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Update on the Current R&D Activity in the U.S.

January 2023

Ting-Leung Sham

Changing the World's Energy Future

Idaho National Laboratory

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Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

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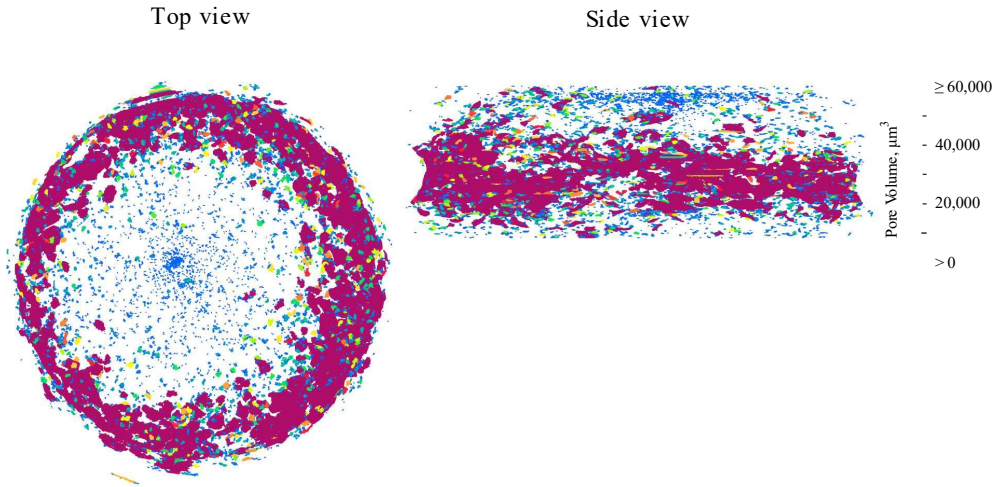
Update on the Current R&D Activity in the U.S.

GIF VHTR Materials PMB
Metals and Design Methods Working Group
January 24, 2023

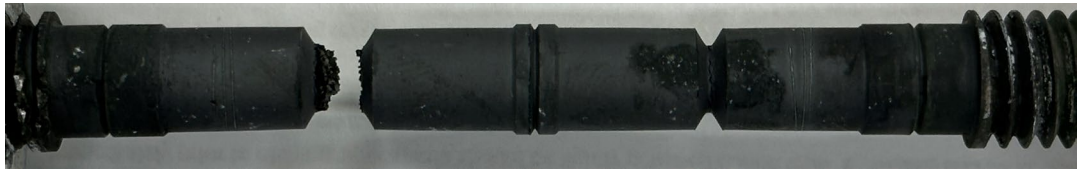
Sam Sham
Idaho National Laboratory

Notched creep rupture testing

- **Weldment V-notch specimen test finished**
  - 800C 60MPa, 15,716 hour rupture life
- **Two double V-notch specimen tests have finished**
  - 800C 80MPa, 10393 hour rupture life, notch strengthening factor of 8.9
  - 850C 63MPa, 4997 hour rupture life, notch strengthening factor of 18.6
  - Longer rupture times are expected to see decreased notched strengthening, until cross over occurs and specimen is notch weakening
- **Unlike uniaxial creep failure where damage occurs uniformly throughout, just prior to failure, notched specimens show damage progressing from the outside (notch tip) towards the center (similar to fatigue)**



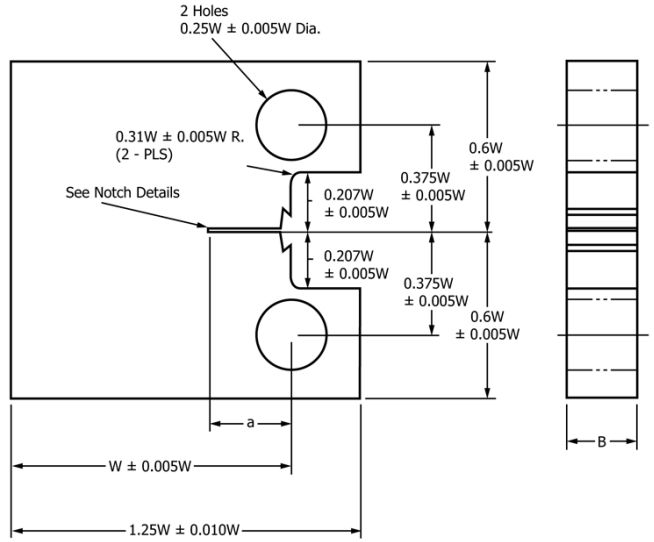
X-ray CT of first double V-notch specimen to finish testing (unruptured notch)



