U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

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Qualification of Materials for Elevated Temperature Nuclear Components

Nuclear Regulatory Commission Workshop
on Materials for Non-Lightwater Reactors
December 10, 2019

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ASME Section III, Rules for Construction of Nuclear Facility Components - Division 5, High Temperature Reactors

Many of the proposed applications for advanced manufactured materials and components are for service in the time dependent material property range

- ASME Section III Division 5 Scope
  - Division 5 rules govern the construction of vessels, storage tanks, piping, pumps, valves, supports, core support structures and nonmetallic core components for use in high temperature reactor systems and their supporting systems
  - Construction, as used here, is an all-inclusive term that includes material, design, fabrication, installation, examination, testing, overpressure protection, inspection, stamping, and certification
  - High temperature reactors include gas-cooled reactors, liquid metal reactors and molten salt reactors (liquid or solid fuel)

ASME Code Qualification of a New Material or Process

- Division 5, Appendix HBB-Y, “Guidelines for Design Data Needs for New Materials”
  - Recently exercised these rules through DOE ART base program on the Alloy 617 Code Case in support of HTGR/VHTR applications

Required testing to introduce a new structural material into Section III, Division 5, or a Division 5 Code Case

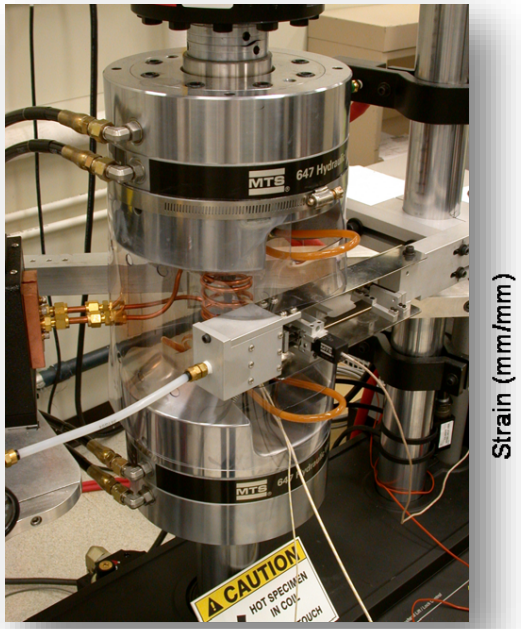
- HBB-Y-2100 Requirement For Time-independent Data
- HBB-Y-2110 Data Requirement for Tensile Reduction Factors for Aging
- HBB-Y-2200 Requirement for Time-Dependent Data
- HBB-Y-2300 Data Requirement for Weldments
- HBB-Y-3100 Data Requirement for Isochronous Stress-Strain Curves
- HBB-Y-3200 Data Requirement for Relaxation Strength
- HBB-Y-3300 Data Requirement for Creep-Fatigue
- HBB-Y-3400 Data Requirement for Creep-Fatigue of Weldments
- HBB-Y-3500 Data Requirement for Cyclic Stress-Strain Curves
- HBB-Y-3600 Data Requirement for Inelastic Constitutive Model
- HBB-Y-3700 Data requirement for Huddleston multiaxial failure criterion
- HBB-Y-3800 Data Requirement for Time-Temperature Limits for External Pressure Charts
- HBB-Y-4100 Data Requirement for Cold Forming Limits
- Validation of Elastic-Perfectly Plastic (EPP) Simplified Design Methods for the new alloy

