Materials for Advanced Ultra-Supercritical Steam Boilers

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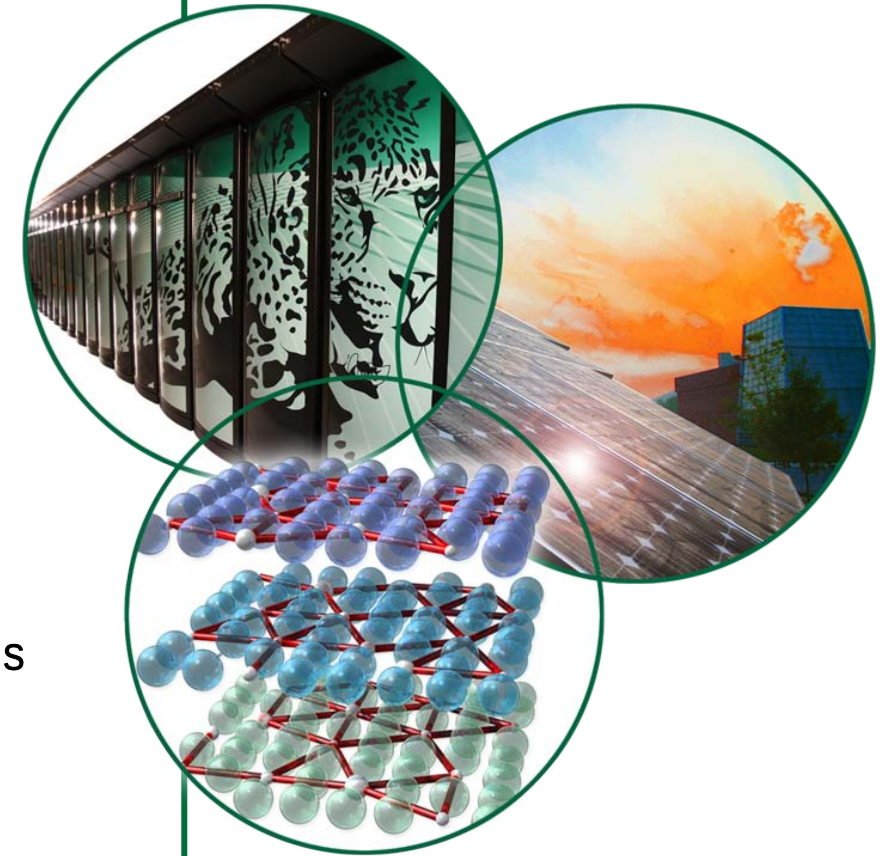

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U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY

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Efficiency Improvements depend on Supercritical Technology

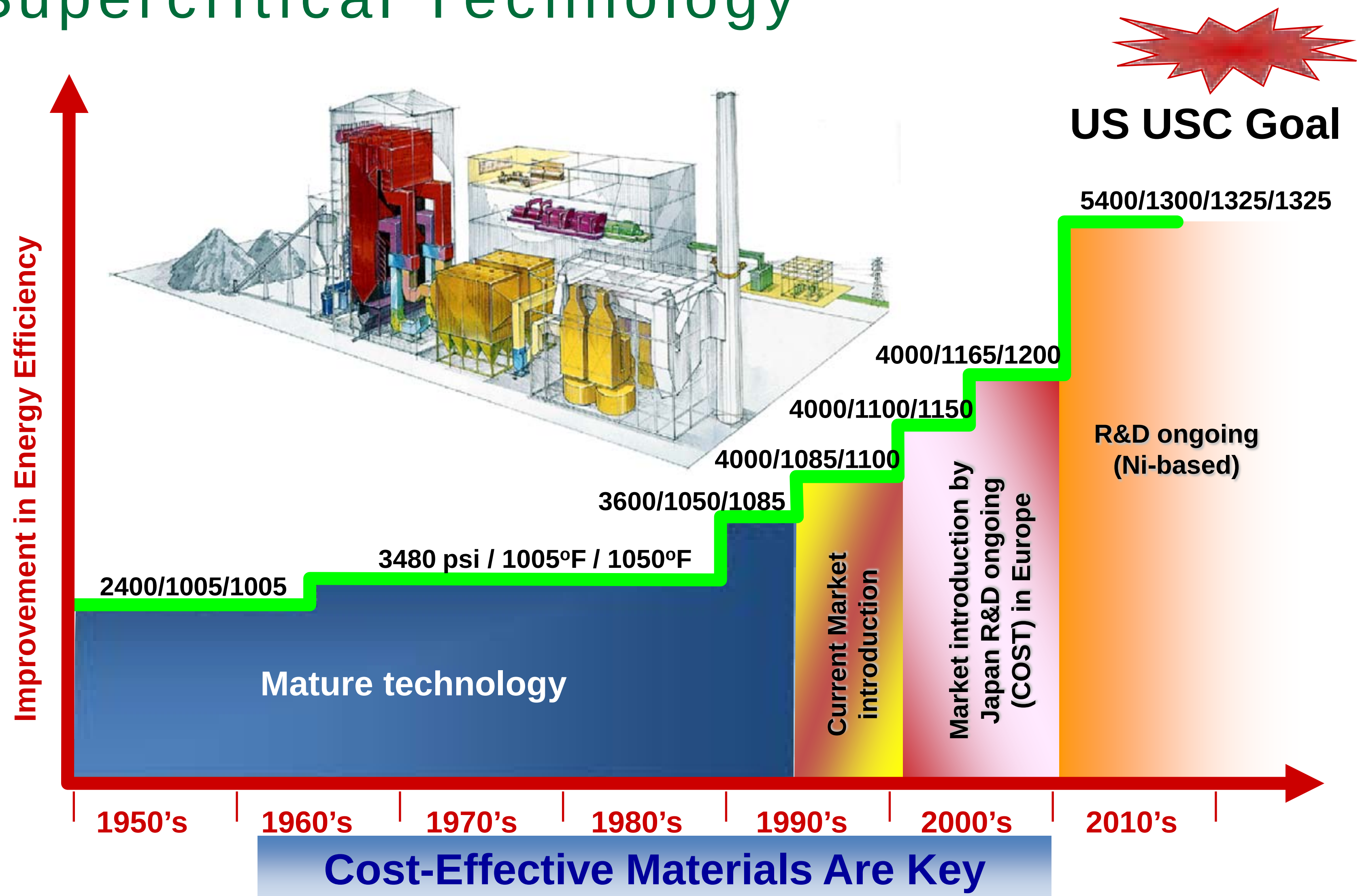

Illustration: EPRI
Data: Alstom

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Maximum Usage Temperature of Steam Boiler Alloys

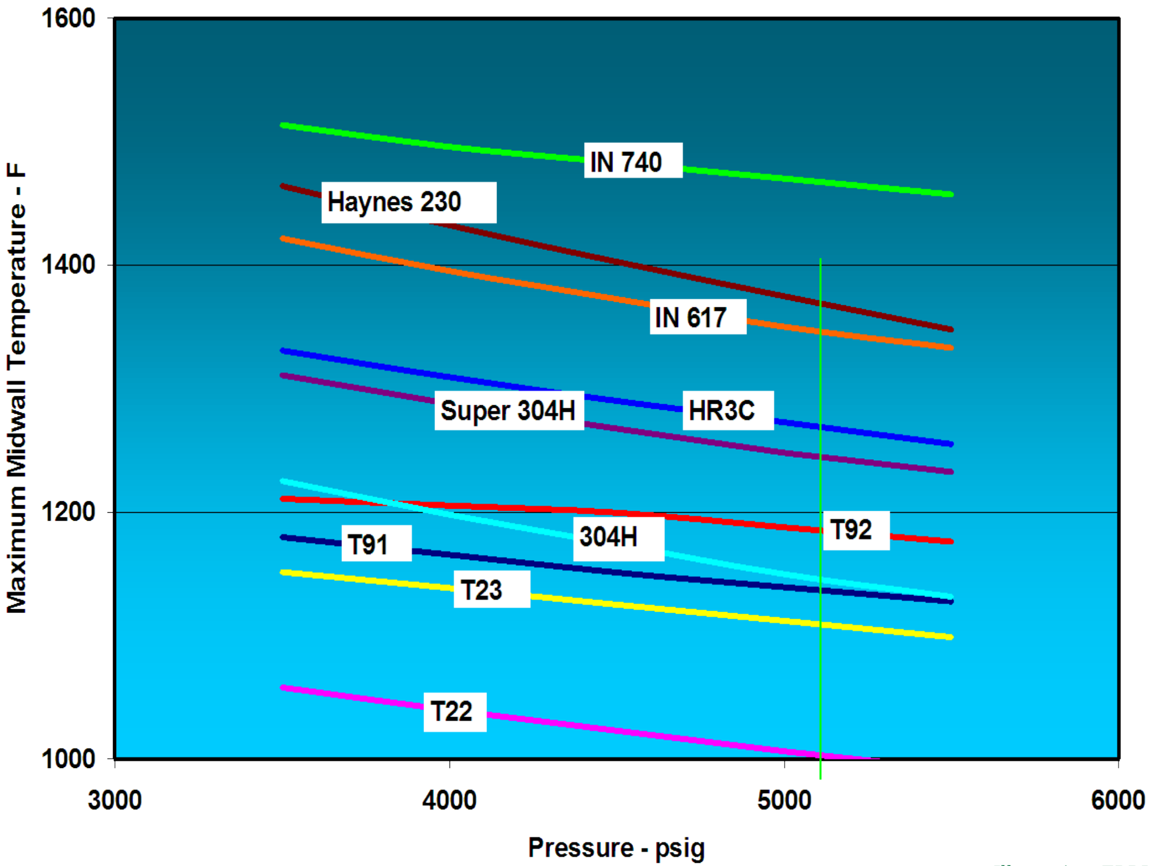
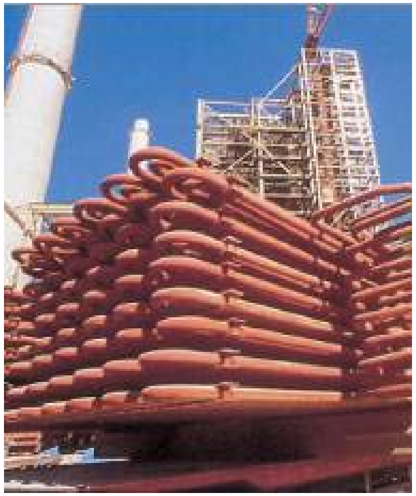


