Improving Economics of Generation 3 CSP System Components Through Fabrication and Application of High Temperature Nickel-based Alloys

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(DOE SETO: GEN3 CSP SYSTEMS)

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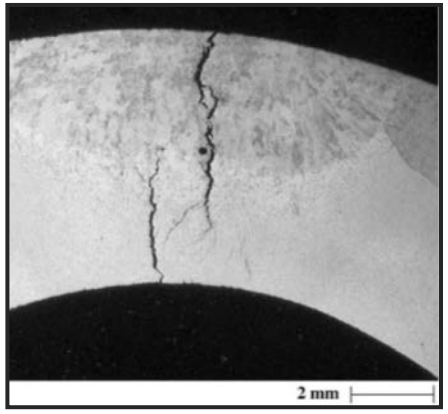
Unanticipated materials challenges in first-of-a-kind applications and demonstrations in power generation

New Environments



Materials Selection & Environmental Effects

New Materials

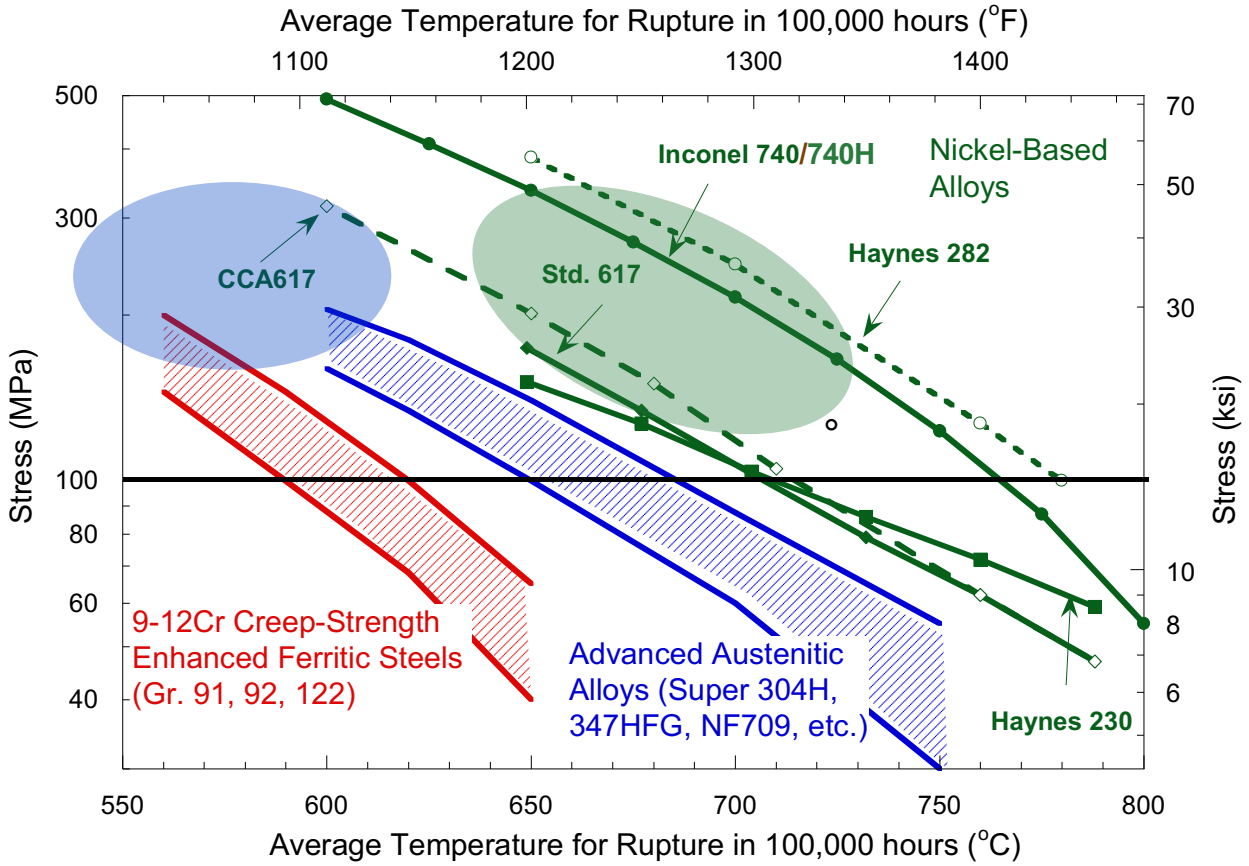
Fabrication challenges

