INL/MIS-24-79192-Revision-0

# High Temperature Metals Program Overview

July 2024



Michael D McMurtrey

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# High Temperature Metals Program Overview

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**July 2024**

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**http://www.inl.gov**

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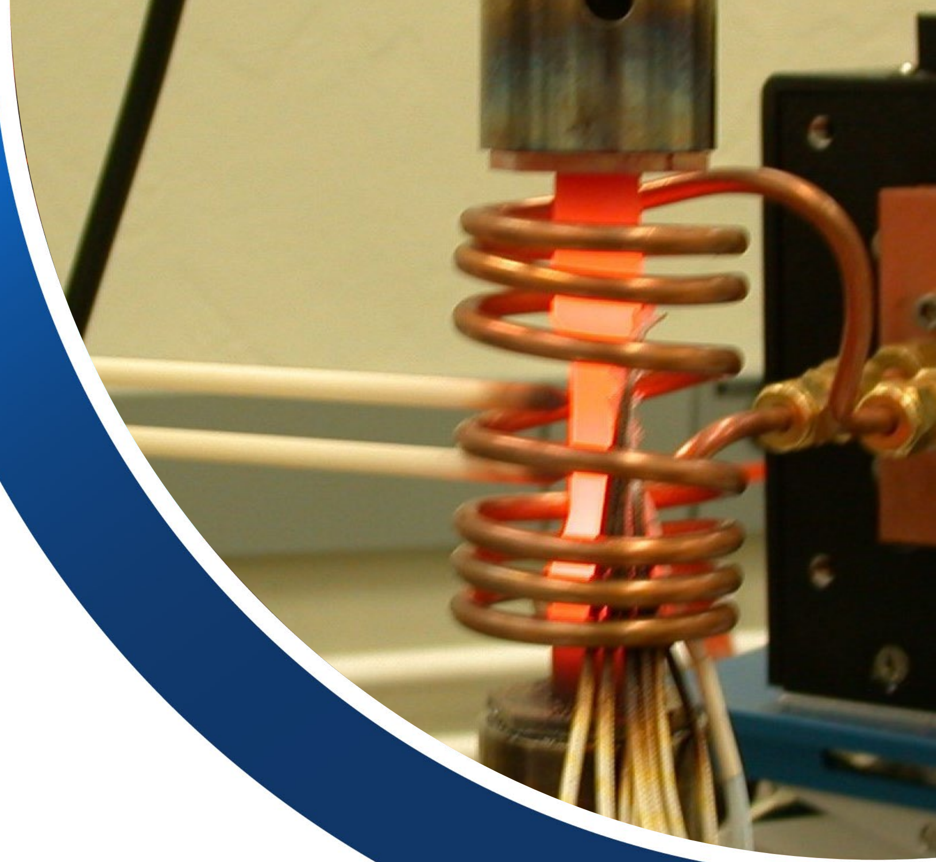
GAS-COOLED REACTOR
ADVANCED REACTOR TECHNOLOGIES PROGRAM



