Seam Welded Tube & Pipe

Track A: High-Temperature Nickel-Based Alloys

John Shingledecker, Ph.D.
Sr. Technical Executive

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SOLAR ENERGY TECHNOLOGIES OFFICE
U.S. Department Of Energy

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SPECIAL METALS
A PCC Company

Projects:
DE-EE0008367, DE-EE0009378

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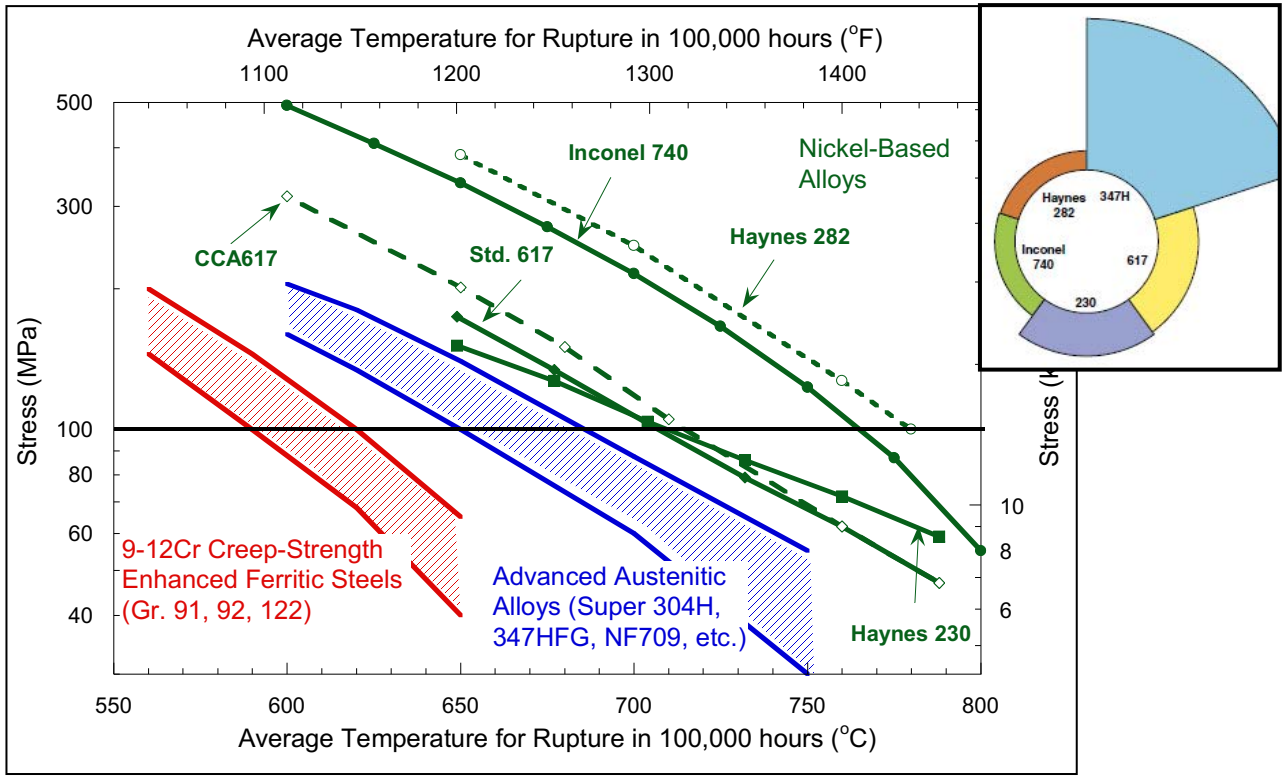
What effects cost?