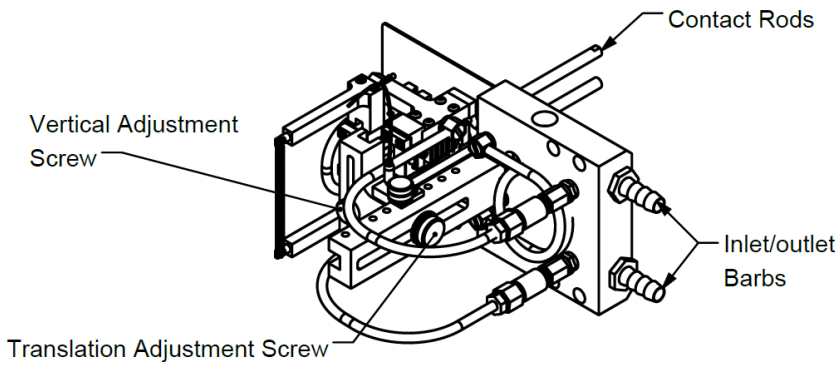
Second double V-notch test to finish, unruptured notch shows cracking, will be characterized with X-ray CT

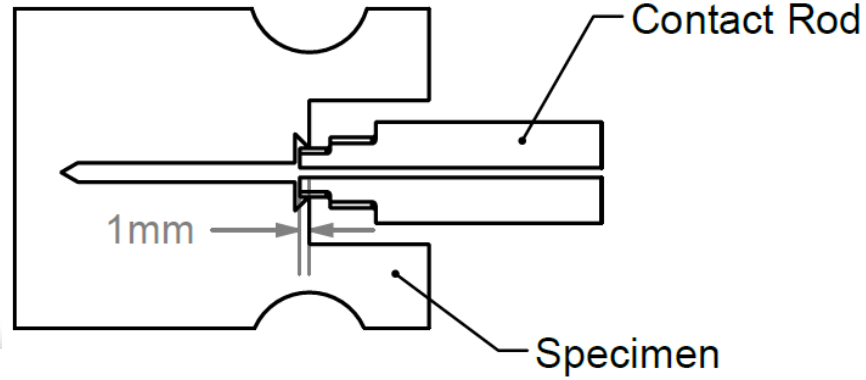
Crack growth tests

- System modification was required for creep and creep-fatigue testing
- Epsilon 3548COD Extensometer has been ordered, to allow load-line displacement measurements, to be paired with direct current potential drop already used to measure crack length
- Sample redesigned in accordance to ASTM E2760 and E1457 to allow for both creep and creep-fatigue crack growth rate testing



Clockwise: Creep and C-F specimen design; Connection of extensometer to specimens; Epsilon Extensometer