Illustration: EPRI

- Only precipitation-strengthened Ni-based alloys like 740 offer strength enough to operate ≥ 760°C (1400°F)/35 MPa (5000psi)

Estimated Total Amount of Tubing for a Generic A-USC Boiler

- Carbon Steel Grades – 420,000lf; 3,750,000 lbs
- T12 Alloy Steel Grade – 500,000 lbs
- T23 to T92 Alloy Grades – 2,600,000 lbs
- Traditional Stainless Steels – 1,600,000 lbs
- Solid-solution Ni-based alloys – 1,100,000 lbs
  - 1.750” OD X 0.400” MW
  - 2.00” OD X 0.165”/0.355” MW
- Precip.-strengthened Ni-based – 850,000 lbs
  - 1.750” OD X 0.290”/0.400” MW
  - 2.00 OD X 0.280”/0.400”MW



Images courtesy of The Babcock & Wilcox Company, www.babcock.com

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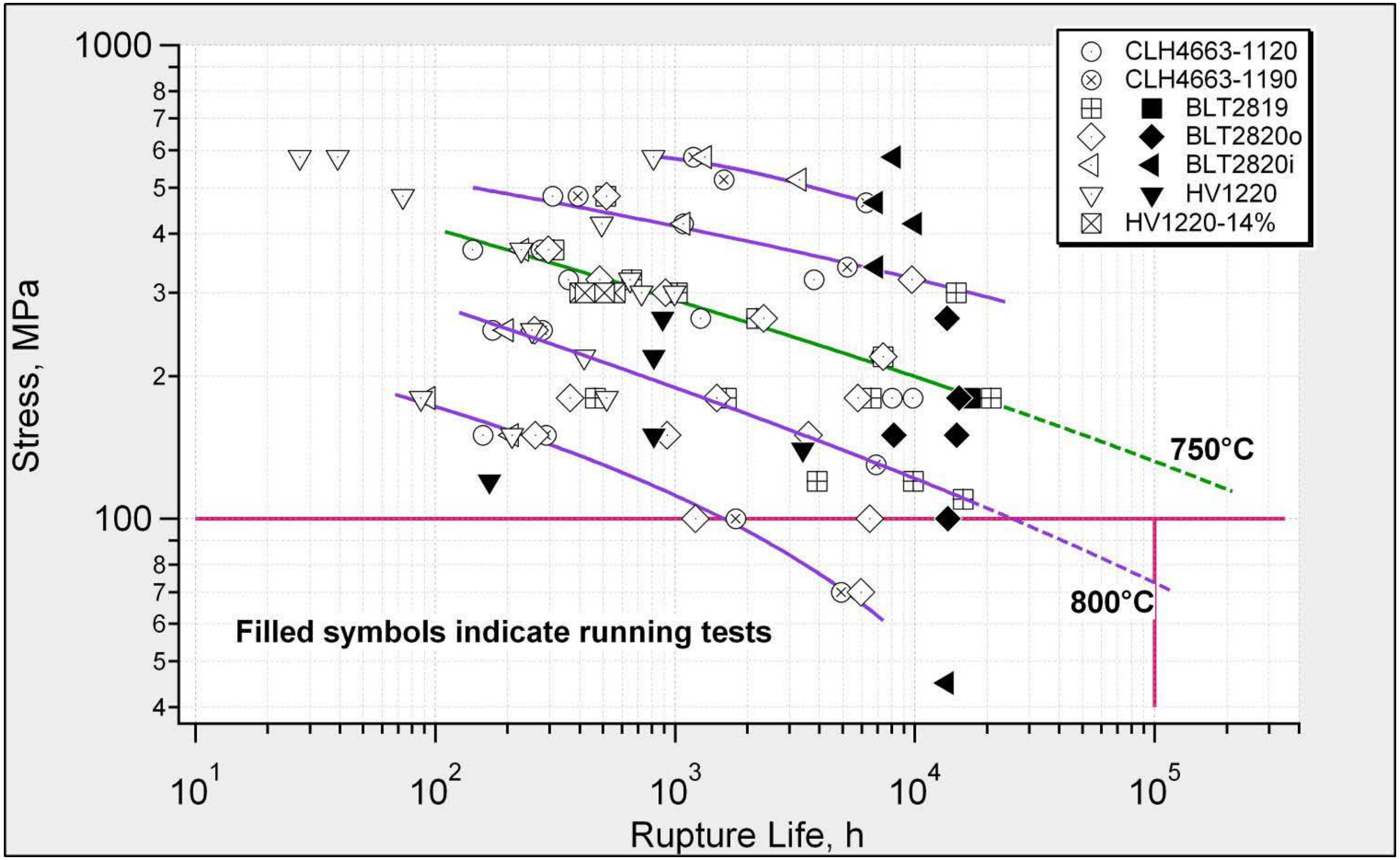
Task 2: Mechanical Properties of Advanced Alloys

<u>Creep-Rupture Testing is Highest Priority</u>

- Characterize and understand creep behavior & mechanisms
  - ASME Code Cases: Inconel 740 & Haynes 282
  - Supplement minimum required data for code-approved alloys: e.g., alloys 230 & 617
  - Identify and understand fabrication & welding issues: e.g., effects of cold-work on creep, weld strength factors
- Provide creep data for boiler design activities
- Characterize and understand issues important to welded construction

