INL/MIS-22-67533-Revision-0

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

June 2022

Changing the World's Energy Future

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Idaho National Laboratory

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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

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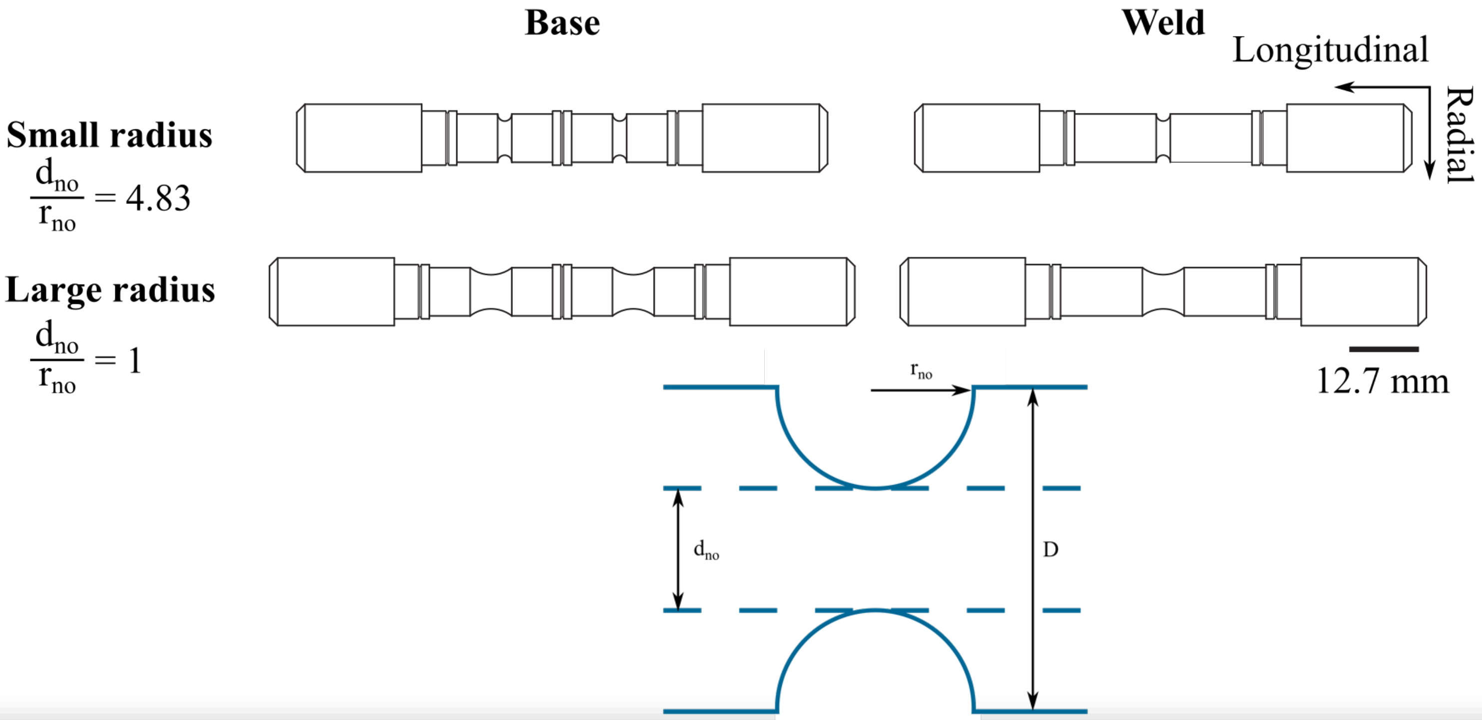
Creep Rupture of Notches

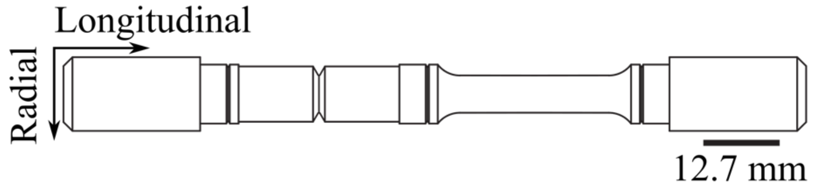
An NRC-sponsored assessment of a previous version of Section III, Division 5 of the ASME BPVC identified an inadequate understanding of the impact of a multiaxial stress, structural discontinuities, and notch effects.

