INL/CON-22-67399-Revision-0

GCR: Alloy 617 Notch Effect Testing Status

June 2022

Ryann Elizabeth Bass

Changing the World's Energy Future

INL is a U.S. Department of Energy National Laboratory operated by Battelle Energy Alliance, LLC

INL/CON-22-67399-Revision-0

GCR: Alloy 617 Notch Effect Testing Status

Ryann Elizabeth Bass

June 2022

Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

Prepared for the
U.S. Department of Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517

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

GCR: Alloy 617 Notch Effect Testing Status

Advanced Reactor Technologies Program

Advanced Materials R&D Program Review

June 7 and 8, 2022

Ryann Bass

Idaho National Laboratory (INL)

Contributors

- Ryann Bass, Mike McMurtrey, Joseph Bass, and Sam Sham (INL)
- Richard Wright (Structural Alloys, LLC, formerly INL)
- Mark Messner (Argonne National Laboratory)

Fiscal Year 2022 (FY-22) Work Packages

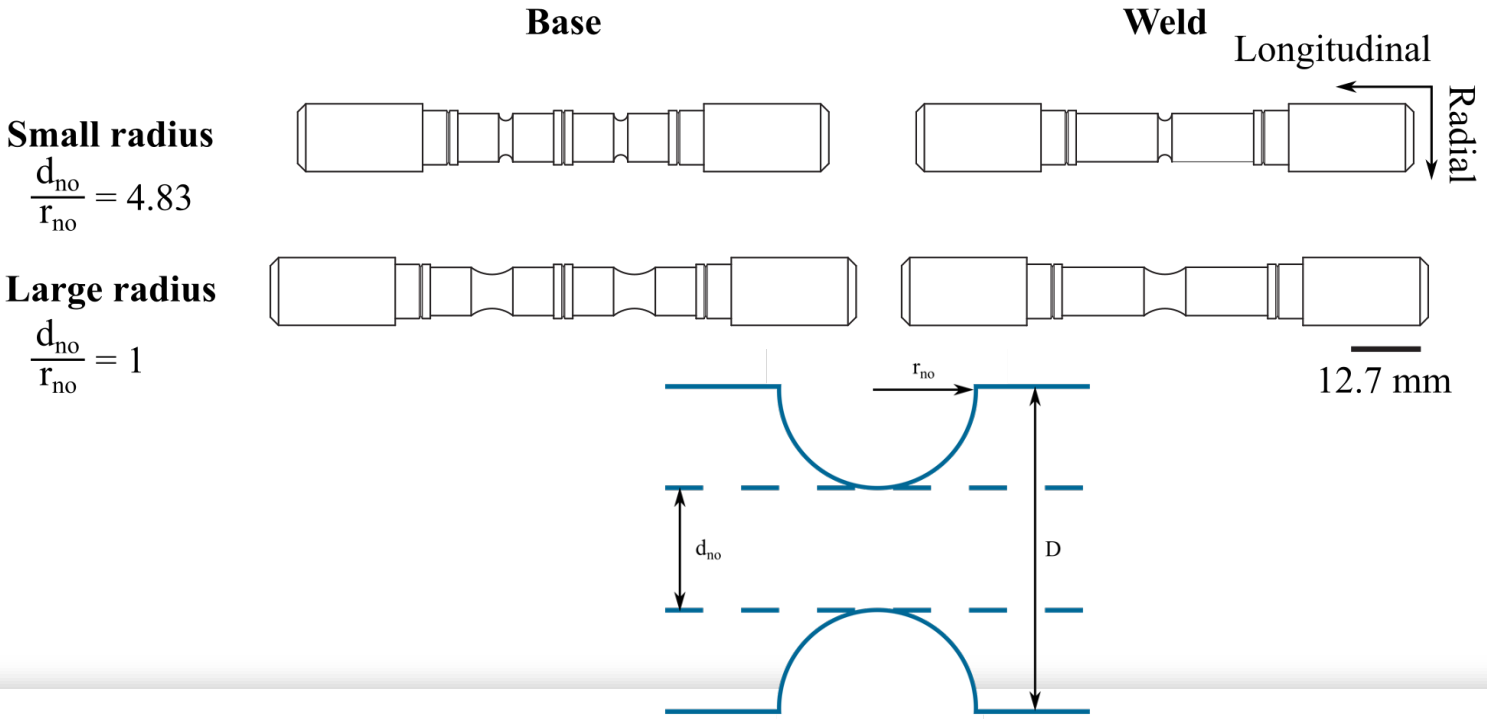
- AT-22IN060405, Long-Term VHTR Material Qualification - INL

Introduction

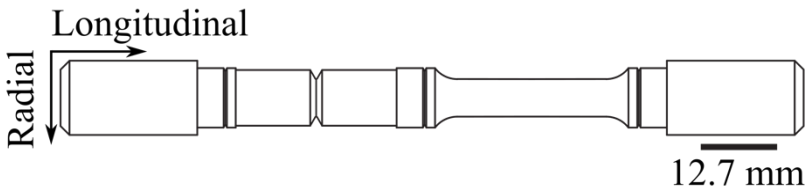
A Nuclear Regulatory Commission (NRC)-sponsored assessment of a previous version of Section III, Division 5 of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (BPVC) identified an inadequate understanding of the impact of a multiaxial stress, structural discontinuities,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

U-notch

(Bridgman notch)