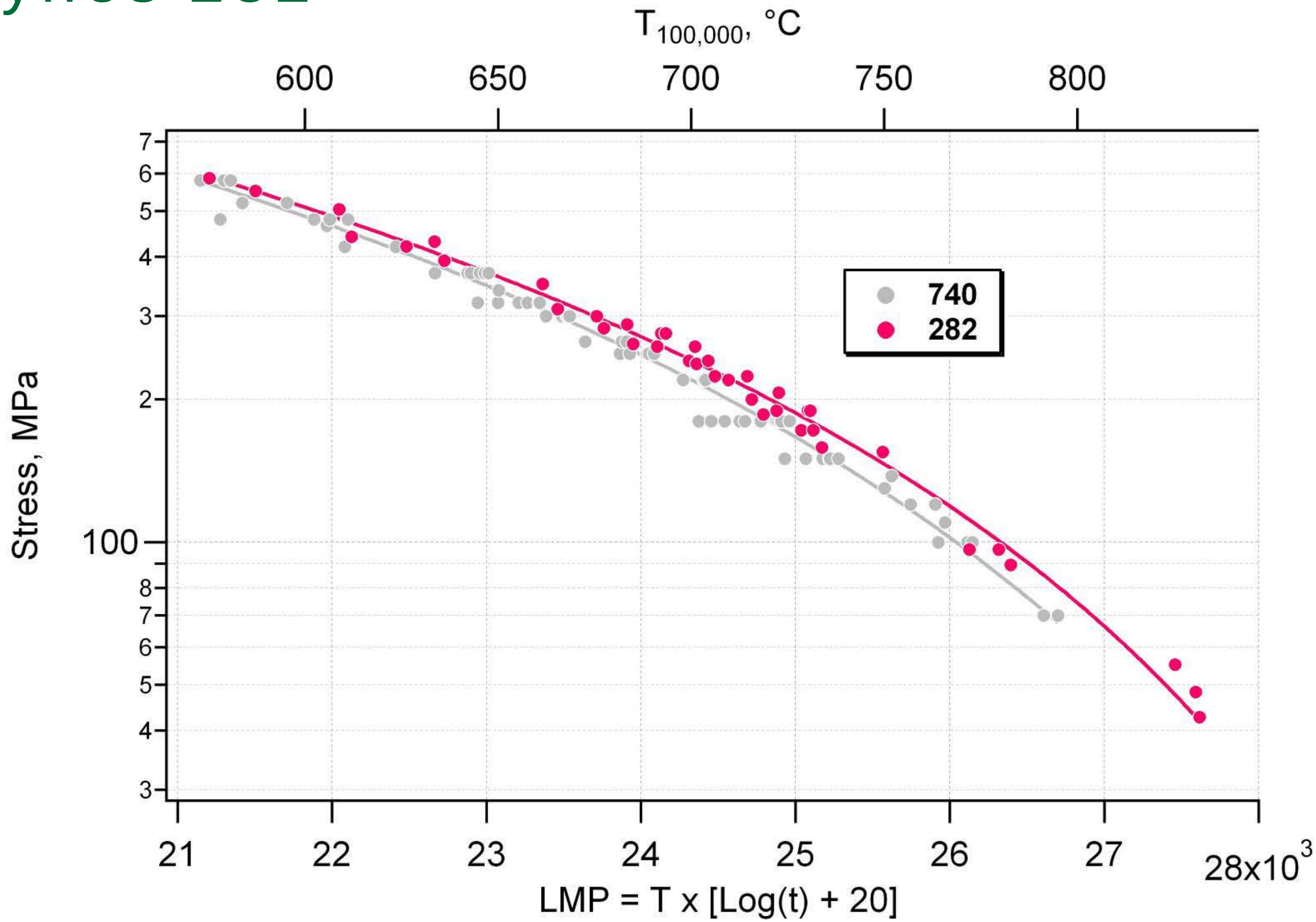
Build confidence for using new high-strength alloys in new applications

Longer-time tests of 740 are confirming strength retention up to ~ 20,000 h



- On-going tests emphasize longer times, ~ 10,000+ h
- Critical for ASME Code approval

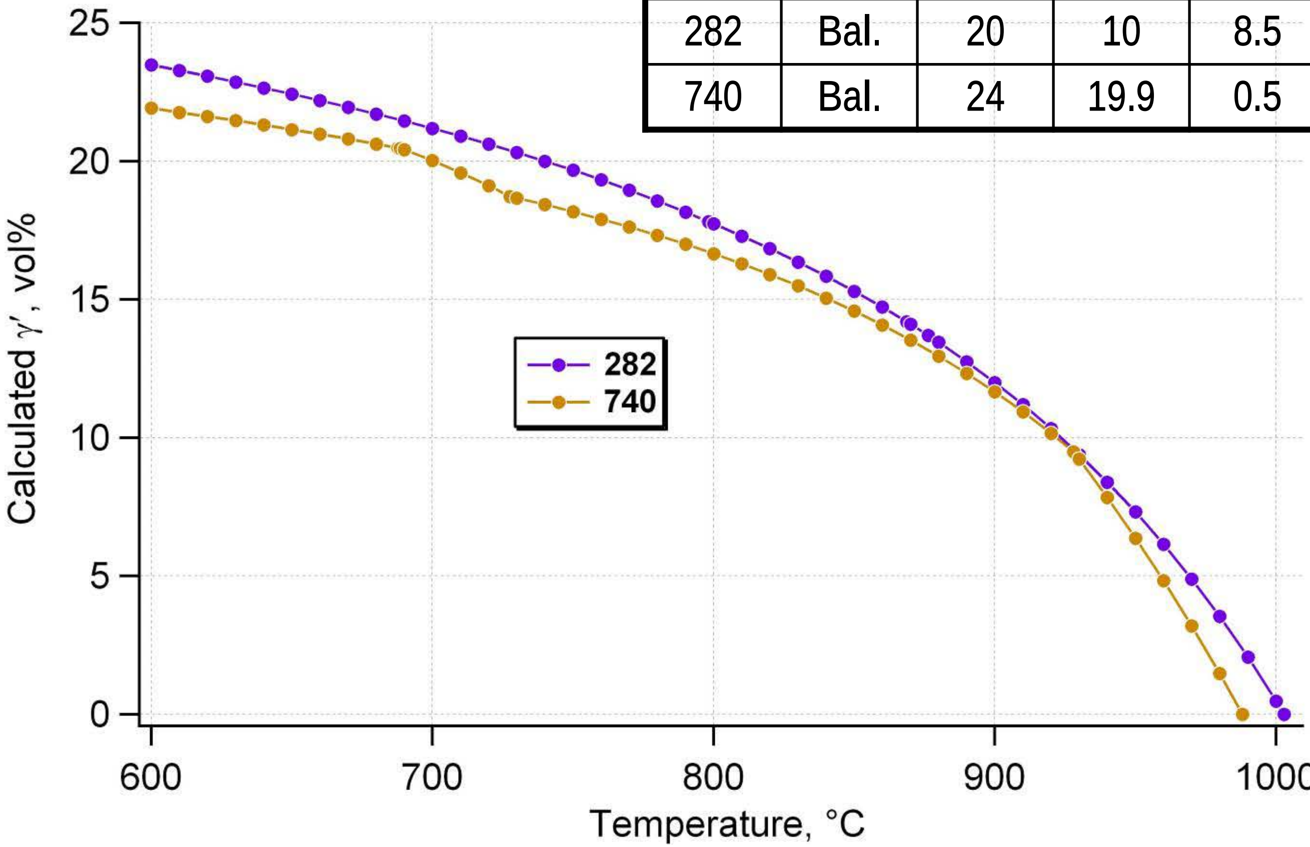
Recent work has heightened interest in Haynes 282



- At the A-USC target of 100,000 h at 750°C, 282 is ~15% stronger

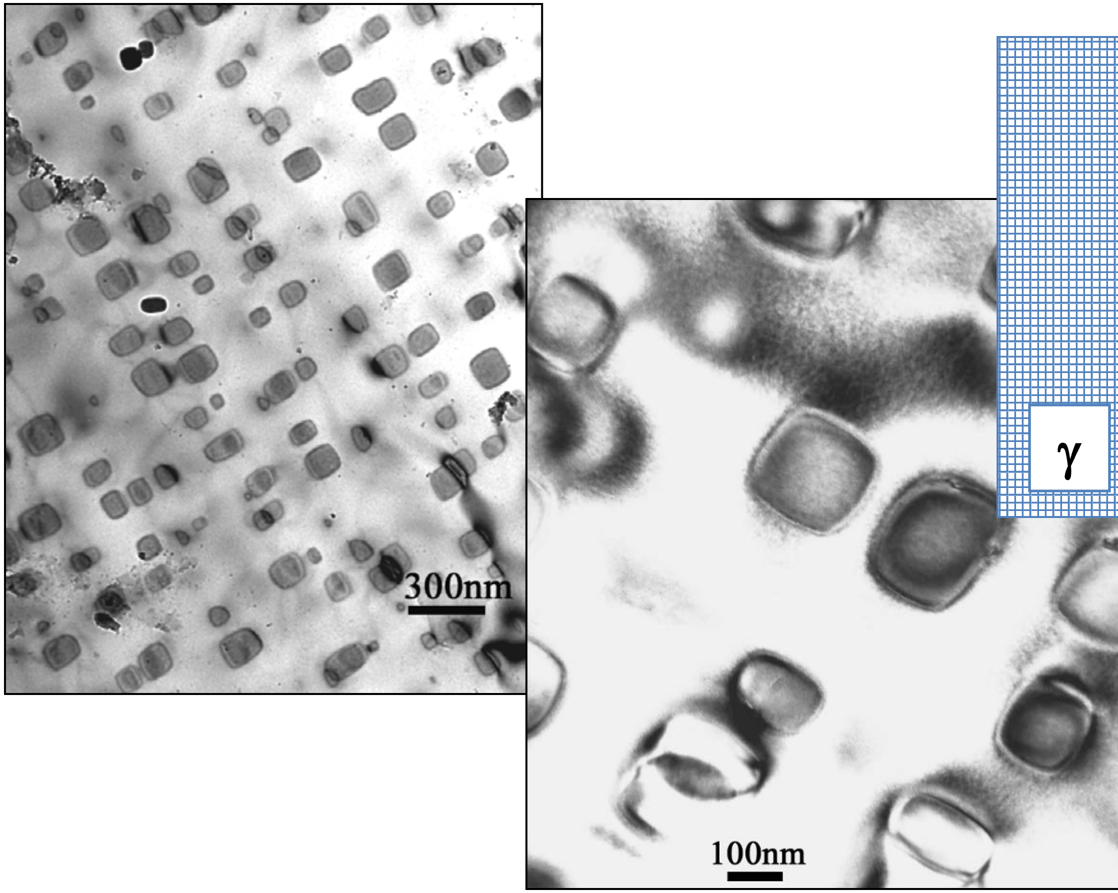
Both alloys are expected to contain about 20% γ′-phase for strengthening

