INL/MIS-22-67452-Revision-0

Surveillance Test Articles Development

June 2022

Changing the World's Energy Future

Heramb Prakash Mahajan, Michael D McMurtrey, Mahmut Nedim Cinbiz, Ting-Leung Sham, Thomas W Walters, Mark Messner, Yoichi Momozaki, Ed Boron

Idaho National Laboratory

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

Surveillance Test Articles Development

Advanced Reactor Technologies Program

Advanced Materials R&D Program Review

June 7 and 8, 2022

Heramb Mahajan

Idaho National Laboratory

The Research and Development Team

- Idaho National Laboratory
  - Michael McMurtrey, Nedim Cinbiz, Heramb Mahajan, Thomas Walters, Sam Sham
- Argonne National Laboratory
  - Mark Messner, Yoichi Momozaki, Ed Boron

Work Packages

- RD-22IN060302, Materials Surveillance Development – INL
- RD-22AN060301, Materials Surveillance Development – ANL

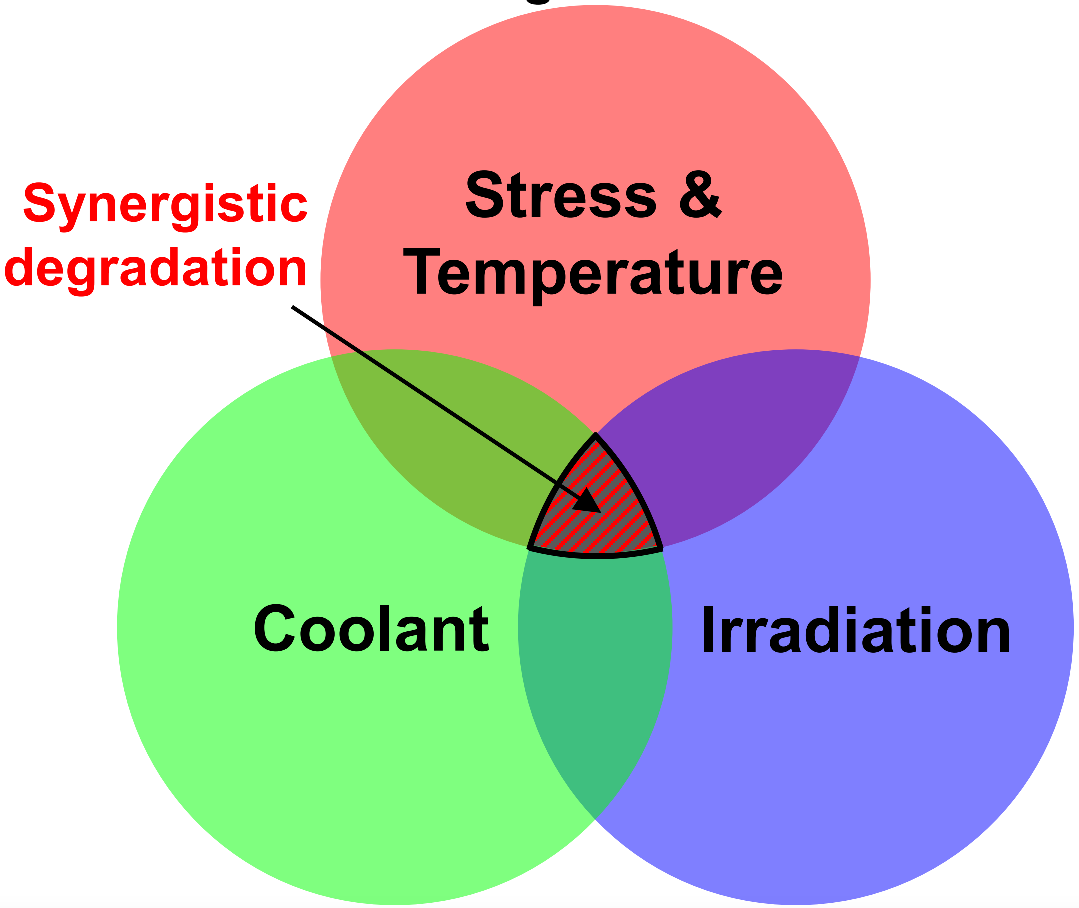
Presentation Outline

- Background of surveillance test article
- Initial test article development and experiments
- Test-setup development – Induction heating, and optical metrology technique for strain measurements
- Development and analysis of new test article design