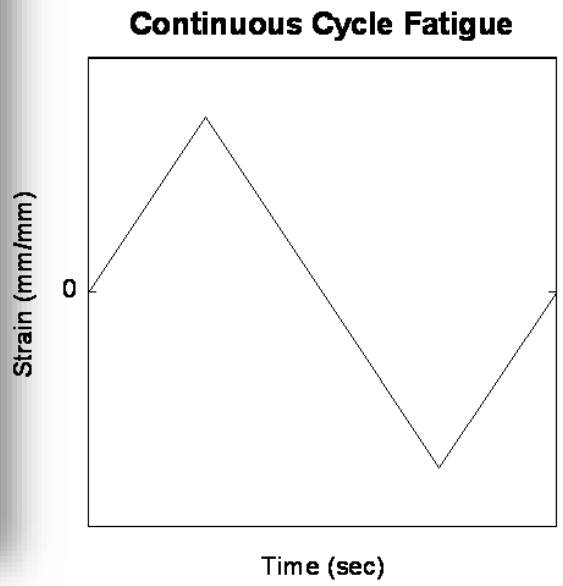
Additional Requirements Outside the Scope of Section III, Division 5

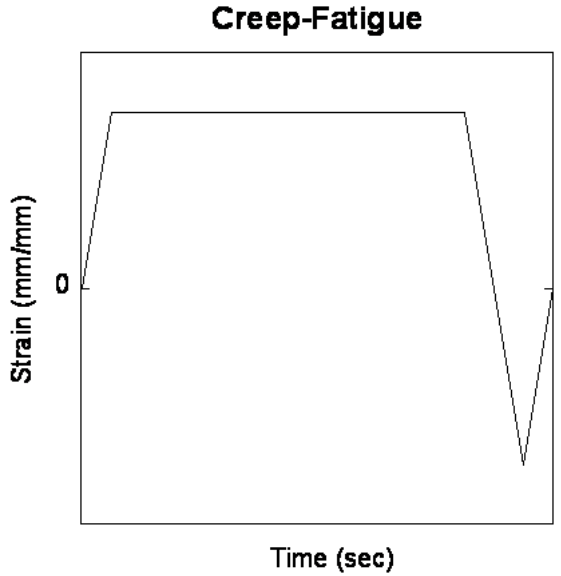
- Design procedures and materials data not contained in Division 5 may be required to ensure the integrity or the continued functioning of the structural part during the specified service life
  - Rules do not provide methods to evaluate deterioration that may occur in service as a result of corrosion, mass transfer phenomena, radiation effects, or other material instabilities
  - Owner/operator has the responsibility to demonstrate to NRC that these effects are accounted for in the design of the component