Codes, Standards, and Specifications

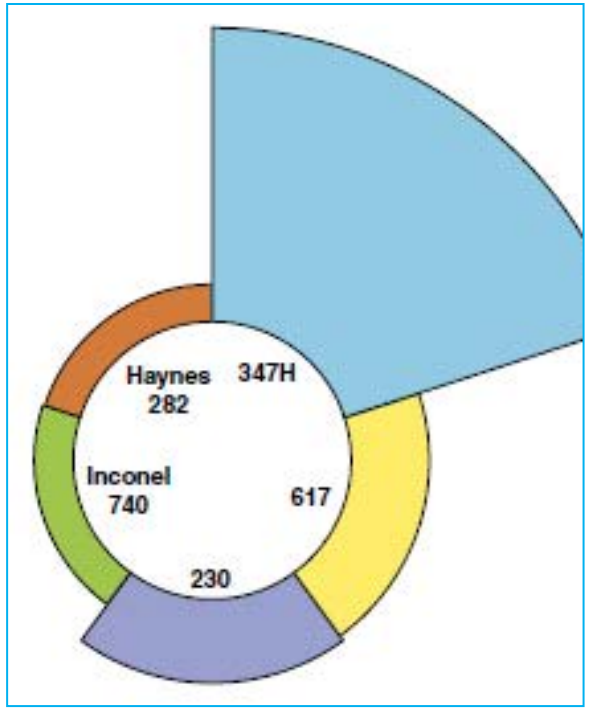
Materials research during Design and continuing through Demonstration reduces overall project risk

Materials Selection for Gen 3 CSP Goal: >715°C

High Temperature Strength, Corrosion Resistance, Ductility, Fatigue, etc. = Age-Hardenable Nickel-Based Alloys will be utilized



Relative Pipe Thickness at 700°C per ASME Allowable Stress



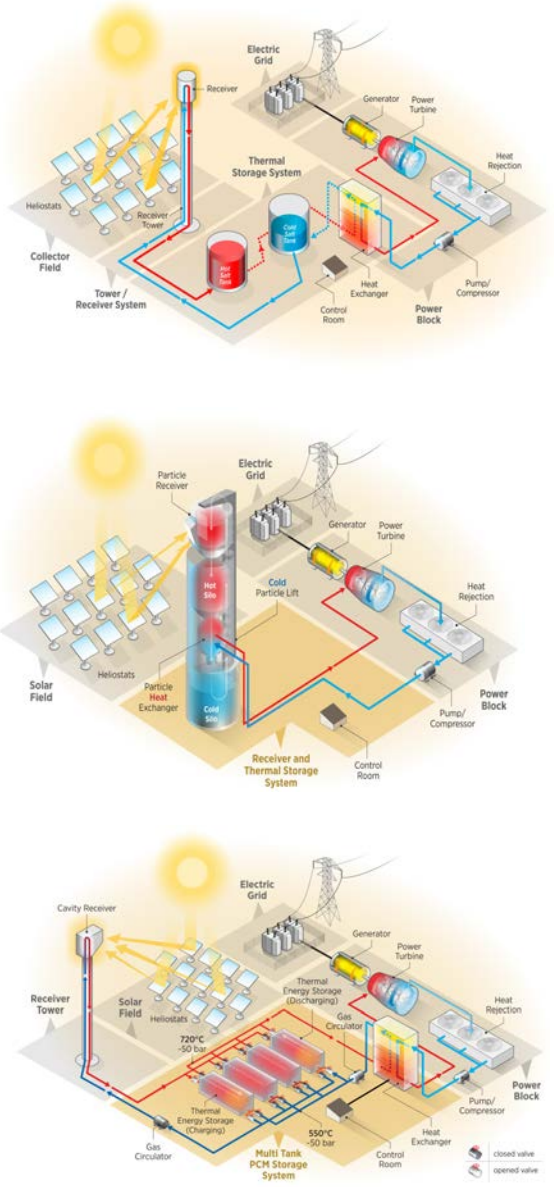
Increased creep strength
=
Higher allowable stress
→
enables thinner walls
=
lower cost, more cyclic flexibility

