Materials for Advanced Ultra-Supercritical Steam Service - Turbines

Phil Maziasz
Oak Ridge National Laboratory

24th Ann. Conf. on Fossil Energy Materials, 25-27 May, 2010, Pittsburgh, PA

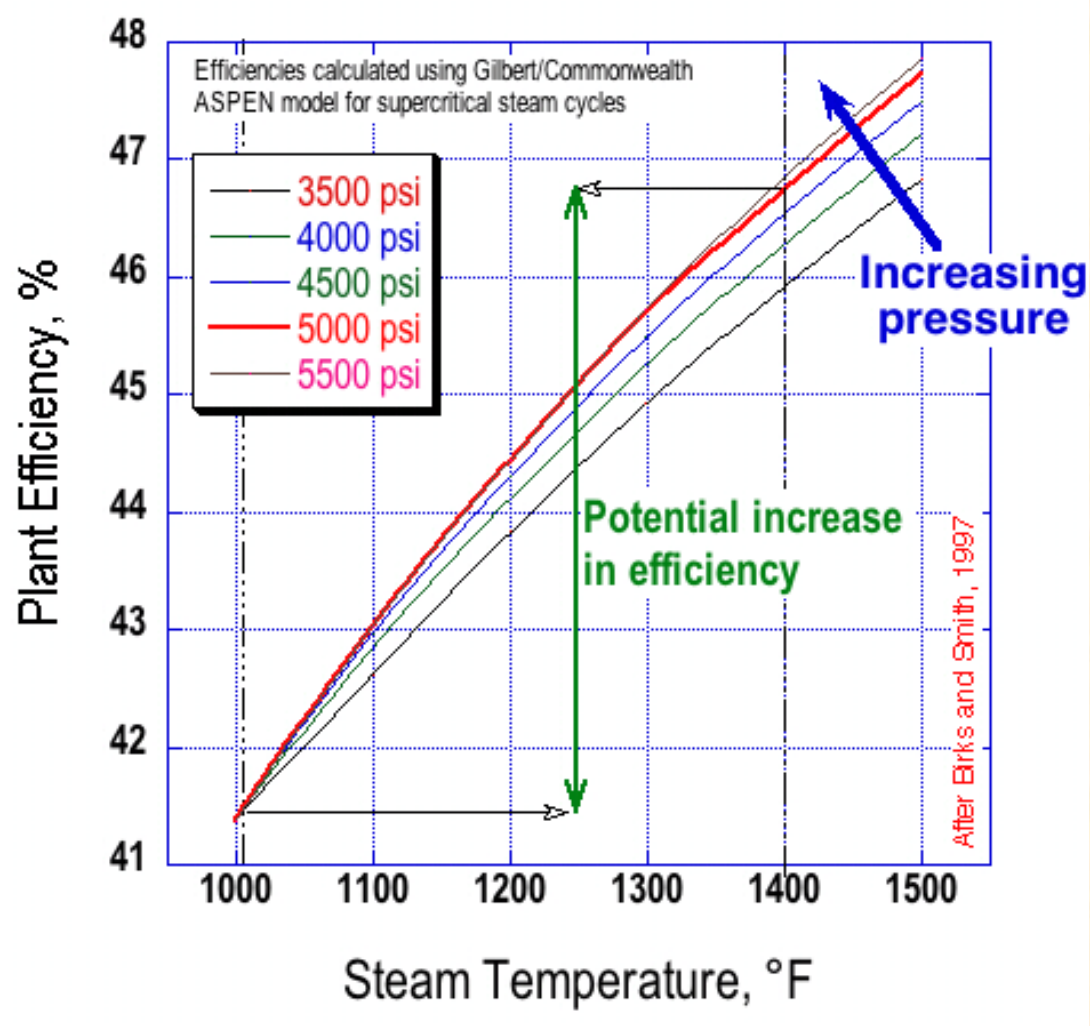
2 x 800 MW Lignite-Fired Power Plant Schwarze Pumpe, Germany

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

DOE/EIO/EPRI – A-USC Steam Turbine Materials Consortium

- Project began in 2006, as the necessary complement to the A-USC Steam Boiler Materials Consortium Project
- Steam Turbine Consortium Project (Phase I) included General Electric, Alstom and Siemens
- ORNL was included from the beginning, to support the needs of the OEMs
- ORNL and NETL/Albany began collaboration in 2008, to provide the initial feasibility testing of cast Ni-based superalloys for turbine casings that were commercially unavailable

A-USC Steam Cycles are Cleaner and More Efficient



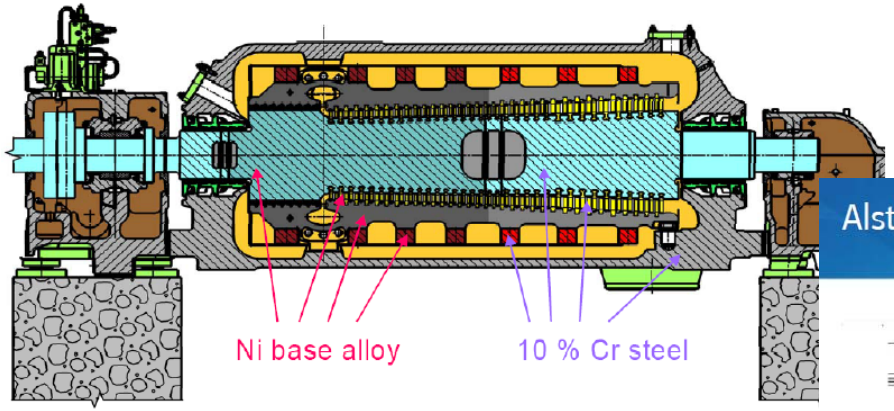
- Goals:
  - AD700: 1292°F/1328°F/5,500 psi (700°C/720°C/375 bar)
  - US: 1350°F/1400°F/5,000 psi (732°C/760°C/345 bar)

>efficiency gain of ≈ **5 percentage points** (approx 13% relative)