	Alloy element, wt%						
Alloy	Ni	Cr	Co	Mo	Ti	Al	Nb
282	Bal.	20	10	8.5	2.1	1.5	
740	Bal.	24	19.9	0.5	1.5	1.3	1.6

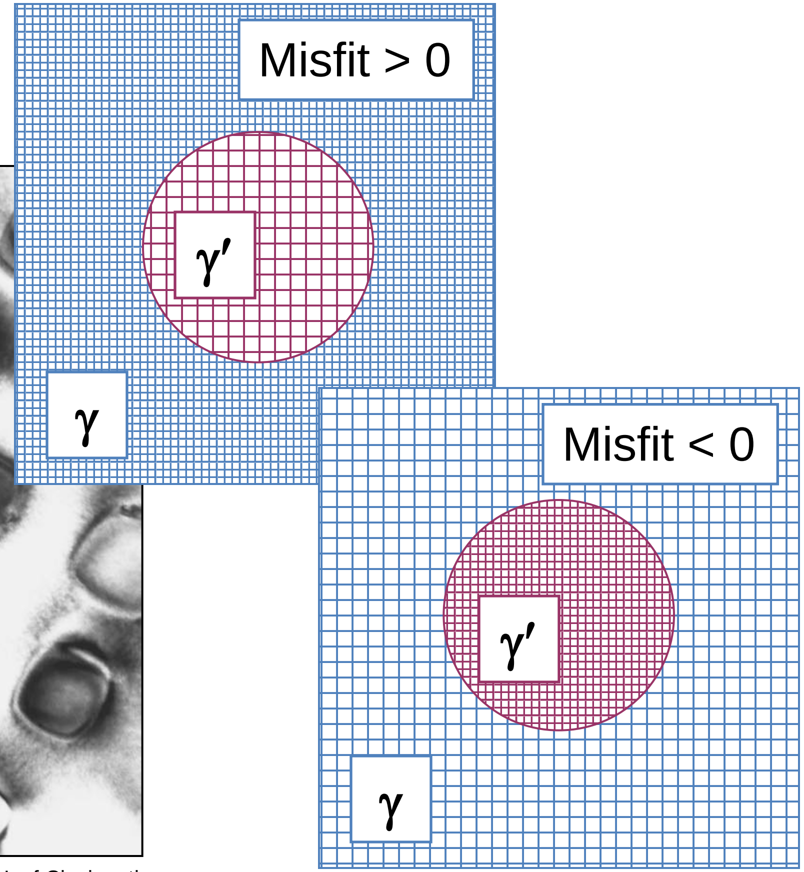


- Why is 282 stronger than 740?

Strengthening depends on magnitude and sense of γ/γ′ misfit

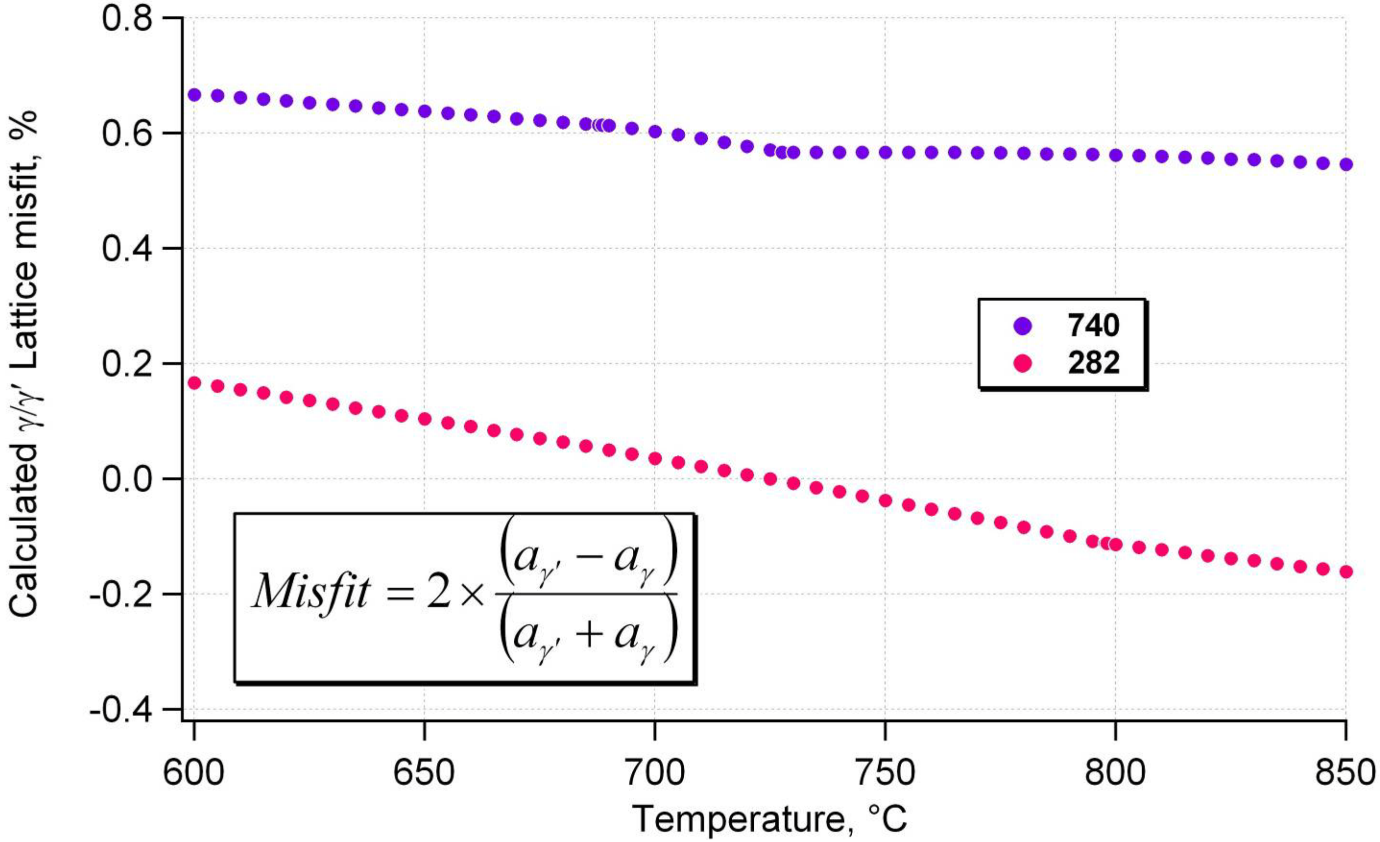


TEM by Q. Wu and V. Vasudevan, U. of Cincinnati



- Misfit ~ 0 minimizes γ/γ′ surface energy, reduces coarsening rates
- Misfit < 0 superposition of stress reduces net stress in γ-phase