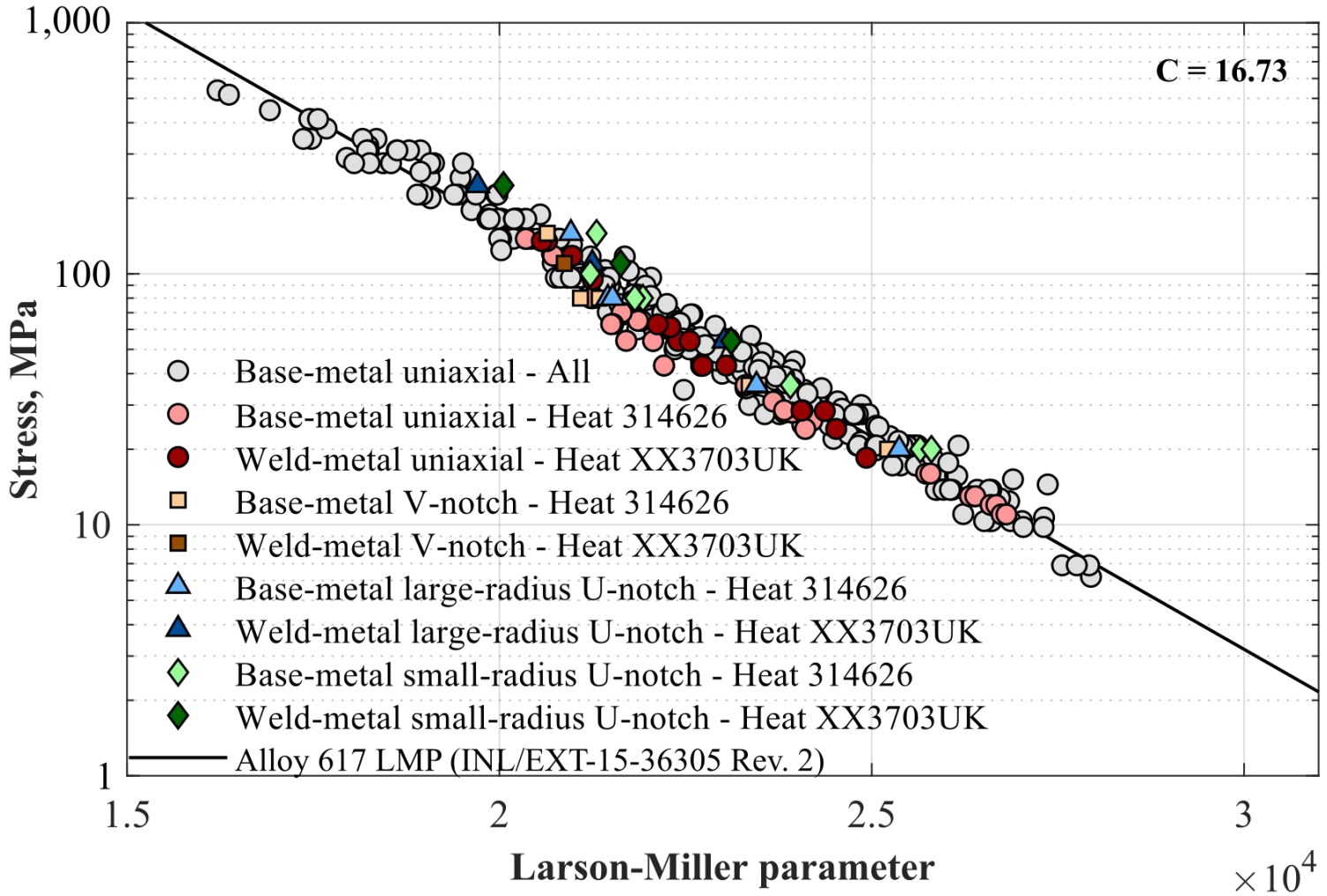
V-notch



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.

Short 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.



Short term

Alloy 617 was found to be notch strengthening.

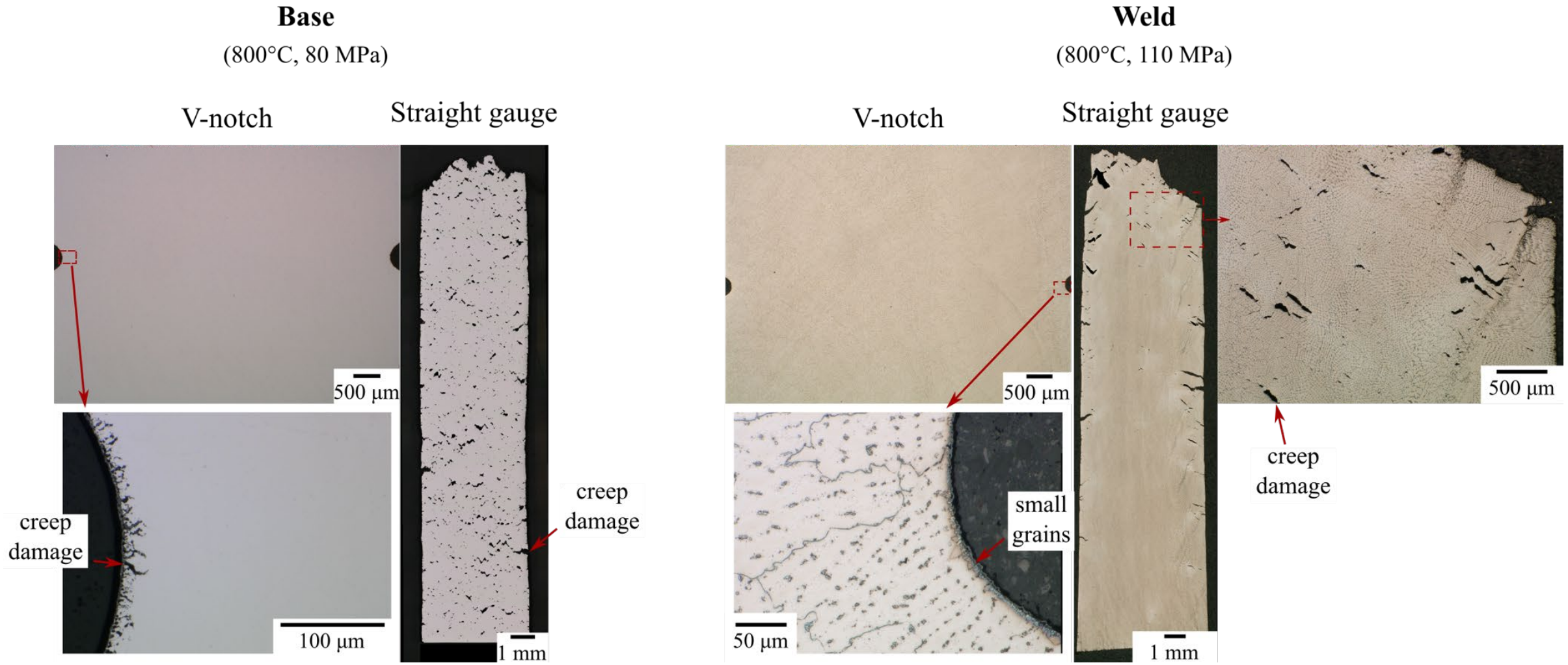
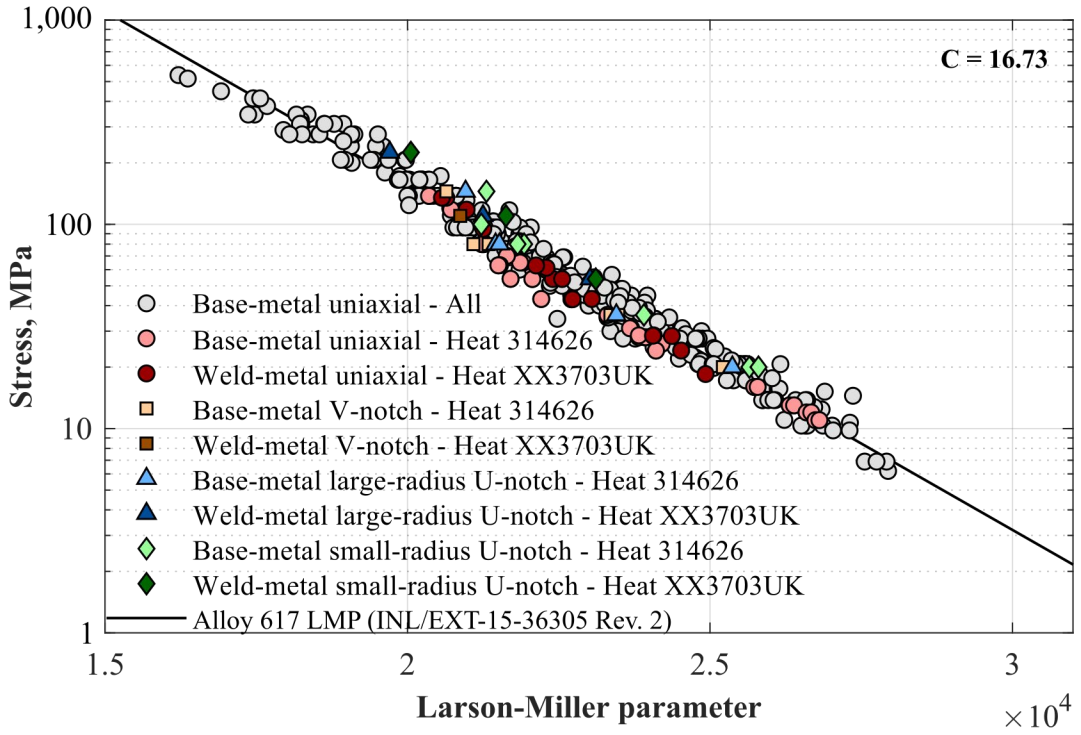