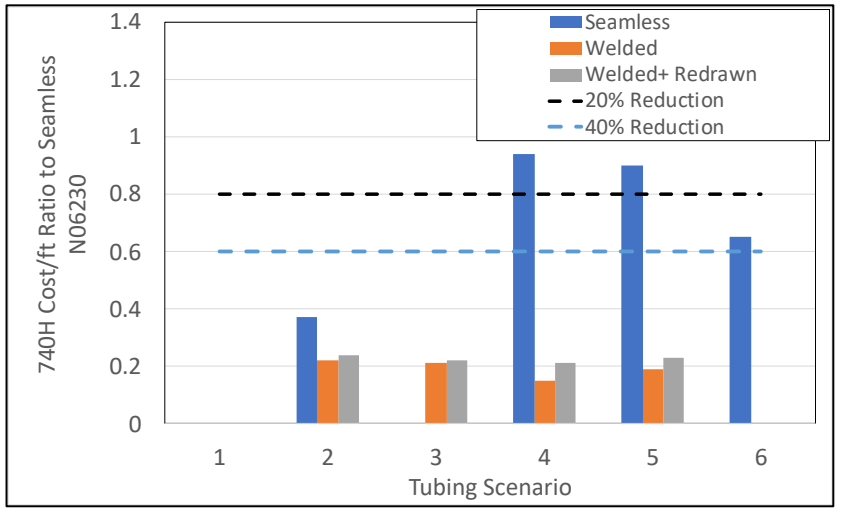
Materials Selection

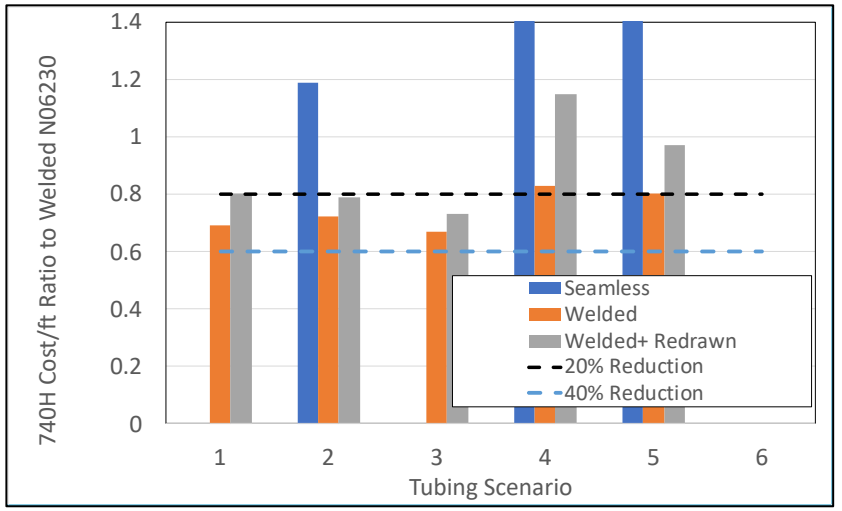
- Higher tensile and creep strength = higher allowable stresses
- Higher allowable stresses decrease wall thickness = reduced cost/lb & improved cyclic capability
- *Note: alloy composition has a significant effect on cost (but for this study, the nickel-based alloys all have similar cost)

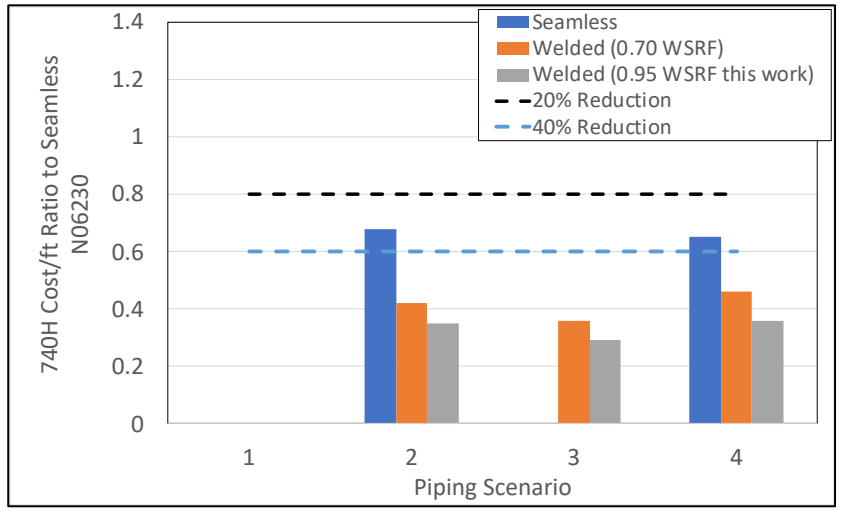
Product Form Selection

- Based on desired sizes
- Differences in product form costs are driven by:
  - Processing time
  - Energy intensity
  - Overall process yield

Putting it together: Techno-Economics







Tubing scenarios

1. Gen 2 CSP Baseline: 1200F, 2” OD
2. Gen 3 Molten Salt Baseline: Conceptual design in ANL 20/03 – 1391F, 1.575 OD
3. Gen 3 Molten Salt Alternative: Scenario 1 scaled to Gen 3: 1350F, 2” OD
4. Gen 3 Gas Pathway Receiver: Current design of 1346F, 0.375” OD
5. Gen 3 Generic 1” tube: Intermediate between Scenario 3 and 4: 1400F, 1” OD
6. Generic Heavy-wall tubing for sCO2: 1305F at high pressure and 3” OD

Piping Scenarios

1. Gen 3 Gas Pathway Piping: 1346F, 28.2” OD
2. Gen 3 Gas Pathway Multi-Pipe Estimate: Modified Scenario 1: 1346F, 9” OD
3. Gen 3 Headers: 1300F, 12” OD (lower stress application)
4. sCO2 Piping: higher stress for Scenario 3: 1300F, 14” OD

Techno-economic study

- Baseline N06230
- 10 typical/anticipated Gen 2/3 product forms
- 740H reduces cost by >20%
- 740H welded products can reduce costs by >40%
  - *For very small diameters and thin tubes, welded production is the only cost-effective route*

