INL/MIS-23-72912-Revision-0

A617 Notch Effect and Crack Growth Testing Status

May 2023

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Idaho National Laboratory

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Joint ART Materials/AMMT Program Review
DOE Headquarters, Germantown, MD
June 5-8, 2023

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Contributors

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- Richard Wright (Structural Alloys, LLC, formerly INL)
- Mark Messner (Argonne National Laboratory)
- Ryann Bass, Joseph Bass (NRC, formerly INL)

Fiscal Year 2023 (FY-23) Work Packages

- AT-23IN060405, Long-Term VHTR Material Qualification - INL

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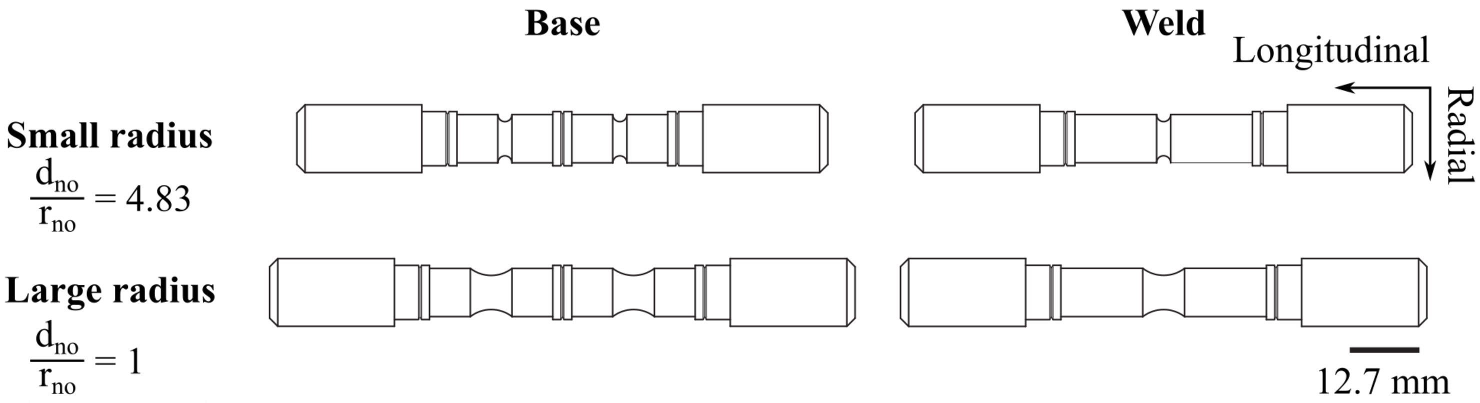
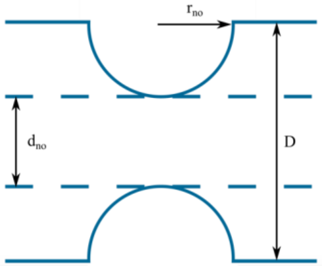
Notched specimen design

A Nuclear Regulatory Commission (NRC)-sponsored assessment of a previous version of Section III, Division 5 of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (BPVC) identified an inadequate understanding of the impact of a multiaxial stress, structural discontinuities, and notch effects.

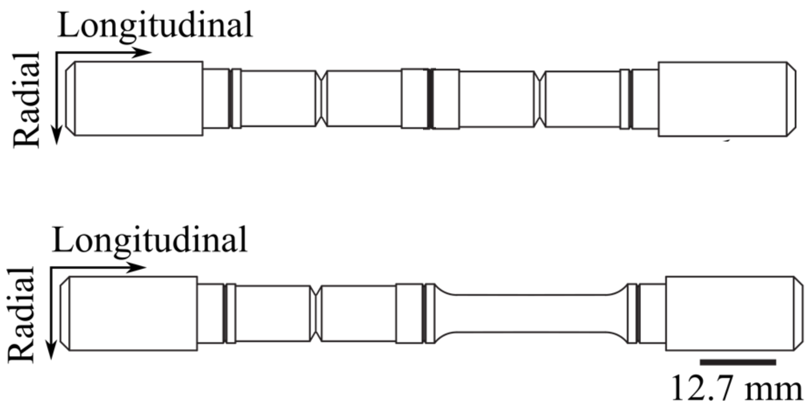
U-notch

(Bridgman notch)