Example: Creep-Fatigue Behavior

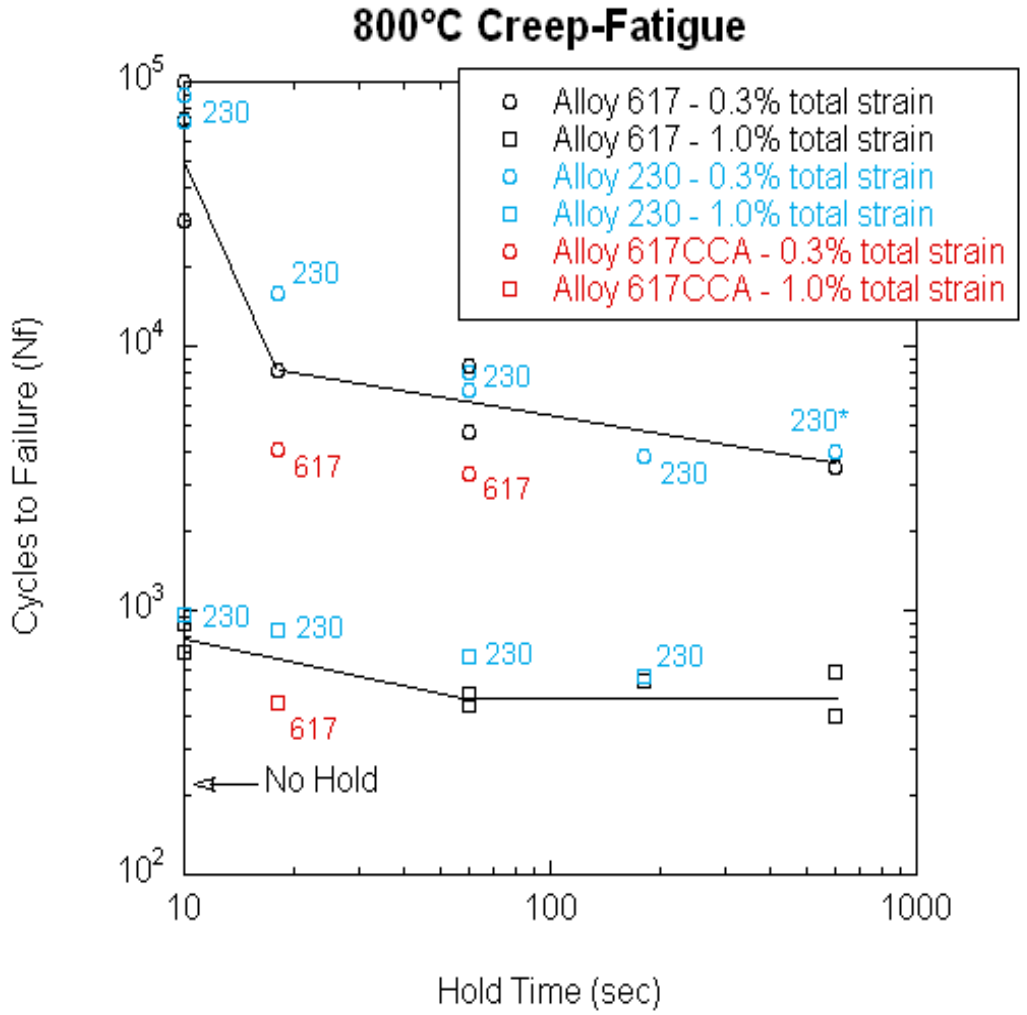
- ASME approach is to develop a damage diagram based on a time-fraction method







Creep-Fatigue Example Results



Why the Interest in Advanced Manufacturing?

- Conventional light water reactor technology is seeking manufacturing methods to reduce lead times, material costs and improve the ability to inspect components
- Vendors of small modular reactors are considering manufacturing methods that can be applied to reduce fabrication cost and enhance the economics of factory fabrication
- Small modular reactor concepts have complex geometries and unique needs for compact systems
- ASME Code issues have arisen with conventionally processed materials (rolled or forged) that are difficult or impossible to inspect due to directional microstructures that are not homogenized with modern mill practices