Materials Degradation during Advanced Reactor Operations

- Synergistic material degradation effects
  - Irradiation
  - Corrosion
  - Stress and temperature exposure (creep-fatigue loading)
- Limited Information on materials degradation in molten salt reactor environment
- Need to establish material surveillance program to assess material degradation

Material Degradation effects

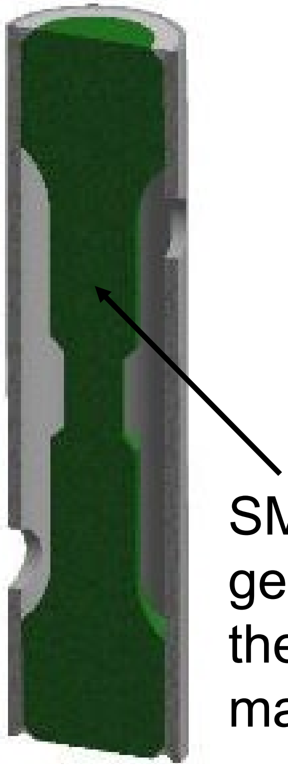


Development of Surveillance Test Articles

SMT specimen
(Yanli Wang, ORNL)

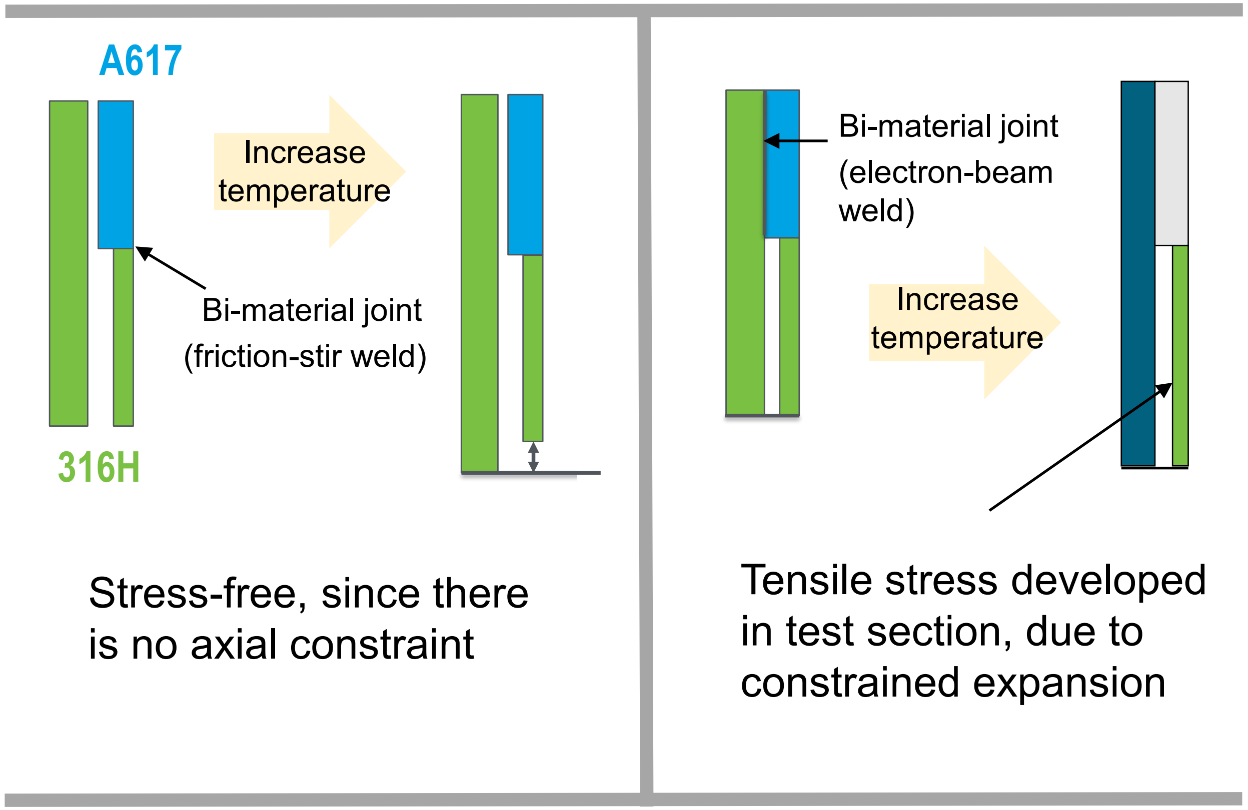
- Motivated by the Simplified Model Test (SMT) specimen
- Thermal expansion mismatch within a test article to passively generate a “load”
- Initial concept for a passively loaded surveillance test article
- Difficult to find the right type of thermal expansion mismatch to induce a tensile “load” in the test material