U-notch

(Bridgeman notch)



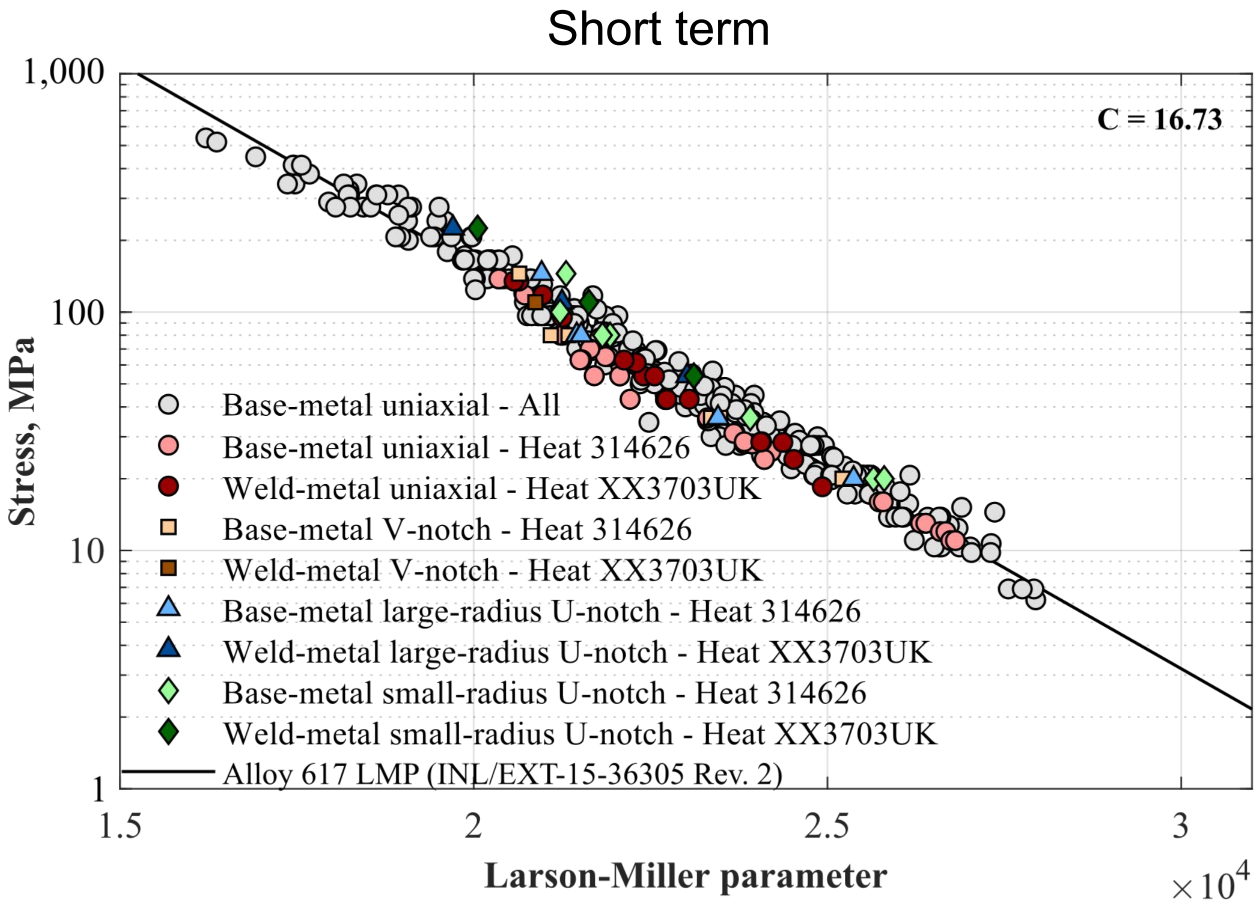
V-notch

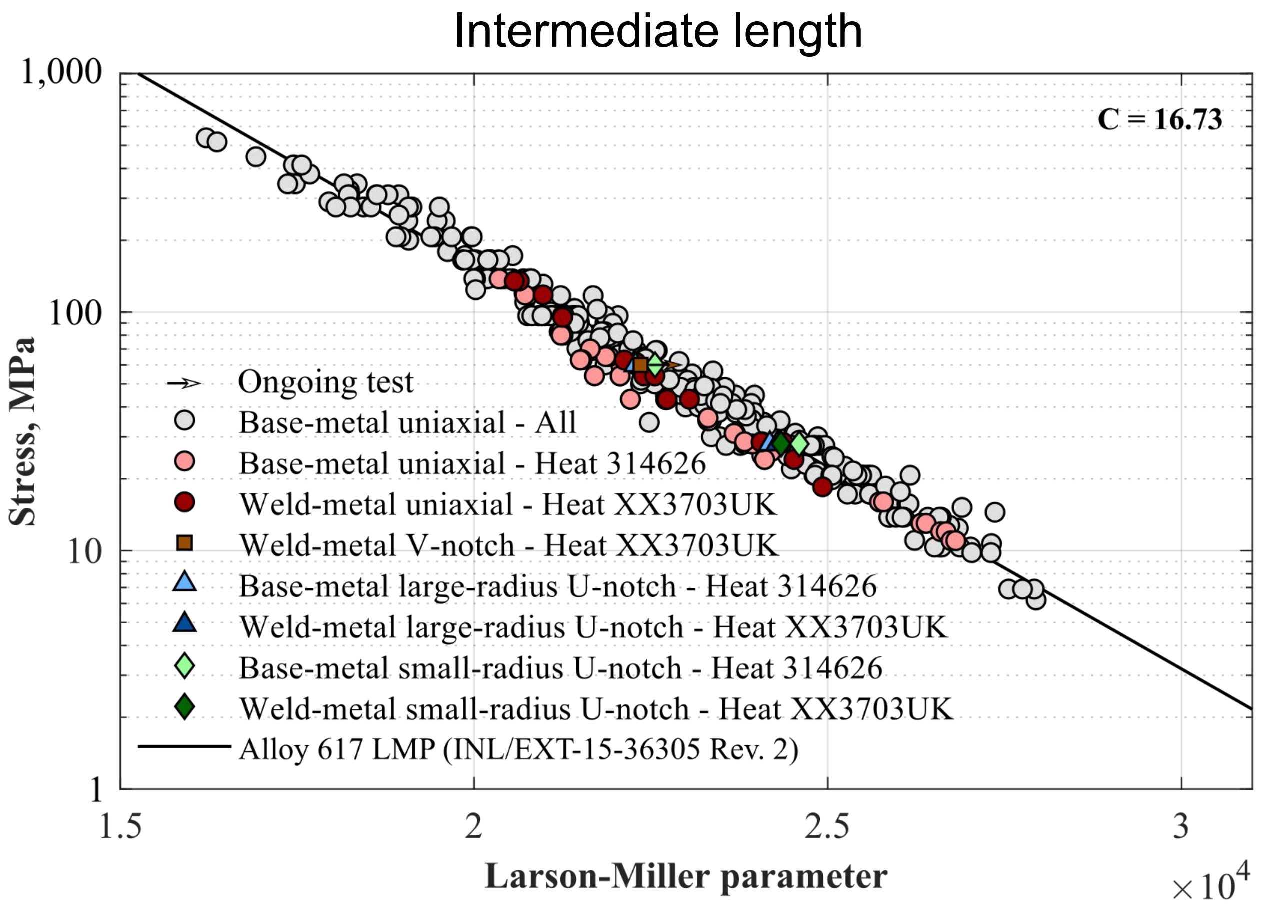


Figures from: Rupp, R.E., & McMurtrey, M.D. (2020). The Impact of Geometric Discontinuities on Alloy 617 Creep-Rupture Behavior (PVP2020-21587). In *Proceedings of the ASME 2020 Pressure Vessels & Piping Conference.* The American Society of Mechanical Engineers.

Creep Rupture Properties

- Alloy 617 base- and weld-metal short-term (aim 1,000 to 2,000-hour rupture life) and intermediate-length (aim 8,000 