Project Activities: Inconel® Alloy 740H®

Manufacturing Development

- Supply chain engagement

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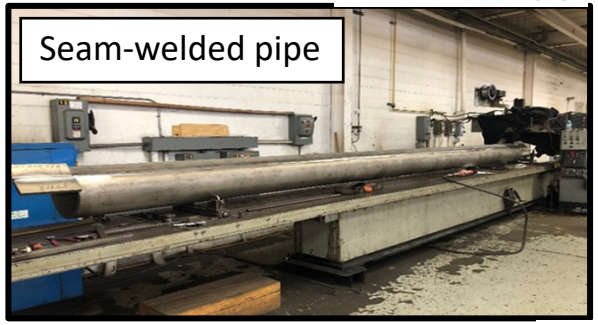

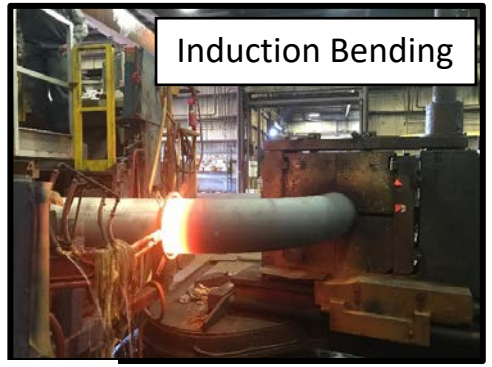

Shaw

Swepco

GTC
Greenville Tube Company

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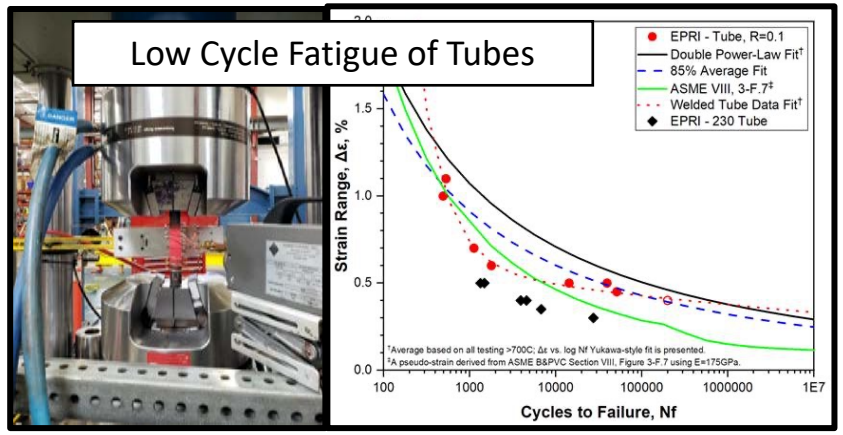
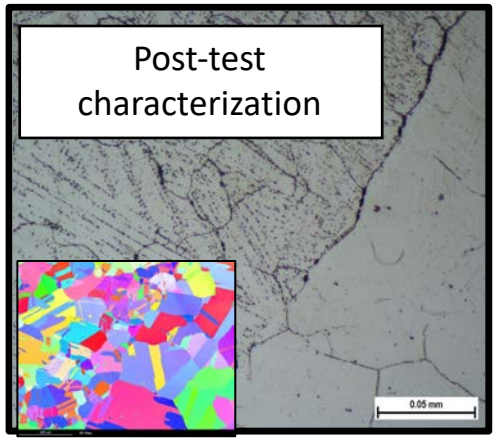
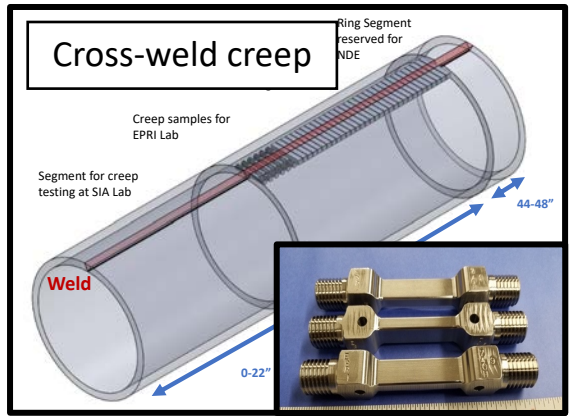
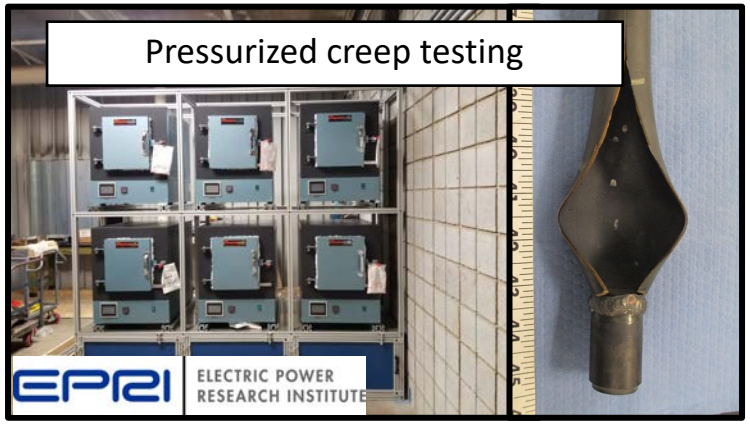
High-Temperature Testing & Analysis