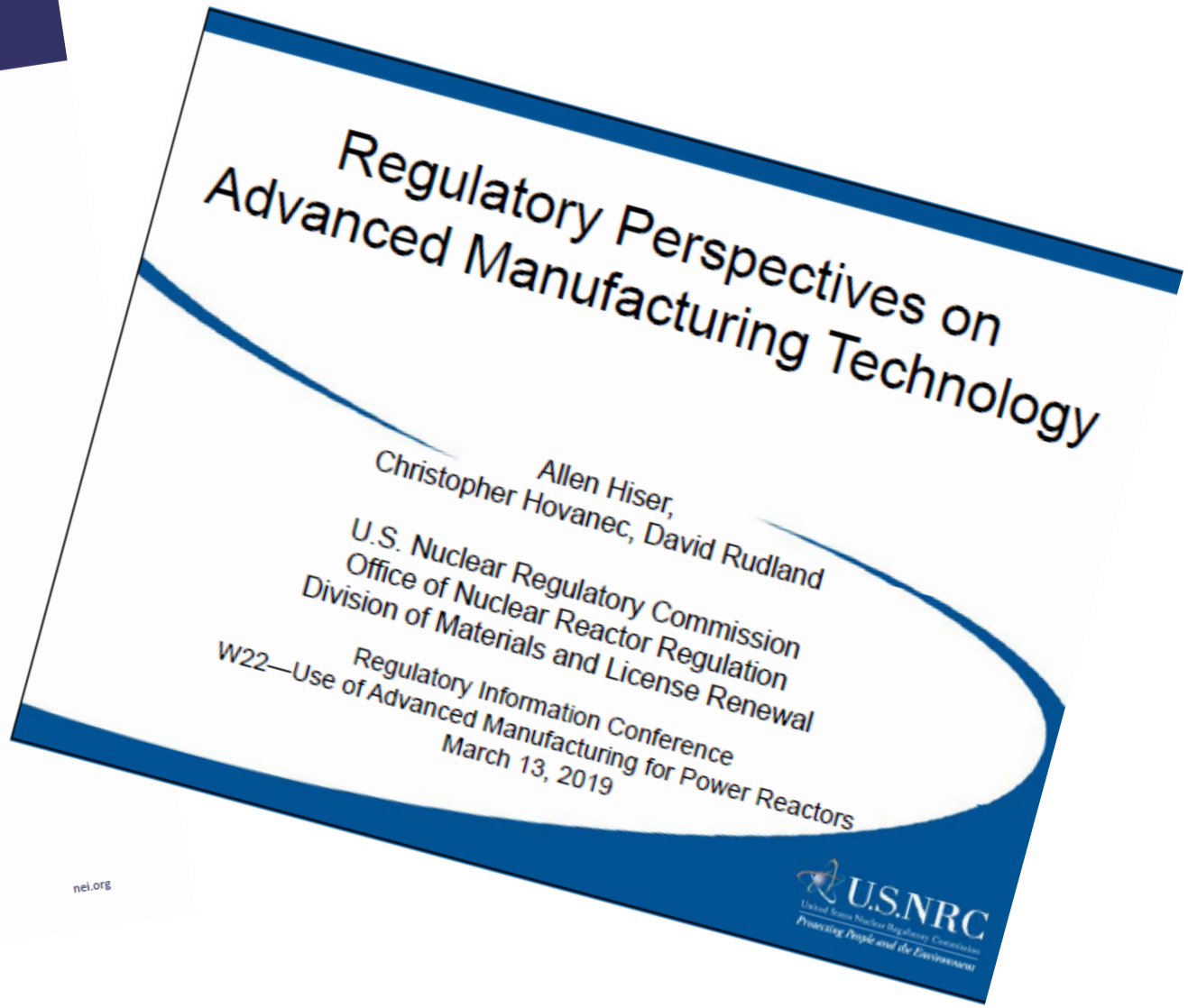
The Potential Consequences of Advanced Manufacturing are Being Assessed


NEI | REPORT

Roadmap for Regulatory Acceptance of Advanced Manufacturing Methods in the Nuclear Energy Industry

Prepared by the Nuclear Energy Institute
May 13, 2019

nei.org


Regulatory Perspectives on Advanced Manufacturing Technology

Allen Hiser,
Christopher Hovanec, David Rudland
U.S. Nuclear Regulatory Commission
Office of Nuclear Reactor Regulation
Division of Materials and License Renewal