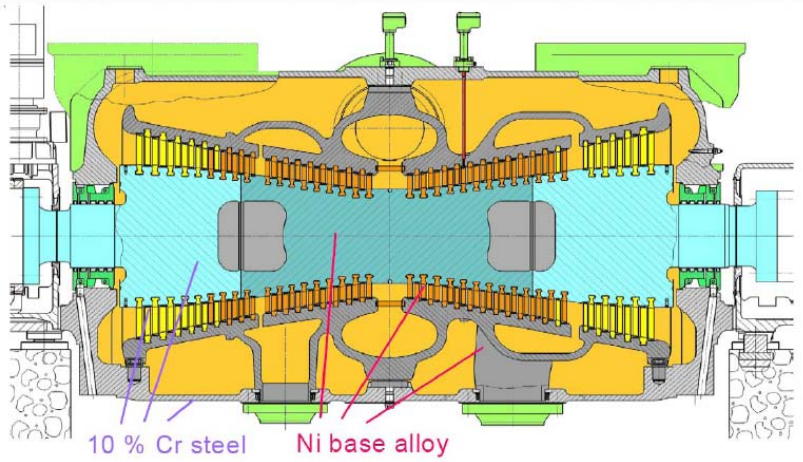
>17% reduction in emissions

A-USC Turbine Designs Using Ni-based Alloys

Alstom HP Turbine Concept



Alstom Double Flow IP Turbine Concept



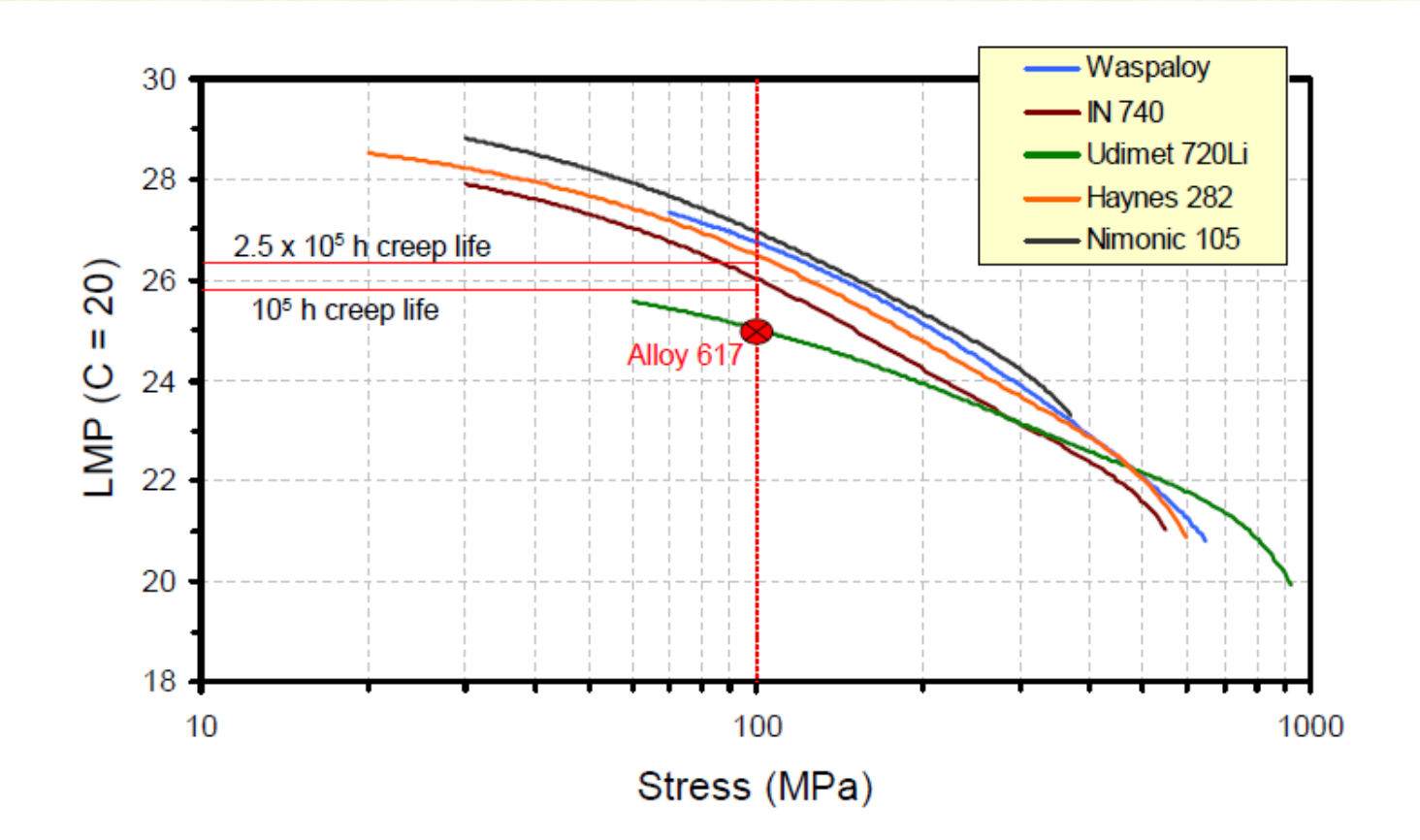
Background for A-USC Steam Turbine Materials – Summary Phase 1 Consortium

- A wide range of Ni-based superalloys were considered initially, but narrowed down to Nimonic 105, HR 282, Udimet 720Li, with IN 740 as a back-up for monolithic rotor application
- Welded rotor combinations included alloys 263/617, and HR 282/720Li
- Nimonic 105 and HR 282 can also be considered for blading and bolting applications