Figure modified from: Rupp, R.E., & McMurtrey, M.D. (2020). The Impact of Geometric Discontinuities on Alloy 617 Creep-Rupture Behavior (PVP2020-21587). In *Proceedings of the ASME 2020 Pressure Vessels & Piping Conference.* The American Society of Mechanical Engineers.

Short term

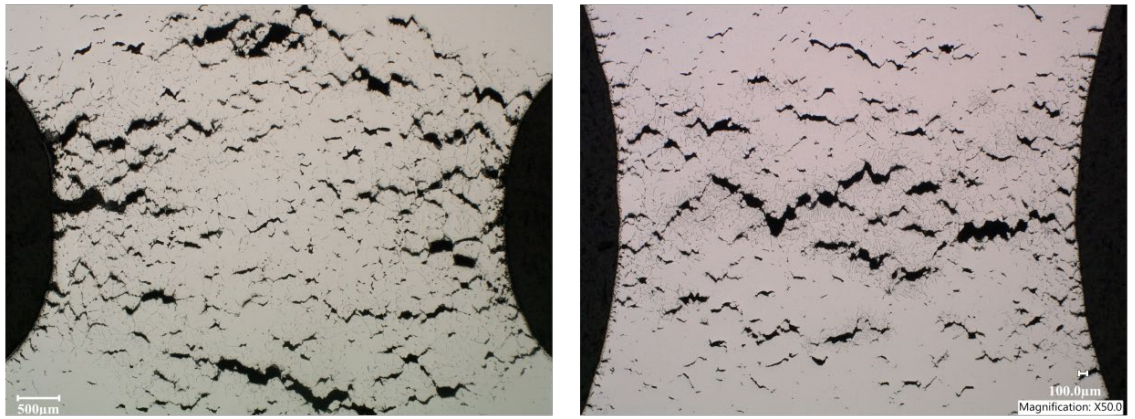
A stronger multiaxial stress increased the rupture life. This may be a consequence of the notch strengthening nature of the material.