Cross section of Initial concept test article



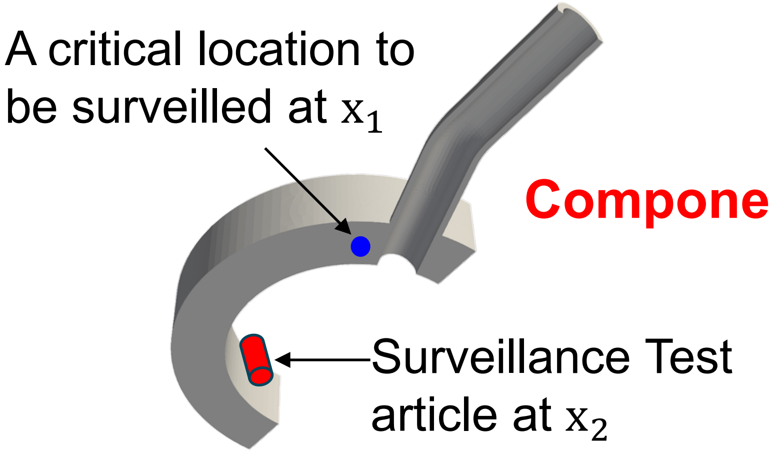
Passive Loading via the Mismatch in Expansion Coefficients

- Relies on large Coefficient of Thermal Expansion (CTE) mismatch
- Provides creep-fatigue loading with a configurable strain range and elastic follow-up factor
- Fabricated a test article with 316H (test material) driven by A617 (driver material)