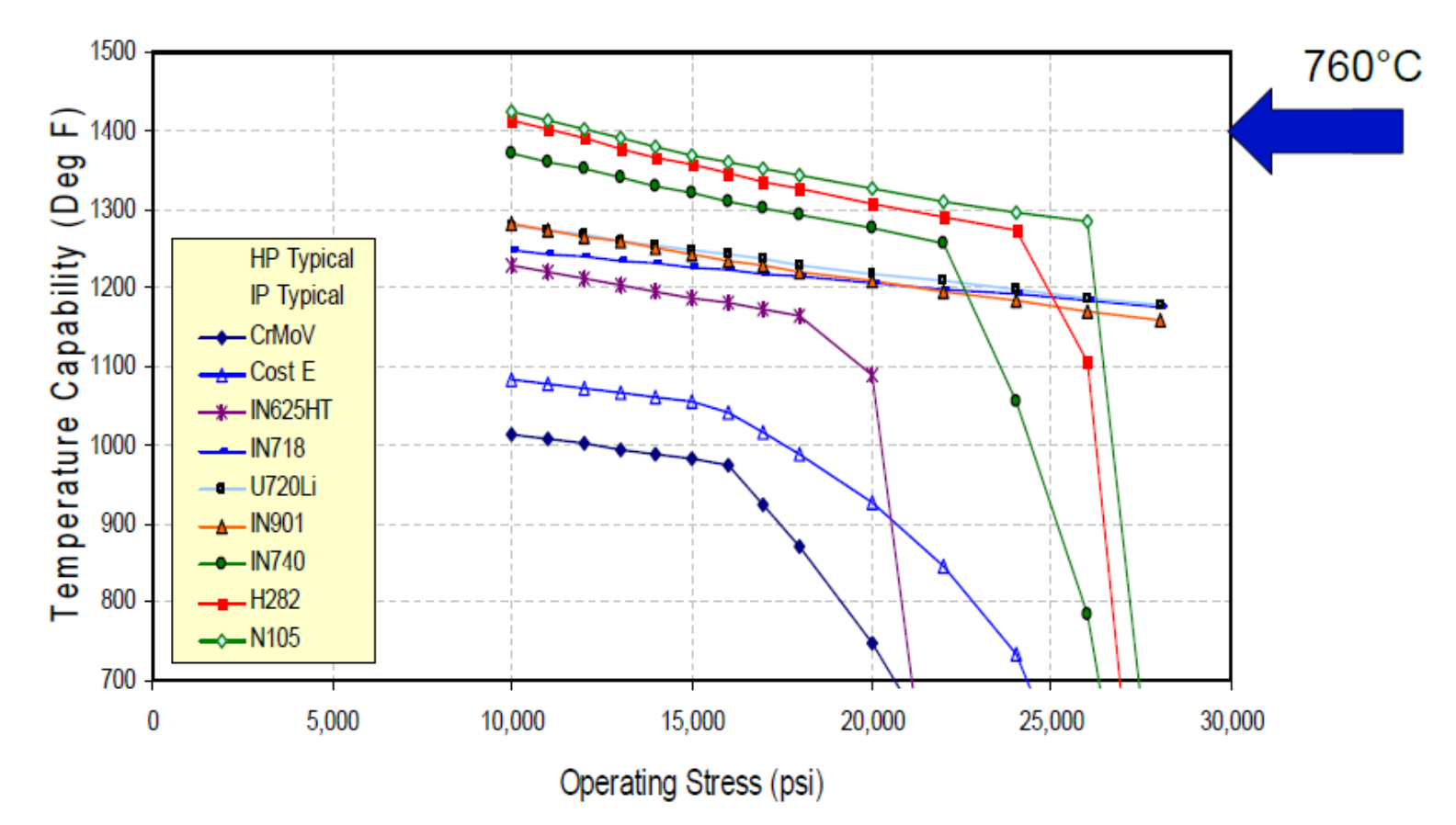
Compositions of Various High-Temperature Commercial Superalloys Considered for A-USC Turbines (wt.%)

- HR282 – Ni-19.5Cr-8.5Mo-10Co-1.5Fe-2.1Ti-1.5Al-0.15Si-0.06C
- Nimonic 105 – Ni-15Cr-20Co-5Mo-3.6Nb-3.2Fe-2Ti-4Al-0.2C-0.05B
- Udimet 720Li- Ni-16.2Cr-3Mo-14.6Co-5Ti-2.5Al-1.3W-0.025C-0.016B-0.037Zr
- Inconel 740 – Ni-25Cr-20Co-0.9Al-1.8Ti-2Nb-0.3Mo-0.3Mn-0.7Fe-0.5Si-0.03C (mod. 1.2Al/1.4Ti)

Nimonic 105 and HR 282 meet the creep-rupture strength requirements (rotor)



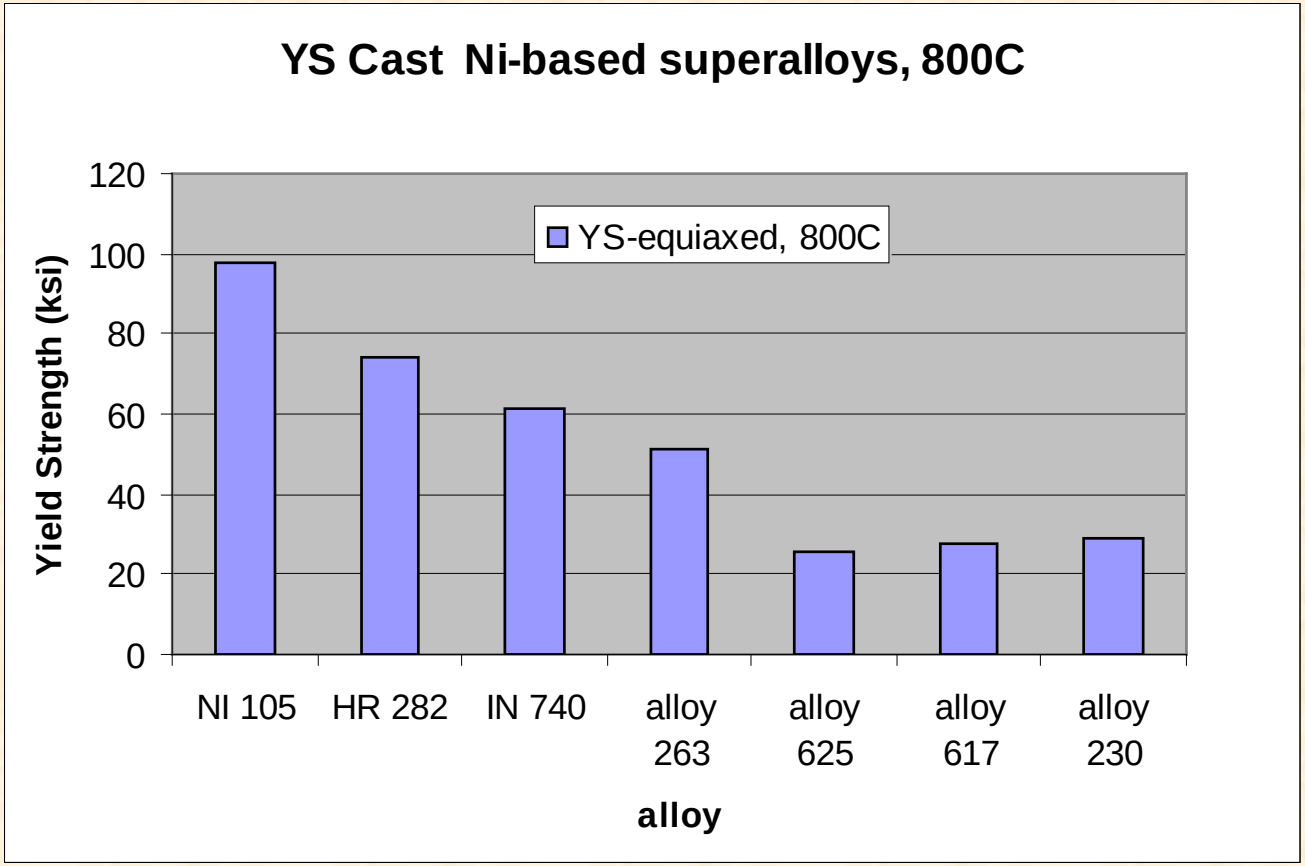
Temperature capabilities of Ni-based superalloys for HP/IP rotor application – NI 105 and HR 282 are best