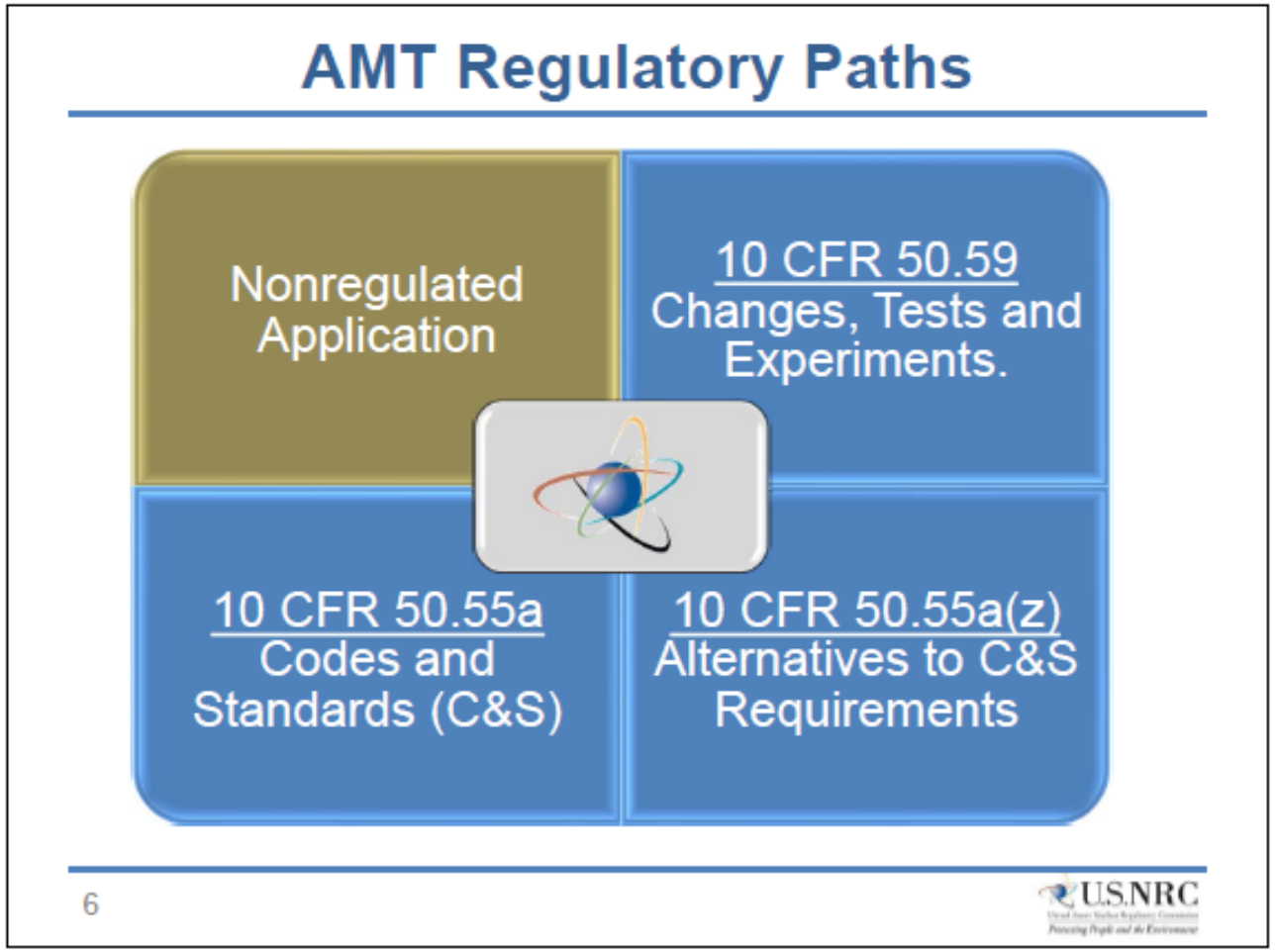
Regulatory Information Conference
W22—Use of Advanced Manufacturing for Power Reactors
March 13, 2019