to 12,000-hour rupture life) creep-rupture properties were not degraded by geometric discontinuities nor multiaxial-stress states.
- A base- and a weld-metal V-notch creep-rupture test with an estimated 100,000-hour rupture life is in progress.





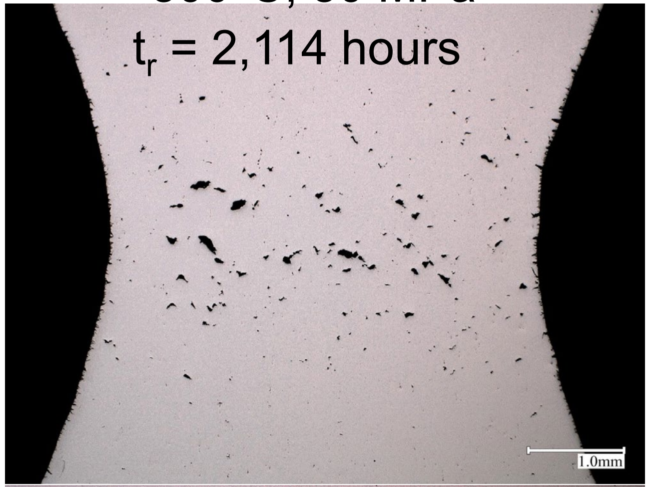
Creep Damage Distribution

A stronger multiaxial stress increased the rupture life. The distribution of creep damage in the unruptured U-notch base-metal specimens after short-term and intermediate-length creep-rupture testing is similar.