- Relevant testing product forms (welded structures)
- New testing capabilities (multiaxial)







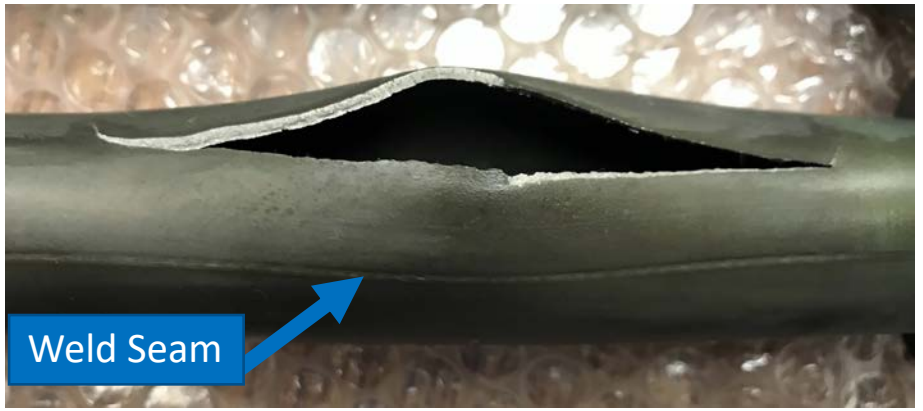


EPRI

Successful Welded Tube Production: Inconel® Alloy 740H®

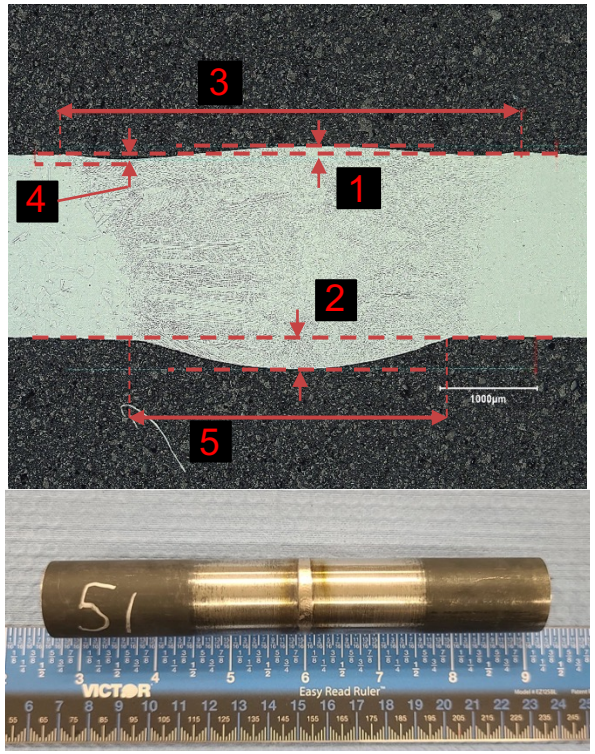
	Coil Weight kg (lbs)	Coil Thickness mm(in)	Coil Width mm(in)	Produced Tube Diameter mm(in)	ASTM Grain Size
Trial 1	112 (247)	1.65 (0.065)	76.7 (3.02)	25.4 (1)	7.5
Trial 2	230 (508)	1.65 (0.065)	157 (6.19)	50.8 (2)	7.5

- Two successful trials:
  - Passed flattening tests
  - Passed NDE (eddy current)
- Yield and Tensile Strength
  - After aging, **all tubes met ASME minimum criteria**
- Tensile Ductility (Elongation)
  - **All materials exceed ASME Min Requirement**
- Pressurized room temperature burst test → **failures outside of weld**
- Demonstrated re-drawn tube (2” tube re-drawn to 1” – met tensile requirements)