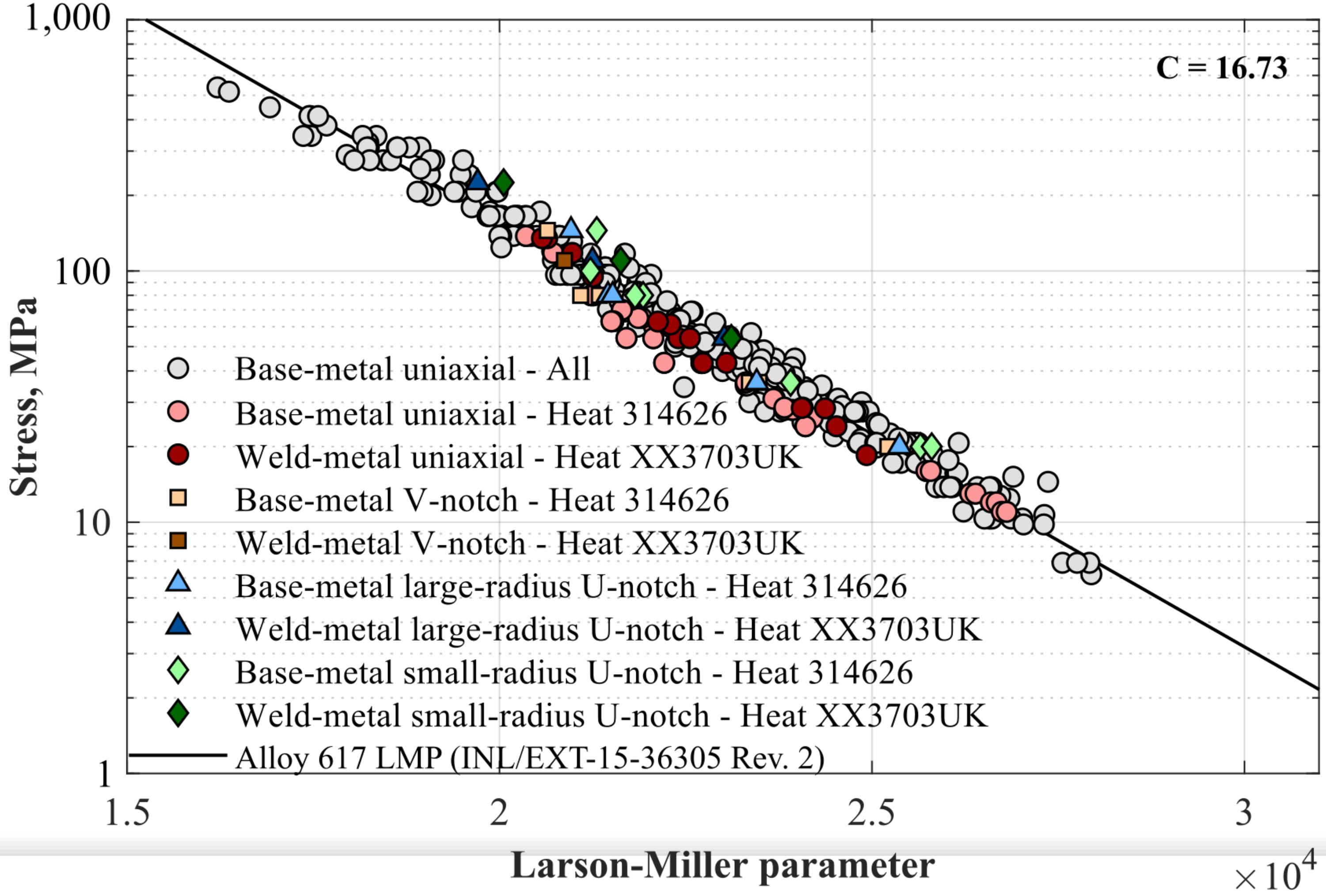




V-notch



Results (short and intermediate term)



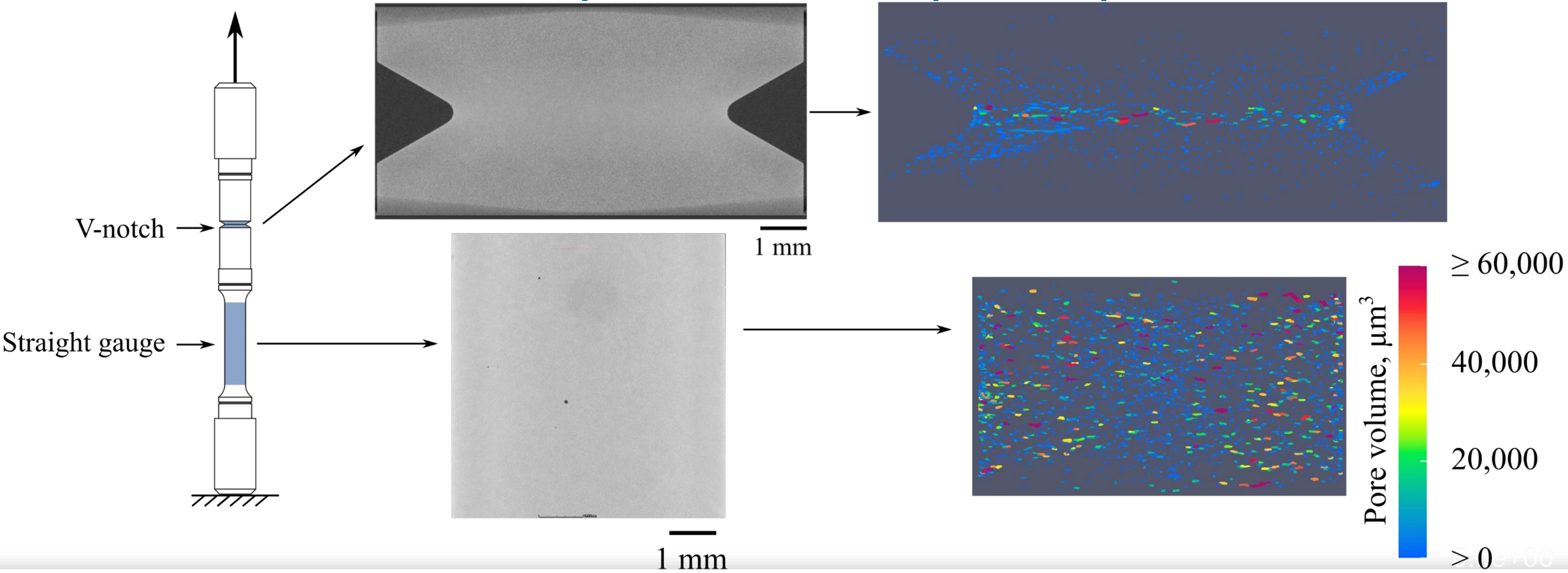
Alloy 617 base- and weld-metal short-term (aim 1,000 to 2,000-hour rupture life) creep-rupture properties were not degraded by geometric discontinuities nor multiaxial-stress states.

1,000°C, 20 MPa

Small radius | Large radius

X-ray Computed Tomography

A technique utilizing X-ray computed tomography (CT) was developed with the goal of being able to identify the failure location prior to rupture.



