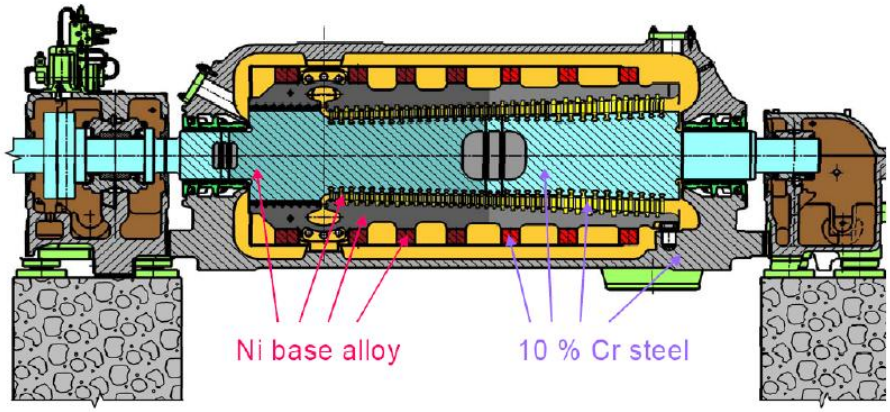
"Least Regret" Strategy for CO_2 Reduction (Viswanathan and Shingledecker, EPRI Conf., Santa Fe, NM, Aug. 2010)