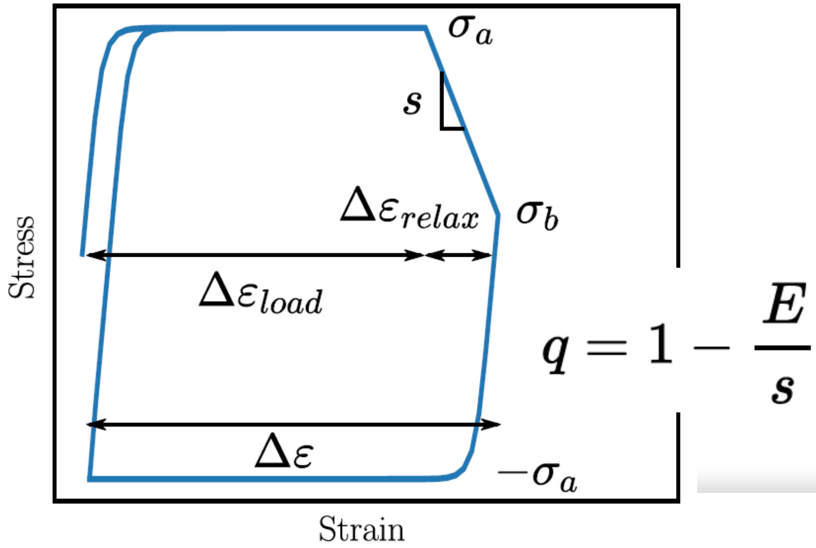


A617: Ni-alloy Inconel 617
316H: Stainless Steel 316H

Structural Integrity Surveillance



Component



Stabilized hysteresis loop

- Thermal hydraulic analysis - development of a temperature history for the coolant and structural components
- Stabilized cyclic stresses and strains at critical location x_1
- The stress-strain hysteresis loop can be characterized by (1) strain range $\Delta\varepsilon$ and (2) elastic follow-up factor q
- Possible to capture structural characteristics at x_1 through surveillance test article at x_2

Completed Furnace Testing of Initial Designs

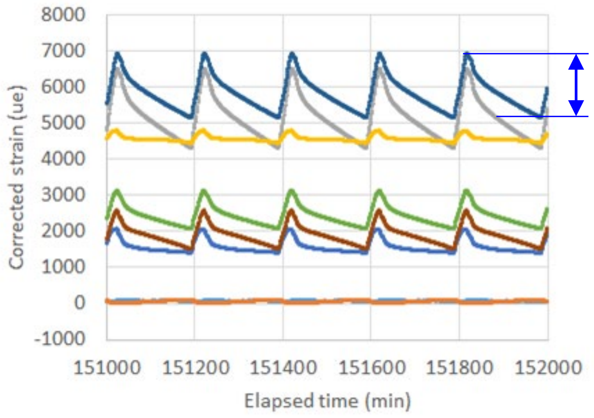
Large specimens

Small specimens

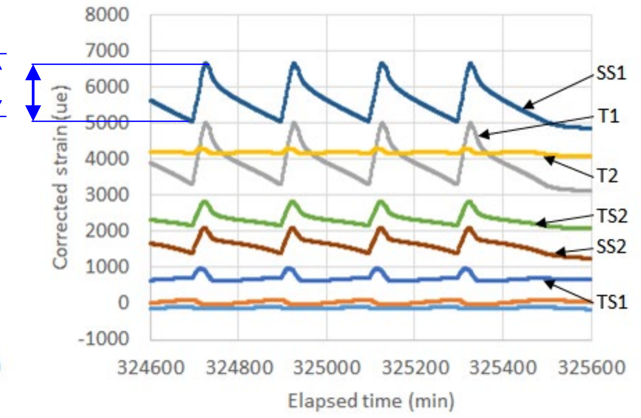
- Initial designs tested with A617 driver
- 3 families of specimens
  - Large: demonstrate failure during test
  - Small: demonstrate realistic-sized samples
  - Reference: to validate the strain-gauge thermal strain correction
- Thermal cycling between 500 and 650^{o}C, over a period of about 200 minutes

Key Results and Lessons Learned

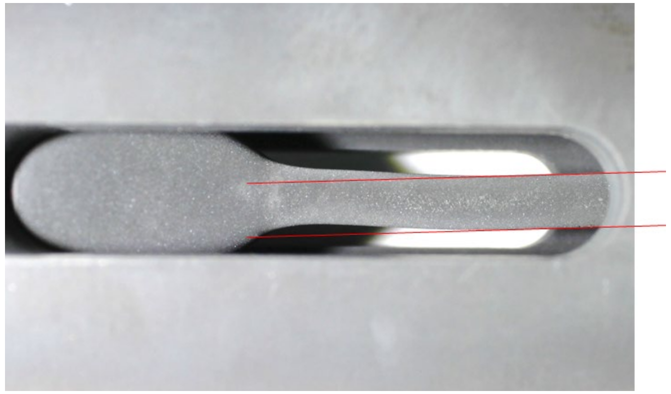
- Demonstrated basic surveillance approach
- Large specimens failed in gauge section
- The bimetallic welds appeared intact at the end of testing (316H-A617)
- Gradual decrease in strain range over time
- Strain gauge reliability was an issue: at least one gauge failed
- Failure mode (buckling) was not what we had expected