1,000°C, 20 MPa

Small radius

Large radius



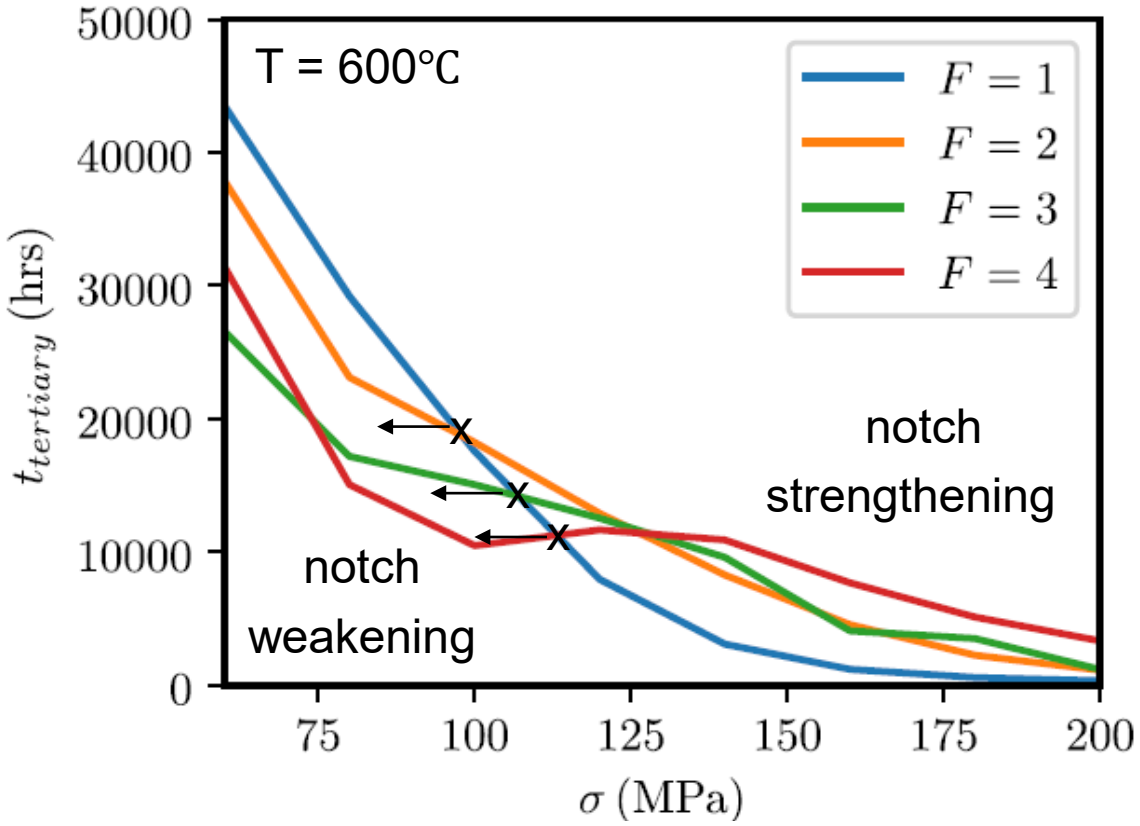
1 mm

Right figure 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.

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

Intermediate length and long term

- Notch rupture behavior is sensitive to a variety of elements including temperature and stress. Consequently, there is a concern of notch weakening at temperature and stress combinations that result in a long rupture life.
- Intermediate-length (aim 8,000 to 12,000-hour rupture life) and long-term (aim 100,000-hour rupture life) creep-rupture testing of the base- and weld-metal are in progress.



$$F = 3\frac{\sigma_m}{\sigma_e}$$

F = triaxiality ratio

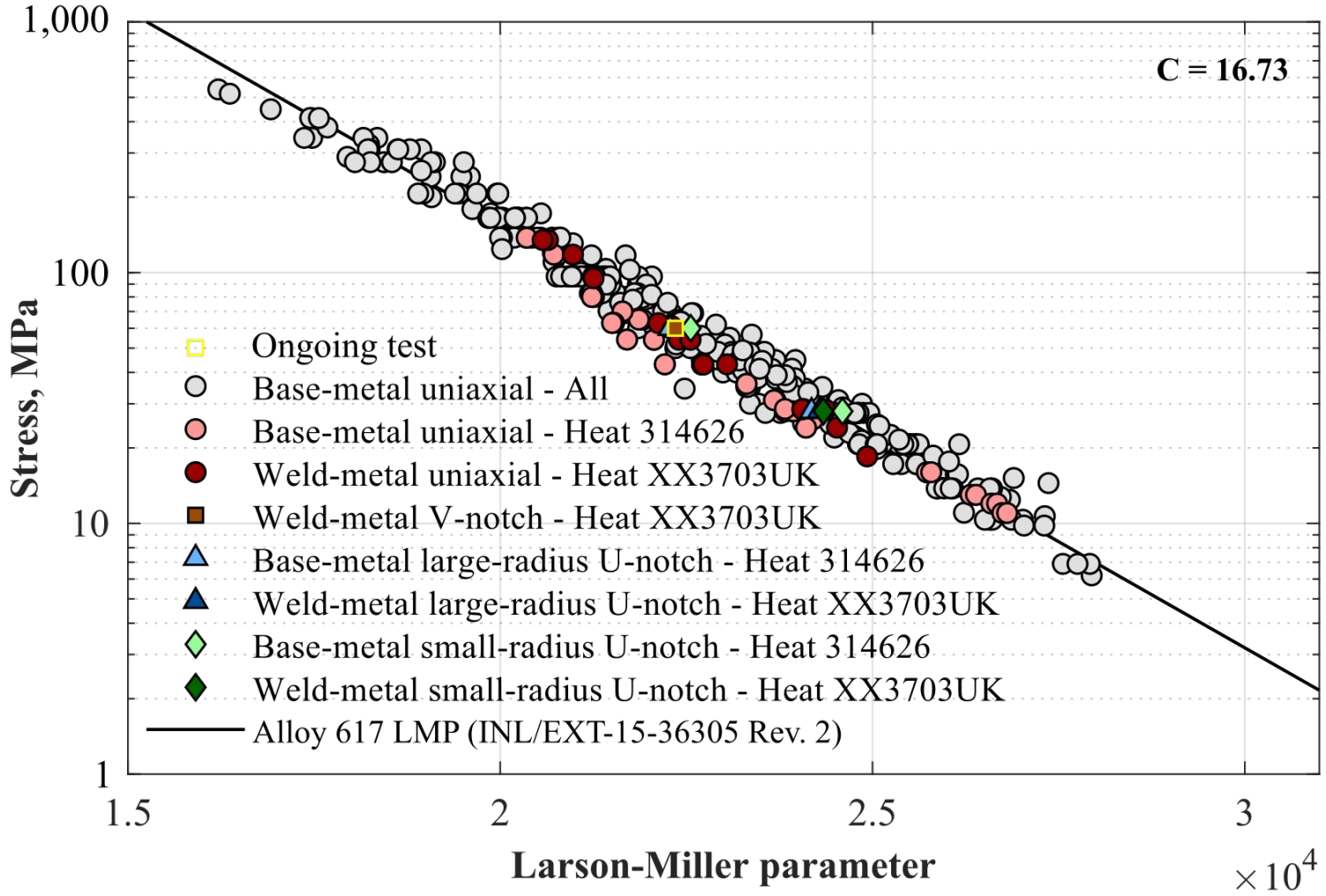
σ_m = mean stress

σ_e = effective stress

Modeling and graphic are from Mark Messner at Argonne National Laboratory. The graphic was modified for this presentation.

Intermediate length

Alloy 617 base- and weld-metal 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 stronger multiaxial stress increased the rupture life.