6/18/2024

# High Temperature Metals Program Overview


**Michael McMurtrey**

*ART INL High Temperature Metals Technical Lead*


**DOE ART GCR Review Meeting**

*Hybrid Meeting at INL*

**July 16–18, 2024**

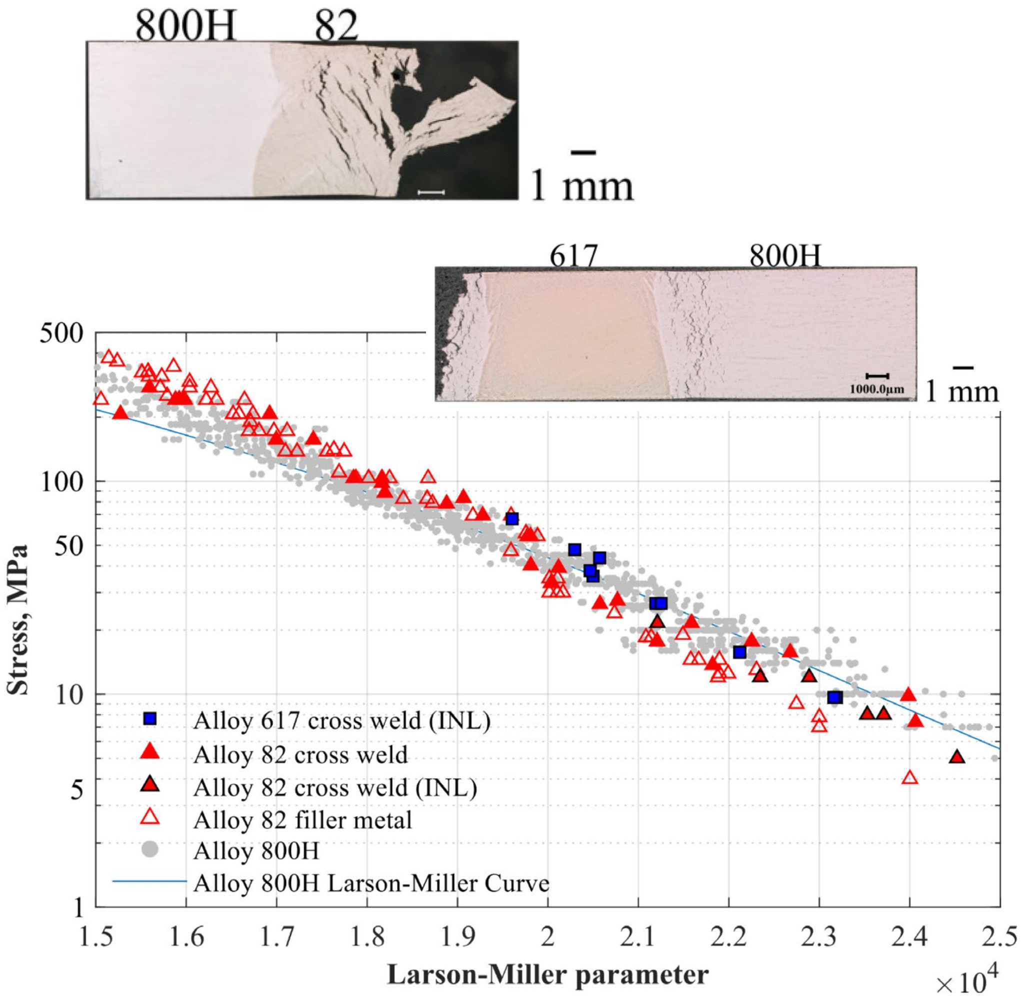
# FY24 Work Packages and Contributors

| FY24 Work Packages | R&D topics |
|---|---|
| High Temperature Design Methodology - ANL, INL, ORNL | • ASME code participation<br>• Continue development of new Class B rules<br>• Variable amplitude fatigue testing to validate the fatigue design rules<br>• Inelastic material models development and limited deformation data generation for all Division 5 Class A materials |
| Long-Term VHTR Material Qualification – INL, ORNL | • Verification of EPP + SMT method<br>• Continue testing of new Alloy 800H weldment<br>• Creep and creep-fatigue crack growth tests in air and in reactor grade helium |

- Contributors
  - Michael McMurtrey, Heramb Mahajan (INL)
  - Yanli Wang, Brad Hall (ORNL)
  - Mark Messner, Hao Deng (ANL)
  - Sam Sham (Now NRC)
  - Bob Jetter, Richard Wright, Bill Corwin (Subject Matter Experts)
- AMMT Program review slides: https://ammt.anl.gov/publications/

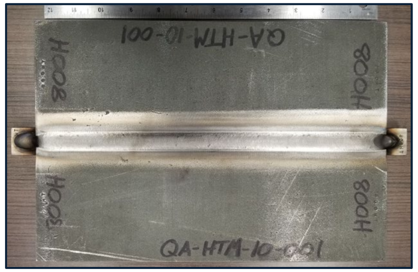
# Assessment of UTP A 2133 Mn filler metal for Alloy 800H weldments

- Stress rupture factors indicate a drop in allowable stresses as a result of weldments causing a reduction in properties
- The welding filler metals qualified for welding Alloy 800H have stress rupture factors that reduce the allowable weldment strength by factors as low as 0.59
- New weld filler metals (previously Alloy 617, now UTP A 2133 Mn) are being examined in an attempt to reduce the reduction in strength for Alloy 800H weldments