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

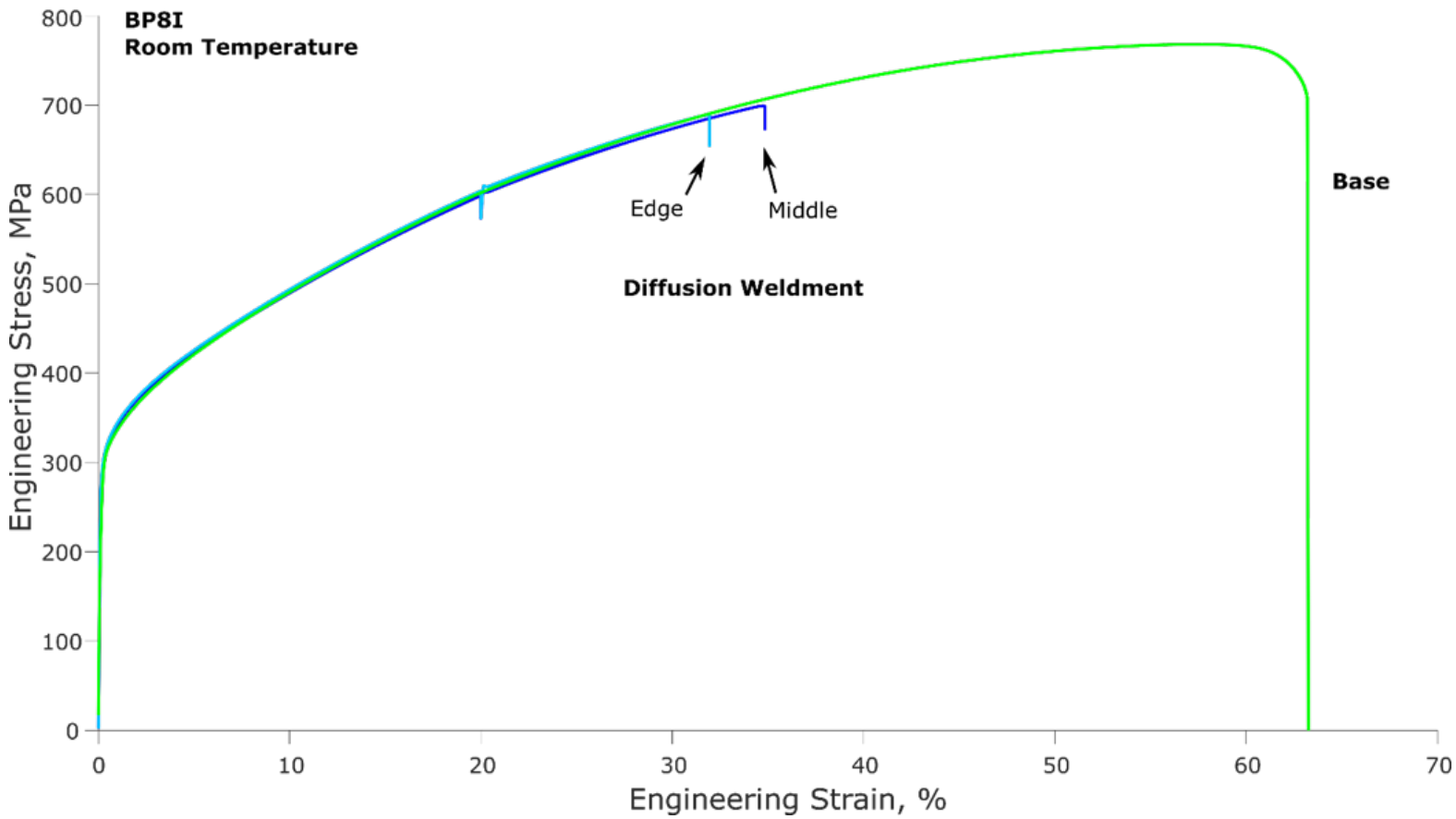
NRC Pathways to Regulatory Acceptance

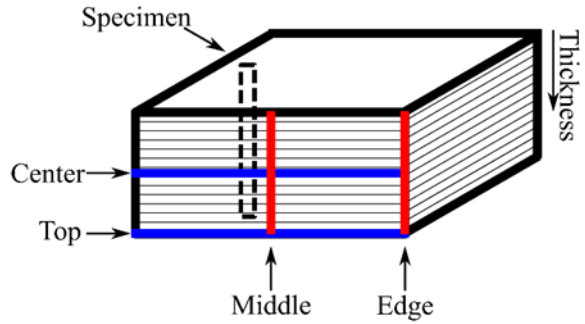
There are several regulatory paths available to a licensee for utilizing an AMT in a nuclear application. The following four regulatory paths are possible:

- Develop a Code or standard that can be incorporated by reference (IBR) in 10 CFR 50.55a.
- Select an unregulated in-service application.
- Submit generic technical reports or plant-specific submittals for NRC approval.
- Implement the 10 CFR Part 50.59, 10 CFR Part 70.72, or 10 CFR Part 72.48 process.