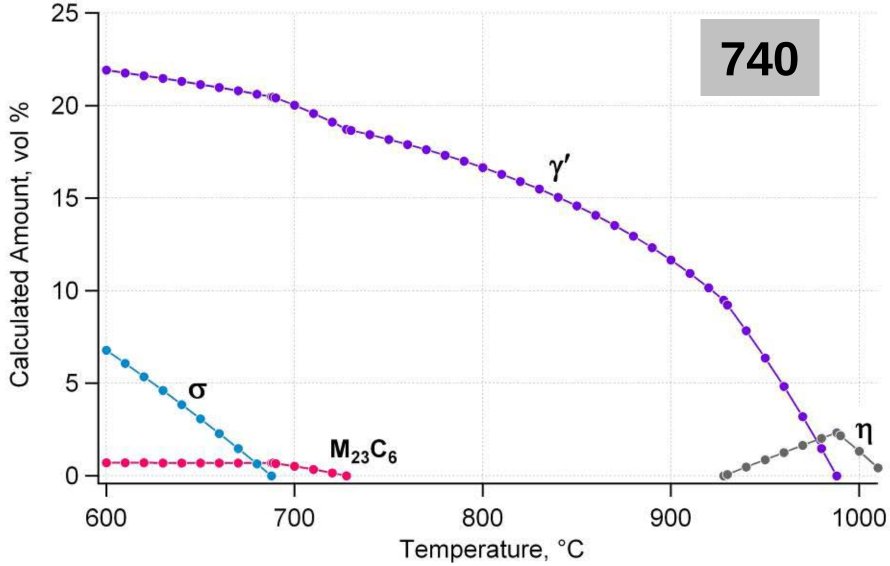
γ/γ′ misfit condition is more favorable for 282

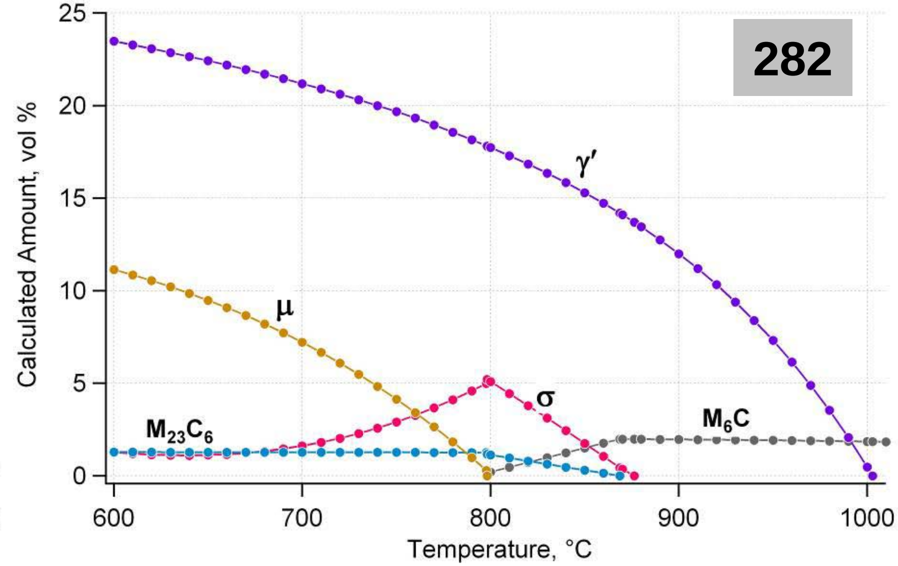


- 282 has an advantage whether or not TCP phases are considered

Increased Mo reduces γ/γ′ misfit but it also increases TCP phases

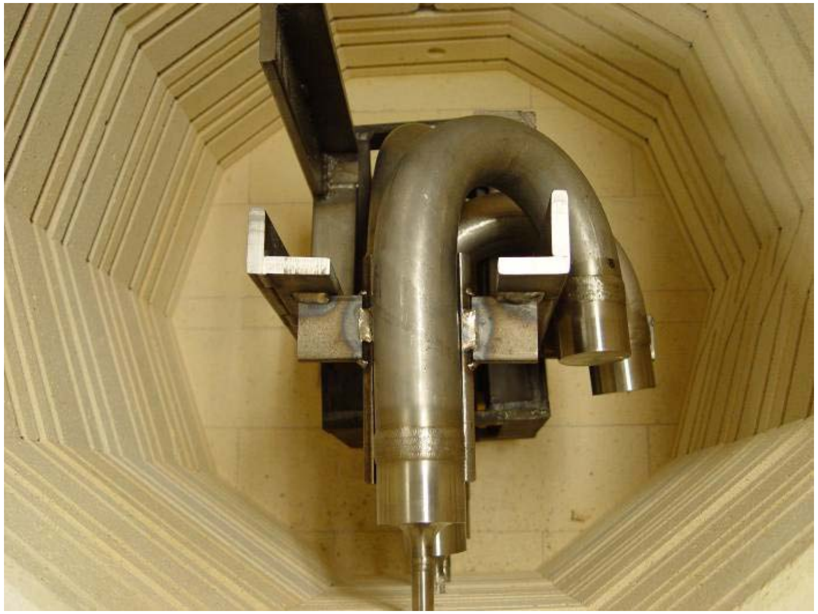
	Alloy element, wt%						
Alloy	Ni	Cr	Co	Mo	Ti	Al	Nb
282	Bal.	20	10	8.5	2.1	1.5	---
740	Bal.	24	19.9	0.5	1.5	1.3	1.6





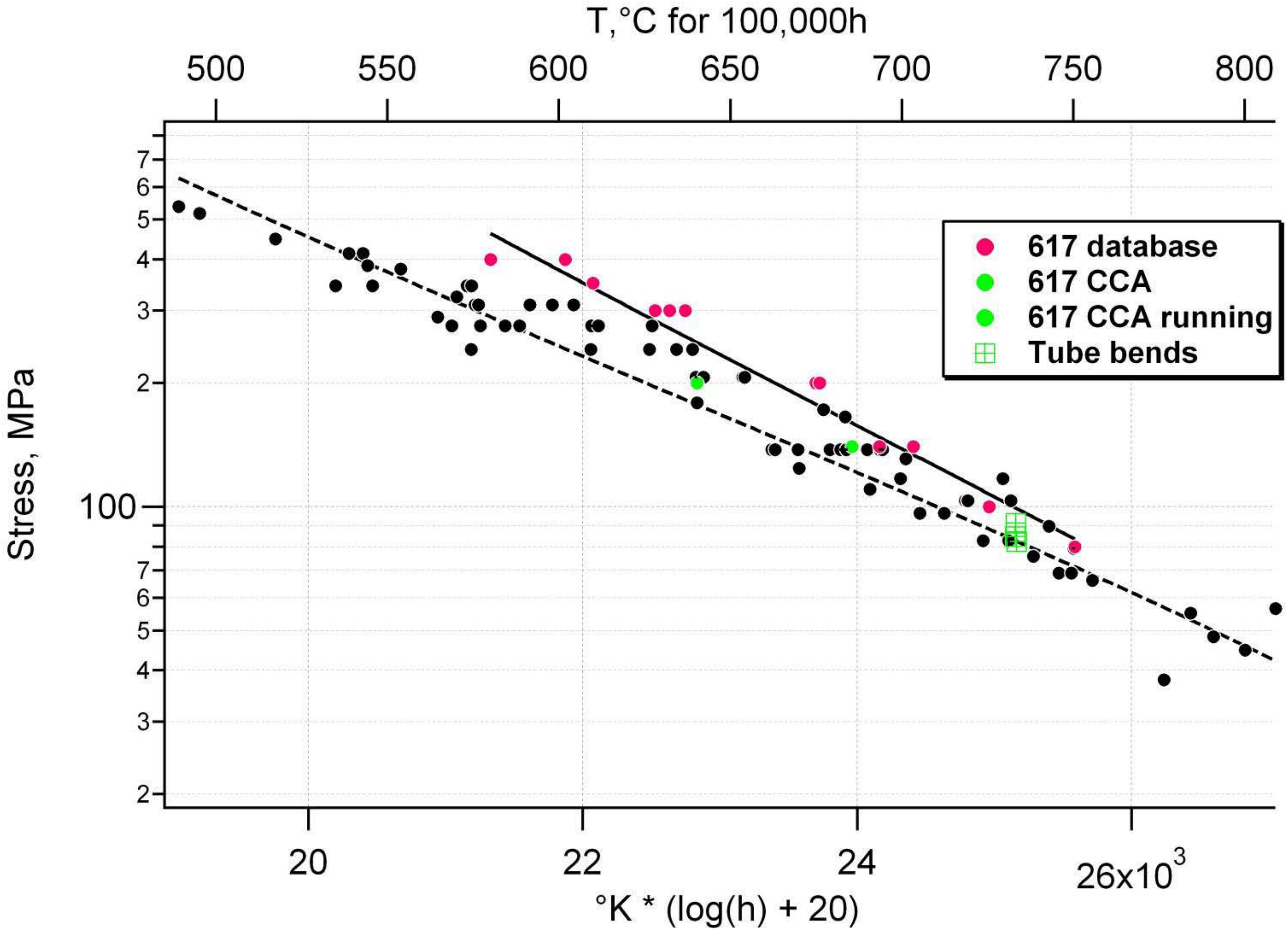
- Mo promotes formation of TCP phases, μ & σ
- TCP phases can be linked to premature creep cavitation