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

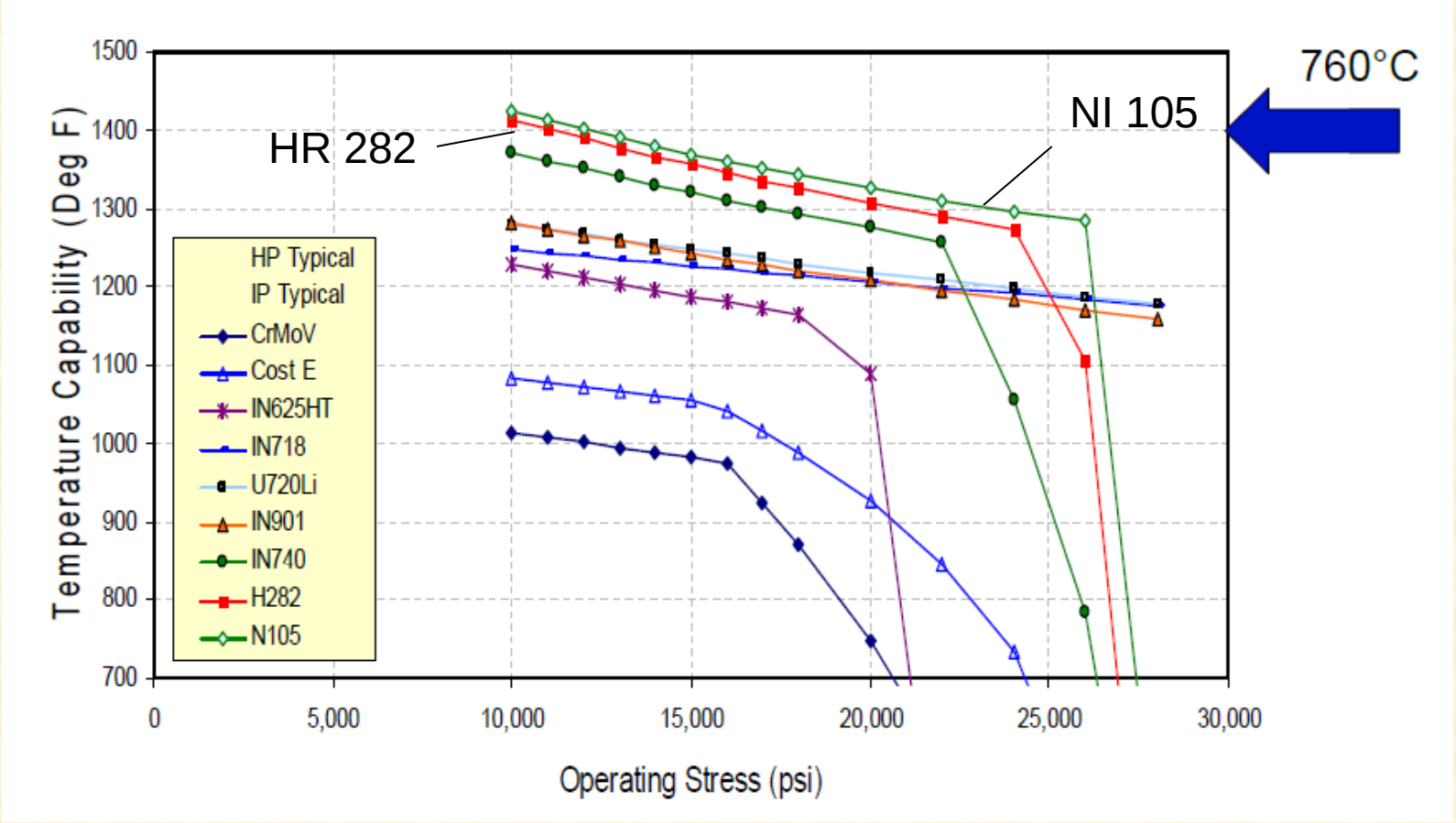


Consortium Phase 1 Result

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

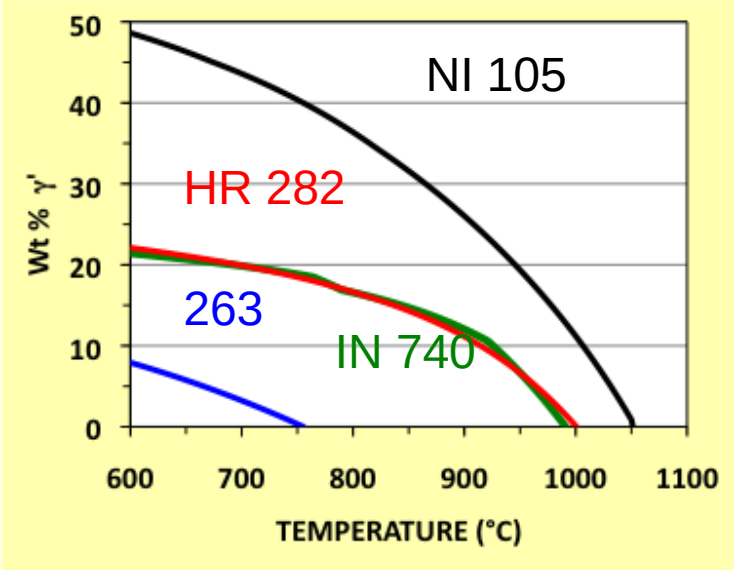
- Cast Ni-based alloys with sufficient creep-strength and temperature capability were also required for turbine casing application
- NETL/Albany cast ingots of Nimonic 105, HR 282, IN 740 and the other Ni-based superalloys of interest in late 2008.
- Homogenization was a critical step in getting good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

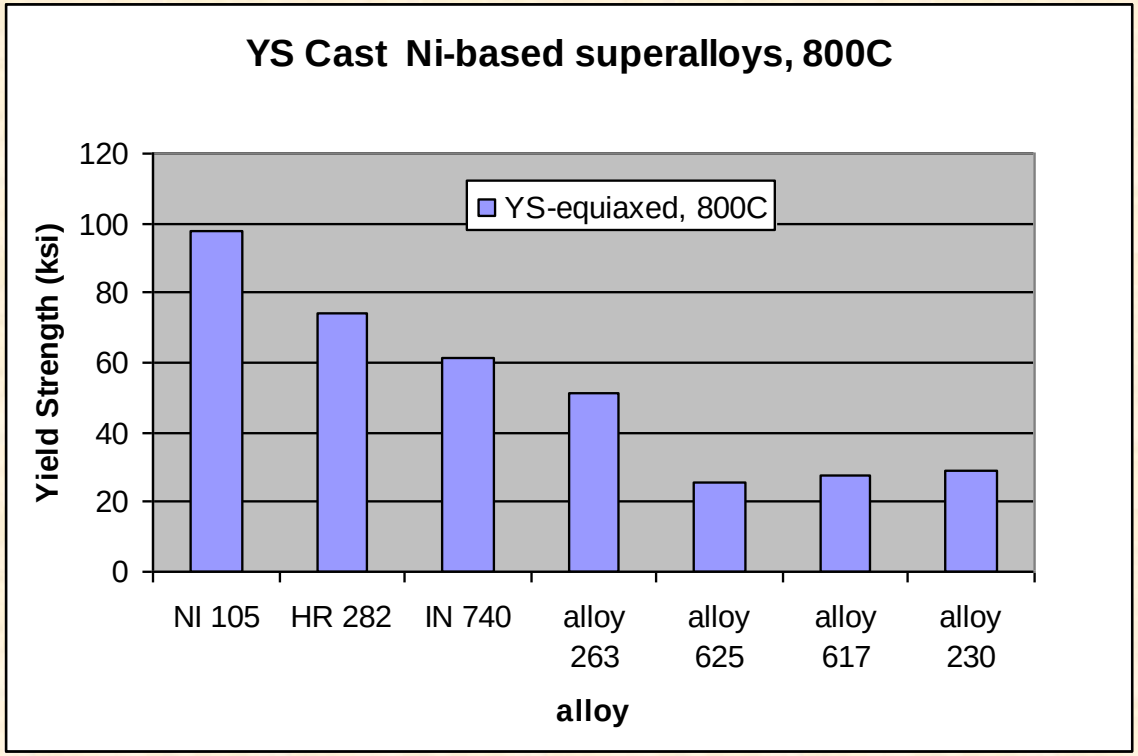
Compositions of Ni-based superalloys being considered for A-USC steam turbine application