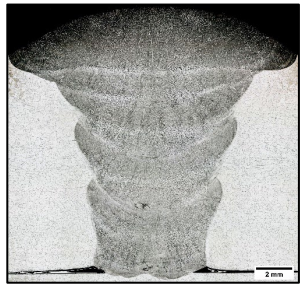


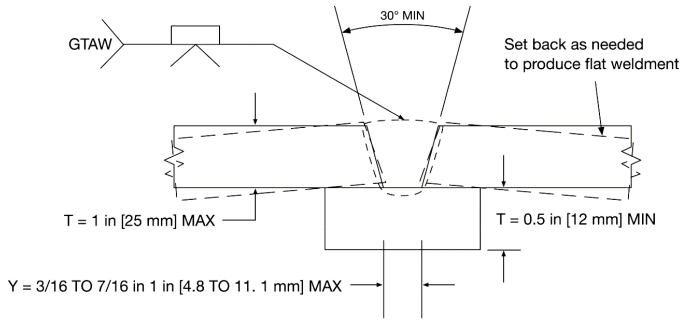


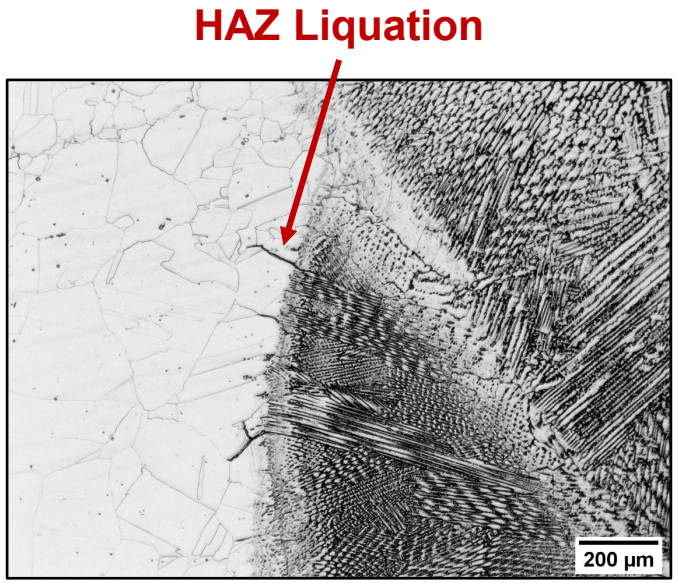
Alloy 800H Weldments (1/2)

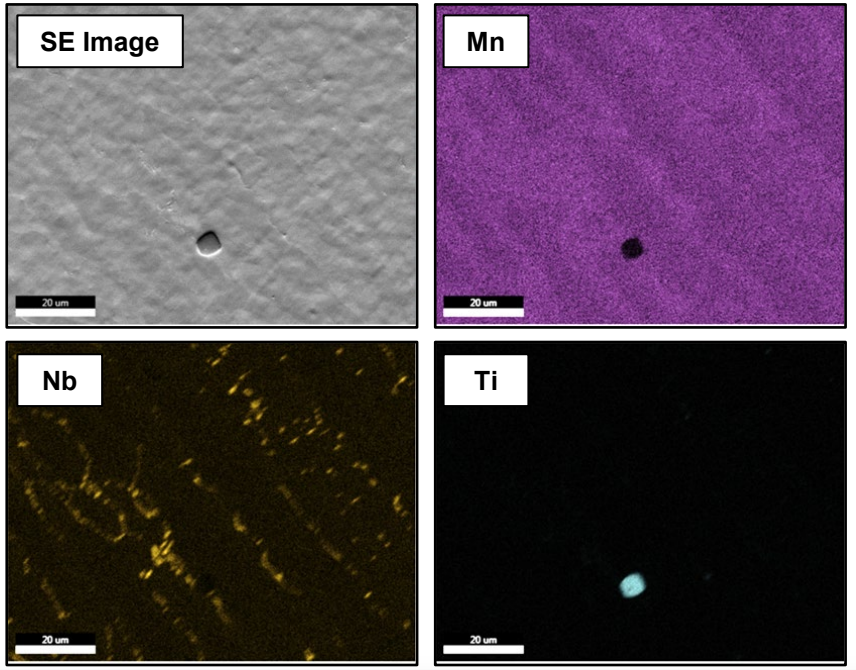
- **UTP 2133 Mn Weld Metal Analysis**

	Fe	Ni	Cr	Mo	Nb	Ti	Al	Co	Cu	Si	Mn	C	P	S
800HT®	46.2	30.6	19.7	-	-	0.54	0.56	0.10	0.20	0.42	1.27	0.061	0.024	0.001
UTP A 2133 Mn	Balance	32.1	21.6	<0.1	1.23	-	-	-	<0.1	0.2	4.8	0.16	0.008	0.001