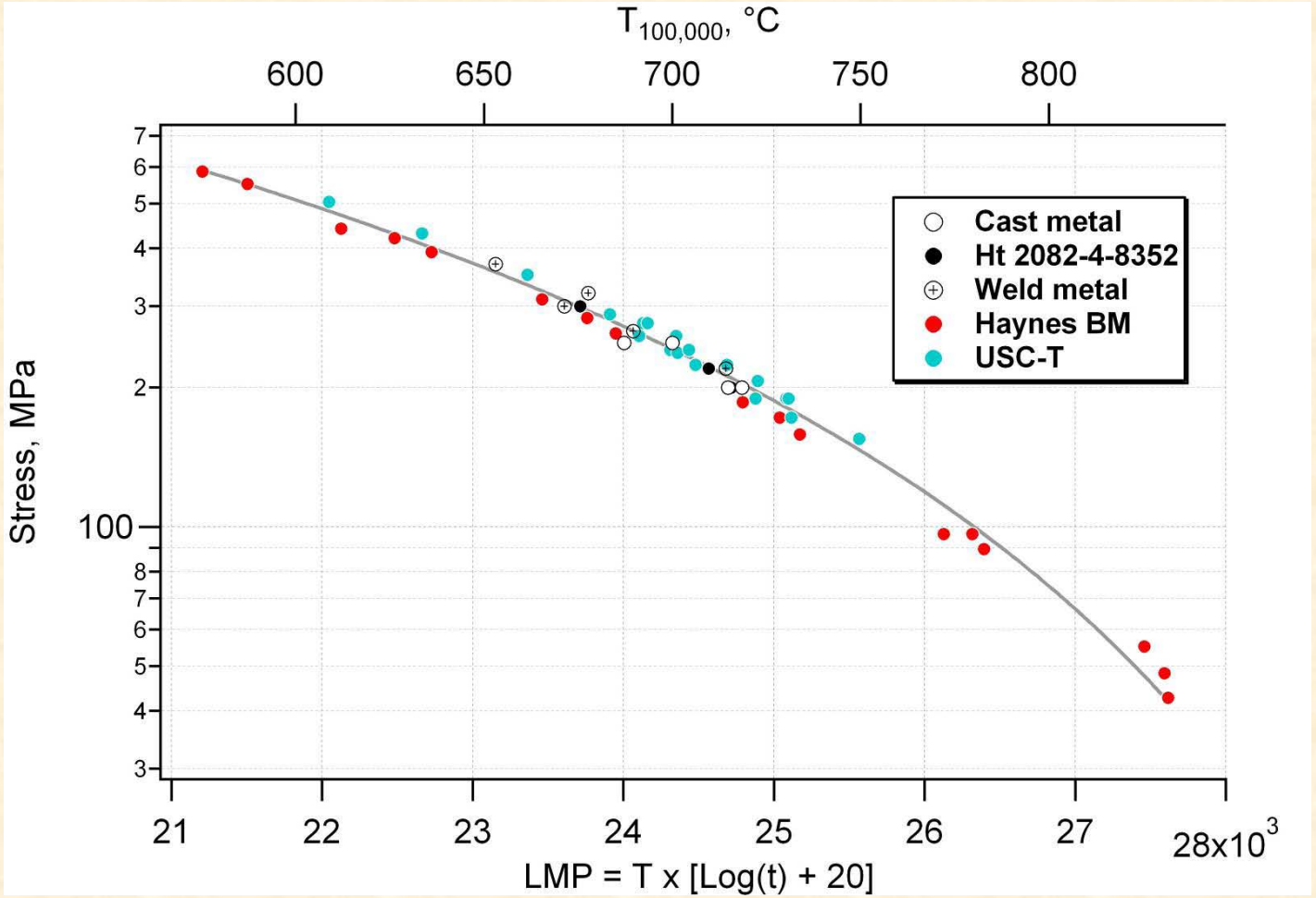
ORNL and NETL/Albany Collaborated to Cast and Test the same wrought Ni-based superalloys