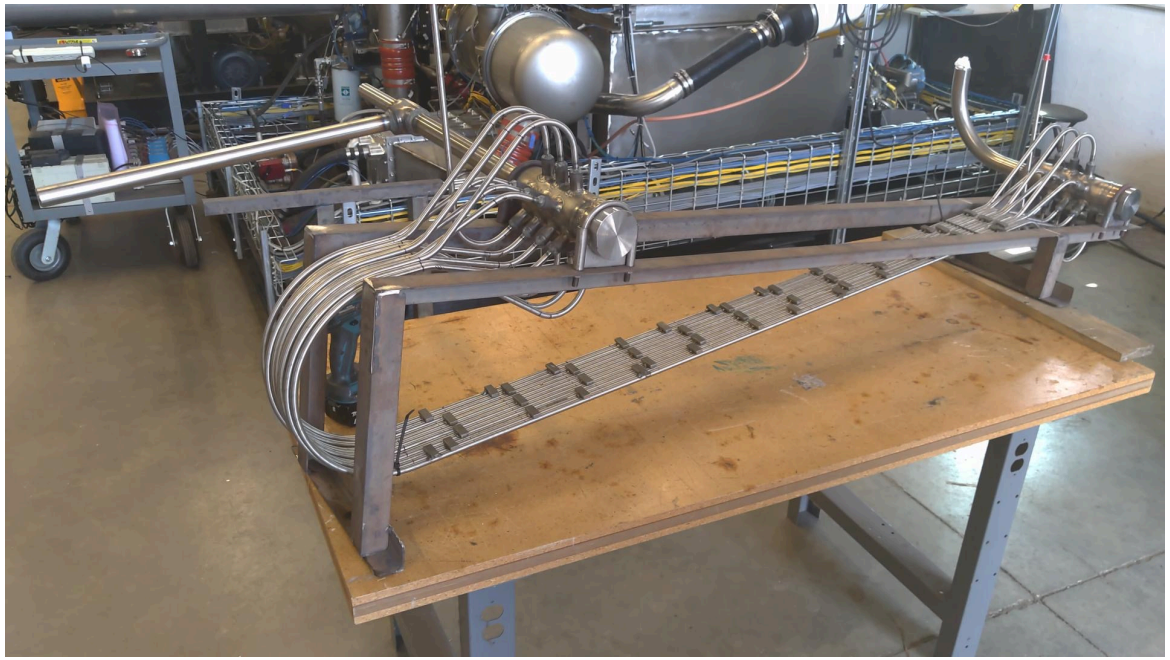
For more information see: J. Shingledecker, et al. “Materials Improvements for Improved Economy of High-Temperature Components in Future Gen 3 CSP Systems.” *Proceedings to SolarPACES2018.* October 2-5, 2018. Casablanca, Morocco. AIP Conference Proceedings 2126, 020004 (2019); https://doi.org/10.1063/1.5117512

Successful Fabrication Activities with Welded Tubes



Autogenous welding (EPRI/SMC) – 1 to 2" Diameter welded and redrawn tubing

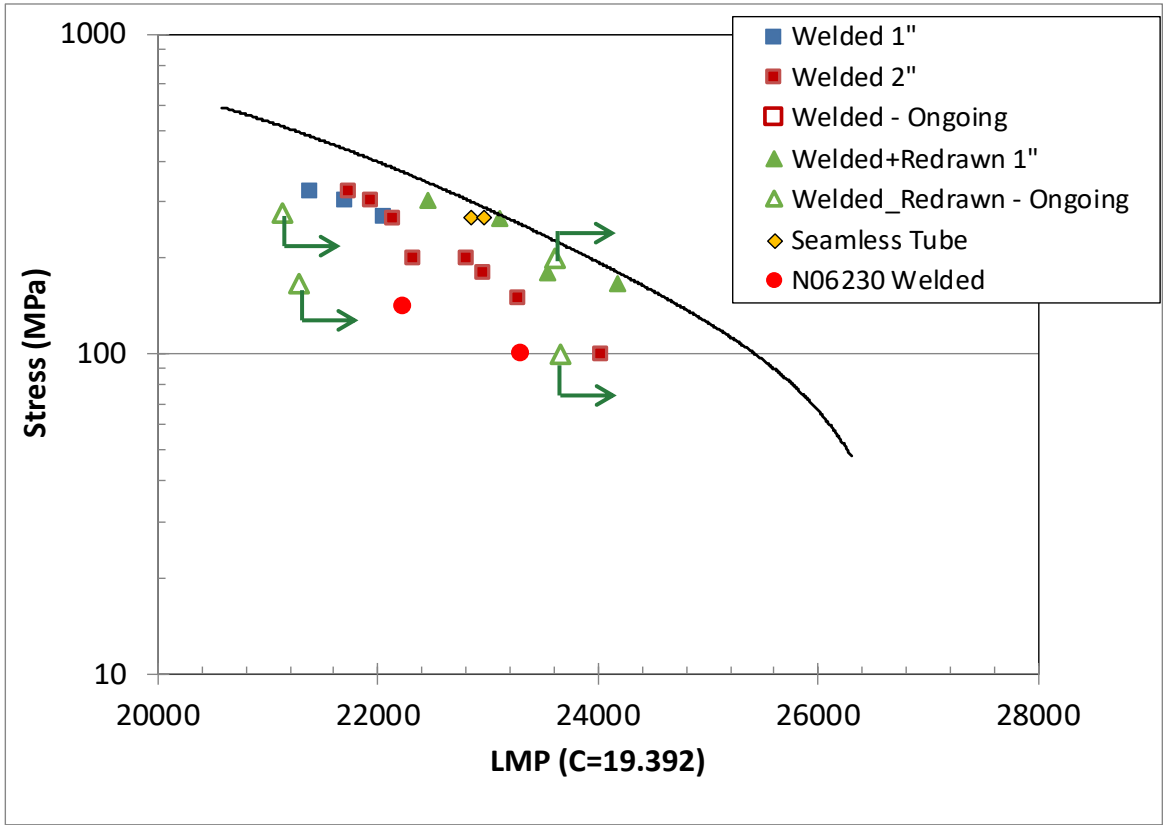
Tube Bending (courtesy of Tebunus Tube Bending/John Cockerill) – 2" Diameter Welded Tubing