- Current Gen 2 Materials (limited solid solution alloys) are not governed by creep
- Time dependent (creep) behavior must be considered for Gen 3

Nickel-Based Materials will be needed for all pathways

Product Forms:

- Thin-wall tubing (receivers, HX)
- Large diameter pipe (piping, downcomers)
- Thin sheets and plates (HXs)
- Forgings/castings (valves)
- Welded structures (headers, HX, piping)



R&D GAPS

- Low-cost manufacture
- Data for Codes and Standards
- Fabrication/Welding Trials
- Gen 3 Environments
- Potential damage interactions: Creep-fatigue, TMF, etc.

Research Goals:

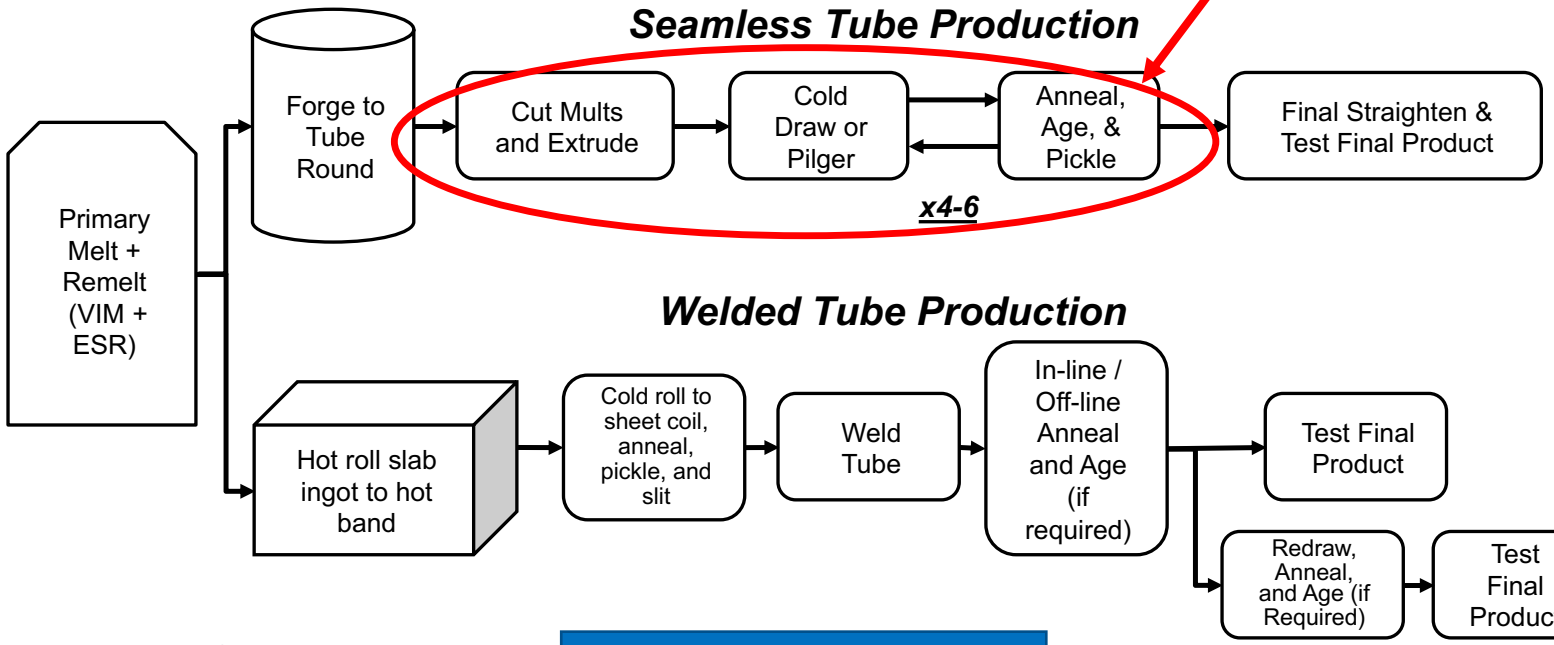
- Enable reduced Nickel-based alloy cost through
  - Materials Selection
    - Use of higher-strength alloys to minimize overall material usage
    - 740H up to 50% less expensive than 230 for pressure boundary components
  - Innovative manufacturing
    - Rolled & welded tubing up to 30% less expensive compared to seamless
- Challenges (some)
  - Processing of new alloy grade
  - Weld structure and performance
  - Code acceptance