- 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 800C

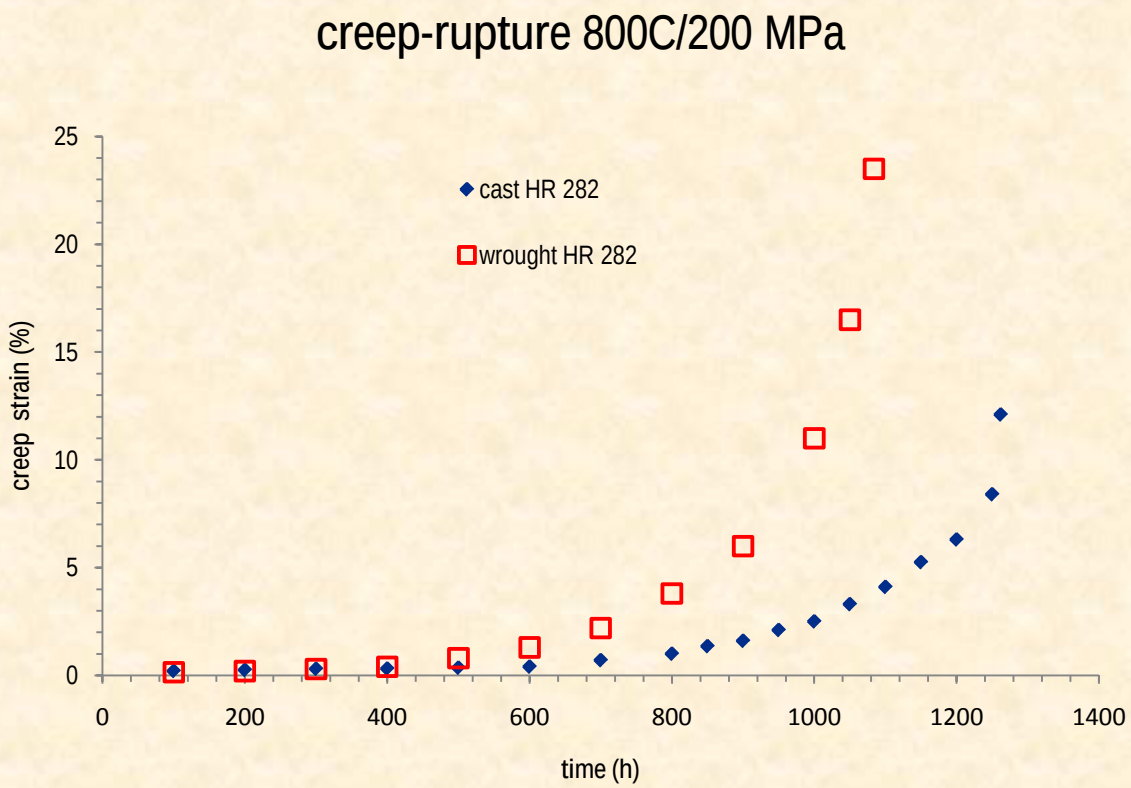
For YS of Cast alloys, Nimonic 105, HR 282 and IN 740 are the strongest



Wrought and Cast Ni-based superalloys generally have similar creep-rupture strength – HR 282