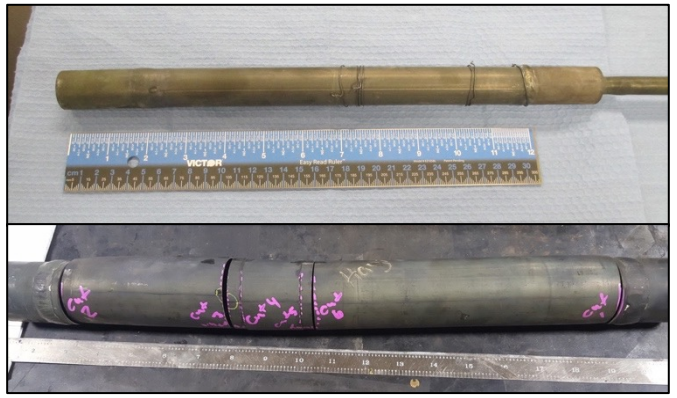


Solar Receiver Test Article (Courtesy of Brayton Energy) – 3/8" Diameter Welded+Redrawn 740H

High-Temperature Performance of Welded Tubes

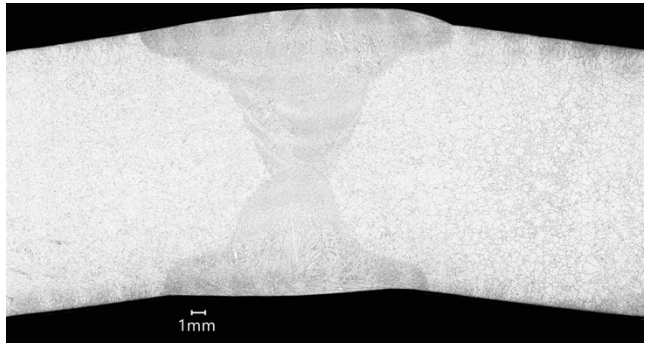
- Pressurized creep test program to evaluate long-term performance of welded tubes and develop stress allowables
  - Longest test durations >4,000 hrs
  - 740H shows a strength debit with failures at weld seam
  - 740H Re-drawn tube performance approaching base metal strength
  - N06230 welded tube also shows a strength reduction
    - Note: greater than is currently approved with ASME's standard tube efficiency factor
- Currently engaging ASME with plans to incorporate this information into the code with new stress allowables in 2022

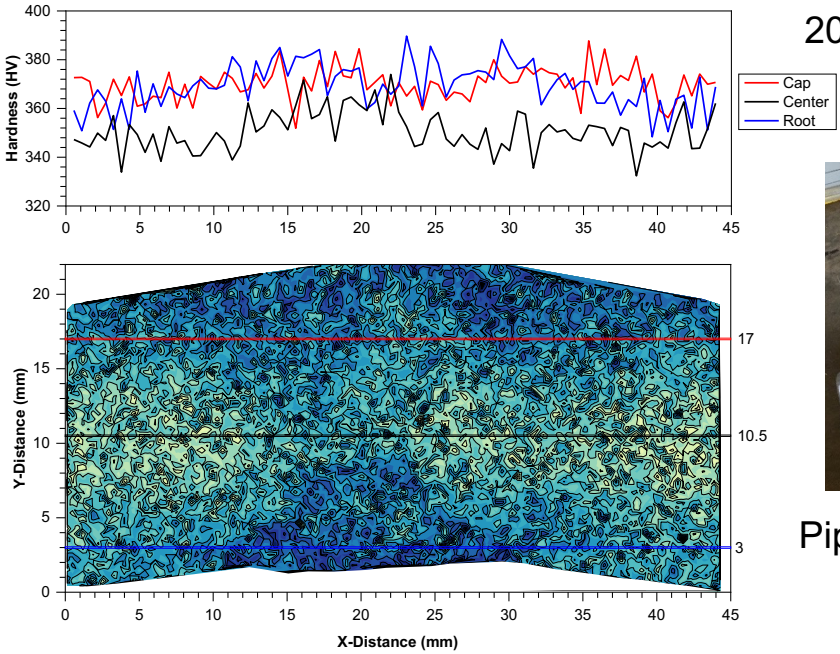




Welded Pipe: World's First 740H Seam-Welded Pipe

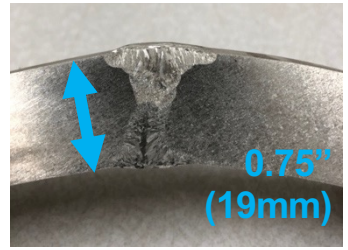
- Start with 48 in x 240 in x 0.75 in annealed plate
- Form 14 in OD Pipe
- GTA weld (740H filler, 8 passes)
- Solution anneal (1107°C)
- Radiography showed acceptable level of porosity, no cracks or LOF
- UST per ASTM E 213 showed no rejectable indications