Pressurized Tube Bend Creep Tests Are Aiding Determination of Cold-Work Limits



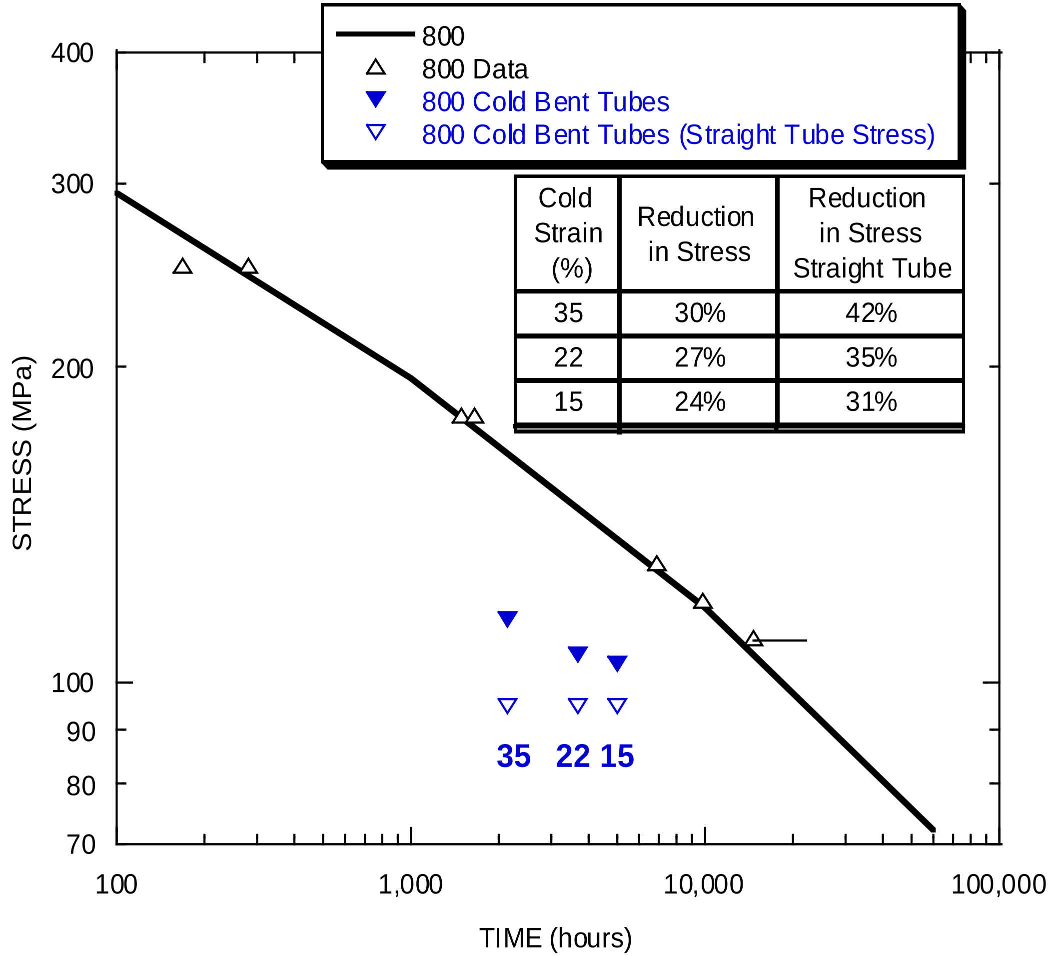
- Currently the ASME B&PV Code (Section I, PG-19) allows cold forming strains of only 10-15% for austenitic materials depending on use temperature
- Cold-bent tubes are being creep tested to provide guidance for determining fabrication rules
  – 740 tested; 617 running

Summary of 617 creep test data



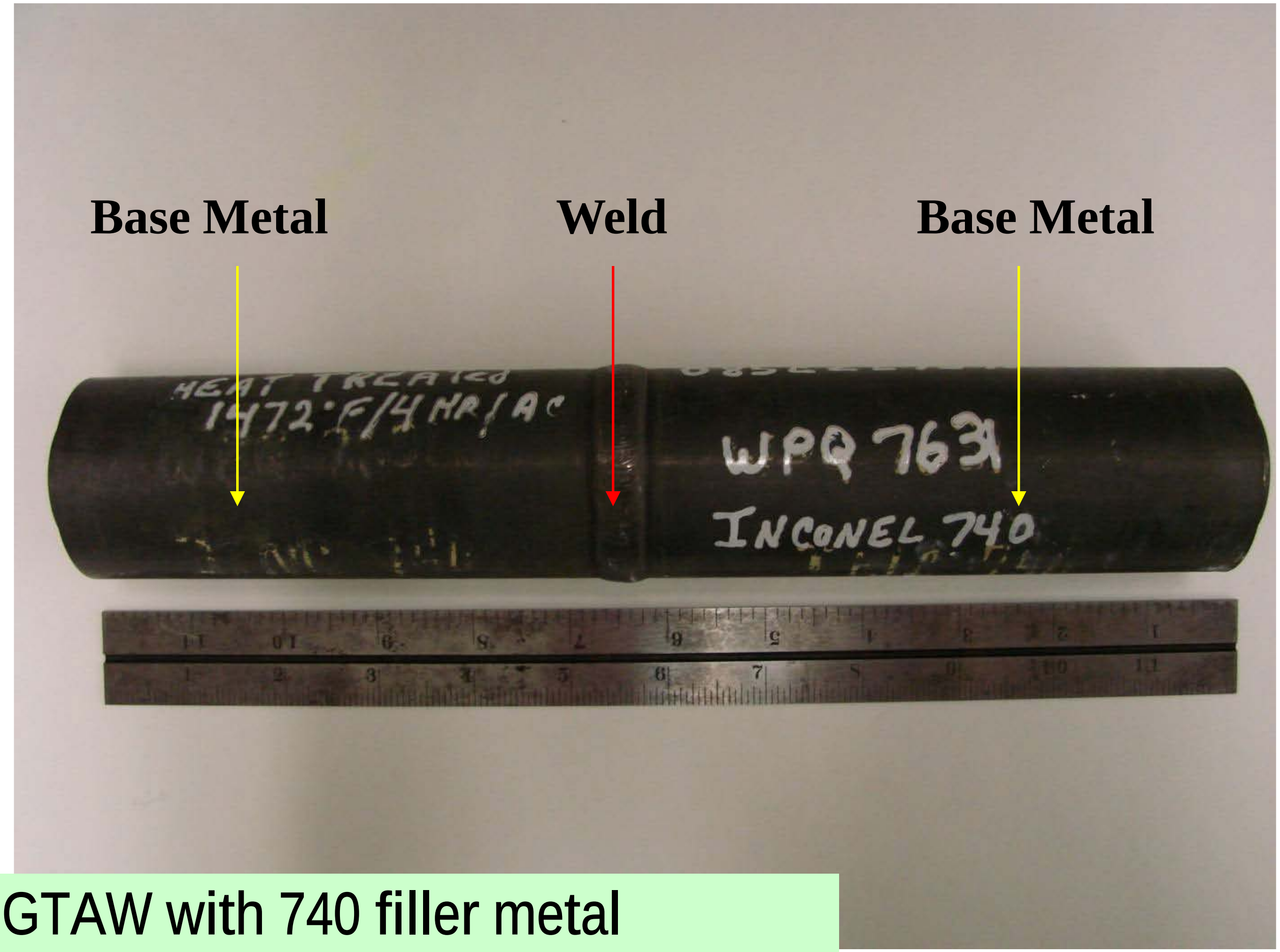
- 617 CCA data converge with 617 database above ~ 750°C
- Running tube bends are consistent with conventional data