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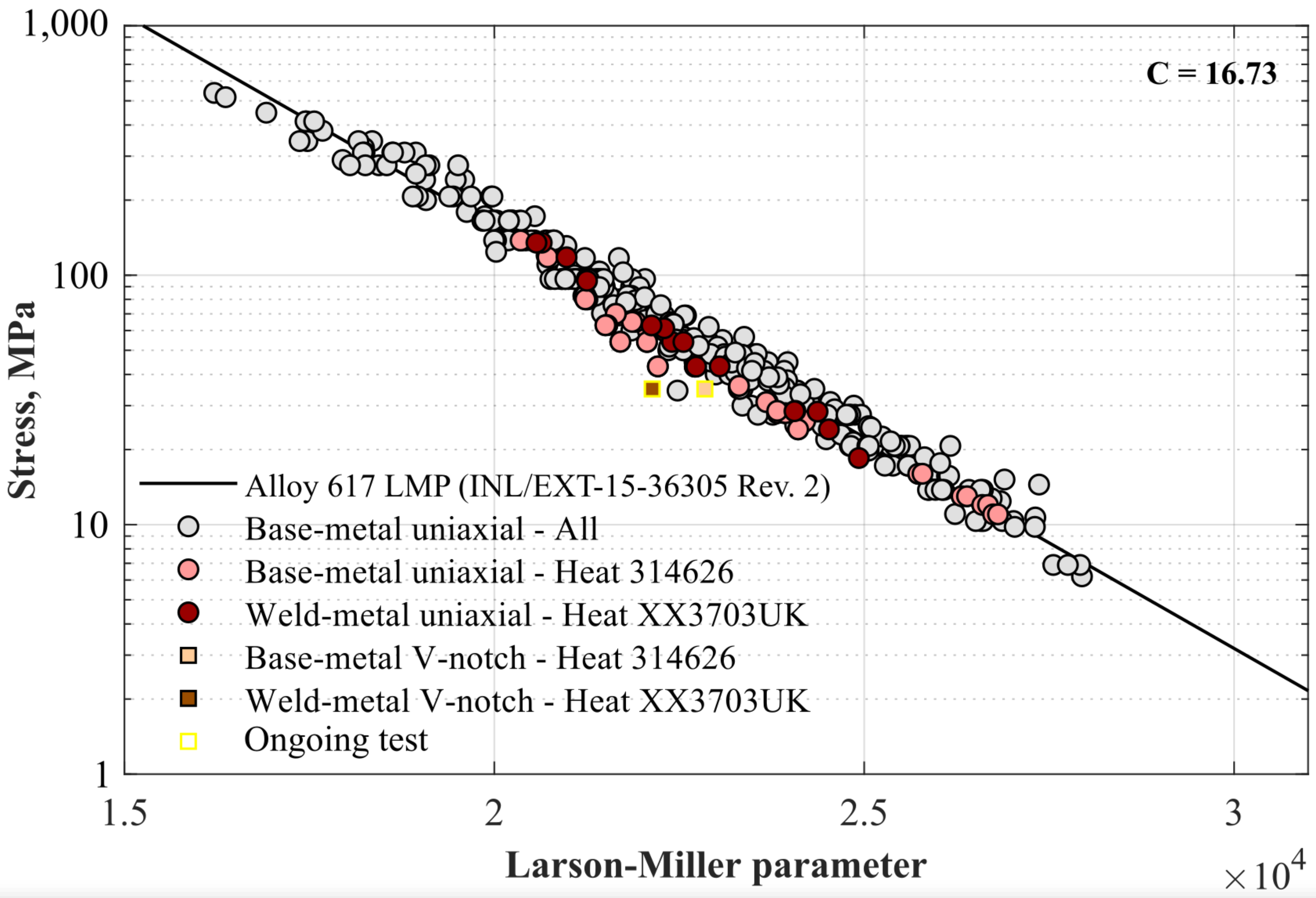
Long term

- A base- and a weld-metal V-notch creep-rupture test with an estimated 100,000-hour rupture life are in progress.

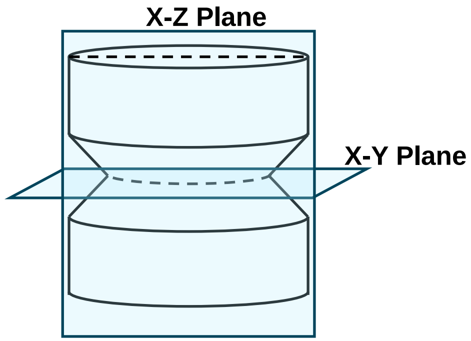


Double V-Notched creep rupture testing

- **Two double V-notch specimen tests have finished**
  - 800 °C, 80MPa, 10393 hour rupture life, notch strengthening factor of 8.9
  - 850 °C, 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
- **Two new tests have been started**
  - 800 °C, 65 MPa to check continued trend of decreasing notch strengthening factor with increased test time
  - 850 °C, 63 MPa with plan for interruptions to take X-ray Computed Tomography (CT) measurements to image the progression of cracking when failure occurs in the V-notch