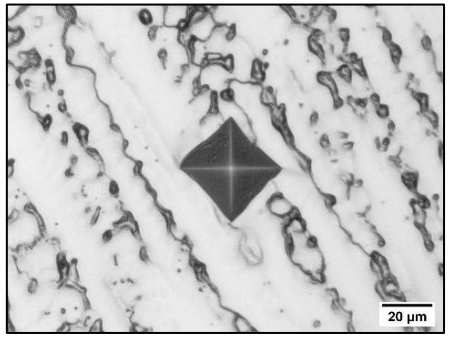




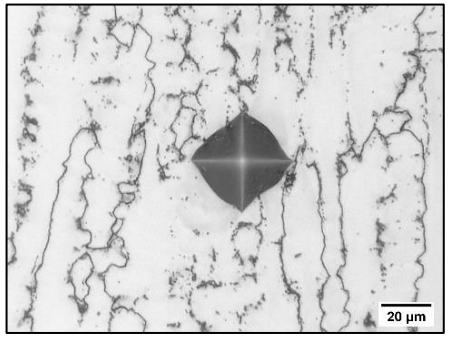
Alloy 800H Weldments (2/2)

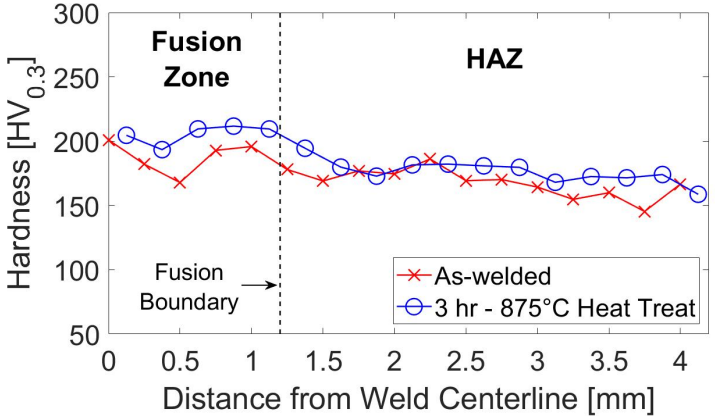
- **UTP 2133 Mn Filler Metal Properties**