September 2021



February 2022



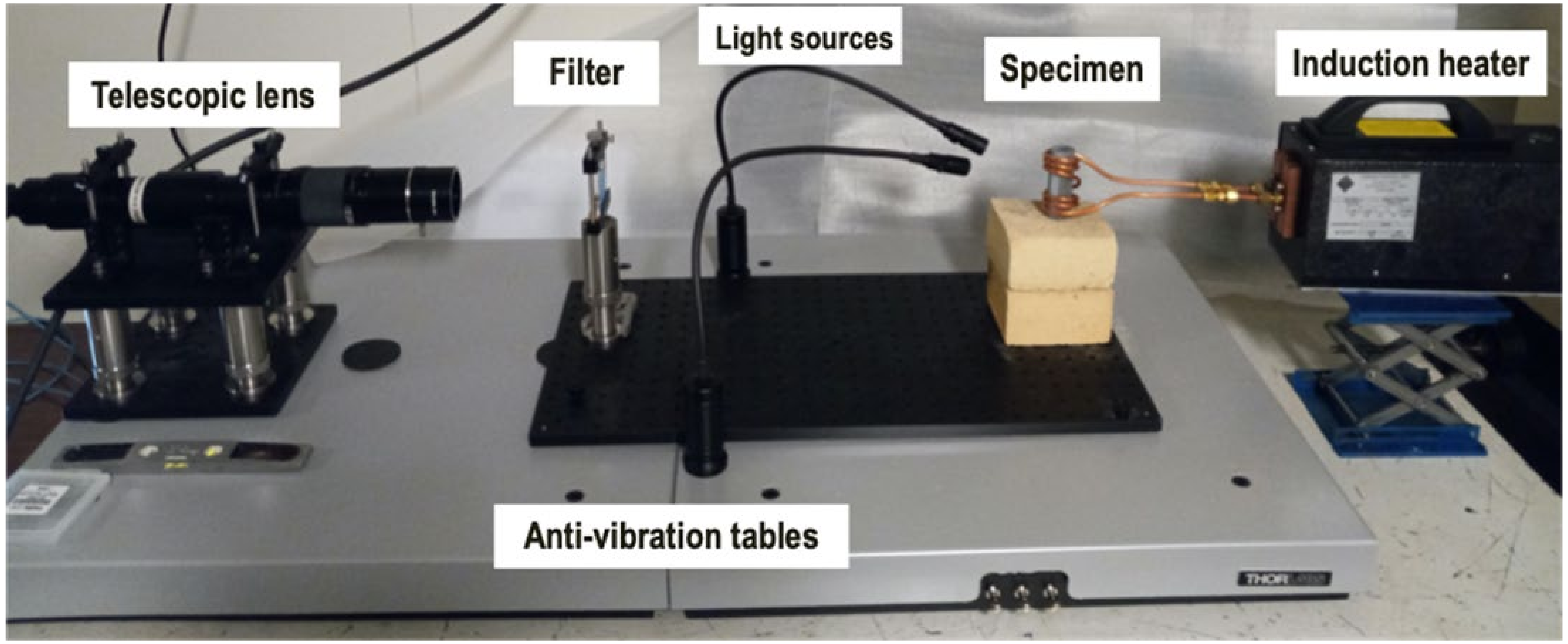
Buckling deflection

Messner, Mark C., Momozaki, Yoichi, and Boron, Ed. 2022. "Report on Thermal Cycling Testing and Bimaterial Weld Development for a Passively Actuated Materials Surveillance Test Article". United States. https://doi.org/10.2172/1846247. https://www.osti.gov/servlets/purl/1846247.