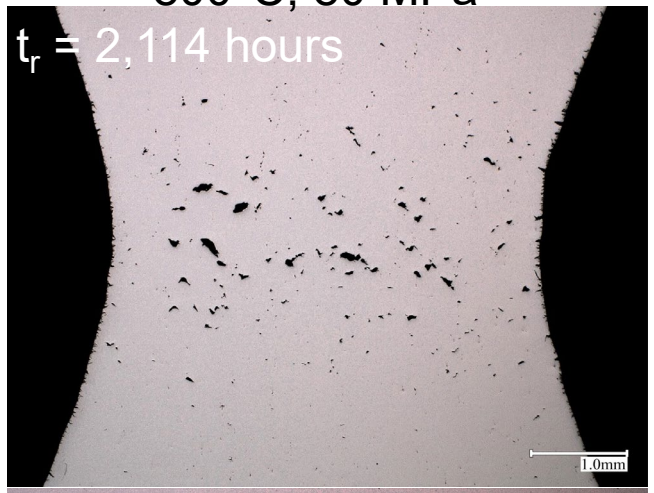
Intermediate length

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

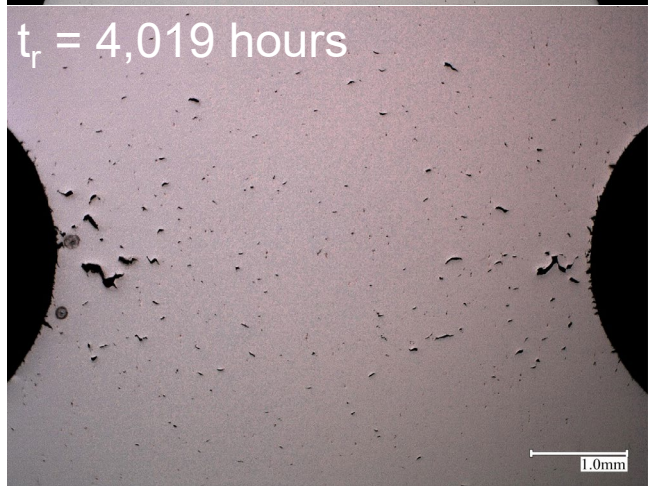
Short term
800°C, 80 MPa

Intermediate length
800°C, 60 MPa

Large-radius U-notch



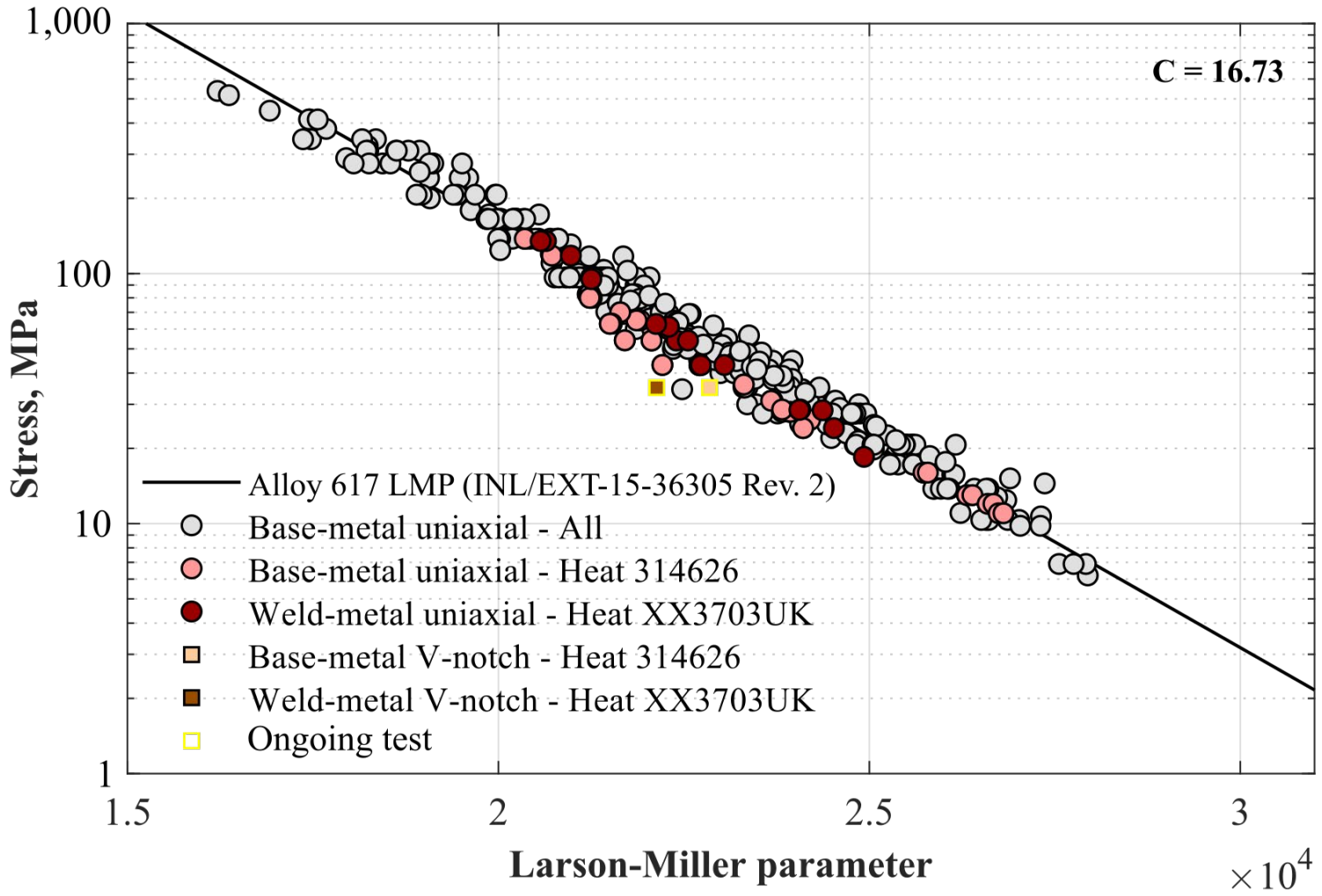
Small-radius U-notch



1.0 mm

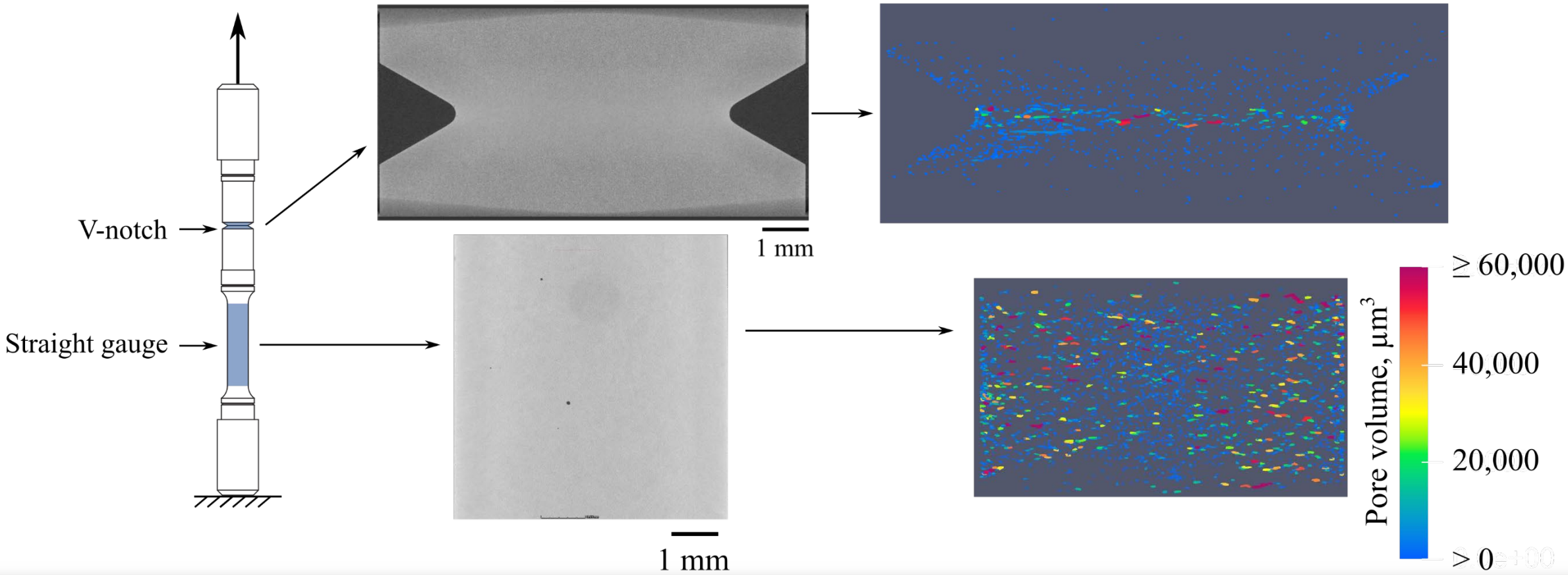
Long term