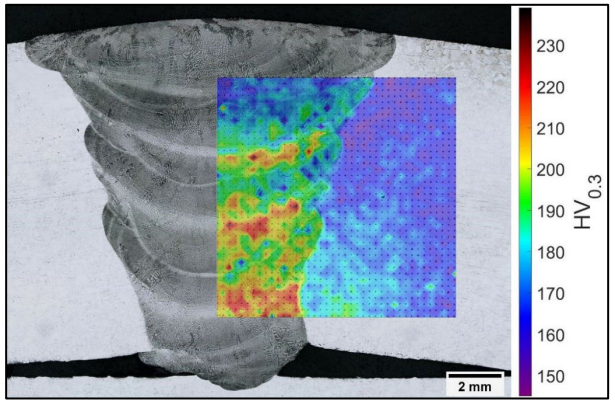
As Welded Fusion Zone

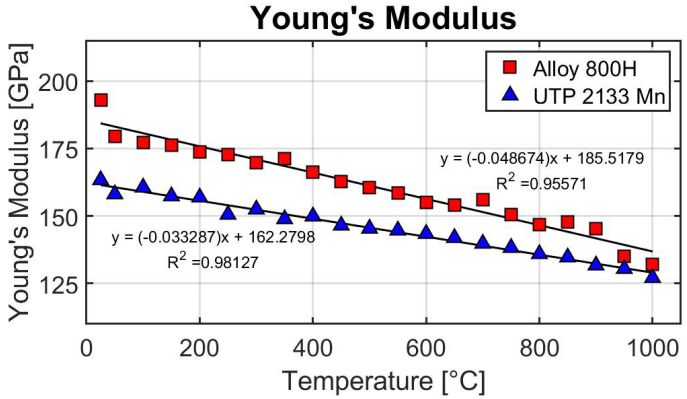


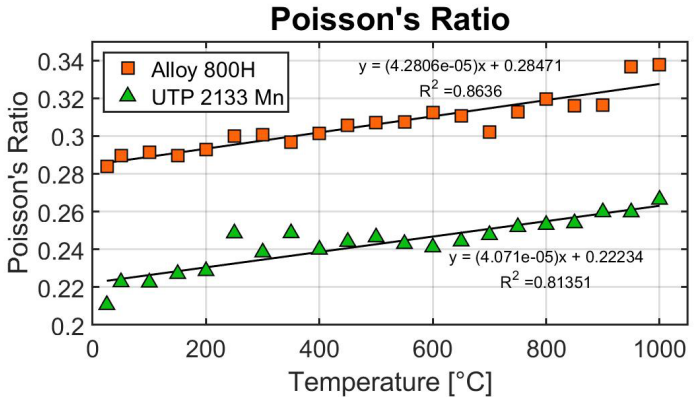
3 hr – 875°C Heat Treat

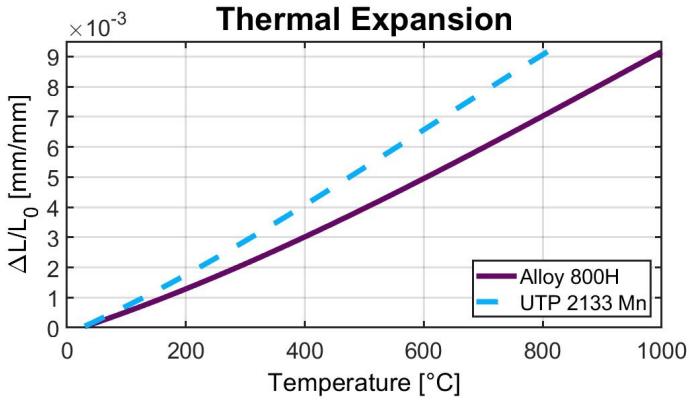










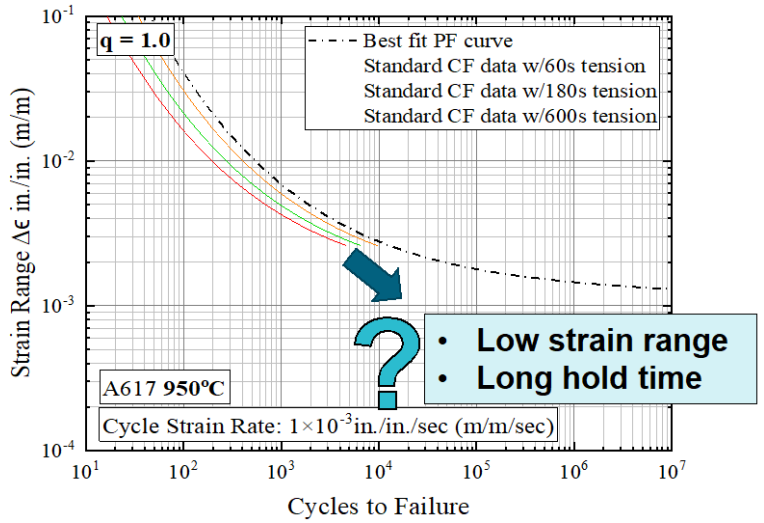


Variable Fatigue Testing

Background

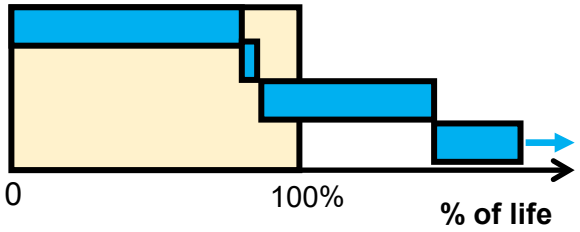
- Available data are limited to standard CF with strain ranges at 0.3% and above. No data available at low strain ranges of <0.3%, and hold time less than 2.5 hr
- Typical design hold time is 1,000 hrs.
  - Practical challenges to perform CF testing to failure with long hold times, i.e., 100 hr hold x100 cycles at 1% strain range=~ 14 months
  - Much longer at low strain ranges

Limited Available data

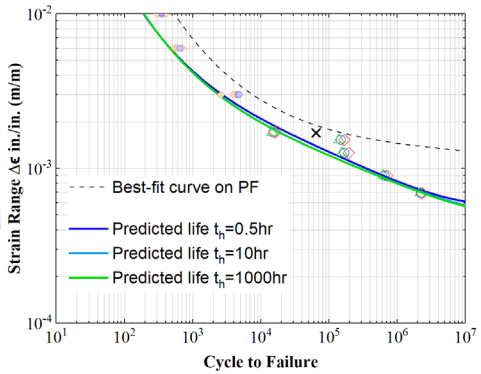


Develop and Verify EPP+SMT Design Curves

- Step 1: ~80% CF damage at high strain range with relatively short hold time
- Step 2: 300 cycles CF damage at low strain range with long hold time of 10 hr
- Step 3: Unintentional accidental overload (twice)
- Step 4: ongoing test the remaining life at low strain range