Induction Heating of the Initial Designs

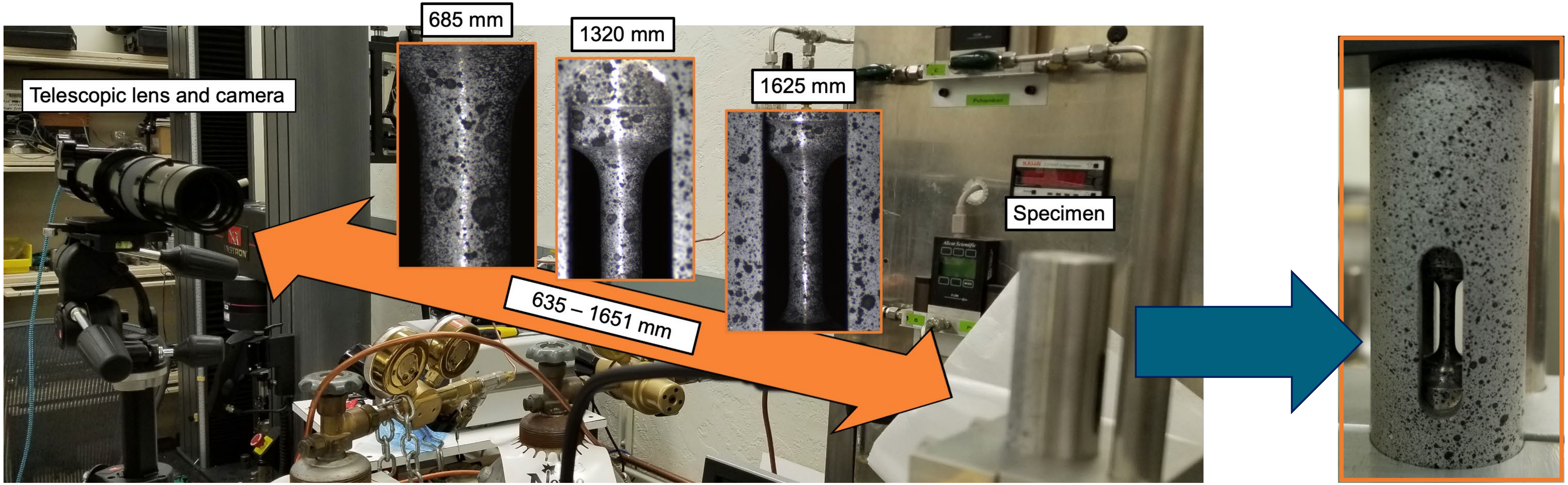
- Induction heating, when combined with air cooling, can be much faster than heating and cooling within a furnace. A full cycle from 500^{o}C to 700^{o}C lasts approximately 6 minutes

- Once the development phase is finished, displacement and multiple temperature readings will be digitally acquired during recording of the digital images



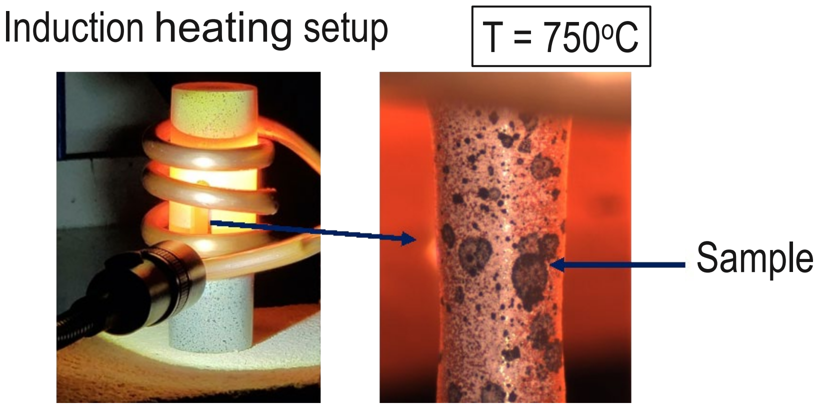
Optical Metrology Setup

- The optical metrology setup involved a telescopic lens and camera system
- Various specimen-to-camera working distances (WDs) were tested