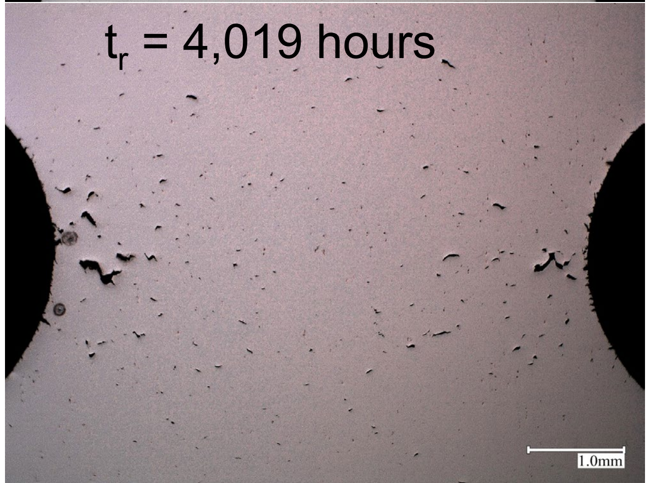
Short term
800°C, 80 MPa

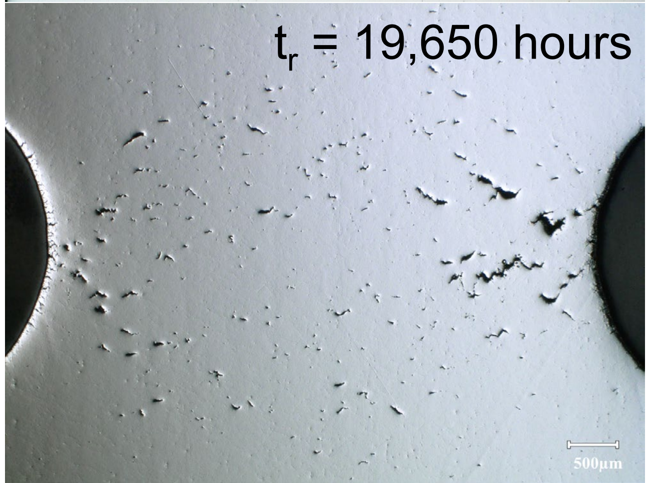
Intermediate length
800°C, 60 MPa

Large-radius U-notch



Small-radius U-notch

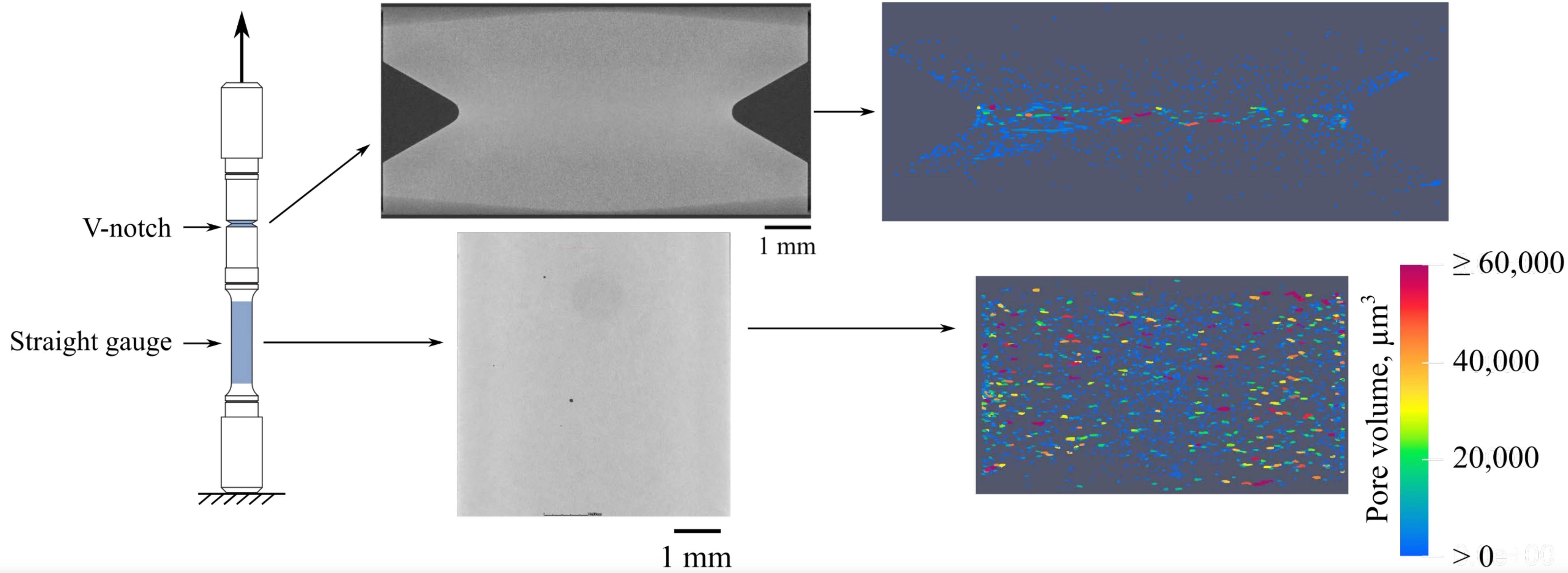




1.0 mm