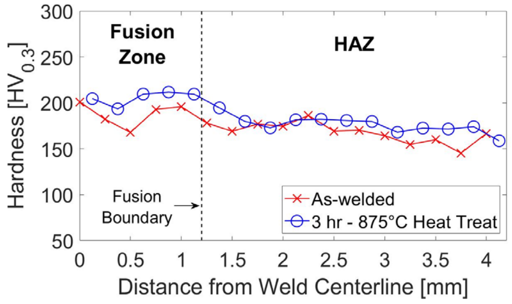


# Assessment of UTP A 2133 Mn filler metal for Alloy 800H weldments

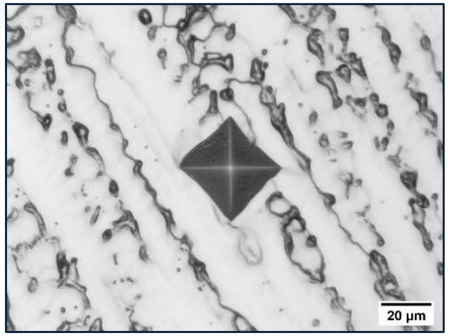
- UTP A 2133 Mn Filler ASME BPVC Section IX Weld Testing
- UTS must be above minimum base metal UTS (450 MPa for 800H)
- Bend tests must not show signs of cracking for face or root bends
- Creep testing underway



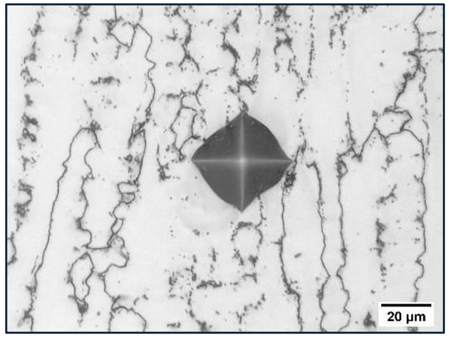


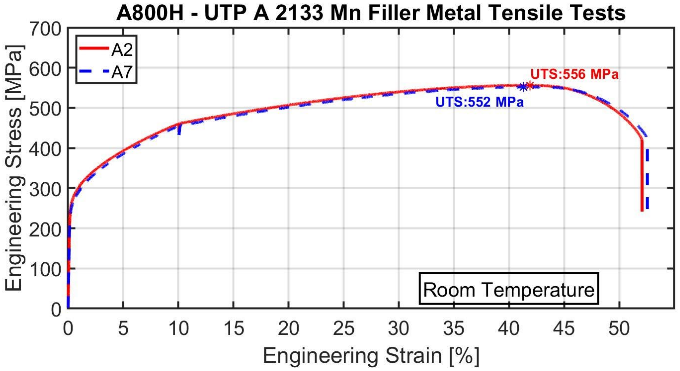




As Welded Fusion Zone



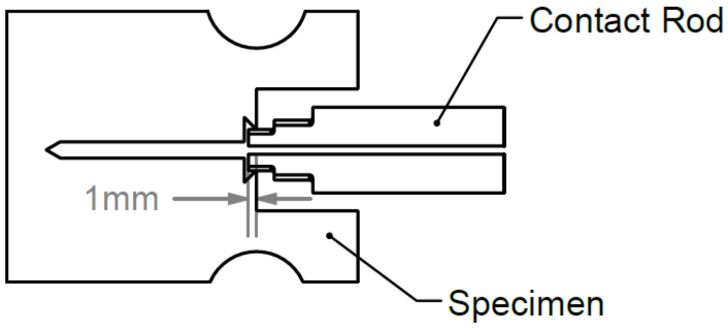

3 hr – 875°C Heat Treat



# High-Temperature Crack Growth Rate Testing

- While Section III, Division 5 provides rules for construction for high temperature nuclear components, it does not provide guidance for in-service inspection or monitoring of components during their lifetimes in operation
- Section XI Division 2 covers reliability and integrity management programs for advanced reactors
- During operation of components, it is critical to understand how flaws and defects grow during normal operation under loads (include cyclic), coolant environments particular to the reactor design, and at high temperature
- Section XI of the ASME BPVC requires information on crack-growth behaviors