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



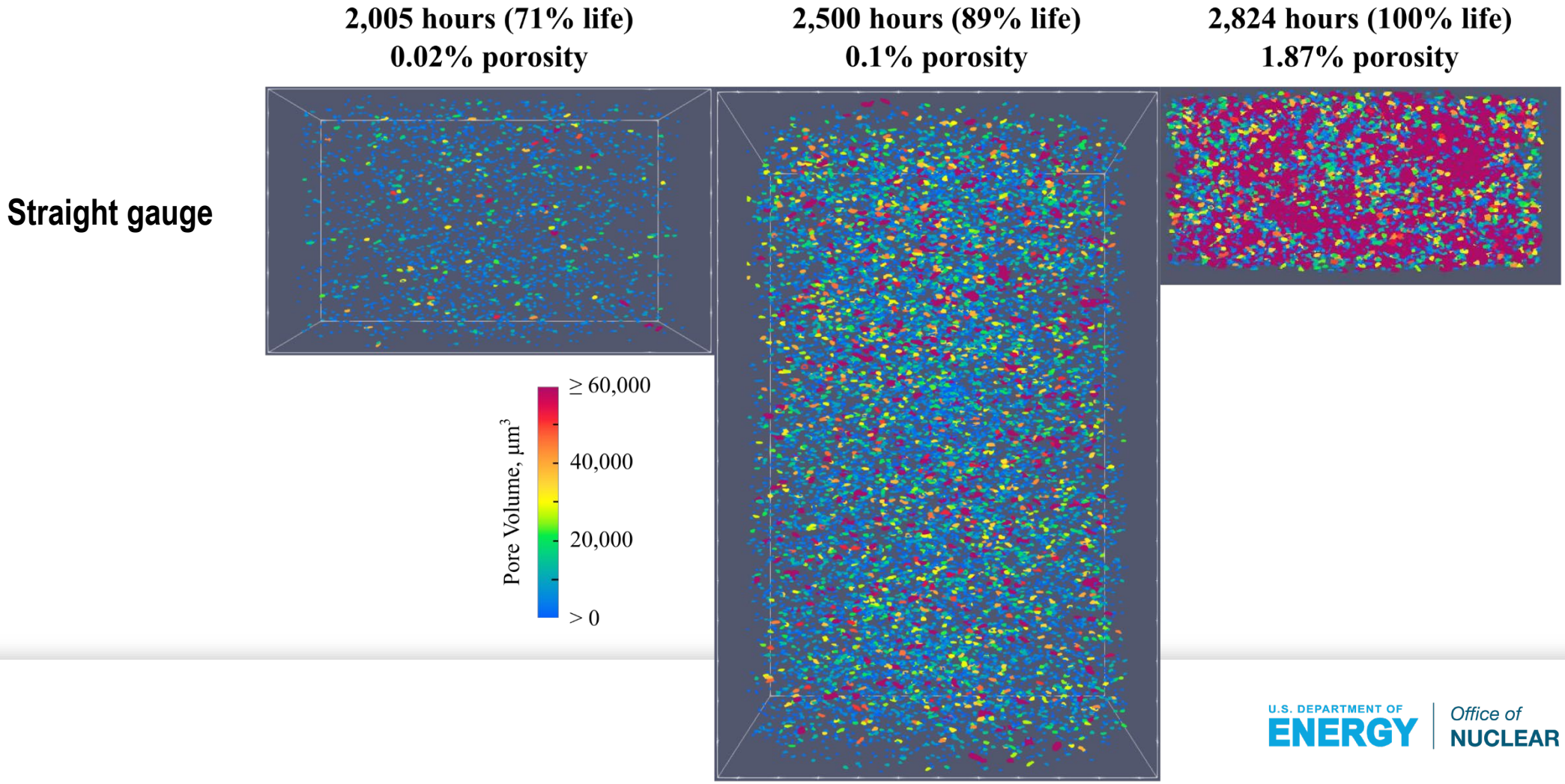
X-ray CT characterization

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



Baseline

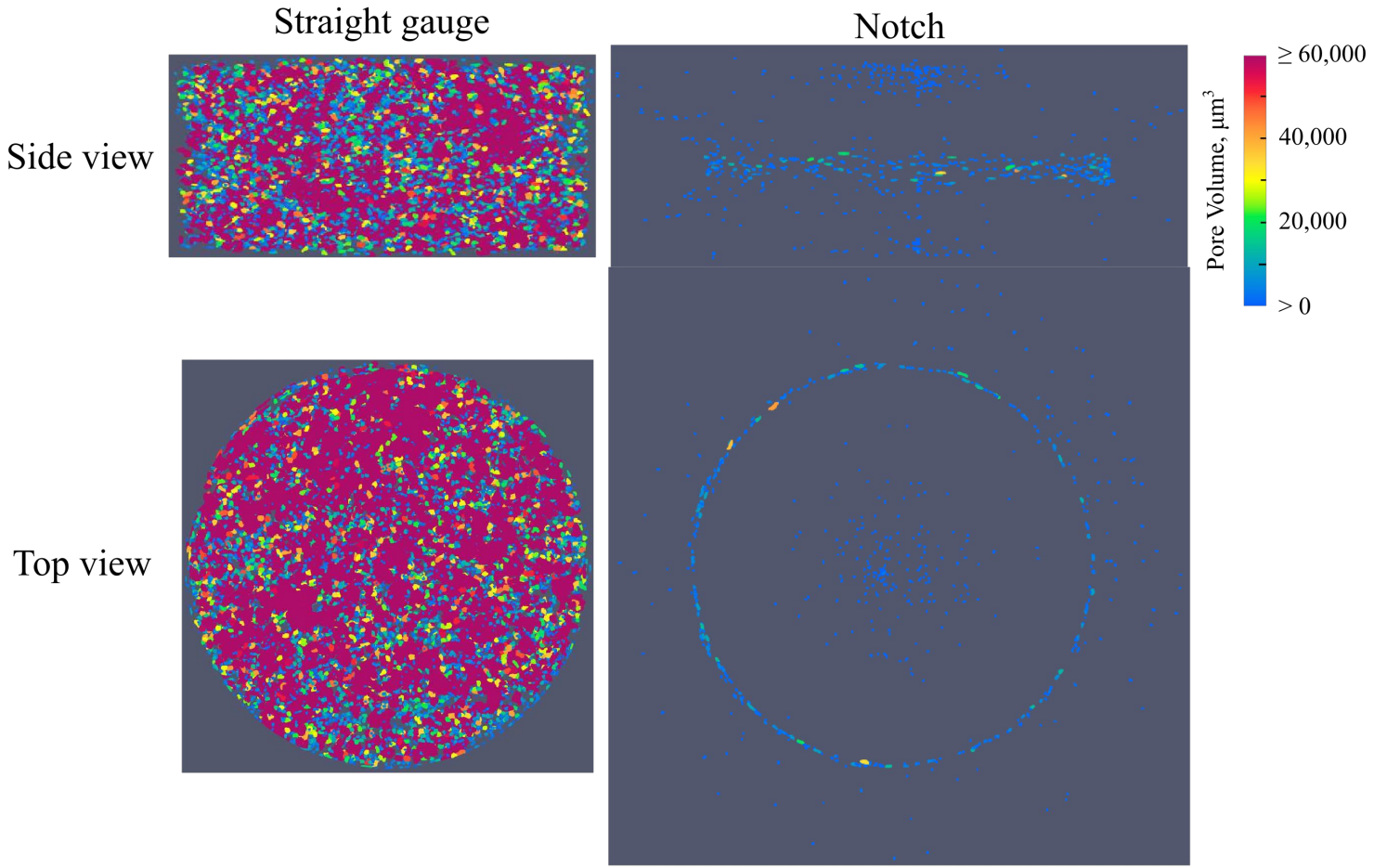
A base-metal V-notch specimen tested at 800°C and 65.3 MPa ruptured in the straight gauge. As the test progressed, the number and size of the cavities in the straight gauge increased.



Baseline

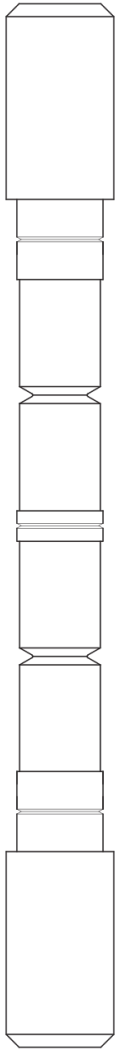
No cavities larger than the resolution of the X-ray CT were detected in the notch for the base-metal specimen tested at 800°C and 65.3 MPa for the two scans collected prior to rupture. Damage in the notch was primarily limited to the surface at the notch tip.