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

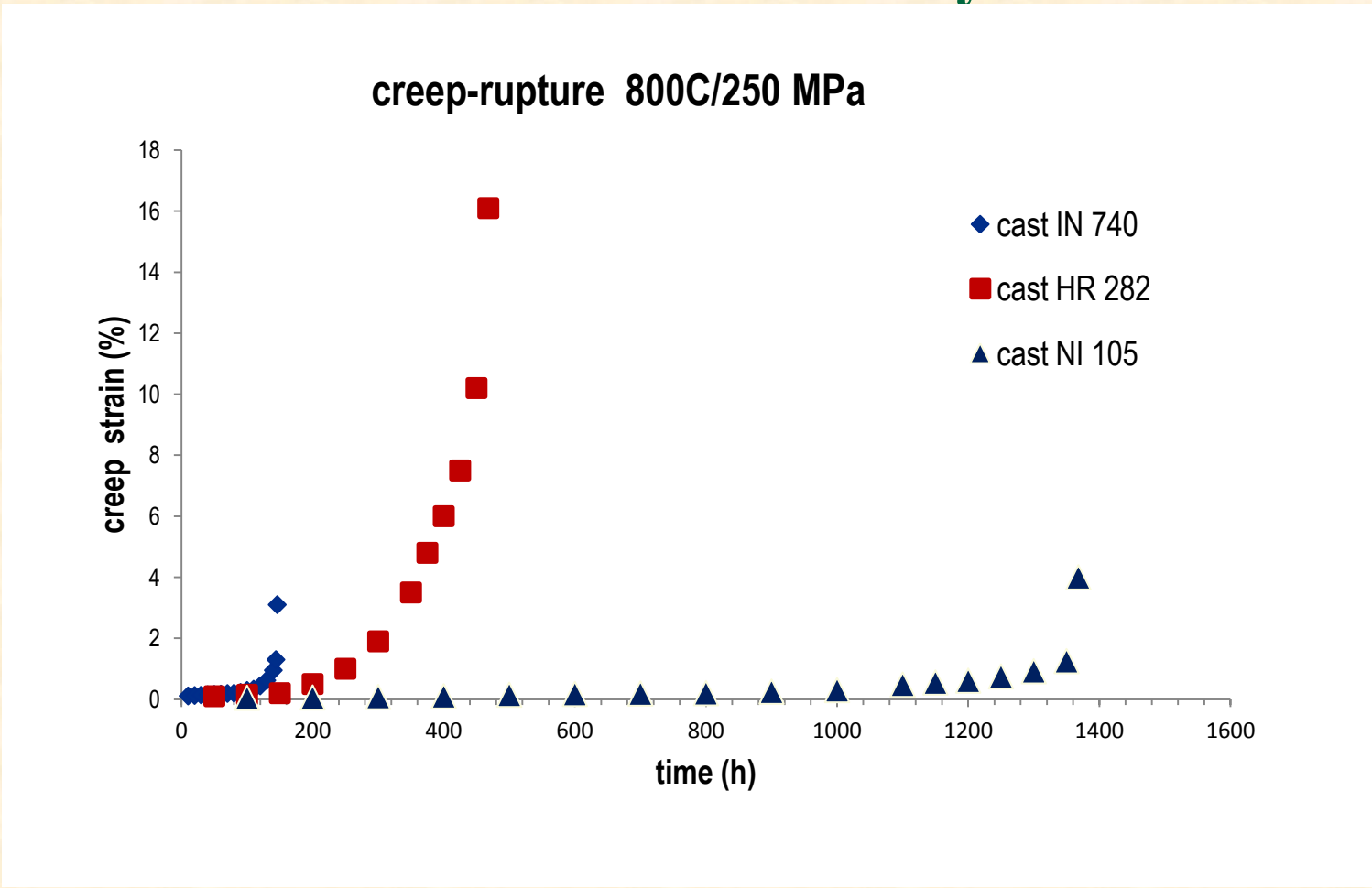
Alloy	(Ti+Al) Wt%
N105	5.8
282	3.6
740	3
263	2.45