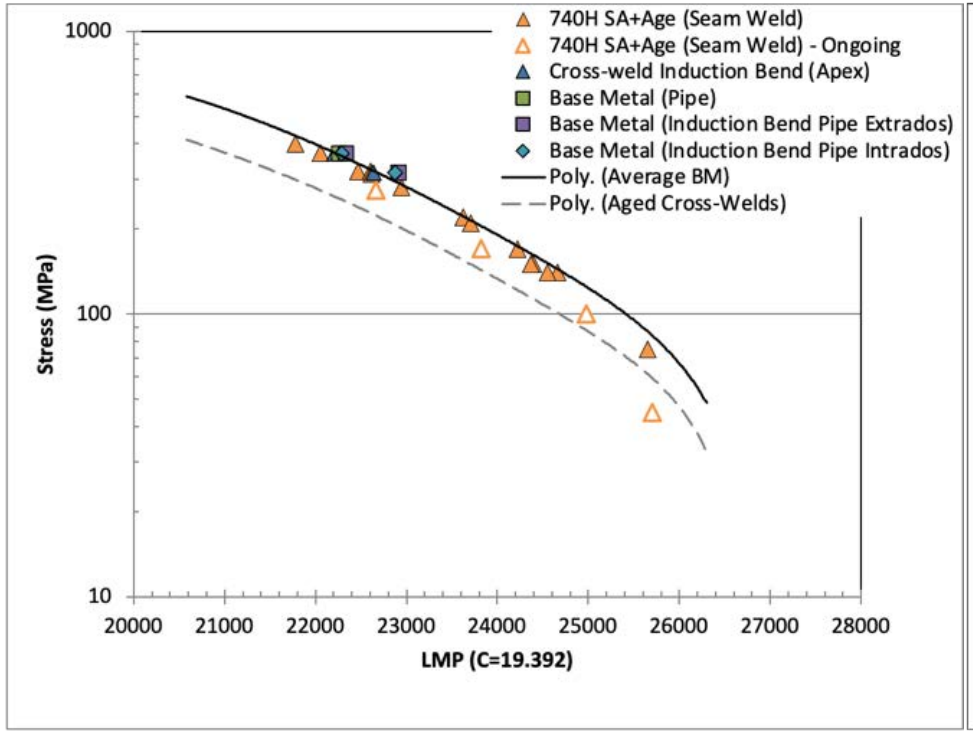


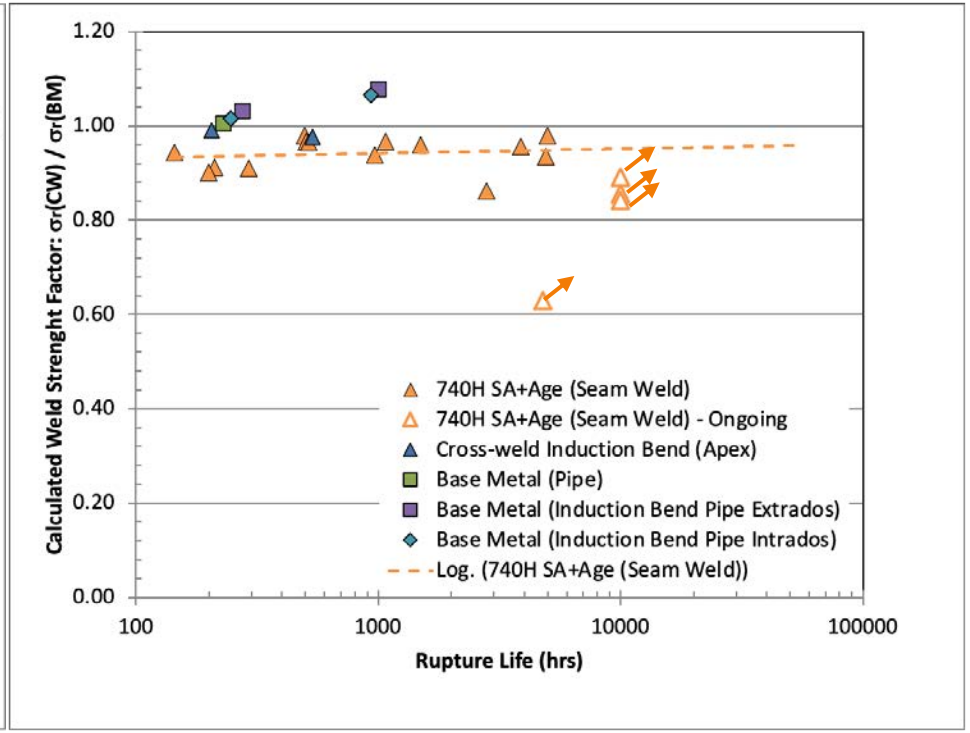
20 ft long welded pipe (Swepco)