Double V-notch tested until the rupture of one of the V-notches

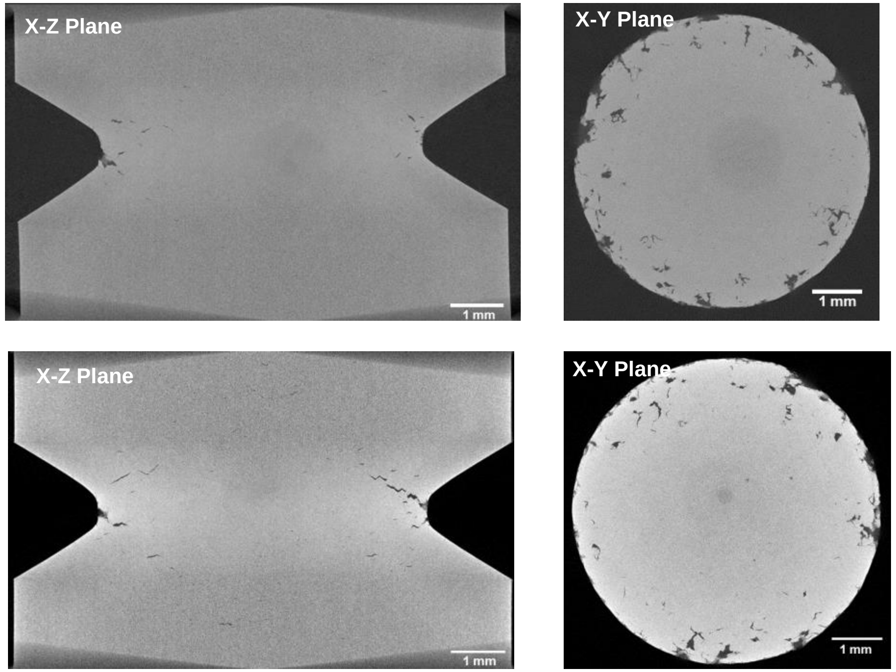
Notched creep rupture testing



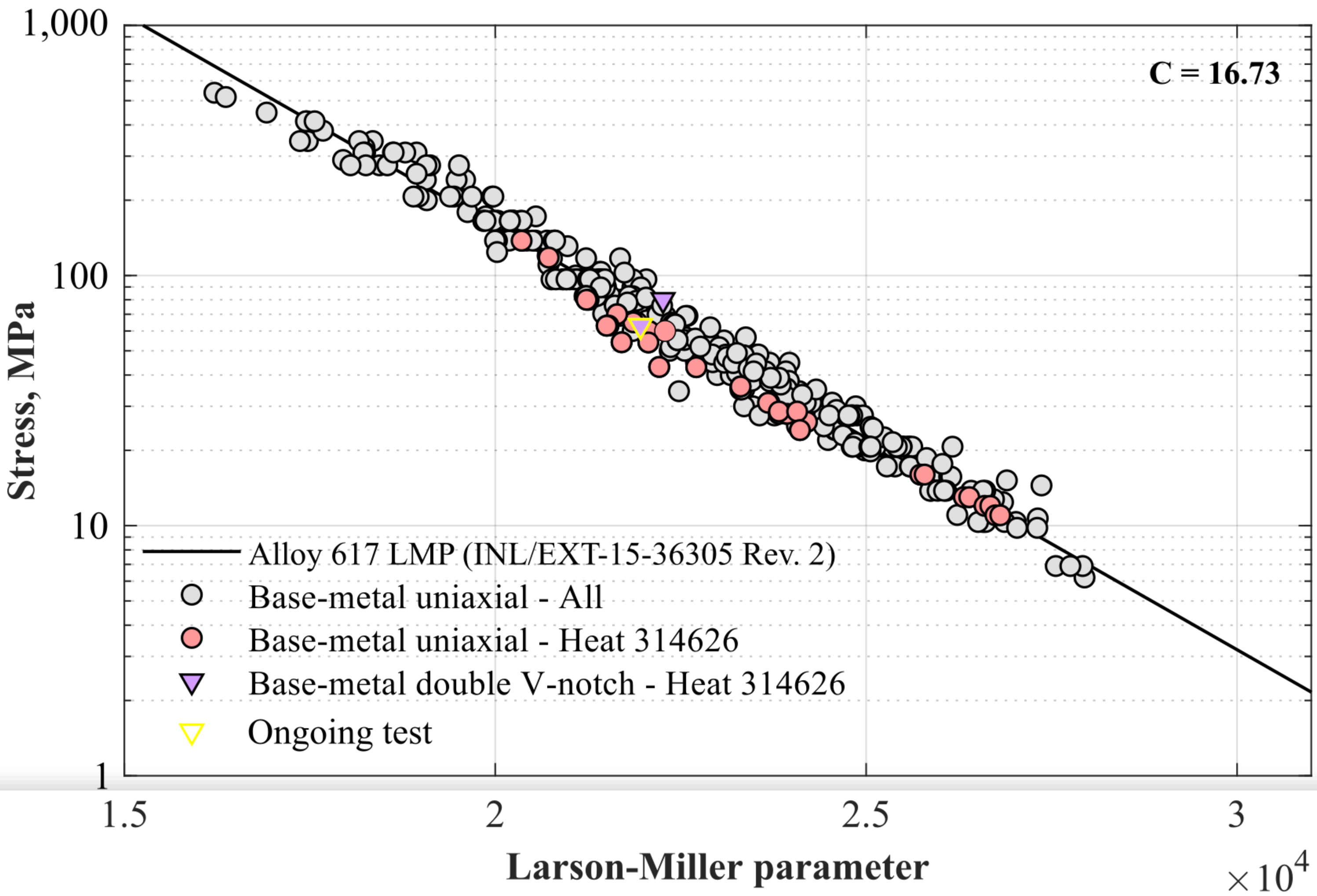
- X-ray CT characterization on non-ruptured notch of both completed double V-notch rupture tests has been performed
- Damage occurs primarily near the notch, but does not move directly across the diameter between notches

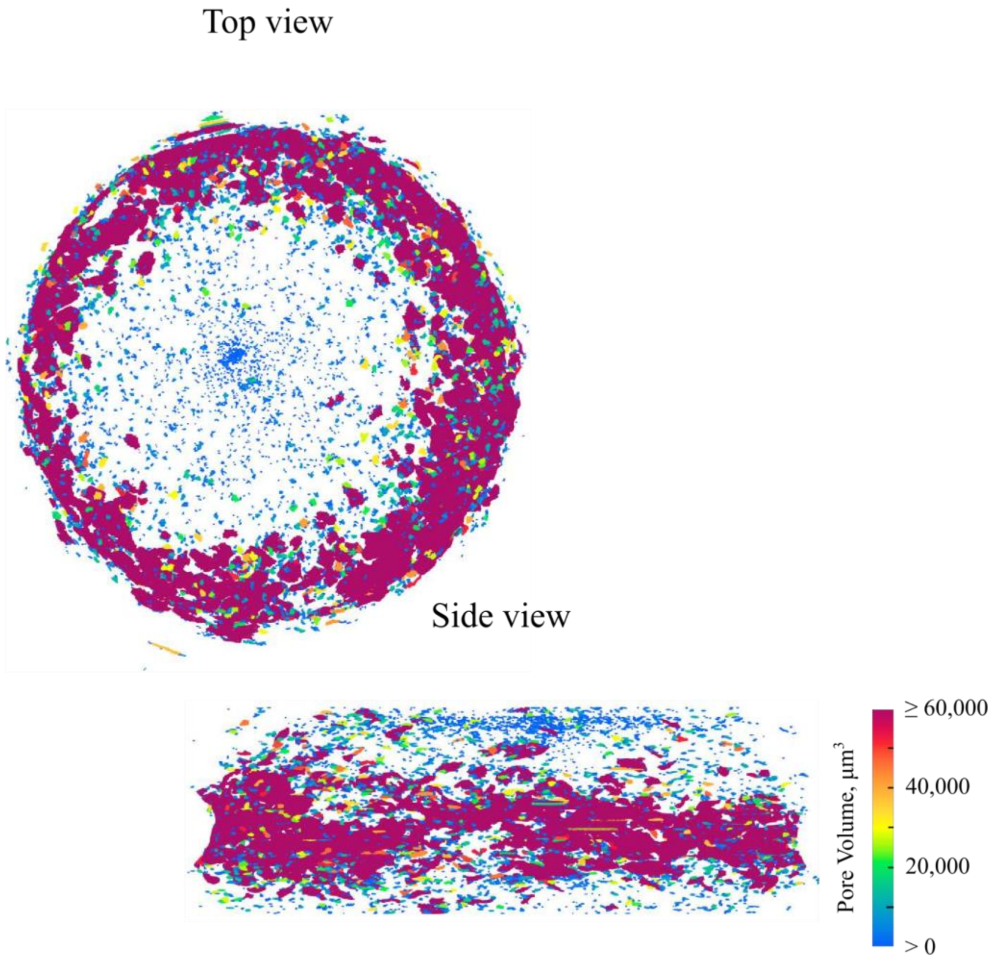
800°C 80 MPa
10,393 hr rupture life

850°C 63 MPa
4,997 hr rupture life



Double V-notch creep results





Creep, fatigue, and creep-fatigue crack growth rate (CGR) testing

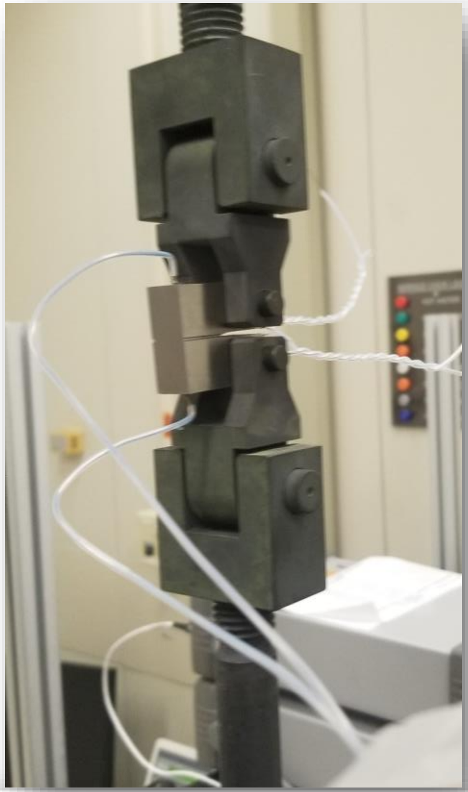
This work focuses on methodologies for high-temperature flaw evaluations to support American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (BPVC) Section XI, Division 2, Reliability and Integrity Management (RIM) Programs.