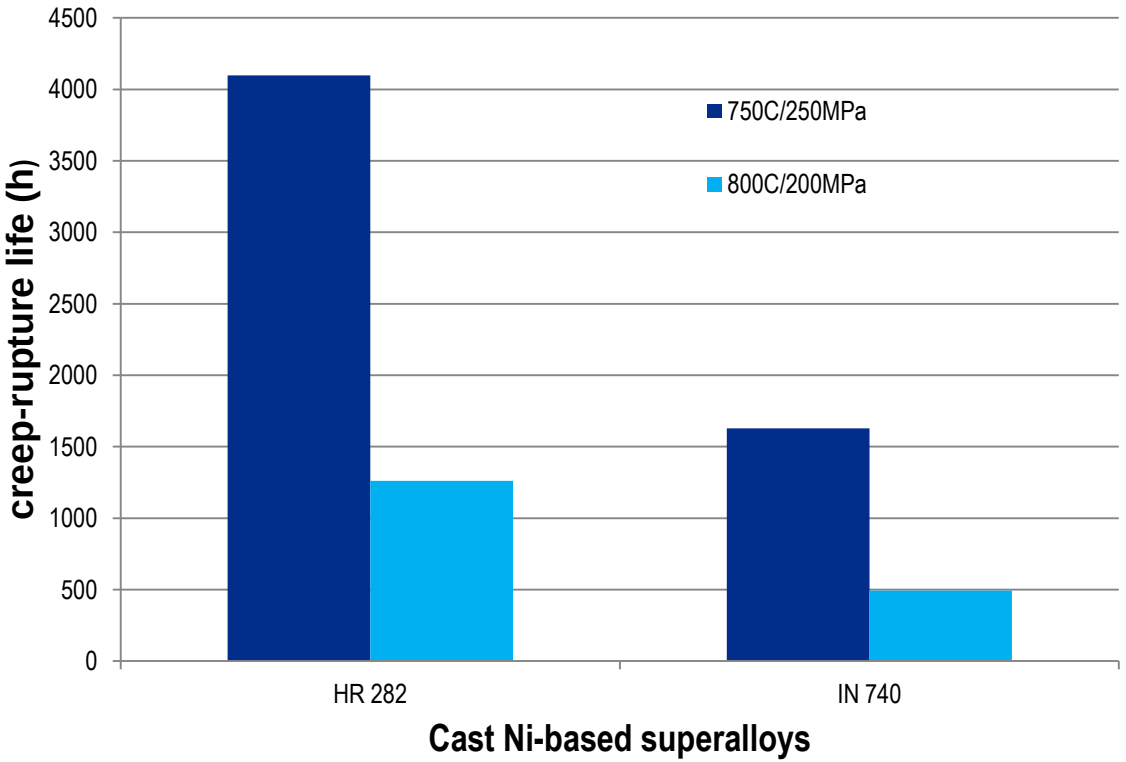


JMatPro

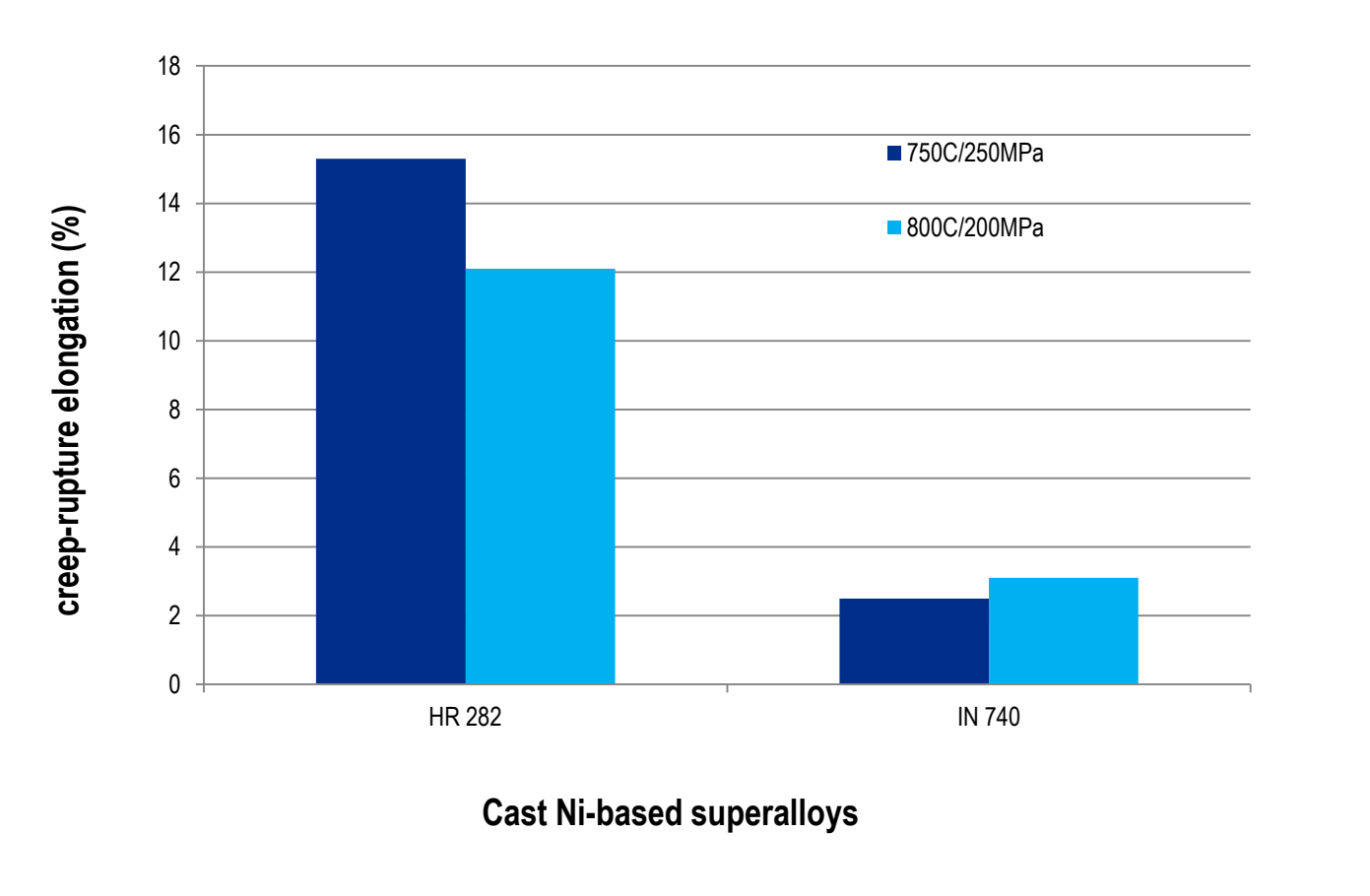
Cast NI 105 has the best creep-resistance, but concerns about rupture ductility and weldability favor cast HR 282 alloy