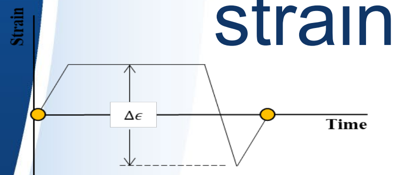



# High-Temperature Crack Growth Rate Testing

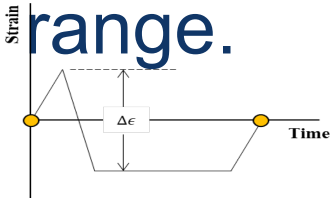
- DCPD indicated significant crack
- Post-test imaging shows more deformation than cracking
- Data analysis ongoing

# Hold Time Effect on Creep-Fatigue Performance of A617 at 850 °C

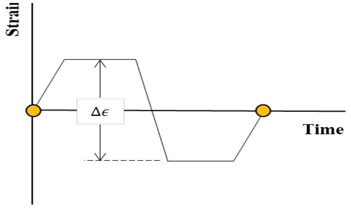
- One of two types of tests for validation of ASME Section III, Division 5 creep-fatigue rules
- Creep-fatigue testing with tension hold is the most damaging to A617 compared to compression hold or combined tension and compression hold at the same strain range.




CF with Tension hold




CF with compression hold



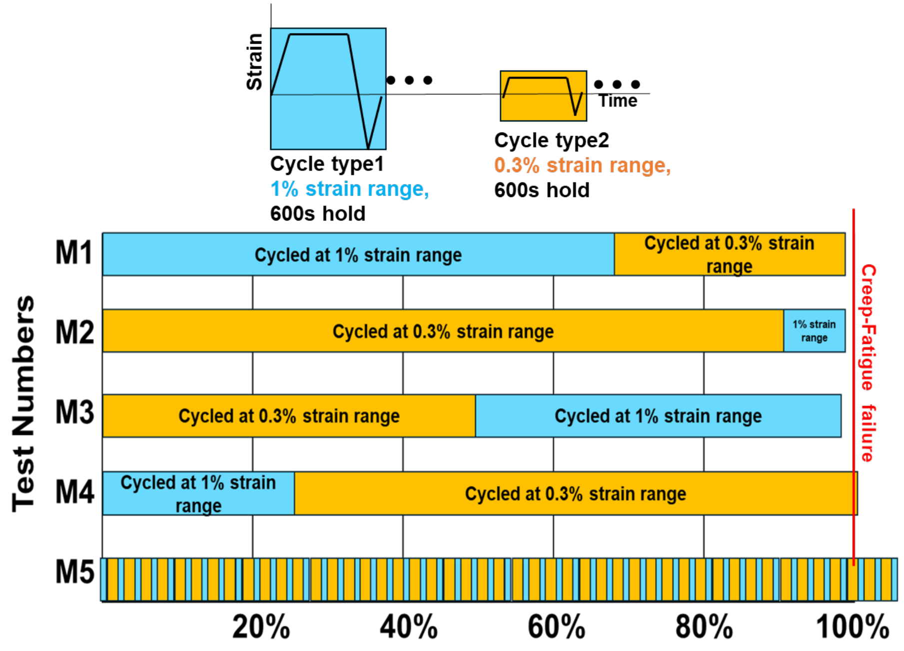

CF with Combined tension and compression hold

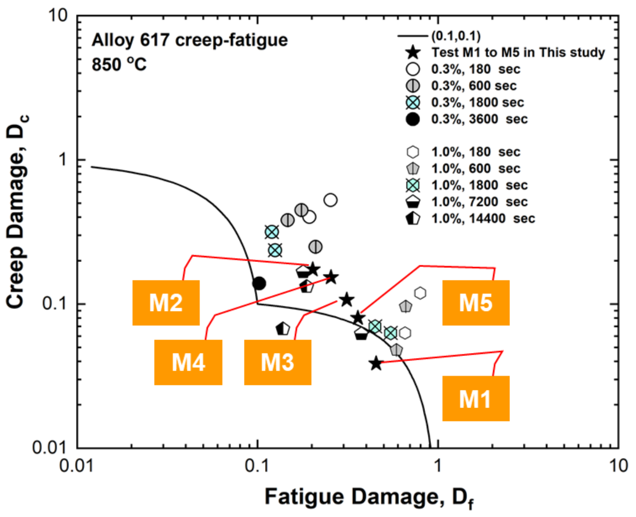
| Test No. | Nominal Strain range, | Tensile hold time, sec | Compression hold time, sec | Number of Cycles to failure |
|---|---|---|---|---|
| T1[1)] | 0.3% | 600 | 0 | 1774 ± 251 (4 tests) |
| TC1[2)] | 0.3% | 300 | 300 | 2285 (one test) |
| C1[2)] | 0.3% | 0 | 600 | 3093 (one test) |