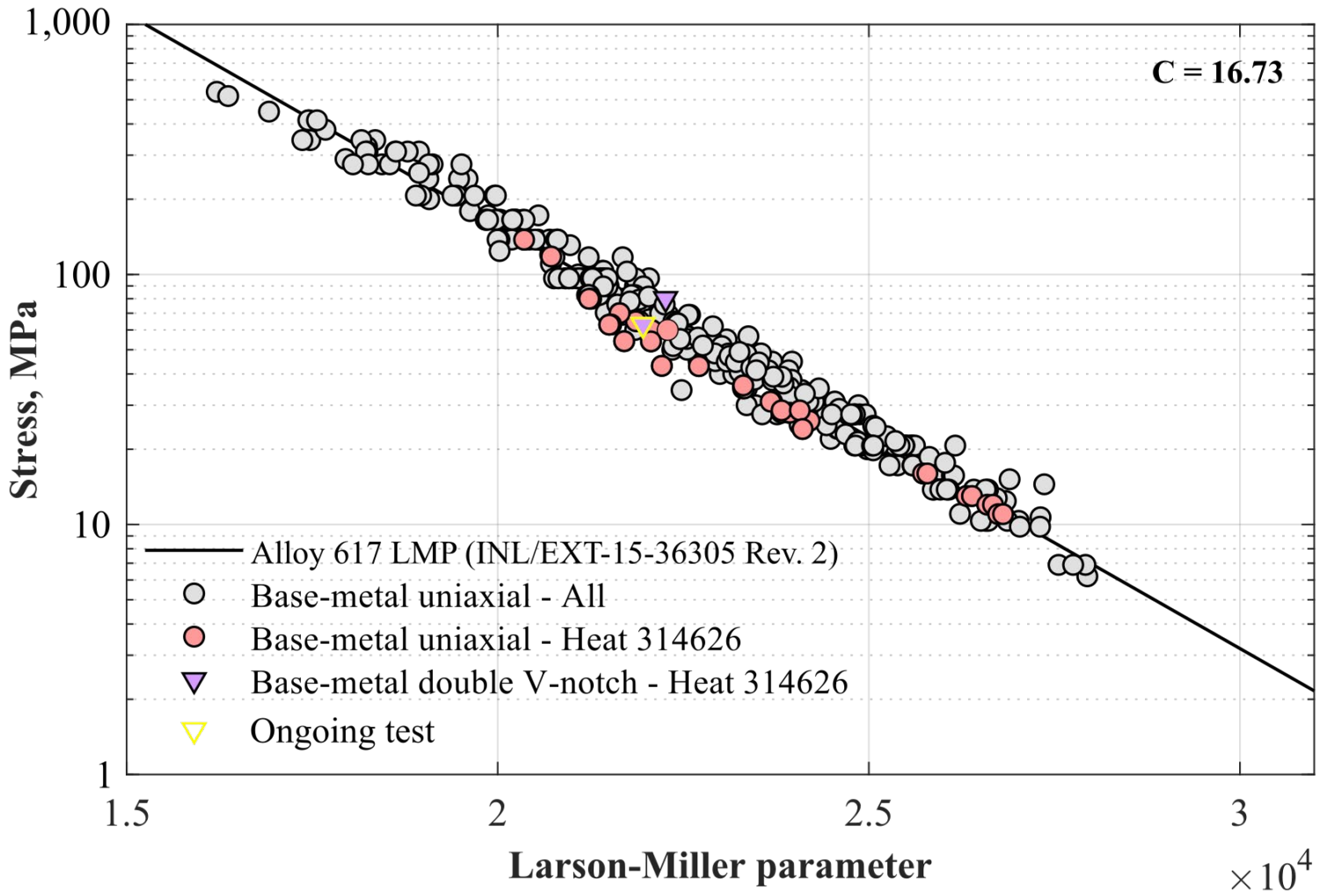
2,824 hours (100% life)



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.



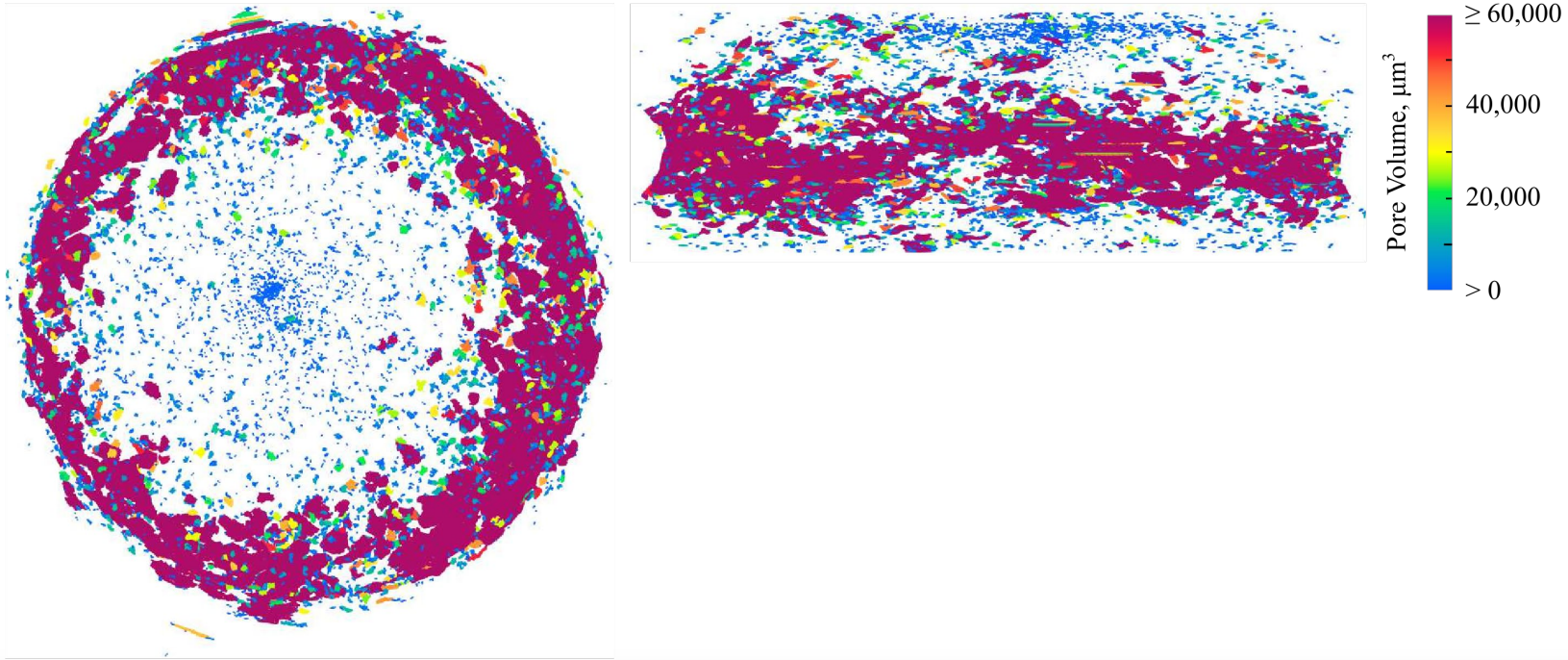


V-notch characterization

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.

Top view

Side view



Summary

- 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.
- Work is ongoing at INL to
  - Evaluate the various damage models by comparing creep damage predicted by finite element modeling with experimental observations.
  - Continue conducting long-term creep-rupture tests and periodically characterize these specimens with X-ray CT.
  - Continue conducting intermediate-length tests and characterize specimens of interest with light optical microscopy.
  - Continue conducting baseline testing with periodic X-ray CT characterization in order to correlate creep damage to rupture life.
  - Utilize the double V-notch specimen to characterize creep damage in the V-notch and quantify the notch strengthening effect.


U.S. DEPARTMENT OF
ENERGY
Office of
NUCLEAR ENERGY