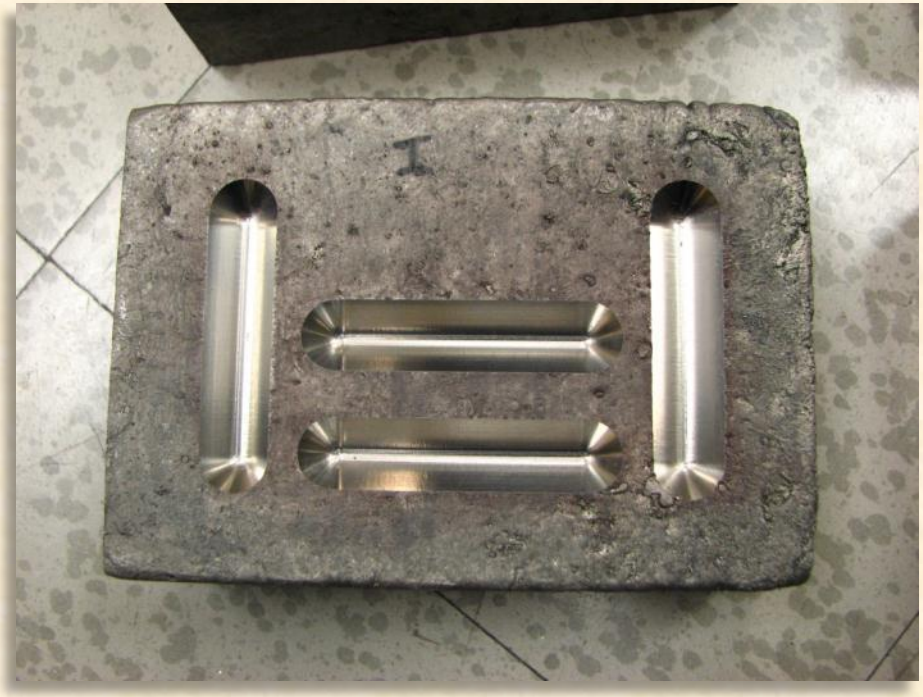
Cast HR 282 alloy has better creep-rupture life than IN 740 alloy at 750-800°C