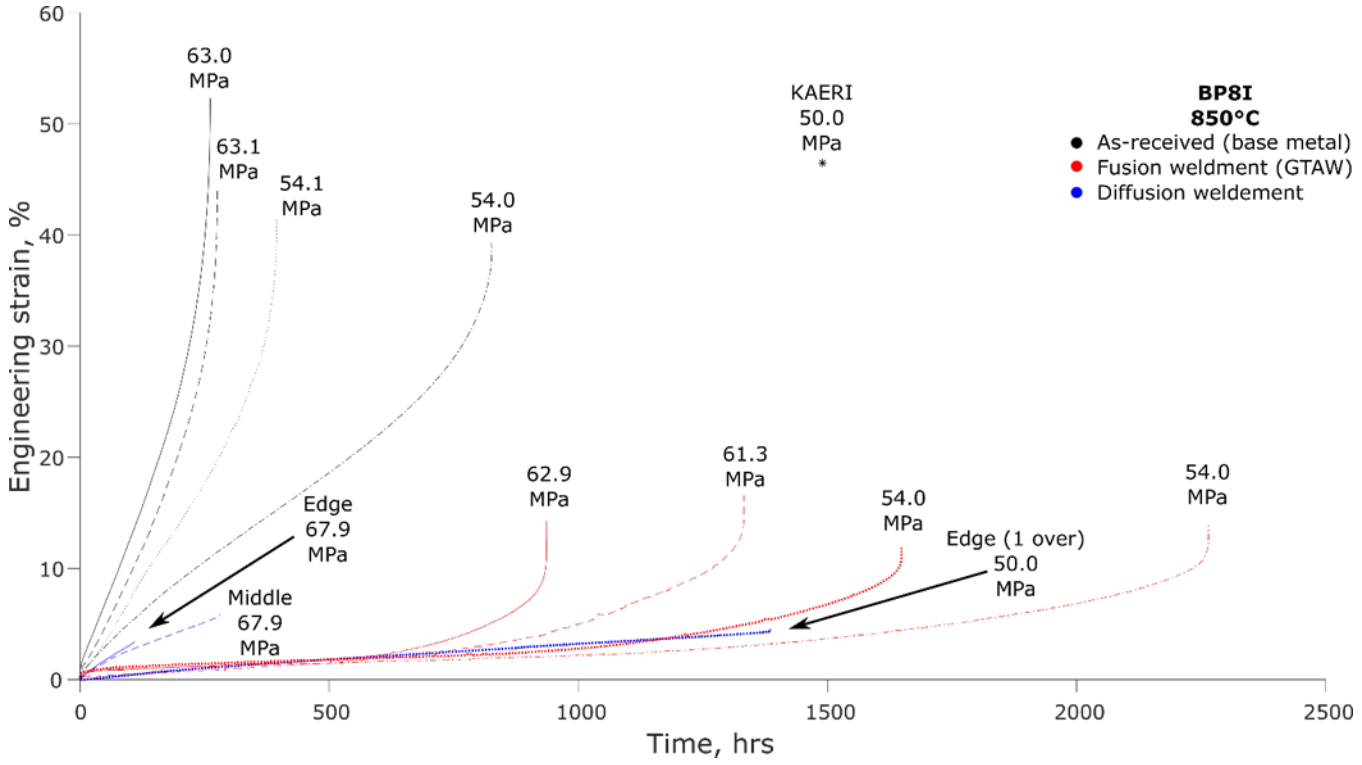


Example: Room Temperature Tensile Properties of Diffusion Bonded Alloy 617

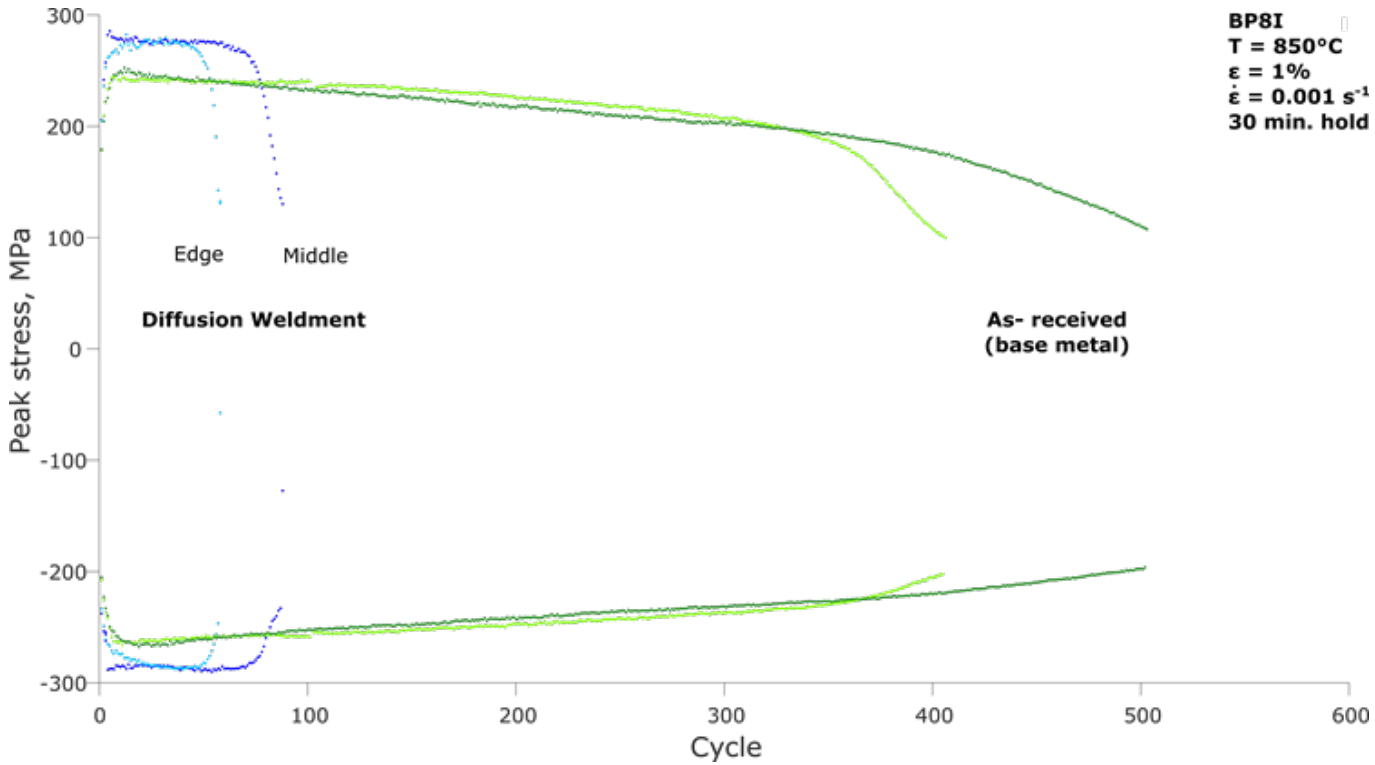




Creep Rupture of Conventional and Diffusion Bonded Material



Creep Fatigue Behavior of Diffusion Bonded Alloy 617



How Can Qualification be Accelerated?

- Characterizing time dependent properties cannot be avoided – but extrapolation by a factor of 3 to 5 in time is reasonable
- One approach is to limit the initial design life, particularly for technology demonstration, and continue testing while demonstration is ongoing
- Cladding concepts may be applicable - e.g., a corrosion resistant layer could be added on a Code qualified material
- Determination of mechanisms giving rise to time dependent properties through simulation validated by experiment could allow acceptable accelerated testing or greater extrapolation