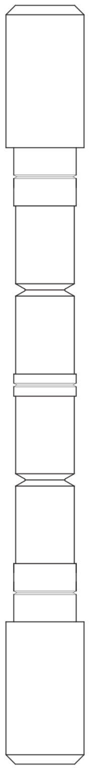
X-Ray CT Characterization

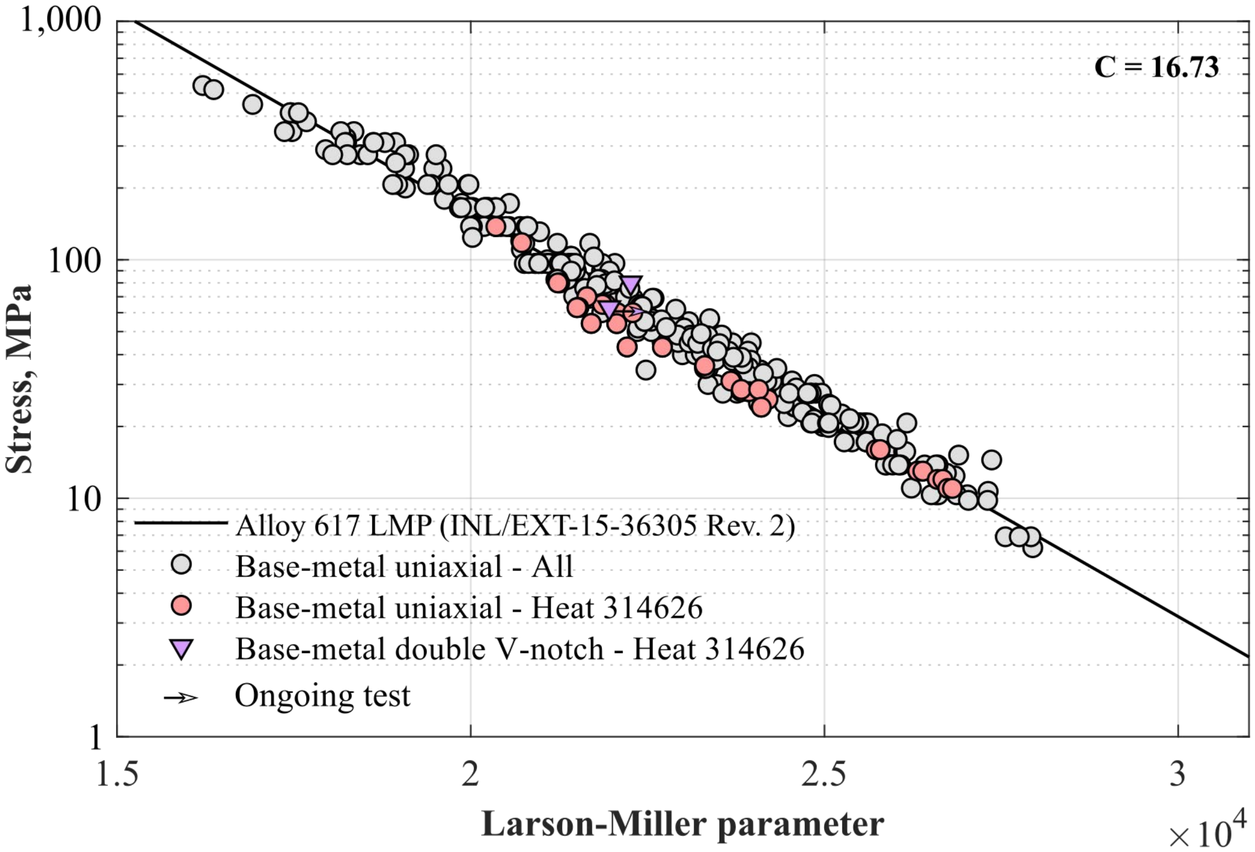
A technique utilizing X-ray computed tomography (CT) was developed with the goal of being able to identify the failure location prior to rupture.