Cast HR 282 also has better creep-rupture ductility than IN 740 at 750-800°C



Completed welds in 282 casting



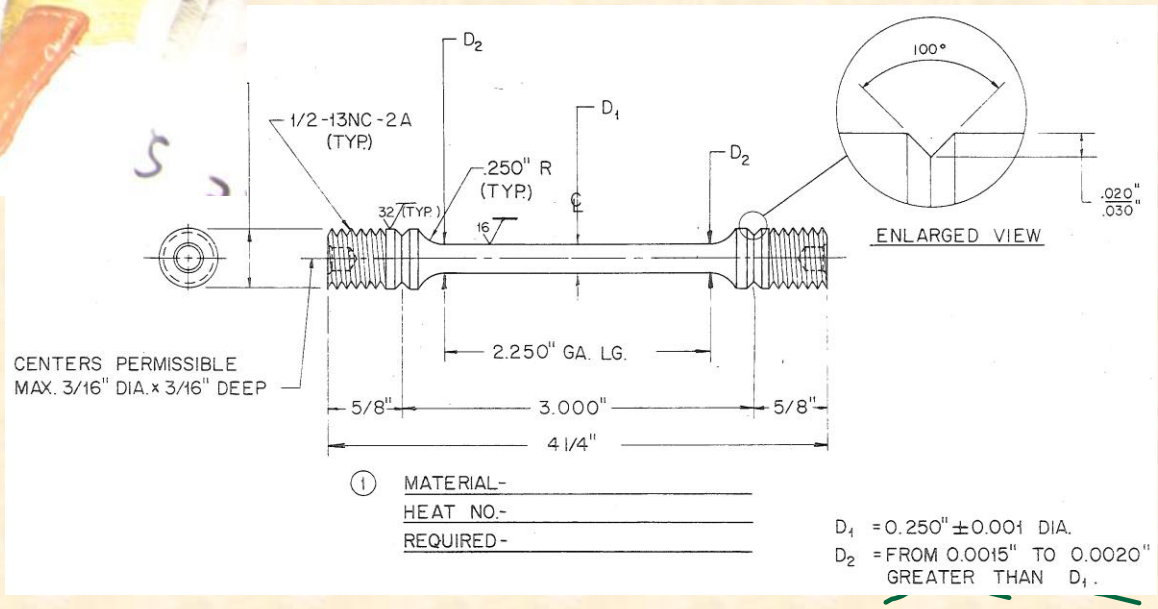
- Grooves were filled by manual gas-tungsten-arc welding
- Filler wire was 282 alloy purchased from Haynes
- Weldability was fine with no visible indications of problems

Completed Weld repair of homogenized casting using GTAW (TIG)

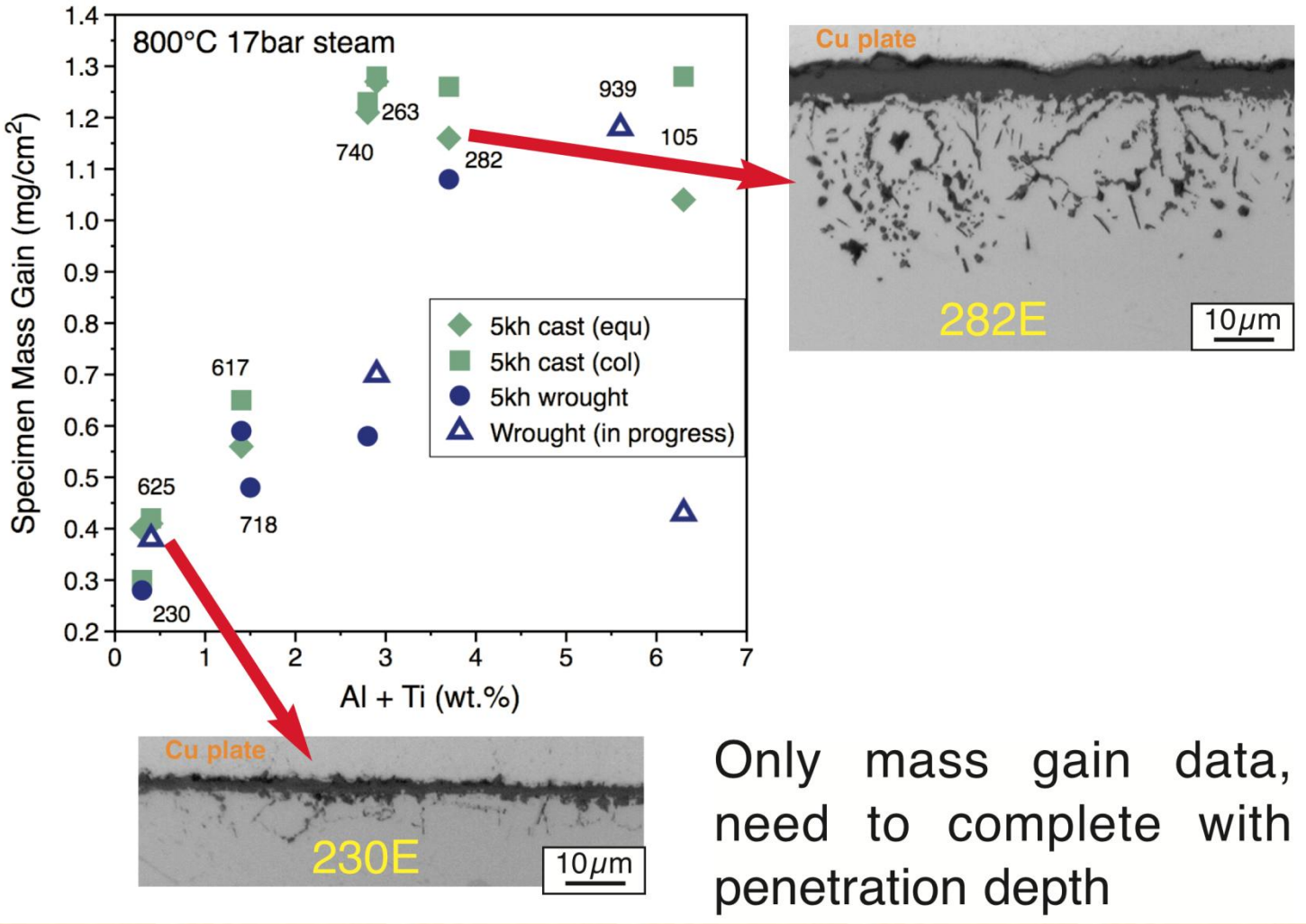
- Shrinkage cavity was ground to clean metal
- Cavity was filled with 282 by manual GTAW with Ar shielding
- Appearance was excellent