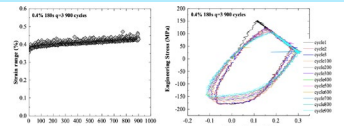


Preliminary Energy Dissipation Based Design Curves

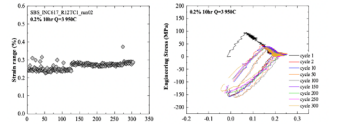


Verification Testing

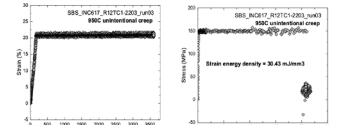
Step 1:



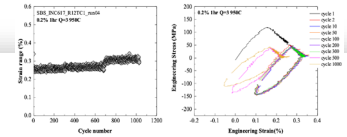
Step 2:



Step 3:



Step 4:



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Multi-axial Stress Relaxation

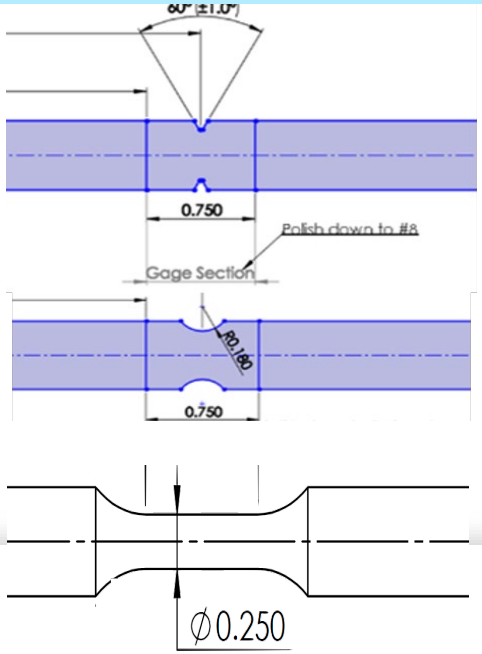
- **Tests are designed to examine the multiaxial stress-relaxation behavior and multiaxial stress-state effect on the creep-fatigue (CF) performance for Alloy 617 at elevated temperatures.**
- **Preliminary tests were completed. The multiaxial stress relaxation behavior, distributions of stress triaxiality factor and elastic follow-up factor in notch specimens are being analyzed using numerical modeling approach.**