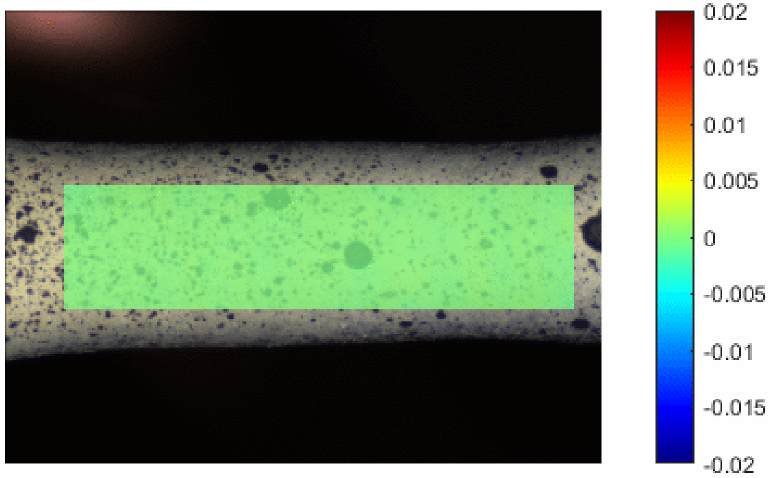


For enhanced speckle resolution, a WD of 685–720 mm was selected

High-Temperature Observation of the Specimen (Preliminary)

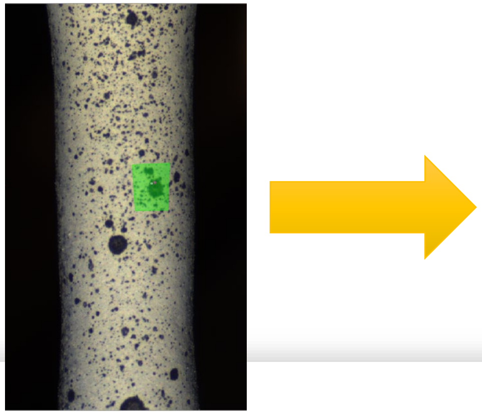


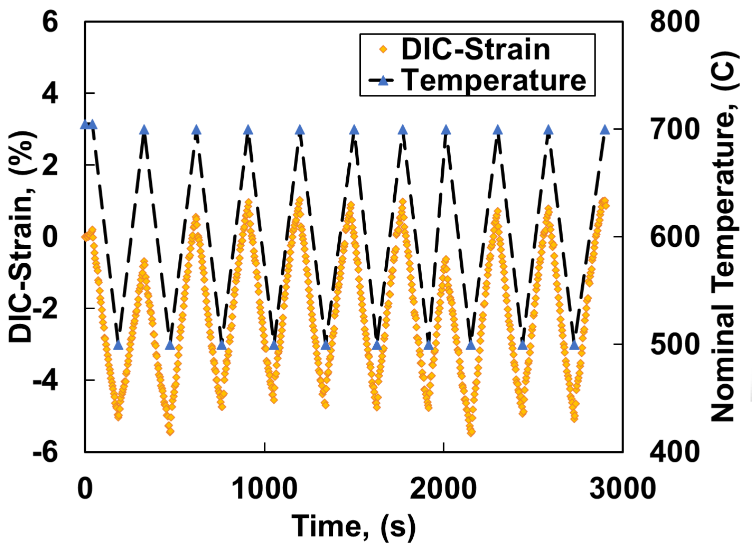
- At above 700^{o}C, permanent deformation was observed, but no specimen rupture occurred
- Digital Image Correlation (DIC) tracking was used to determine the displacement, using the Digital Image Correlation Engine (DICE)*
- Tuning of the DIC speckle pattern and calculations are still in progress