Initial testing indicates cold-work effects are more significant for Inconel 740



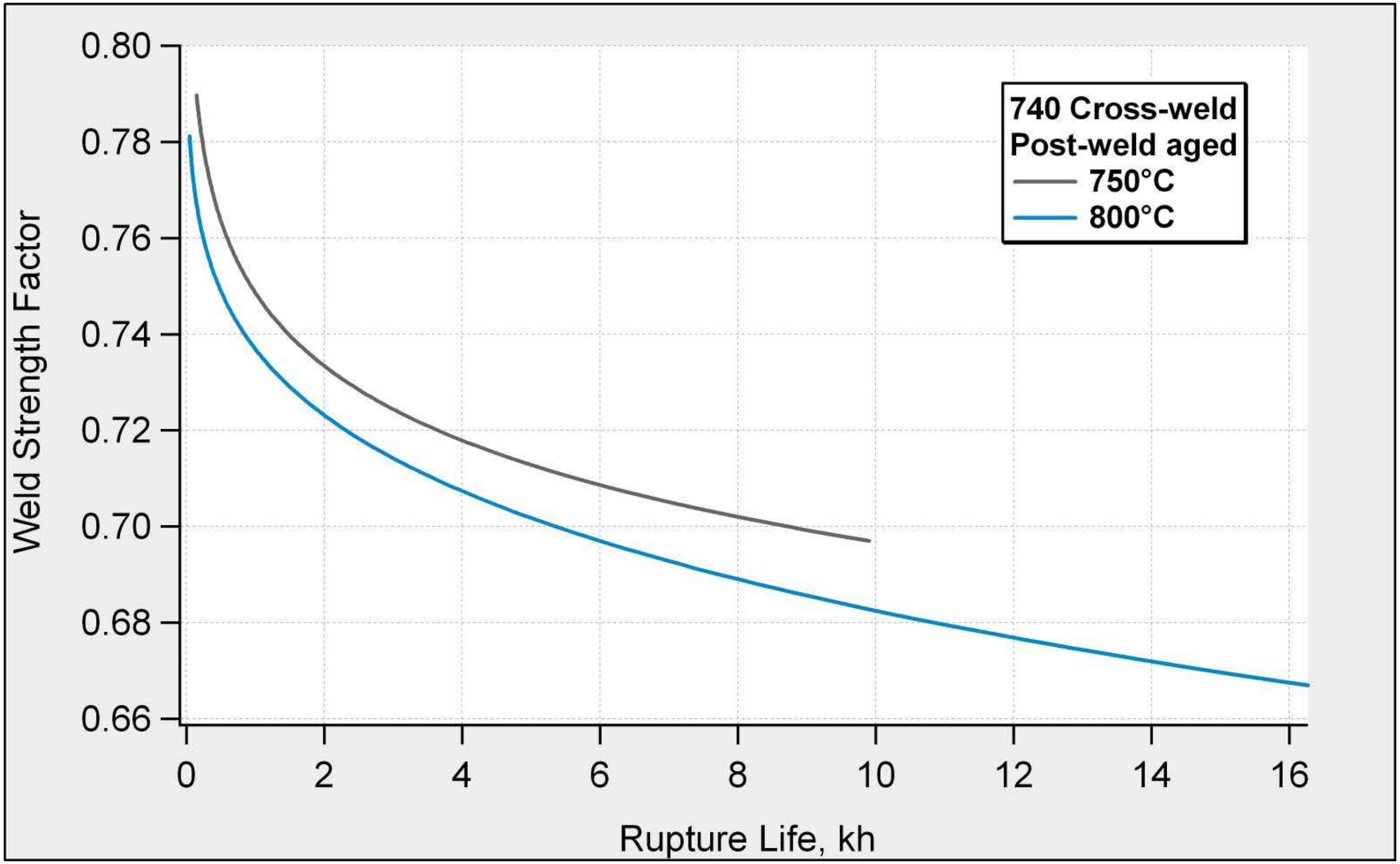
- Next step: Re-solution anneal bends and duplicate tests
- More-specialized testing is underway to aid understanding

Weld Strength Factor issues are under study for 740



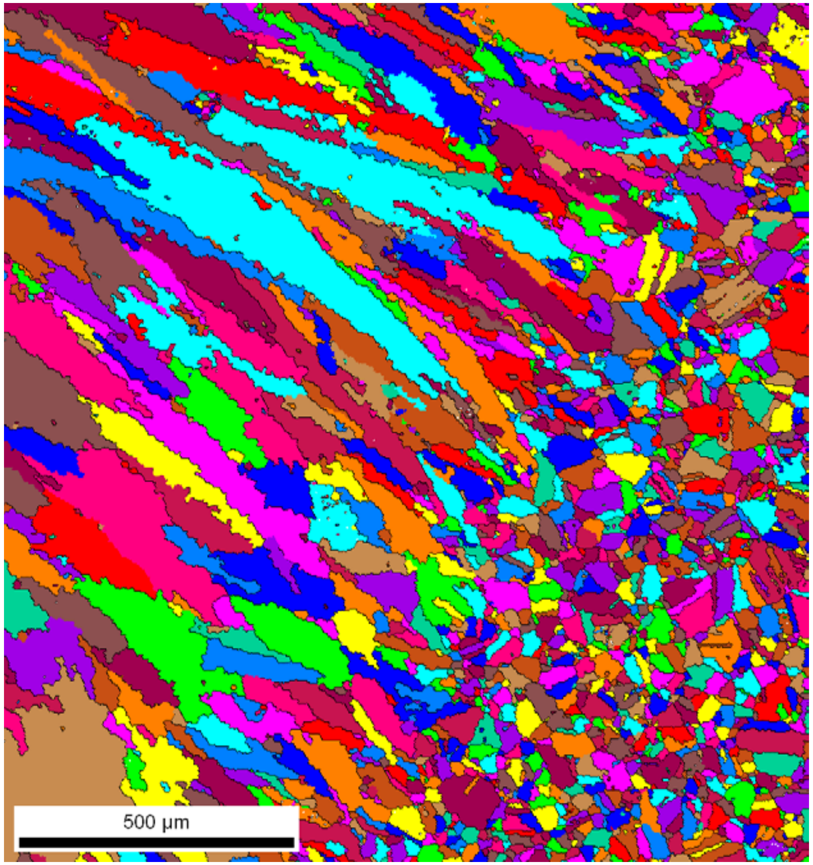
- GTAW with 740 filler metal
- 2-inch-OD x 0.4-inch-wall 740 tube

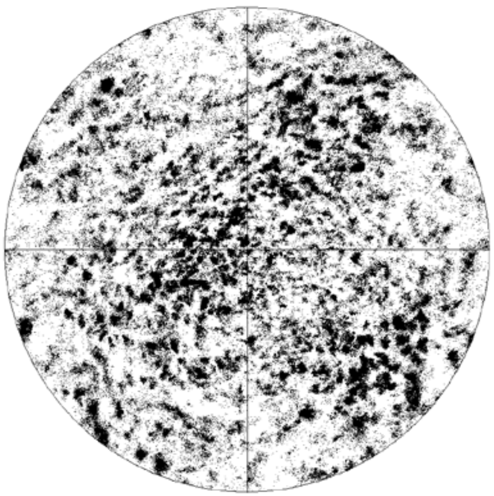
WSF results from GTA welded 740 tubes

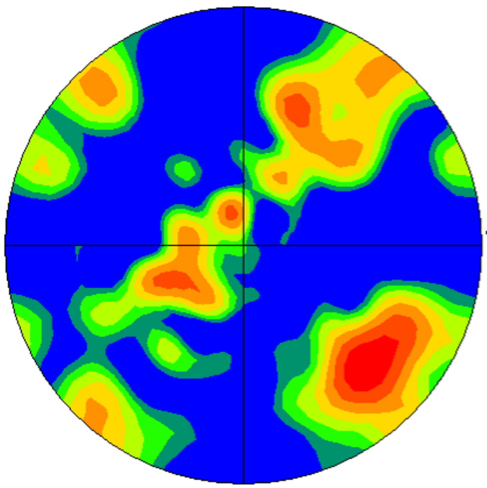


- WSF decreases: ~ 0.1/10,000 h at both temperatures
- WSF averages: 750°C – 0.74; 800°C – 0.73