Design of the Multiaxial Stress Relaxation Tests using Notch Geometries

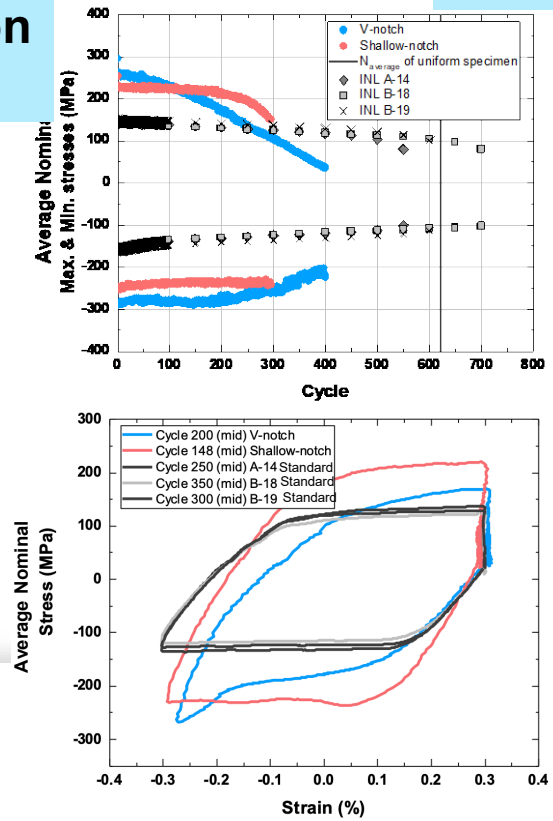
Sharp V-notch in the gage

U-notch in the gage

Standard uniform gage



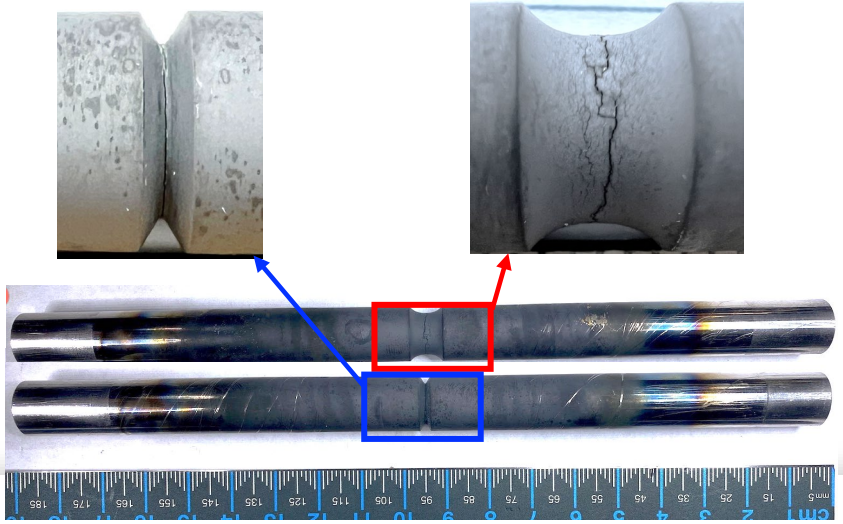
Examples of the Test Results



Creep-fatigue testing of A617 at 950C with 600-sec hold and 0.6% nominal strain range

V-notch

U-notch



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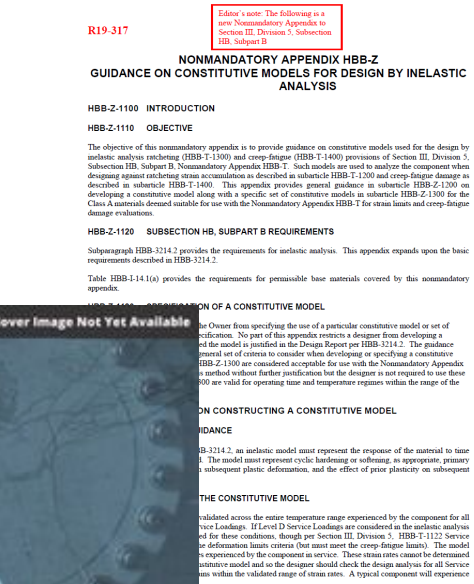
ASME approved 316H and Alloy 617 models as additions to the 2023 Code and the Alloy 617 Code Case

- Goal: provide a new Code appendix with guidance on how to construct and use inelastic material models and include a “reference” model designers can use without further V&V for each Class A material
  - Previously approved: Grade 91
  - Added to 2023 edition: 316H
  - Added to Alloy 617 Code Case: copy of general guidance + specific constitutive model
  - Slated for completion in FY23: 800H
- New appendix now covers many of the materials called out by HTR vendors



R19-317

Editor’s note: The following is a new Nonmandatory Appendix to Section III, Division 5, Subsection HB, Subpart B

NONMANDATORY APPENDIX HBB-Z
GUIDANCE ON CONSTITUTIVE MODELS FOR DESIGN BY INELASTIC ANALYSIS

HBB-Z-1100 INTRODUCTION

HBB-Z-1110 OBJECTIVE

The objective of this nonmandatory appendix is to provide guidance on constitutive models used for the design by inelastic analysis ratcheting (HBB-T-1300) and creep-fatigue (HBB-T-1400) provisions of Section III, Division 5, Subsection HB, Subpart B, Nonmandatory Appendix HBB-T. Such models are used to analyze the component when designing against ratcheting strain accumulation as described as subarticle HBB-T-1200 and creep-fatigue damage as described in subarticle HBB-T-1400. This appendix provides general guidance in subarticle HBB-Z-1200 on developing a constitutive model along with a specific set of constitutive models in subarticle HBB-Z-1300 for the Class A materials deemed suitable for use with the Nonmandatory Appendix HBB-T for strain limits and creep-fatigue damage evaluations.