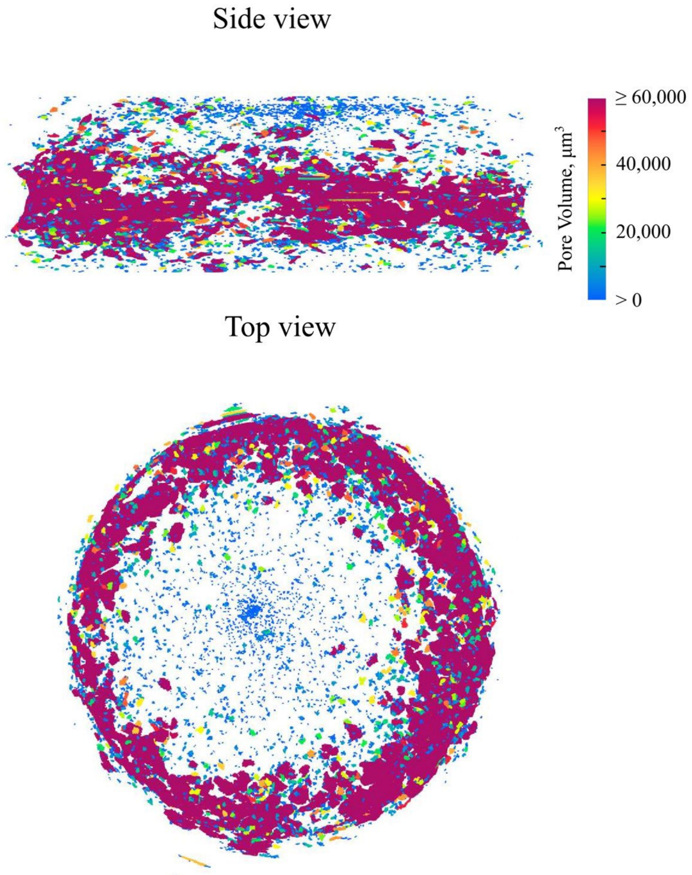


V-Notch Characterization

- All completed V-notch creep-rupture tests have failed in the straight gauge with little to no creep damage observed in the V-notch.
- Work is in progress to characterize the distribution of creep damage in the V-notch and to correlate it with the percent of rupture life. Most of the creep damage in the non-ruptured V-notch for a base-metal double V-notch specimen tested at 800°C and 80 MPa to rupture was primarily limited to the surface of the specimen at the minimum diameter.







Improvement of Alloy 800H Weldment

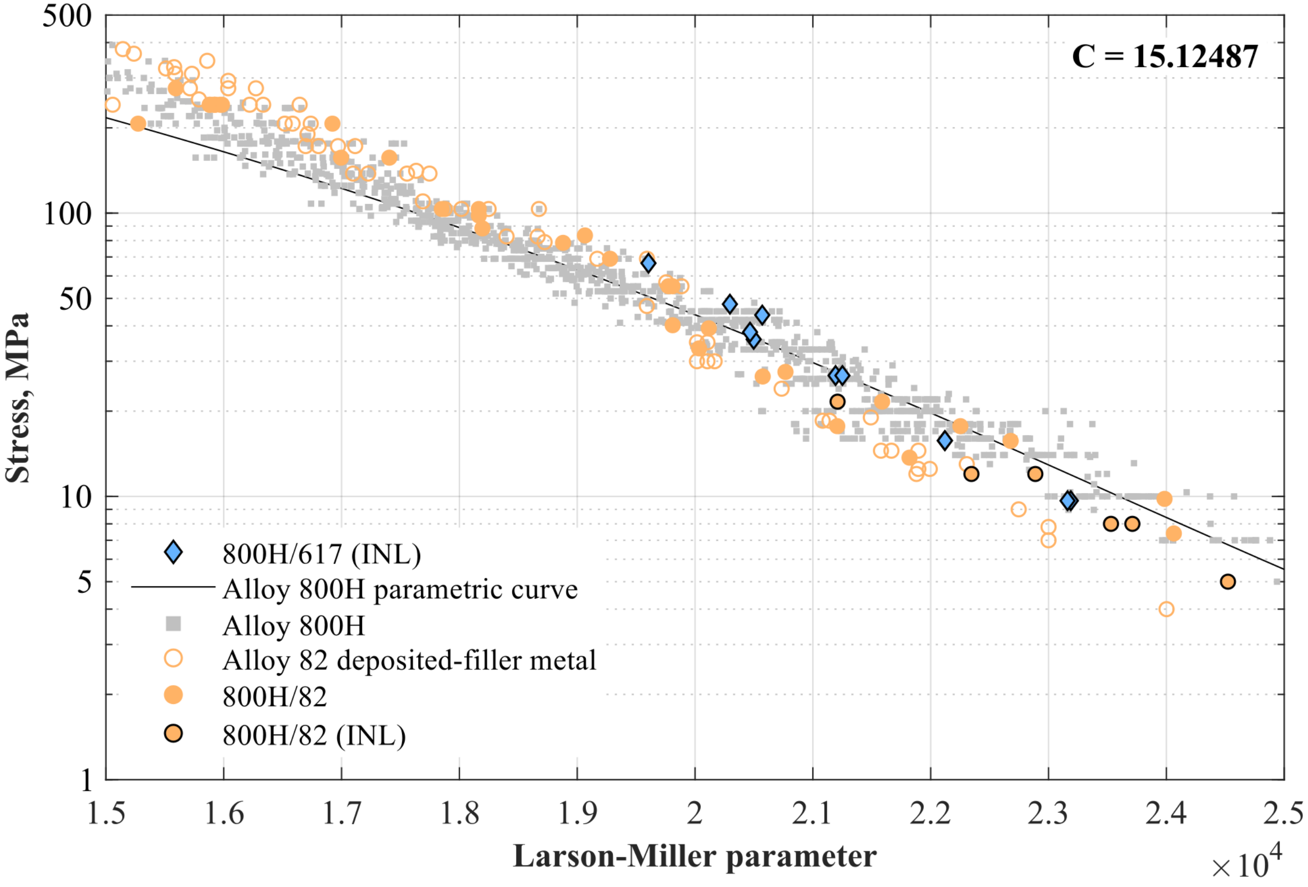
The expected minimum stress-to-rupture of the weld is a function of the stress rupture factor (R) and the expected minimum stress-to-rupture (S_r) of the base metal.