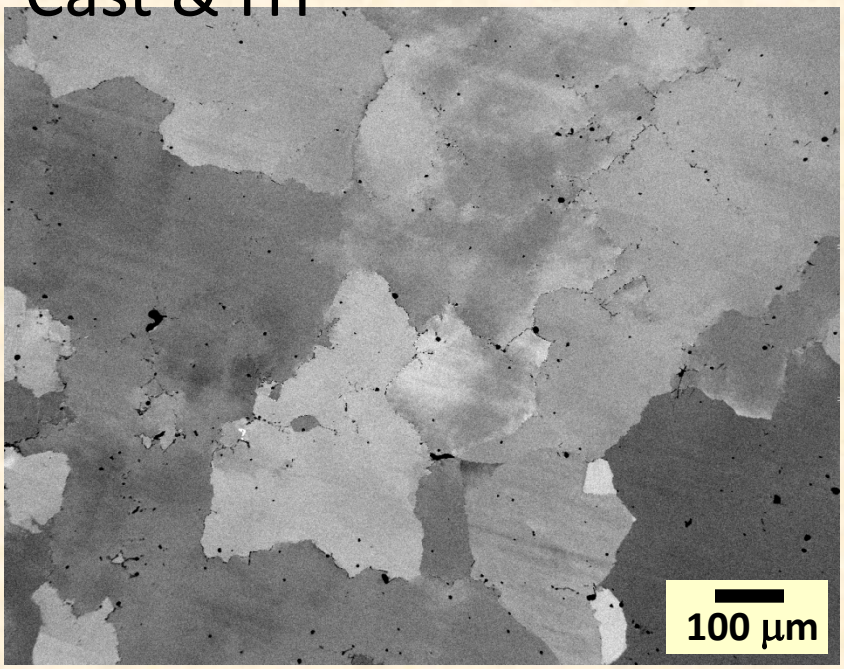


Comparison of Creep Curves – HR 282

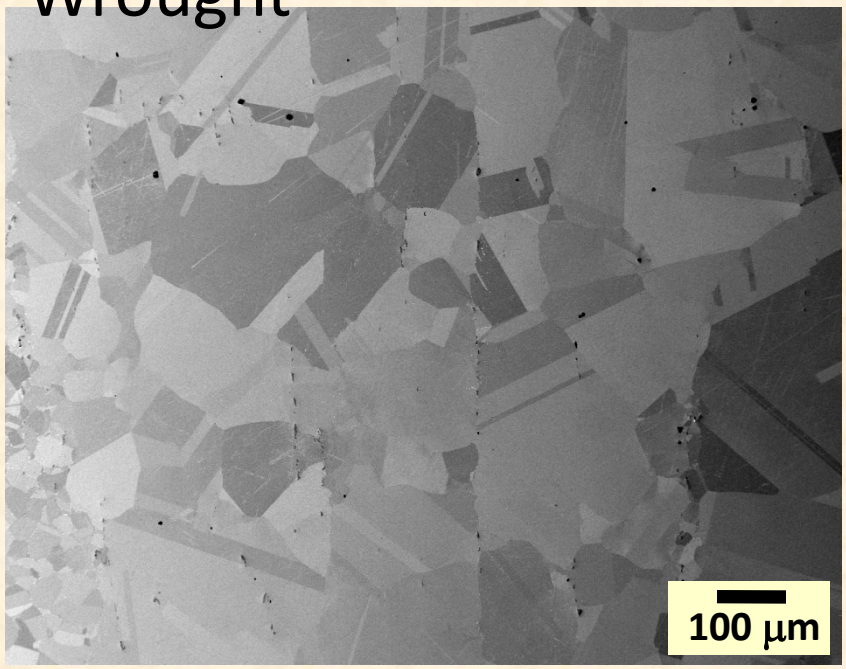


Cast Ni-based alloys have coarser grain size than wrought – HR 282

Cast & HT

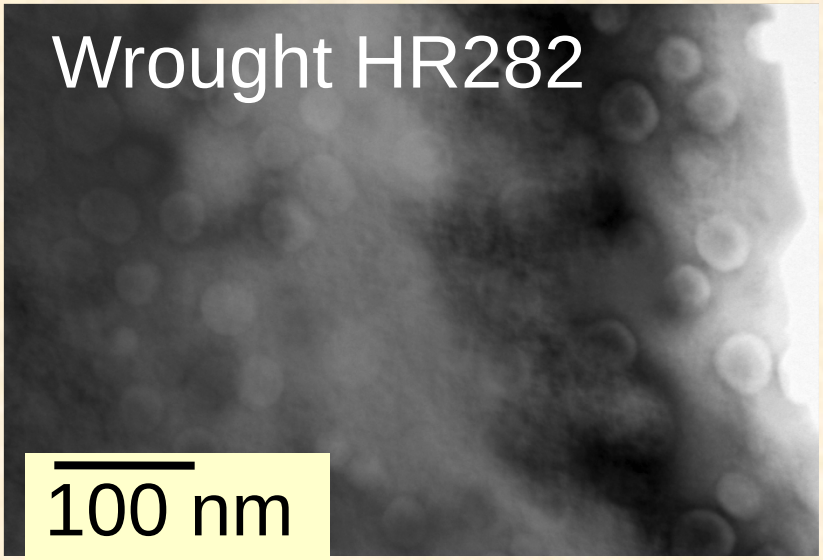


Wrought

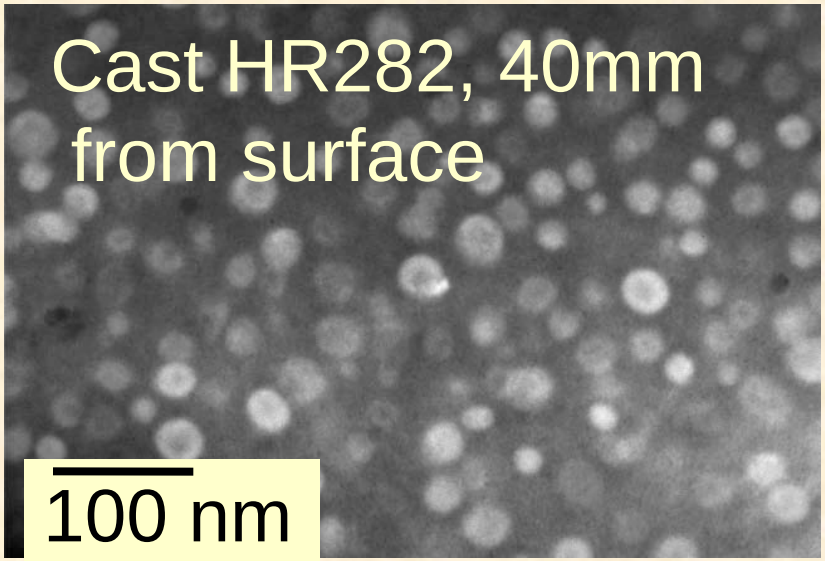


BSE SEM Images; unetched

The γ' Distribution in Cast HR282 is Similar To γ' in Wrought HR282