Crystallographic imaging indicates weld properties should be anisotropic

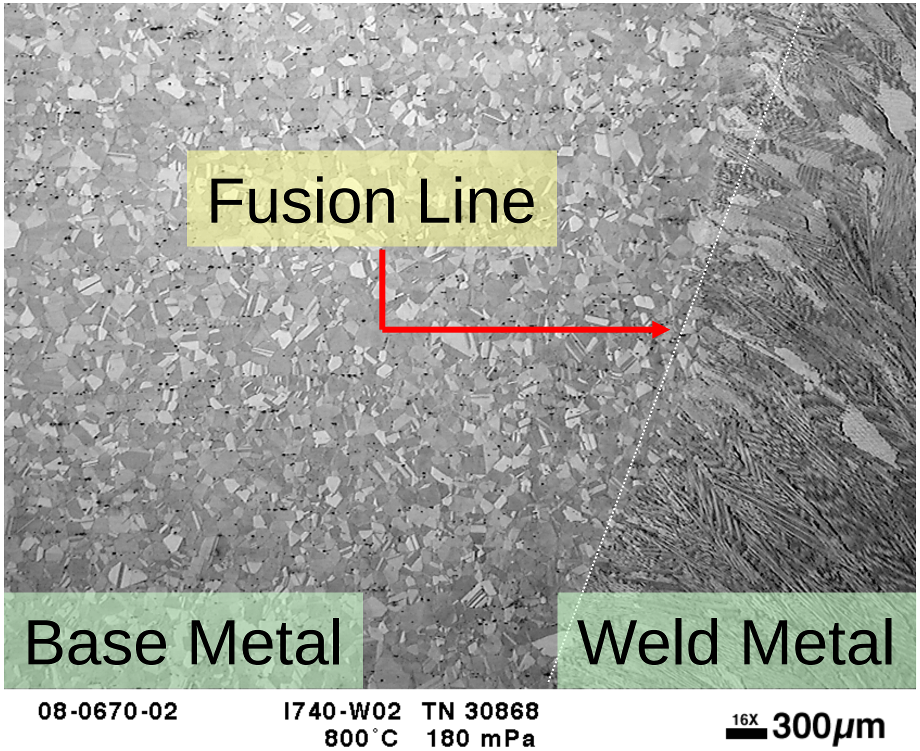




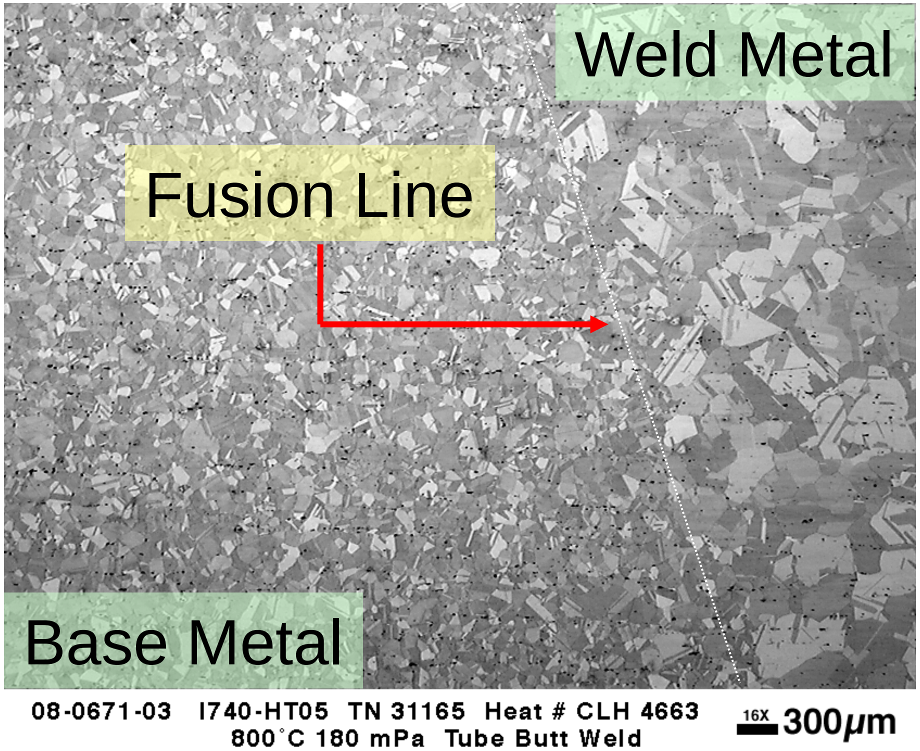


- Directionality could contribute to reduced strength of cross-weld tests
- Big effect? Ways to reduce?

Weld Microstructures Can Be Modified By Heat Treatments

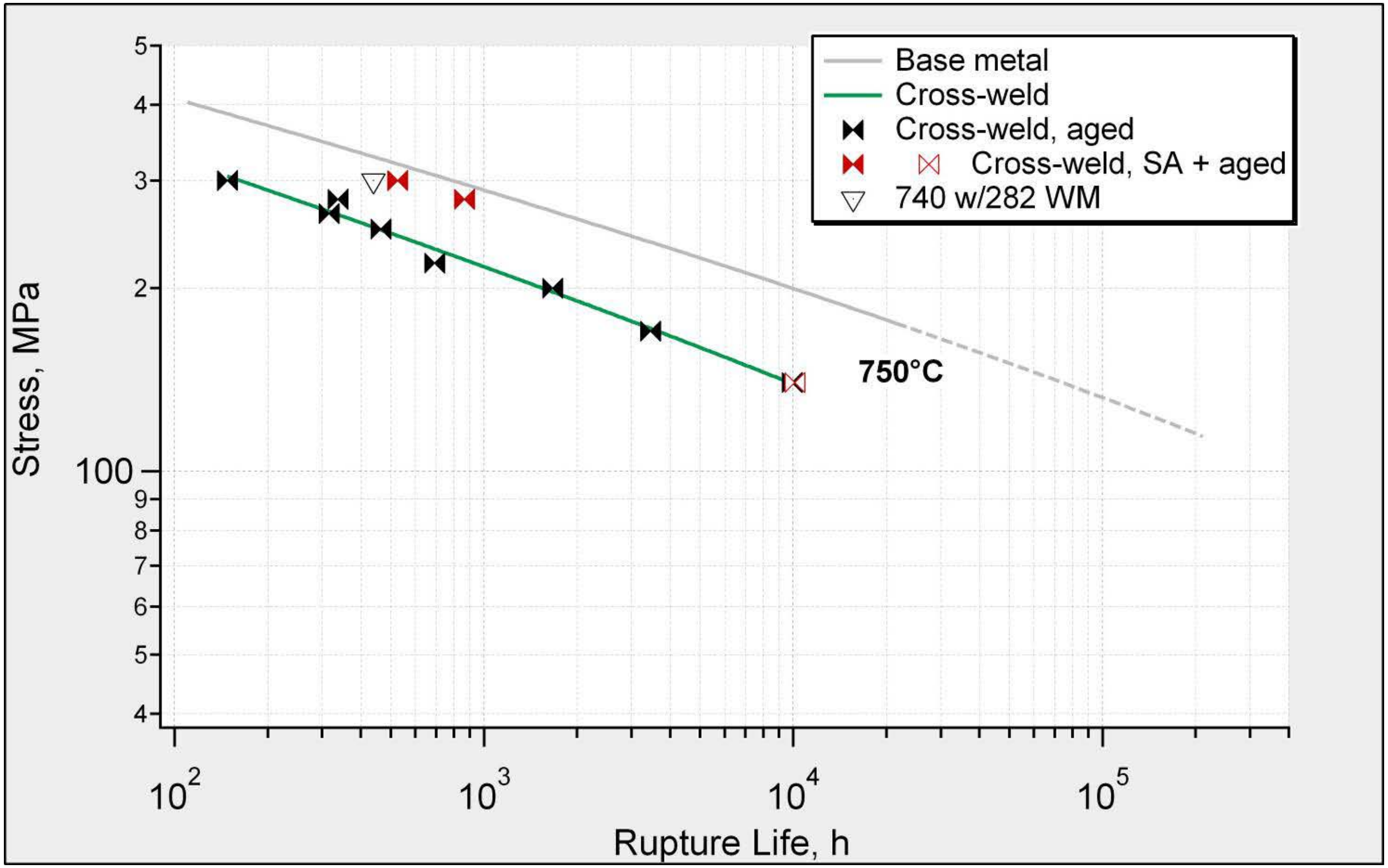


HT #1
Aged at 800°C/4 h



HT #2
Solution anneal at 1120°C/1 h
Aged at 800°C/4 h

Summary of cross-weld creep testing



- 750°C/300 MPa data for 282 weld metal compare favorably with SA 740 weldment
- Tests at 700°C, 750°C, & 800°C are continuing

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Substantial progress is being made to qualify Advanced Alloys for A-USC

- Long-term creep-rupture testing
  - Inconel 740
    - ASME Code Case data package submitted for initial consideration
  - Alloy 282
  - Alloys 230 & 617
- Weldment strength studies
  - Understand sources of, and minimize Weld Strength Factors
- Cold-work effects
  - Characterize, understand, and minimize cold-strain effects on creep properties

Building confidence to use new high-strength alloys

Milestones & Status:

- Summarize at Quarterly review meeting results from tube-bend rupture tests of CCA617
  - 12/2009, completed
- Summarize at Quarterly review meeting progress to improve weld strength factors
  - 06/2010, on-schedule, completed
- Summarize at Quarterly review meeting creep-test results from third heat of Inconel 740
  - 12/2010, on-schedule
- Prepare draft creep data package for ASME Code Case for Inconel 740
  - 06/2011, completed

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