- **Impurities in cooling gas can cause oxidation, carburization, and/or decarburization in Alloy 617 which can affect crack-growth rates.**
- **High-temperature crack-growth tests in air and in reactor-grade helium would provide data for establishing the crack-growth correlations in support of the ASME BPVC Section XI high-temperature flaw evaluation Code Case.**
- **Alloy 617 crack-growth testing is in progress to develop crack-growth data and to gain an understanding of the environmental effects (particularly impurities in the environment) on the crack-growth behavior of Alloy 617.**
- **Alloy 617 is qualified for the construction of ASME BPVC Section III, Division 5 components for a maximum service life and temperature of 100,000 hours and 950°C, respectively.**

Setup (fatigue)

- **A test frame with attached direction current potential drop (DCPD) system provides real time crack-growth information which allows for constant stress intensity testing (K) to be performed.**
- **Crack growth can be measured by the DCPD because as a crack propagates, the electrical resistance in a specimen increases and the resulting potential drop can can be correlated to the crack length.**
- **Crack-propagation data can provide insights on fatigue, creep-fatigue, and creep behavior which are necessary in a component safety analysis.**

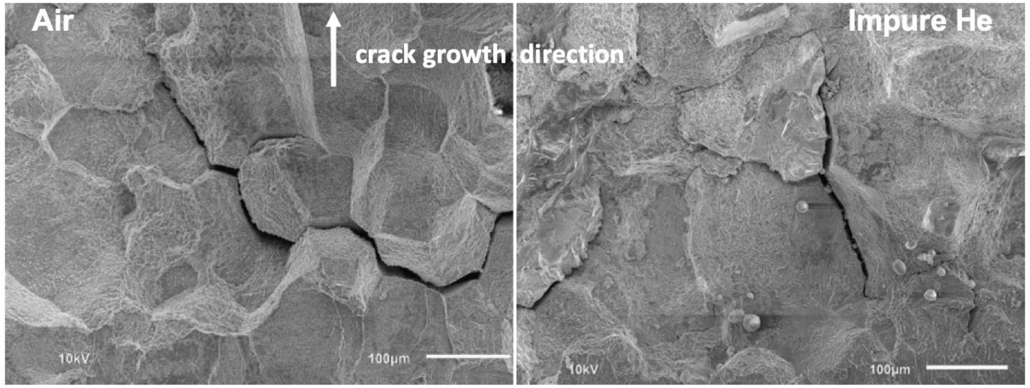
Loaded Specimen



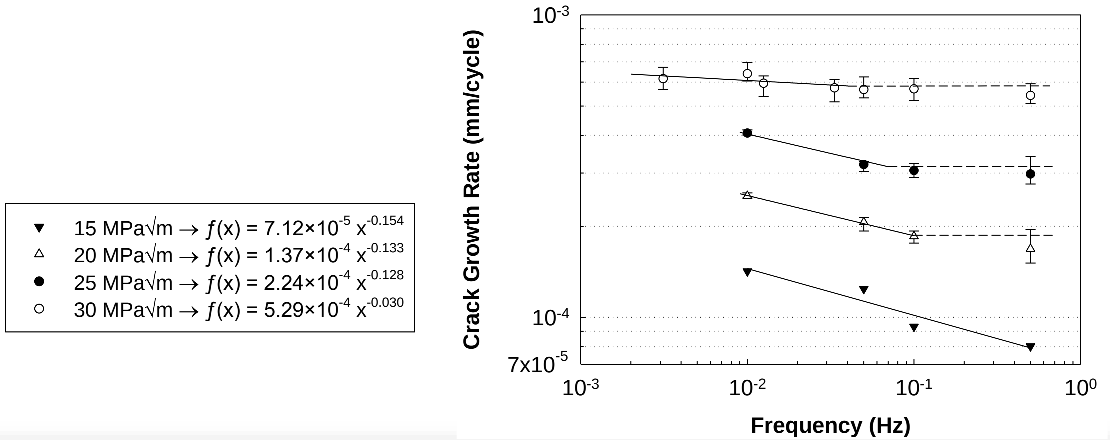
Previous Work

- **Previous Experimental Work:**
  - **At INL, the effects of environment on crack-growth rates in Alloy 617 were investigated up at 650 and 800 °C.**
  - **Constant stress intensity creep, creep-fatigue, and fatigue were run.**
    - **Variable load frequency fatigue tests**
    - **Variable hold times in creep-fatigue testing**
  - **Carburized, aged, and unprocessed specimens were tested**
- **Previous Results:**
  - **Intragranular cracking was observed for all testing excluding creep tests.**
  - **It was theorized that oxidation was causing time-dependent behavior in the crack-growth rates.**
  - **Aging did not have an appreciable effect on the crack growth rates while carburization showed increased crack growth.**

Creep Crack Propagation[1]



Time Dependent Crack Growth Rates[1]



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[1]Benz, Julian, et al. "Fatigue and Creep Crack Propagation behaviour of Alloy 617 in the Annealed and Aged Conditions ", Third International Workshop on Structural Materials for Innovative Nuclear Systems, Idaho National Laboratory, INL/CON-13-30214, October 2013.