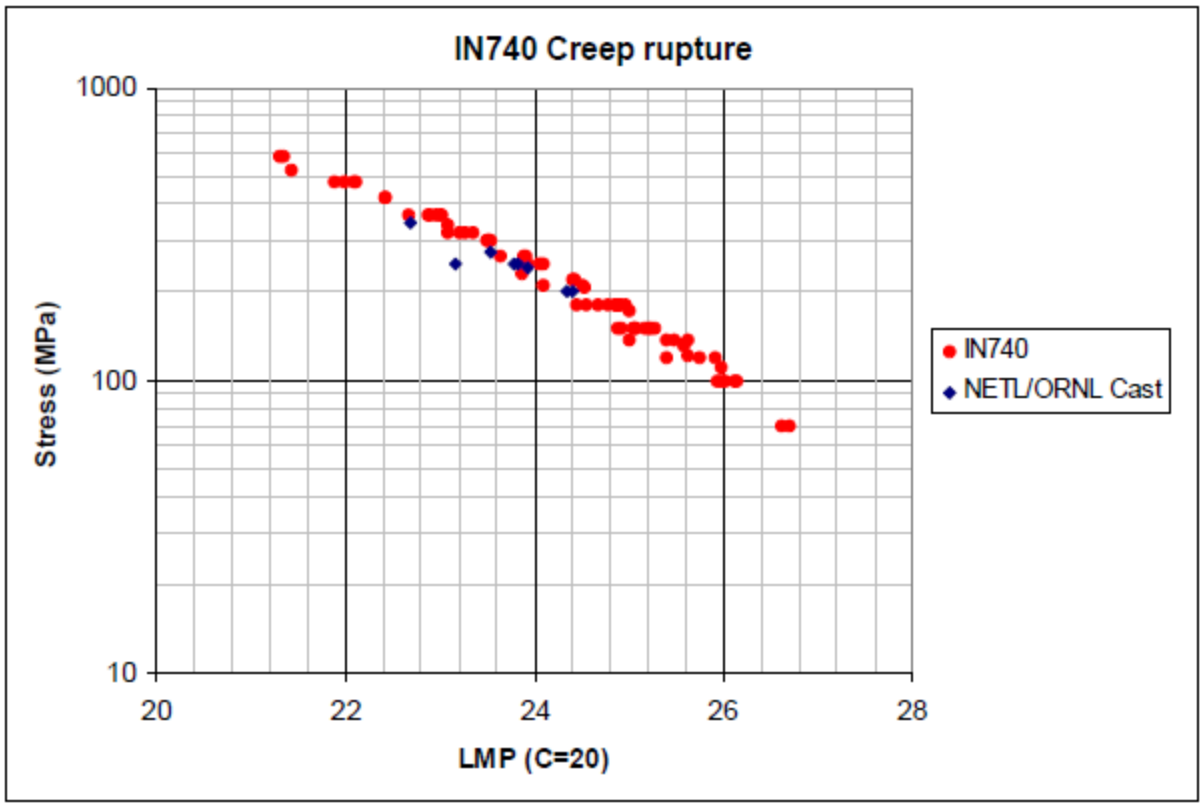


Solution Annealed
Age 1010°C/2h/AC + 788°C/8h/AC

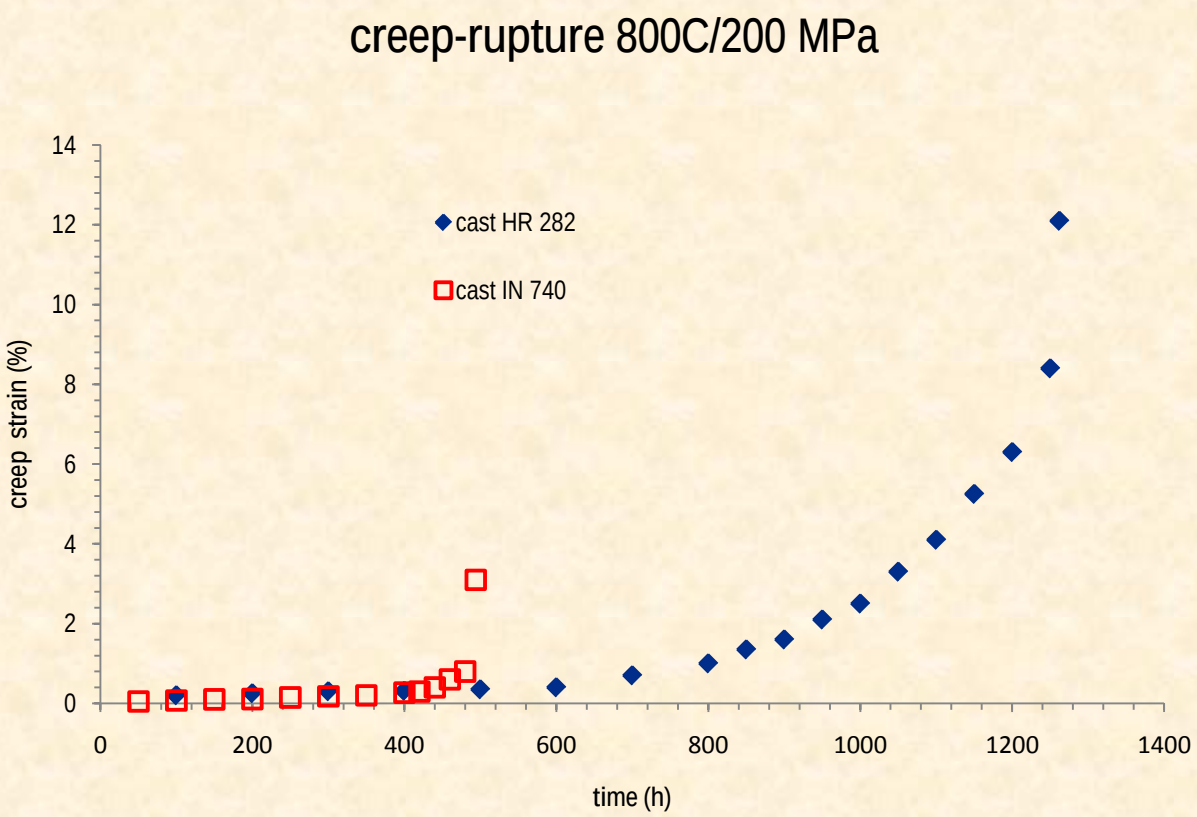


Homogenized 1100°C/3h + 1200°C/9h/GFC
Age 1010°C/2h/AC + 788°C/8h/AC

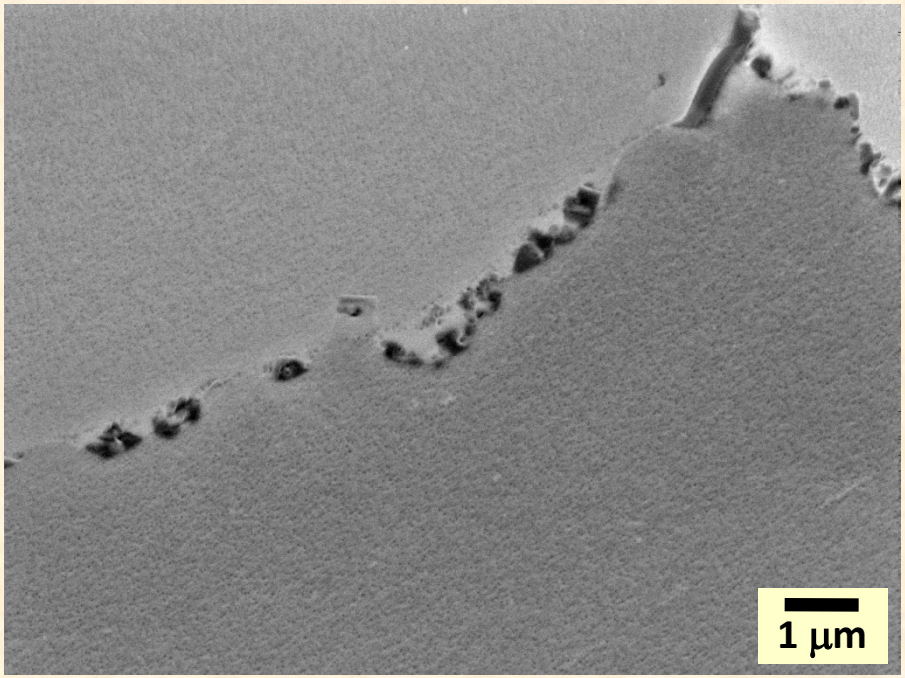
Wrought and Cast Ni-based superalloys generally have similar creep-rupture strength – IN 740