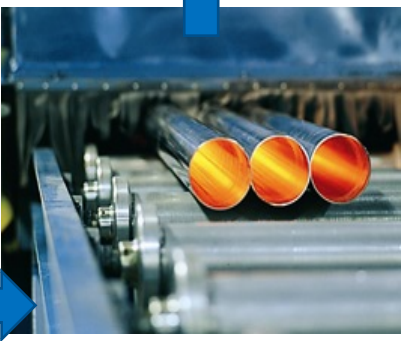
Project Organization & Team – Key Areas of Progress

- **Task 1**: Project Management - EPRI
- **Task 2**: Collaboration with Gen 3 CSP Teams & Code Interactions – EPRI
  - Materials for testing, test conditions, specific design and component requirements
  - Engage codes and standards to ensure testing will address current deficiencies
- **Task 3**: Manufacturing – Special Metals (and partners)
  - Baseline materials
  - **Welded tube (thin wall)**
  - **Welded pipe (Large diameter)**
  - **Subcomponent manufacture (bending, welding)**
  - Techno-economics (enable cost estimates and savings for design teams)
- **Task 4**: High-Temperature Mechanical Testing & Data Analysis – EPRI
  - Tensile/Fatigue (time independent)
  - Creep (time dependent): determination of weld strength reduction
  - Pressurized creep of welded tubing – *Unique to CSP receivers to gain code acceptance*

Tube Processing

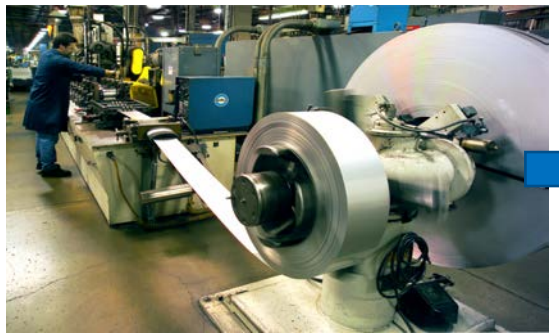
Multiple steps: High energy use, lower yield