Testing of Narrow-gap GTAWs supplied by GE

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

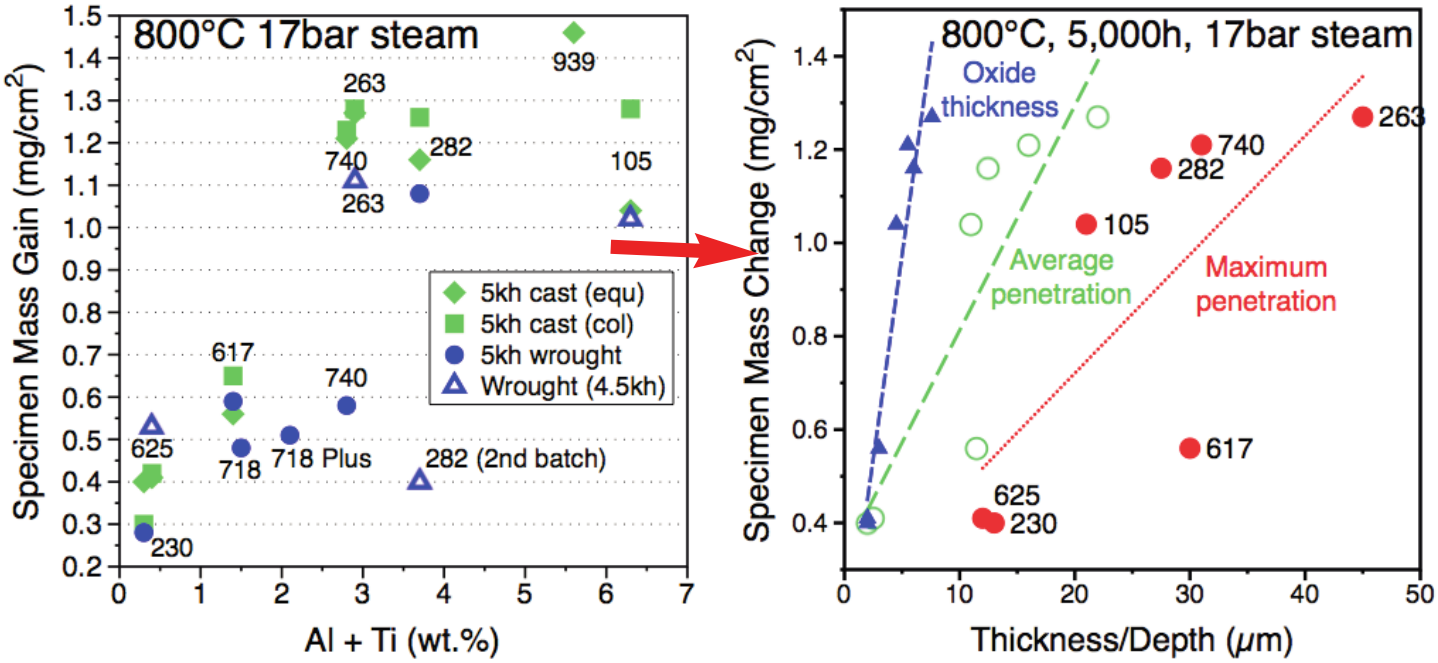


Stronger cast Ni-based superalloys also have more oxidation after 5000h in 17bar Steam at 800°C