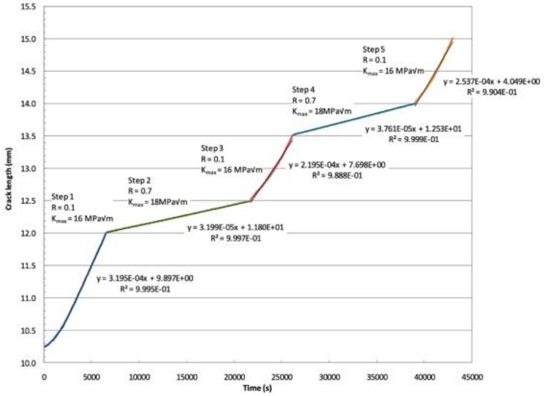
Validation work

- **Most of the 2022 fiscal year (FY-22) has been spent completing necessary preparatory work including:**
- **Acquiring Components:**
  - **Alloy 617 compact-tension (CT) specimens (0.5T) have been machined.**
  - **Laboratory equipment necessary to perform crack-growth testing in air using a DCPD to measure crack growth has been assembled.**
- **Crack Growth Validation Testing:**
  - **A test plan developed in a previous study at INL was implemented.**
  - **The results show good agreement with previous results for the same test plan.**
  - **A discrepancy of approximately 5 percent was observed between the computed crack length from the DCPD and the optical crack measurements.**

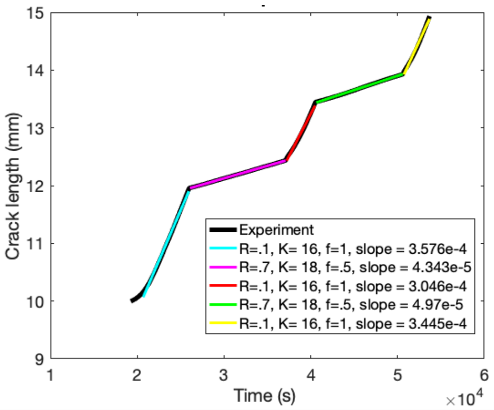
Alloy 617 CT Specimen

Validation Test Results

Previous Study[1]



This Work



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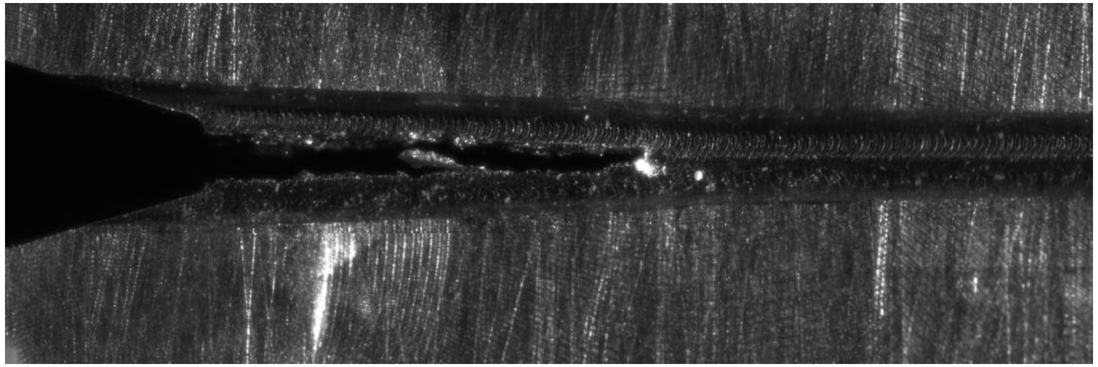
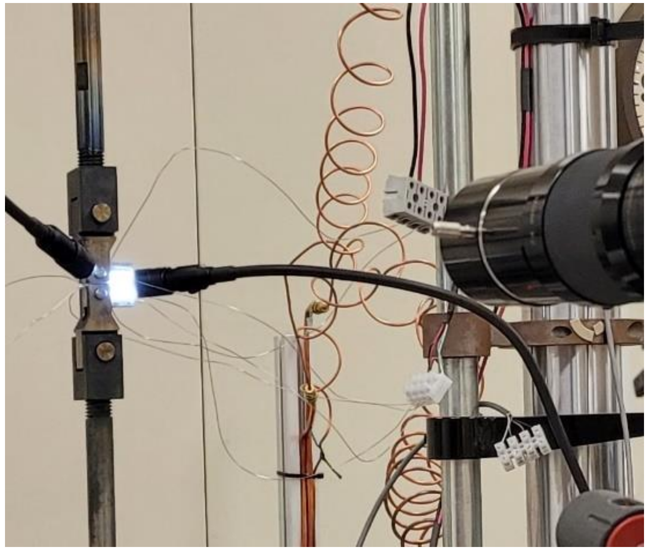
[1]Wright, Richard, et al. "Initial Results on Characterization of Elevated Temperature Crack Growth of Alloy 617", Engineering Calculation and Analysis Report, ECAR No.: ECAR-1539, Idaho National Laboratory, 5/25/2011.

Crack growth tests

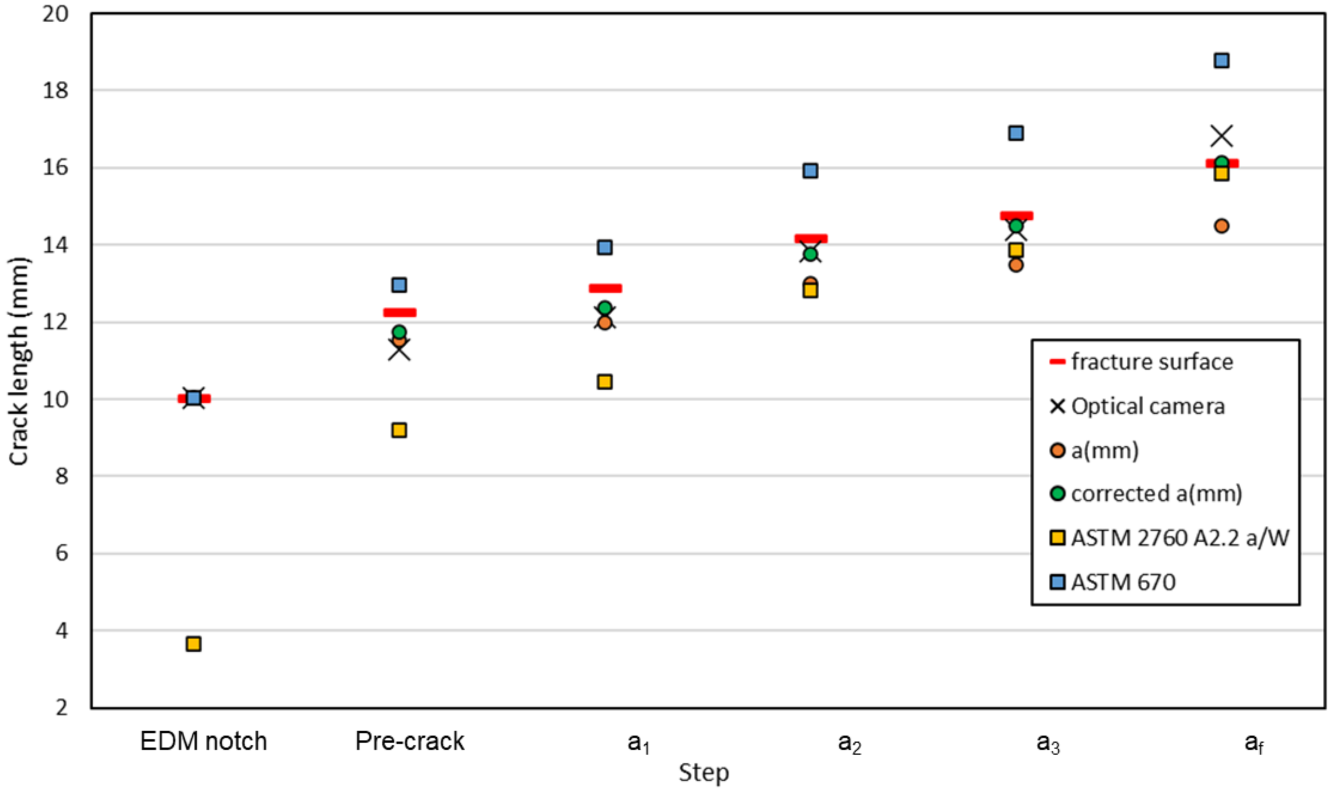
- Testing was performed to examine accuracy of direct current potential drop (DCPD) measurements
- The setup (left image) included an optical camera to image the crack during the test (top image), as well as the DCPD wire connections
- Test segments were run at changing K_{max} and R values to create distinguishable crack sections on fracture surface (right image)