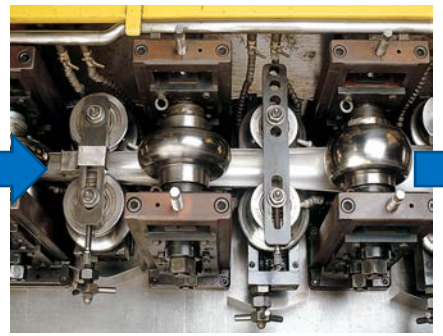


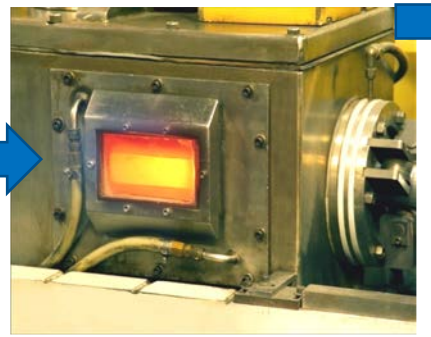


Images Courtesy: RathGibson

Welded Tube Production



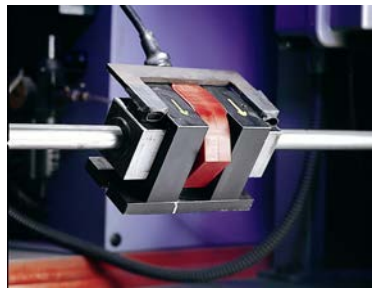




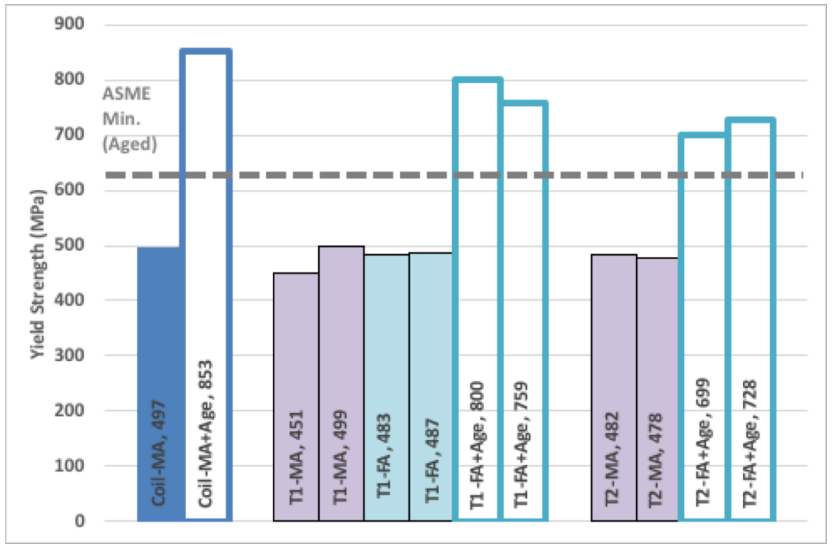
Successful Welded Tube Production: Inconel® Alloy 740H®

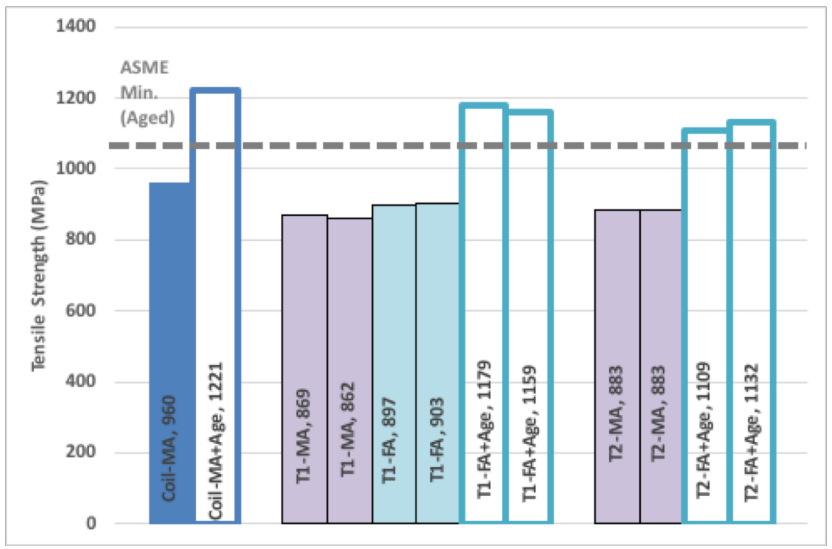
	Coil Weight kg (lbs)	Coil Thickness mm(in)	Coil Width mm(in)	Produced Tube Diameter mm(in)	ASTM Grain Size
Trial 1	112 (247)	1.65 (0.065)	76.7 (3.02)	25.4 (1)	7.5
Trial 2	230 (508)	1.65 (0.065)	157 (6.19)	50.8 (2)	7.5