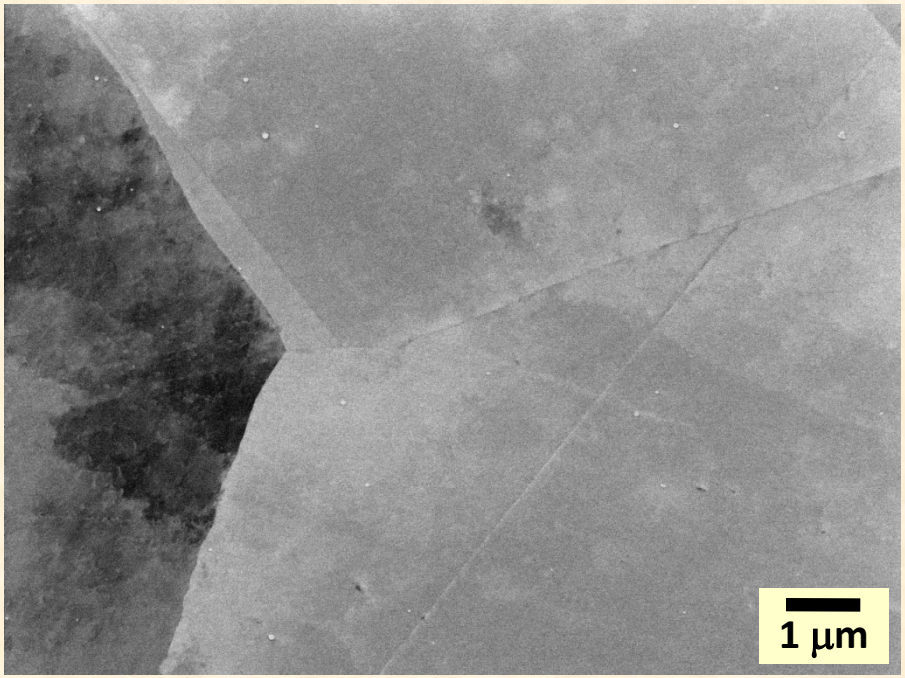


Cast HR 282 has better creep-resistance and rupture ductility than IN 740



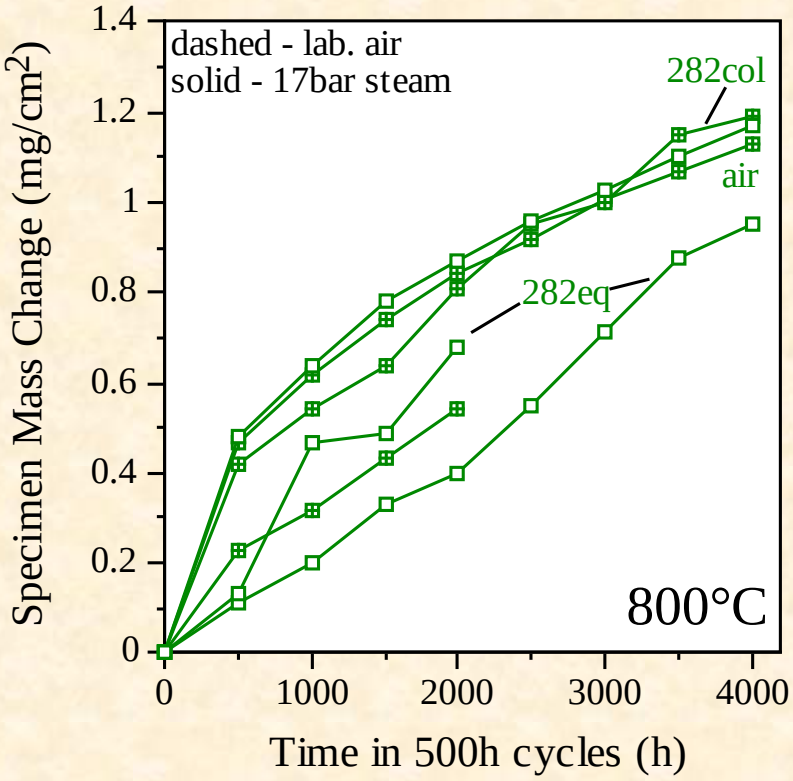
Significantly heavier grain-boundary precipitation may be causing lower creep-ductility in cast NI 740

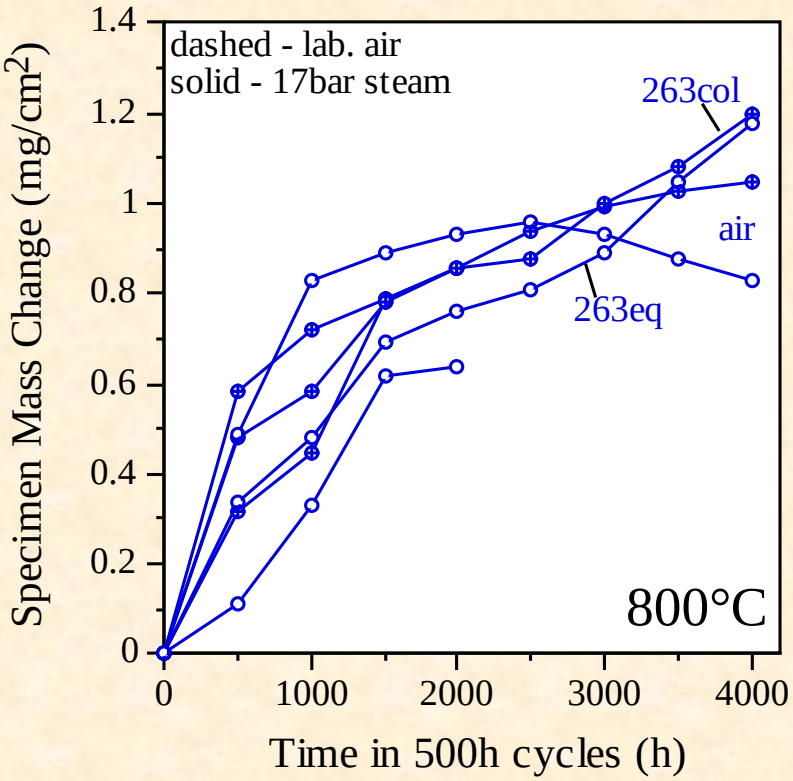




SEM Images; SE-BSE signals mixed; unetched

Oxidation in Steam and Air is Similar for Cast HR 282 at 800C





Summary

- Several commercial wrought Ni-based superalloys appear to have acceptable high-temperature properties for A-USC steam turbine component applications
- Initial screening tests suggest that cast HR 282 has good combination of creep-strength and ductility for A-USC steam turbine casing application
- More detailed properties studies are needed, and prototype component production trials would be helpful to supplier base and to turbine OEMs

DOE/FE 2010 Project Review

- 2009 project milestones – Make and test new cast Ni-based superalloys. Down-select best 2-3 alloy by Dec. 2009. (Successfully met, cast HR 282 is best so far)
- Goals of this project align with A-USC Consortium Steam Turbine Project
- Future Plans – complete initial data, cast new heats to test weldability and weldment properties of cast HR282 and 263 alloys. Work with Consortium and vendors for next-steps needed for commercial scale-up.