where,

$$R = \frac{\text{average rupture strength of the filler metal}}{\text{average rupture strength of the base metal}}$$

An alterative filler metal is desired to improve the creep-rupture strengths of Alloy 800H weldments for the qualified temperatures and services lives.

Alloy 617 Filler Metal



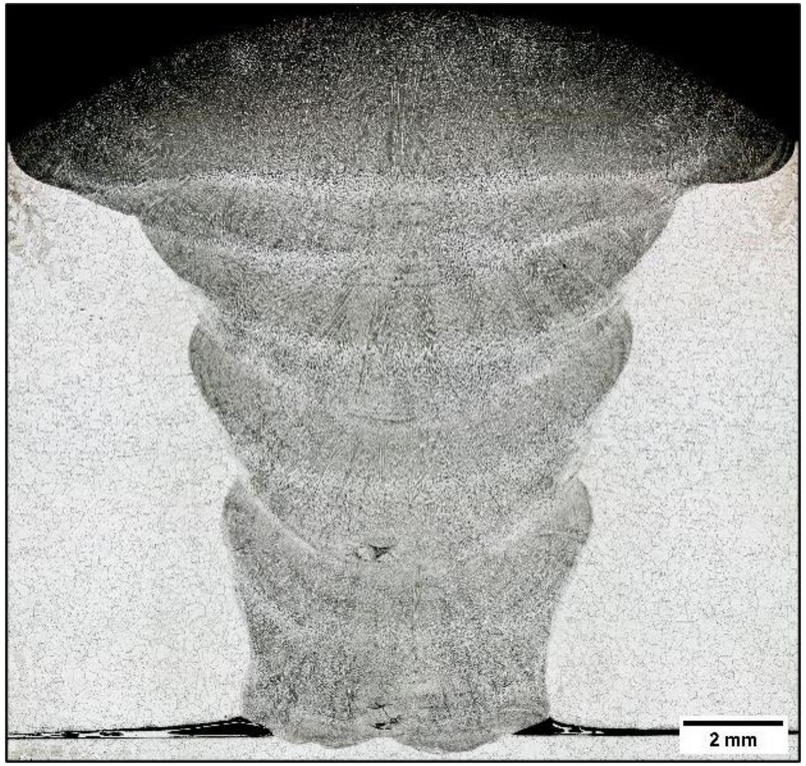
Swindeman, Robert, Swindeman, Michael, Roberts, Blaine, Thurgood, Brian, and Marriott, Douglas. “Verification of Allowable Stresses in ASME Section III Subsection NH for Alloy 800H.” Technical Report No. STP-NU-020. ASME Standards Technology, LLC., New York, NY (2008).

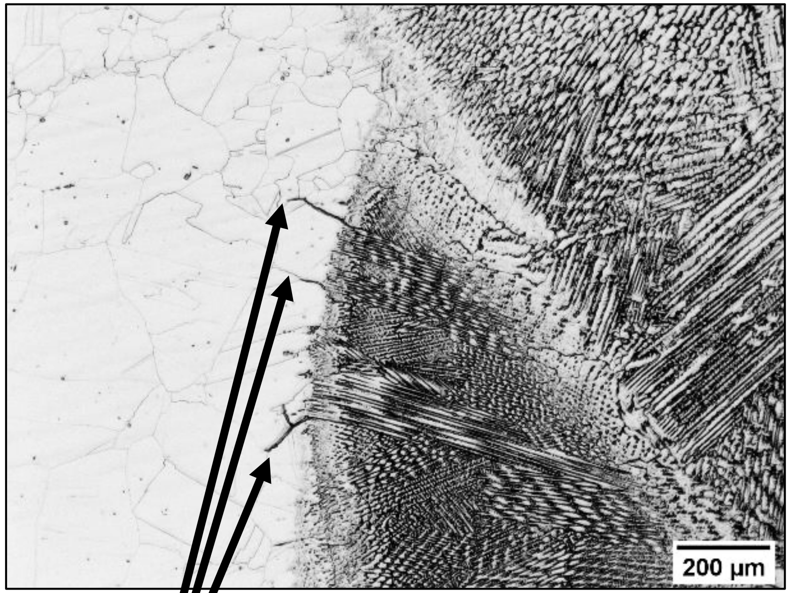
UTP A 2133 Mn Filler Metal

1.15 kJ/mm (29.3 kJ/in) heat input

lack of fusion defect

1.31 kJ/mm (33.2 kJ/in) heat input





liquation

High Temperature Crack Growth of Alloy 617

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.