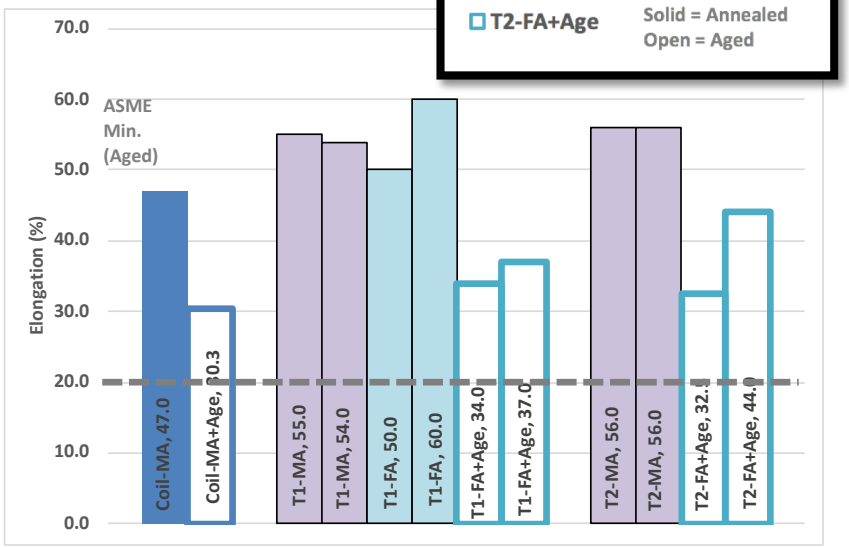
- Two successful trials:
  - Passed flattening tests
  - Passed non-destructive evaluation requirements (eddy current) – no cracks or discontinuities

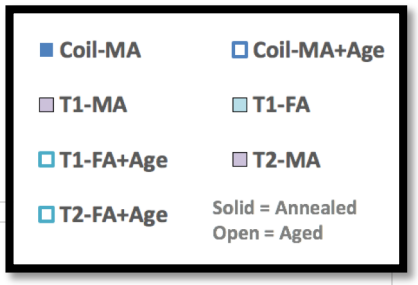


Tensile Test Results

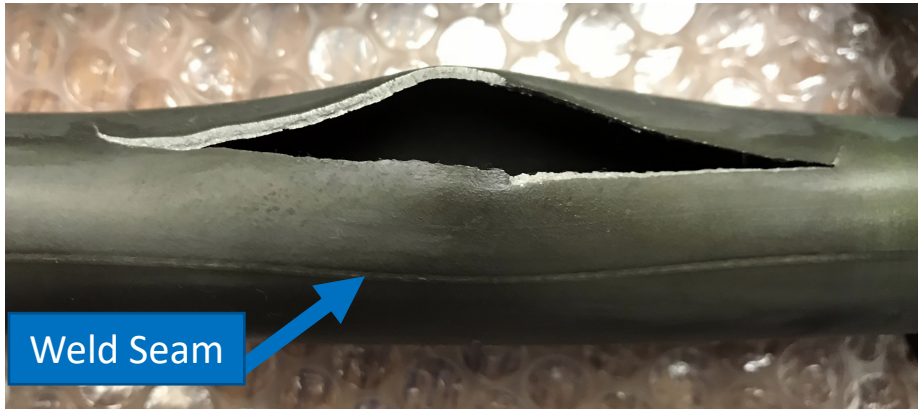








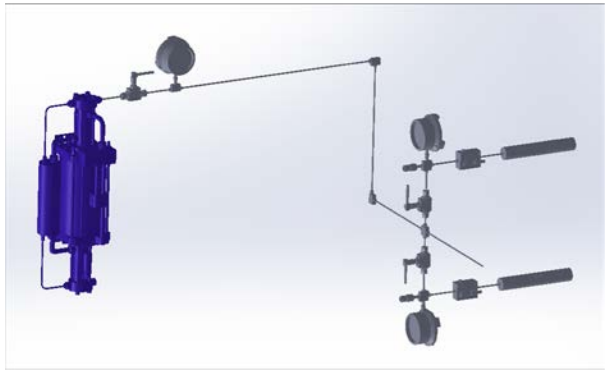
- Yield and Tensile Strength of Mill Annealed Tubes was equivalent to starting coil stock
  - After aging, **all tubes met ASME minimum criteria**
- Tensile Ductility (Elongation)
  - Mill Annealed tube & aged tubes > Coil
  - **All materials exceed ASME Min Requirement**
- Pressurized room temperature burst test → **failures outside of weld**