Ni-base alloys: mass-depth

steam testing at 17 bar, 800°C



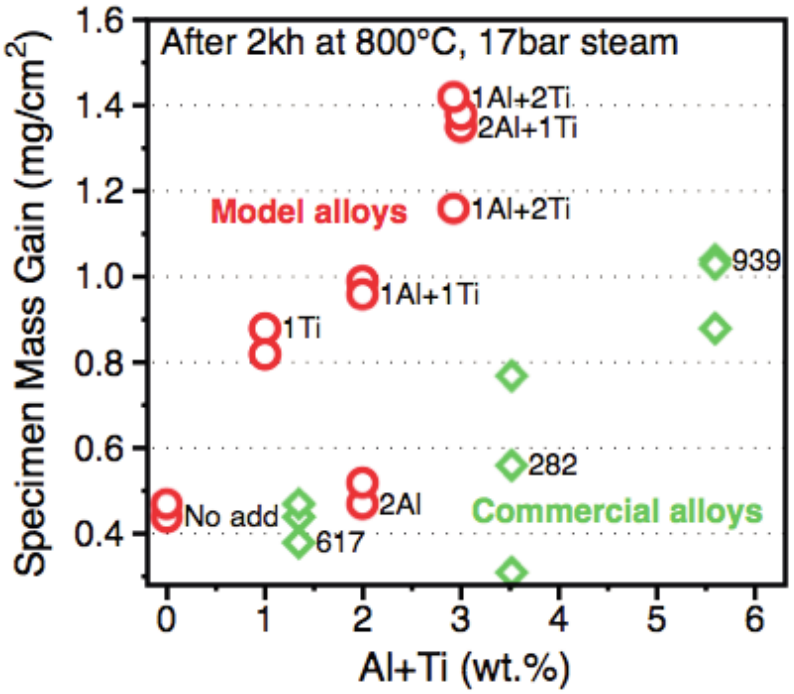
Penetration vs. mass gain - poor relationship

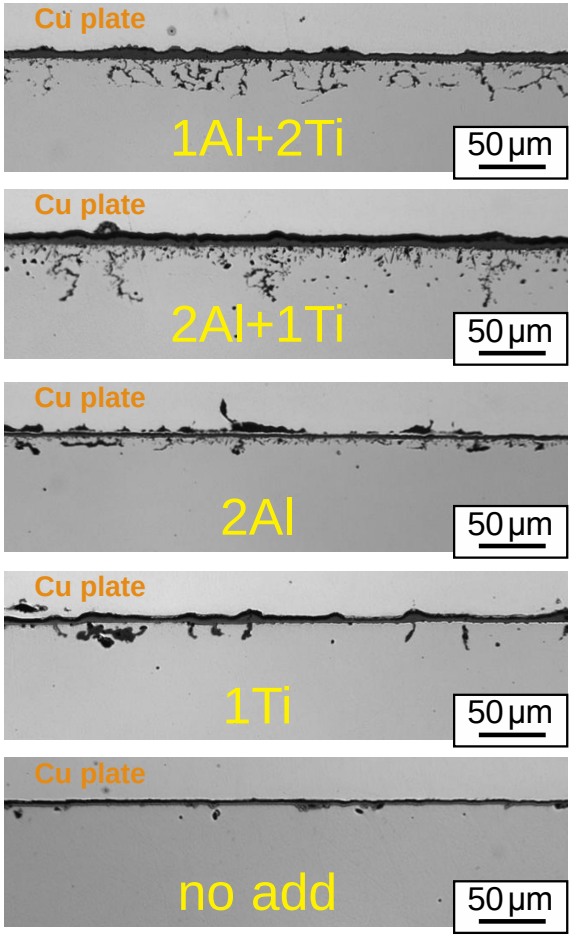
Oxide thickness vs. mass gain - good prediction

Need to do metallography!

Ni-base model alloys: 800°C

2,000h steam testing at 17 bar (1472°)





Model Ni-22Cr alloys
- mass gains higher
- quantification of oxide depths in progress

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 2012 Project Review – FY11 Milestones

- 2011 project milestone – Creep-test cast HR 282 at 700-750^{o}C (Feb., 2011) – Completed
- 2011 project milestone – Analyze microstructures of cast HR 282 and 263 alloys after steam oxidation at 800^{o}C/5000h (April, 2011) - Completed
- Goals of this project are aligned with A-USC Consortium Steam Turbine Project (Phase 2)

DOE/FE 2012 Project Review – FY12 Milestones

- 2012 project milestone – Complete initial screening tests for weldment and weld-properties of new heats of cast HR 282 (Oct, 2011, delayed) – in progress
- 2012 project milestone – Complete analysis of long-term creep-tested cast HR 282 specimens (March, 2012) - Completed
- Goals of this project are aligned with A-USC Consortium Steam Turbine Project (Phase 2)

DOE/FE 2012 Project Review – Future Plans

- Complete creep testing on commercial joining and weldments properties of new cast ingots of HR282 and 263 alloys, in collaboration with General Electric.
- Develop new capability for fatigue testing in steam and begin testing (interest from General Electric)