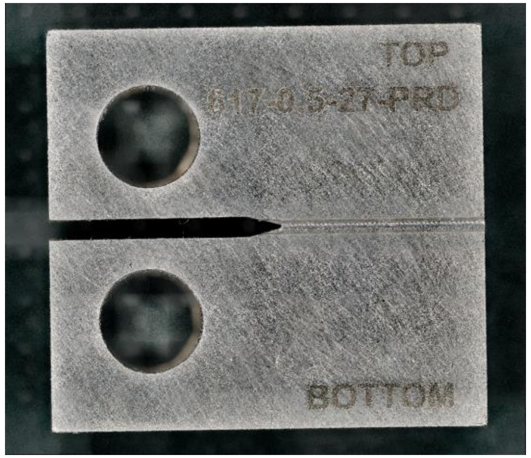
Crack growth tests

- **A total of six crack length measurements**
  - a – calculated directly from DCPD
  - corrected a – calibrated a, based on initial and final crack length measurements
  - Average measurements from the fracture surface micrographs
  - Measured from the optical camera
  - Calculated based on ASTM-2760 correlations
  - Calculated based on ASTM 670 correlations
- **Overall, measurements generally agree with optical camera and fracture surface measurements**



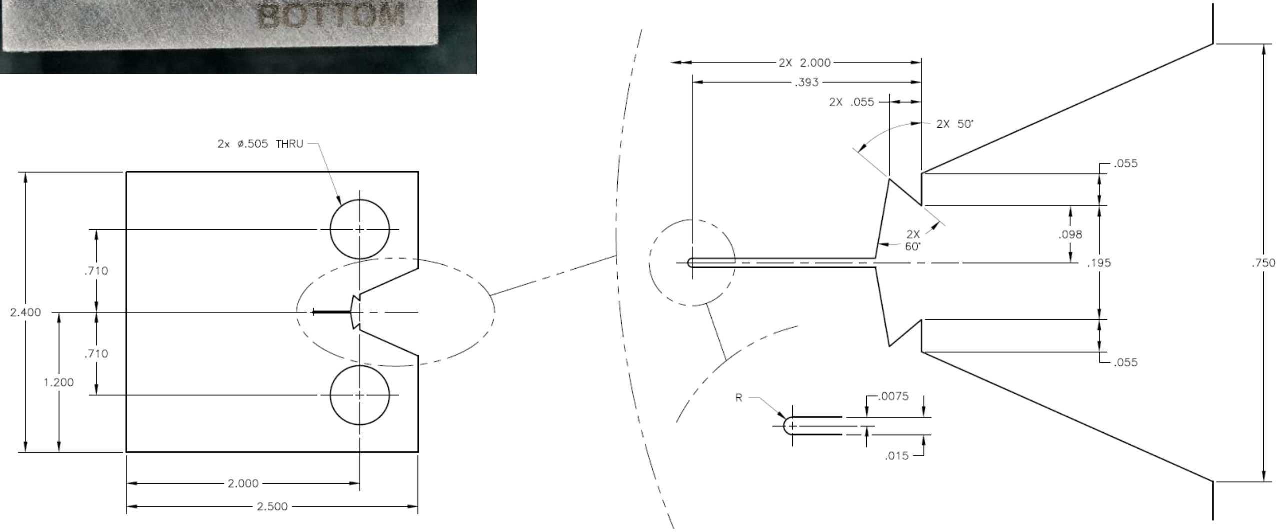
Creep-fatigue CGR testing

- Creep and creep-fatigue CGR testing do not follow linear-elastic fracture mechanics and require additional information
- New specimen design and extensometer required