*1) Data from INL and ORNL; 2) Data from ORNL*

# Creep-Fatigue Damage Summation Evaluation: Multi-Cycle Type Tests on Alloy 617 at 850 °C

- Instead of uniform loading profile, two cycle types were applied in each test.
- All five tests exhibited total CF fractions within 100±10%, despite significant variations in strain profile, straining sequence, and the applied CF damage fraction of each cycle type.

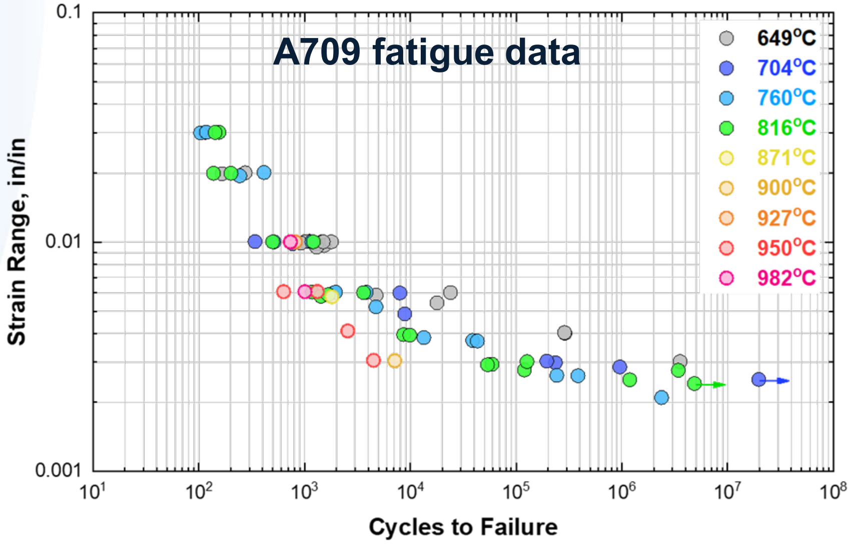



- Based on this analysis, it is reasonable to conclude that the distribution of different cycle types in a design problem does not significantly affect the CF damage analysis results at elevated temperatures.

# High Temperature Metals from other Programs

- 100,000 hour code case for Alloy 709 (Fast Reactor)
- Development of a materials surveillance program (MSR)
- Examination of PM-HIP 316H properties (MR)
- Code case for additively manufactured 316H (AMMT)





Surveillance test article

# GCR metals needs

- Continuation of current work not finishing this year
- Extension of allowable stresses to longer lifetimes for existing Division 5 Class A materials (e.g. 304H/316H to 500,000 hours, 617 to 150,000 hours) – Initiated under ART
- Address exceptions and limitations of the NRC endorsement (Reg. Guide 1.87, Rev. 2) of Section III, Division 5 (2017) - Needed
- Develop reliability-based design methods that utilize statistical methods for determining margins in Div. 5 - Needed
- Confirmatory compatibility test of Alloy 709 in reactor grade helium to expand GCR materials list - Needed
- Cladding and compact heat exchanger code cases – Initiated under R&D projects (GAIN and NEUP IRP)
- Additional structural alloys Needed, some preliminary exploratory work done under ART
  - Refractory metals to expand operating temperature envelope
  - Low/no cobalt nickel alloy (e.g. 625) for high temperature alloy near core
- Welding support Needed, some exploratory work done under iFOA
  - Method/guidance on dissimilar Div. 5 alloy joining
  - High energy density welding (laser beam, electron beam) for Div. 5 and/or B31.3
- Additional code development Needed
  - Development of an “all temperature code”
  - Develop rules for negligible creep and fatigue for Class A and Class SM components
  - Simplify design of core support components through HGB/HBB merge

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# Thank you

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