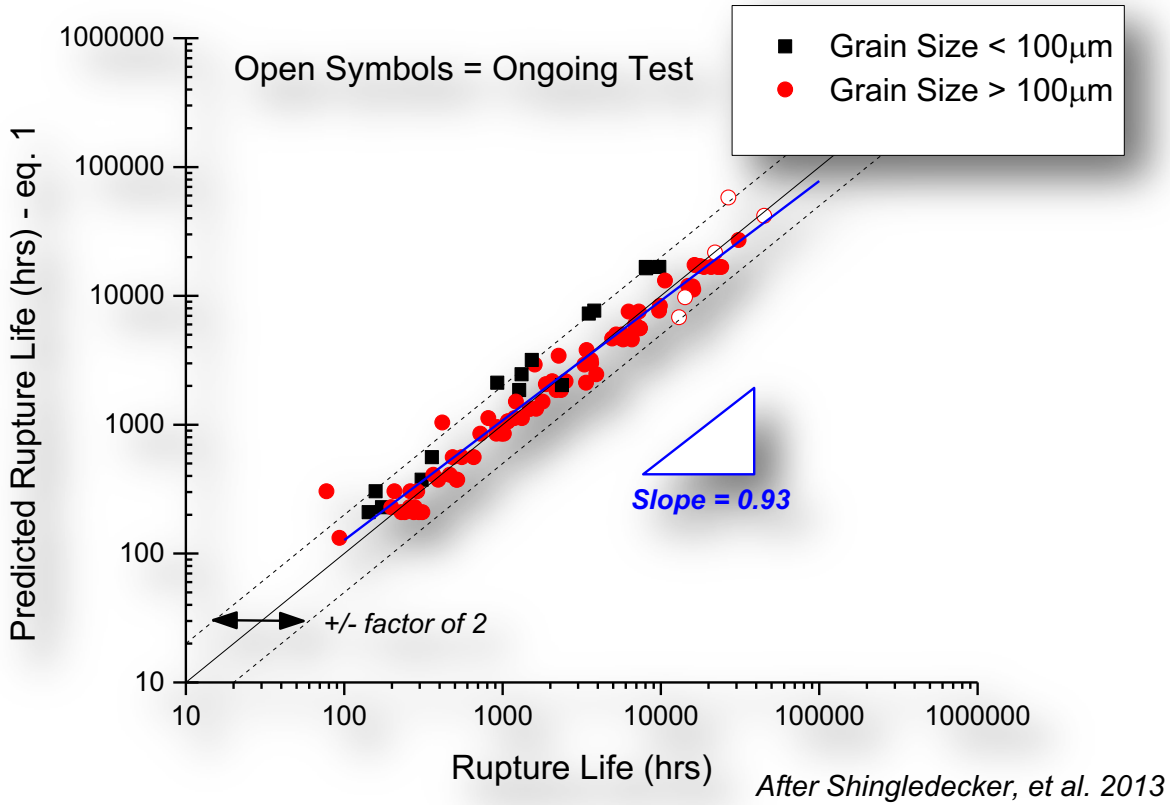


Key next steps for tubing

- **Room temperature properties ≠ high-temperature behavior**
- How will these tubes perform at Gen 3 CSP Conditions (~700ºC)?
  - Creep Considerations:
    - Processing (heat-treatment)
    - Grain Size
    - Weldments
  - Fatigue

EPRI Facility for Pressurized Creep Testing of CSP Thin-walled tubes





After Shingledecker, et al. 2013

Research on alloy 740H shows grain-size effect on long-term creep in typical wrought product with lower-scatter band (weaker) properties when grain size is finer than ASTM 3.5

Summary

- Age-hardenable nickel-based alloys are key candidates for Gen 3 CSP Systems
- Reduced alloy (product form) cost through advanced manufacturing is needed to improve overall economics
- Ongoing research to evaluate Inconel® Alloy 740H®
  - Production of: Welded tube, welded pipe, CSP specific processes
  - Long-term data: Creep of welds, pressurized creep, low cycle fatigue
  - Validate economic assumptions
  - Gain code acceptance for new processes

Research to date on welded tubing shows promising results

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