Background and Previous Work

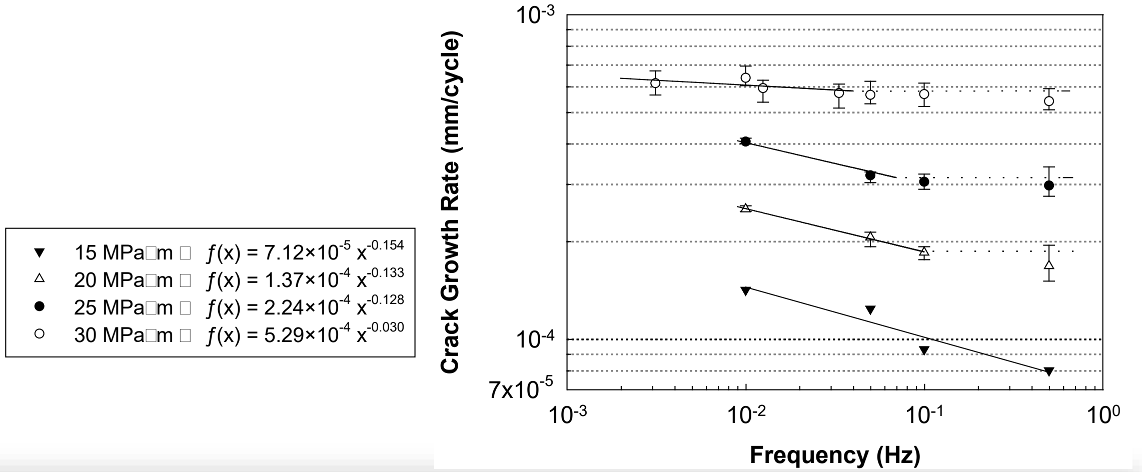
Experimental Testing:

- 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_{IC}) to be performed.
- Crack-propagation data can provide insights on fatigue, creep-fatigue, and creep behavior which are necessary in a component safety analysis.

Previous Experimental Work:

- At INL, the effects of environment on crack-growth rates in Alloy 617 were investigated up to 800°C. Alloy 617, however, 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.
- It was theorized that oxidation was causing time-dependent behavior in the crack-growth rates.

Loaded Specimen



Current Status

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.

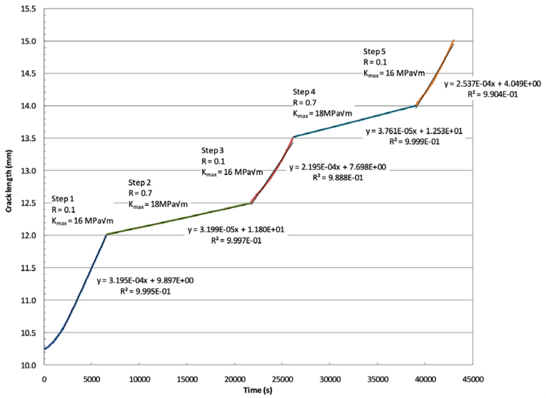
Crack Growth Validation Testing:

- 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.

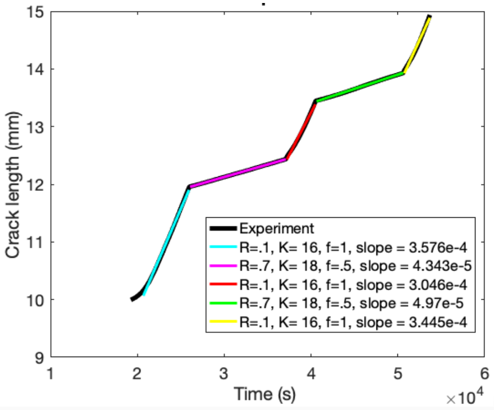
Alloy 617 CT Specimen

Validation Test Results

Previous Study[1]



This Work



[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.

Future Work

Planned Testing

- A DCPD system will monitor crack growth due to fatigue loading with constant stress intensity at temperatures up to 1000°C in air and impure-helium environments.
  - A second test frame will be used to conduced environment controlled (impure helium) testing.
  - Environmental control equipment including a gas chromatograph currently resides in the laboratory, but work is needed to complete and confirm functionality of the environmental control system.
- Variation in temperature as well as loading frequency will help answer questions associated with the effect of environment on crack-growth rates.

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