Old CT specimen used for fatigue CGR

New design for creep and C-F



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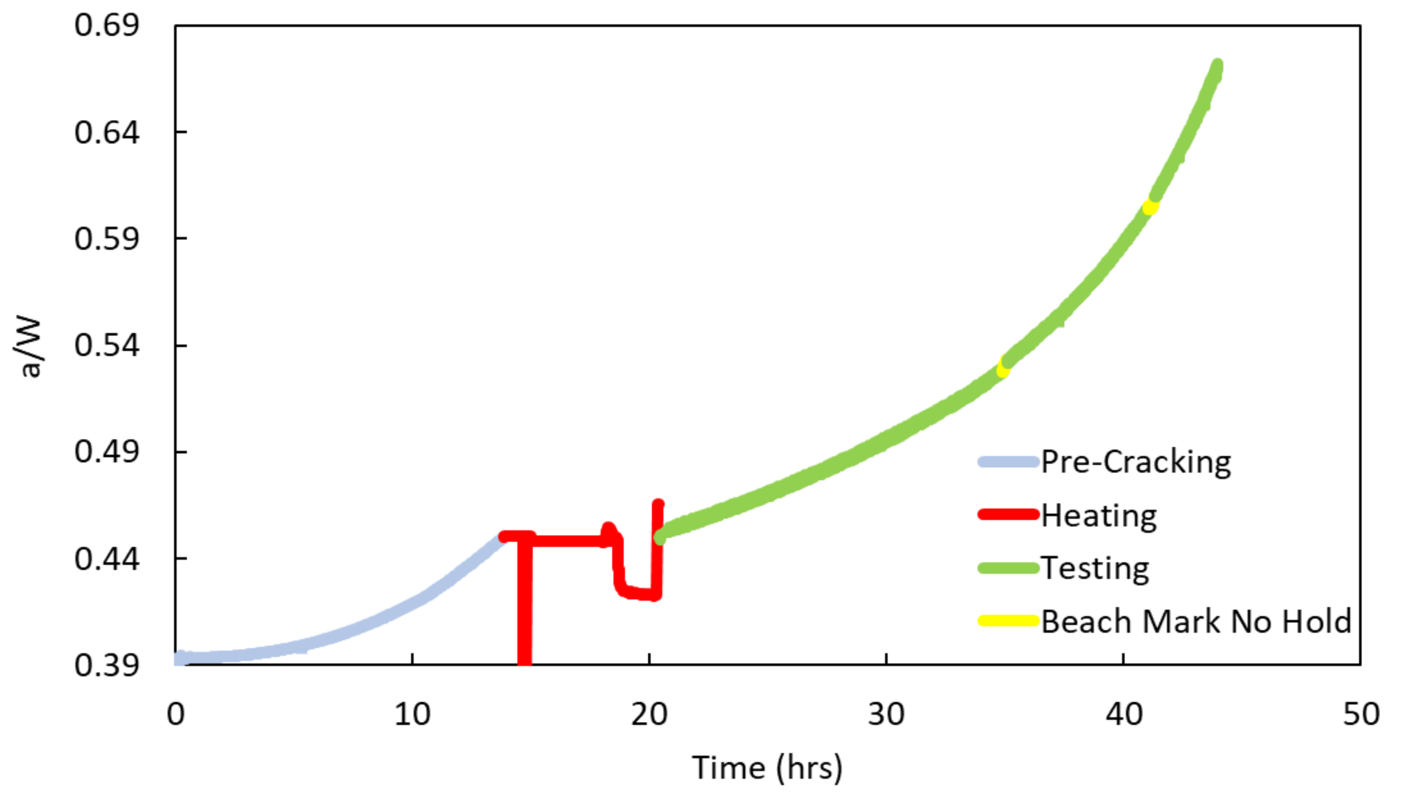
Creep-fatigue CGR results

- **Single test performed, using load line displacement, as measured by the actuator displacement**



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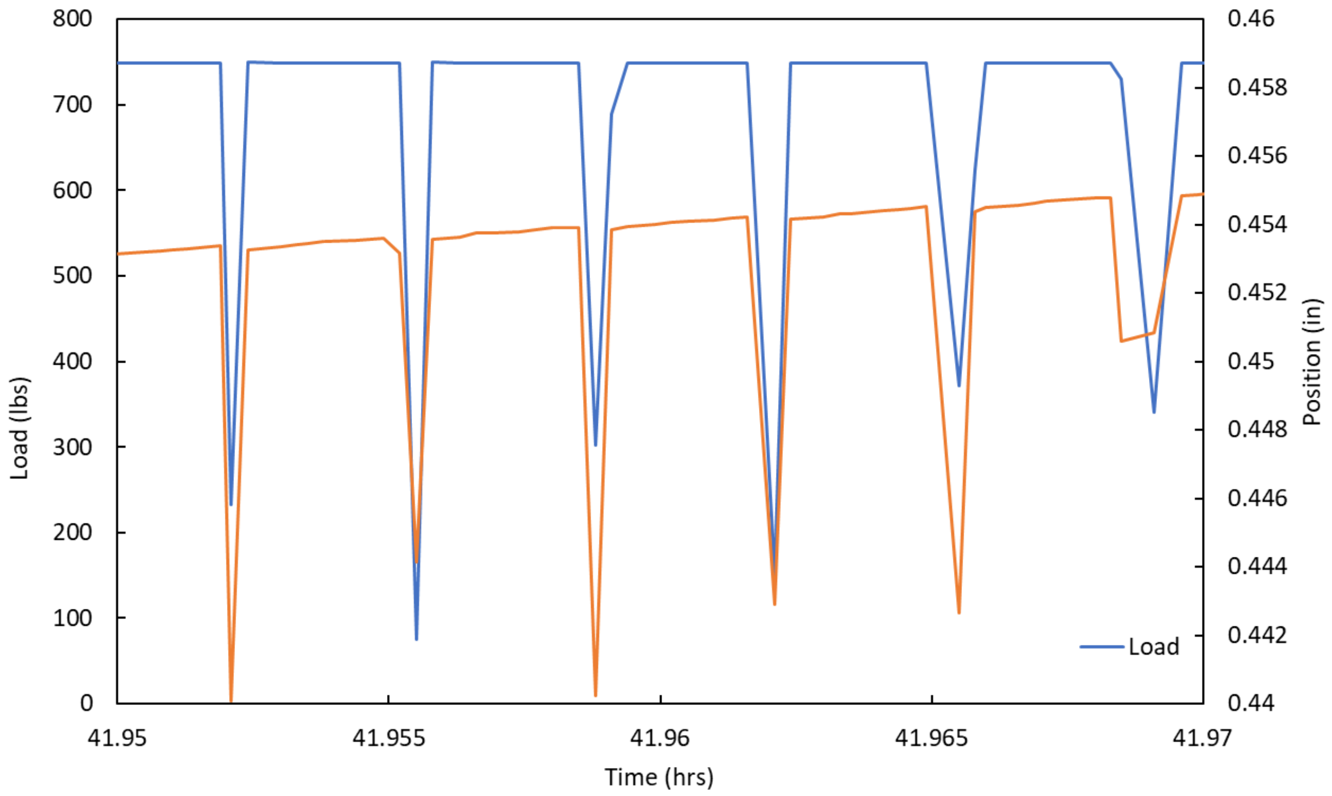
Creep fatigue results

- **Load line displacement by actuator movement is not ideal**
  - Extensometer is now at INL, allowing for more accurate readings
- **Software used for DCPD was primarily made with stress corrosion cracking in mind, and not for cyclic testing**



Next Steps

- **Finish double V-notch analysis and longer tests**
  - Determine if trend for diminishing notch strengthening continues
  - Examine damage structure of V-notch failure mode prior to failure
- **Continue long-term testing of V-notch base and weld metals**
- **Creep-fatigue test will be performed using extensometer measurements for load line displacement and validated**
- **Creep-fatigue and creep CGR testing in air**
- **Creep-fatigue and creep CGR testing in impure helium**

Thank you

Email Address

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