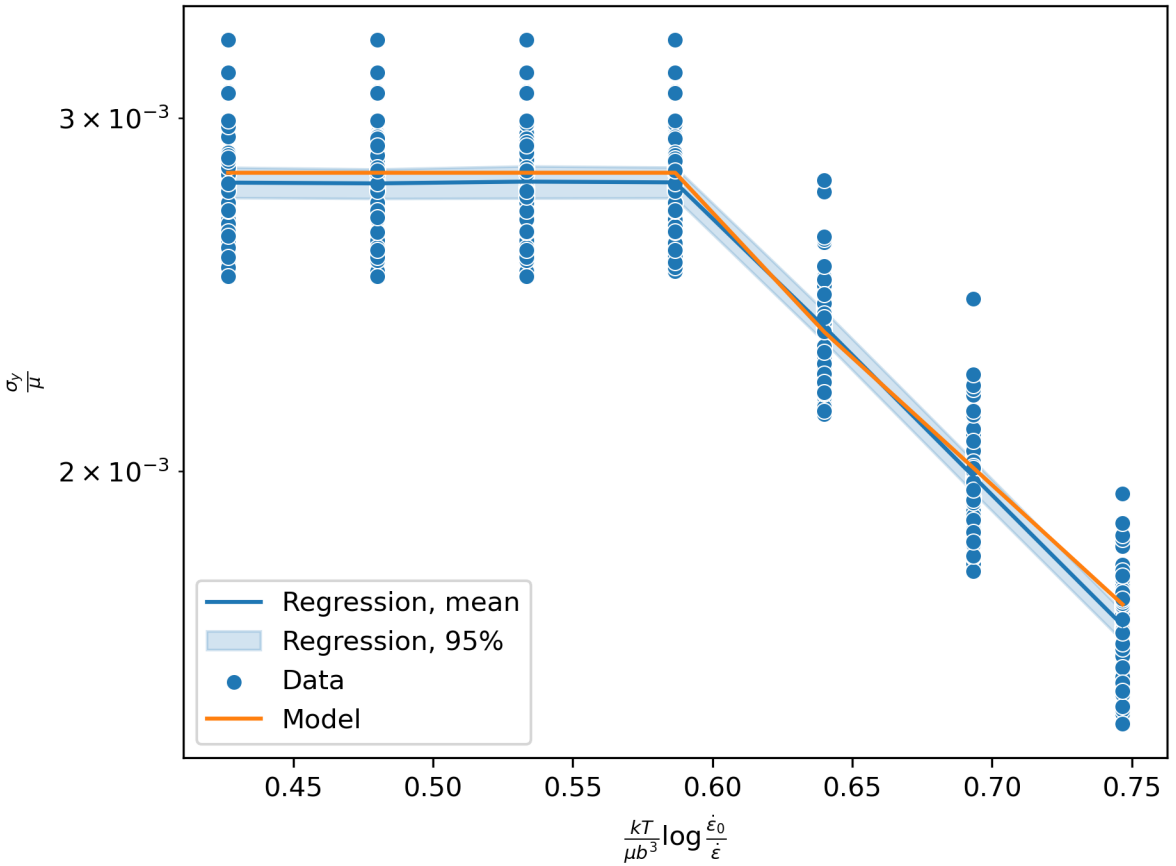
HBB-Z-1120 SUBSECTION HB, SUBPART B REQUIREMENTS

Subparagraph HBB-3214.2 provides the requirements for inelastic analysis. This appendix expands upon the basic requirements described in HBB-3214.2.

Table HBB-I-14.1(a) provides the requirements for permissible base materials covered by this nonmandatory appendix.

Continue work to finish 800H model, examine "universal" constitutive model form

- All three approved models + draft 800H model have bespoke model forms, tailored for each material
  - This may improve accuracy
  - But it makes the models unwieldy to describe in the Code and means you need to implement separate models for each material
- Ongoing work includes completing the 800H model and examine universal models forms that fit the available test data for all four materials



Trainable model for material rate sensitivity across a wide range of flow stresses

Future Work

- Continue the tasks that were outlined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