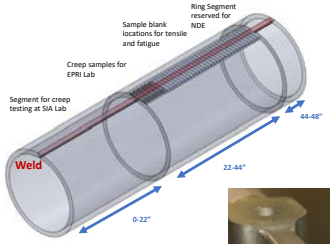
Pipe segment received by EPRI



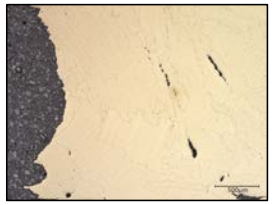
High-Temperature Performance of Seam-Welded Pipe







HAZ/FL – 100X

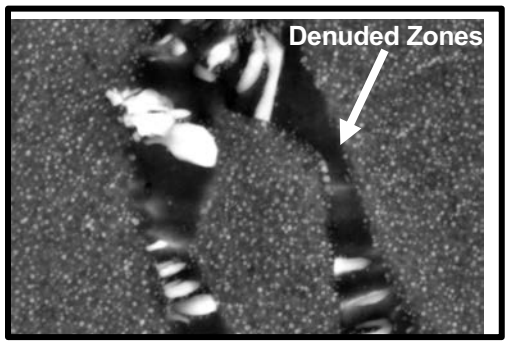


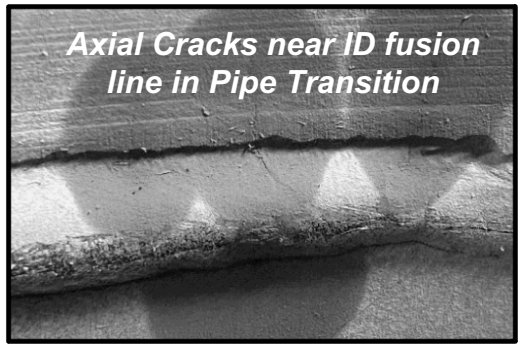
Weld Metal – 100x

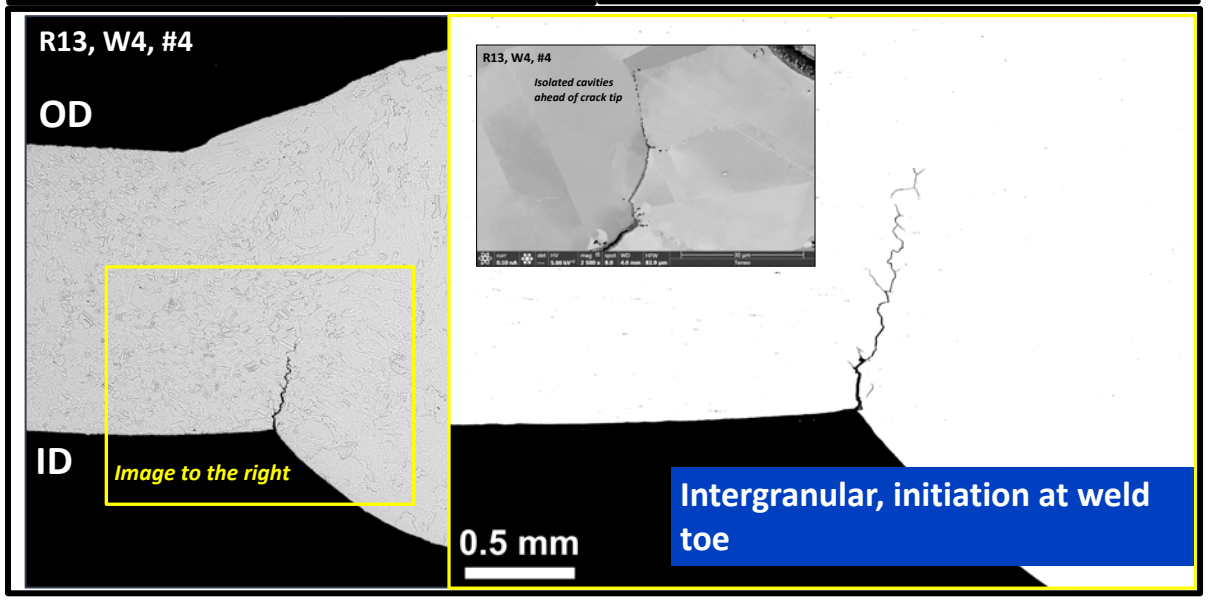
- Standard and large sample testing has now exceeded 10,000 hours
- Short-term tests also conducted on base metal and cross-welds from the induction pipe bend
- WSRFs >0.90 for all test and appear to be trending towards unity at long-times (open symbols are samples in-test)

Ongoing research to enable reliability in Gen 3 CSP

- Example: GTI/Optimus STEP Program sCO_2 (700C+) fired heater
  - ~3% of tube-to-tube butt welds exhibited cracking after PWHT
    - Failure analysis confirmed Stress Relaxation Cracking (SRxC) mechanism
    - Methods for field NDE developed
  - No cracking in tube-to-header, end plates, drains, etc.
- New DOE Study SRxC (EPRI, Lehigh, Special Metals)
  - Assess root cause from examples of 740H cracking
  - Gleeble studies to evaluate fabrication variables
  - Transfer learnings into a specification document







First large-scale application of 740H welding (>1,600 welds) including a range of weld geometries and thicknesses