Cycling between 500-700 ^{o}C
Temperature is currently measured at the specimen's top surface via contact temperature readings

No optical filter applied

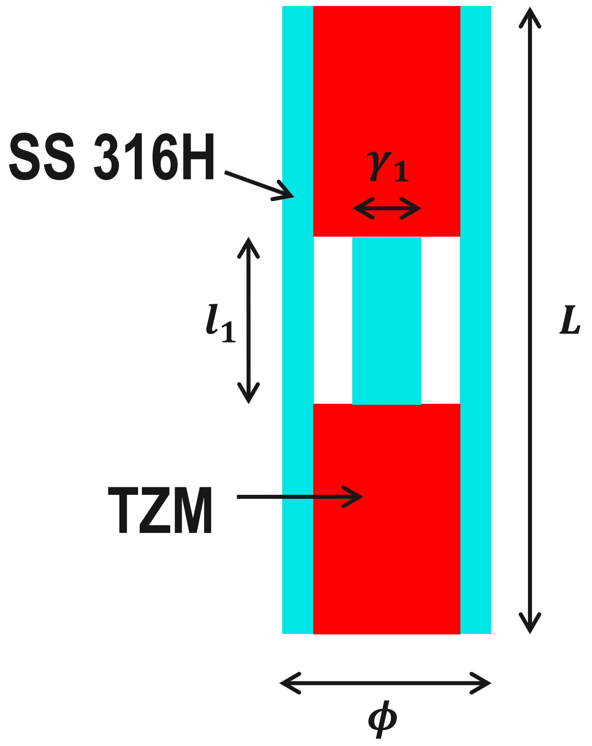




*DZ Turner, Digital Image Correlation Engine (DICE) Reference Manual, Sandia Report, SAND2015-10606 O, 2015

Developed Small Test Article Geometry

- High CTE mismatch between Titanium-Zirconium-Molybdenum (TZM) alloy and 316H
- Smaller test articles with larger strain ranges are possible
- Planned faster temperature cycles with period of 30 minutes
- Initial dimensions of small test article through test article sizing app
- Finite element analysis to estimate stress at TZM-316H weld



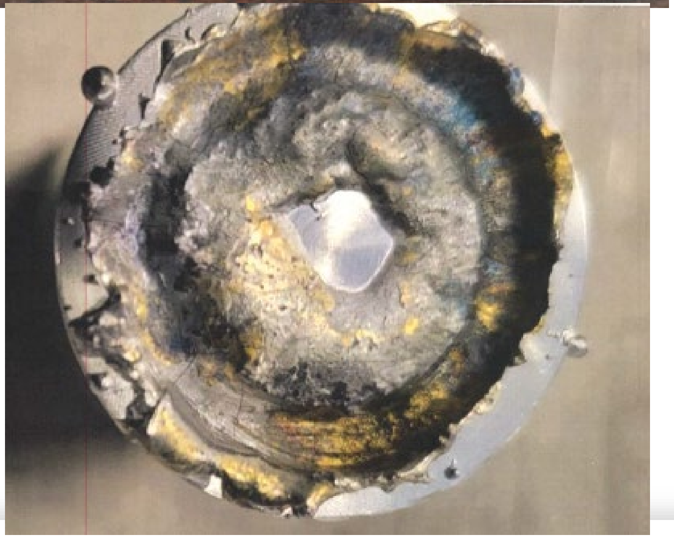
Diameter: 25.4 mm (1 inch)
Length: 101.6 mm (4 inch)

Preliminary Bimetallic Weld Tests: 316H/TZM

Stir friction: successful after some iterative development with vendor

Yellow: some intermetallic or oxide

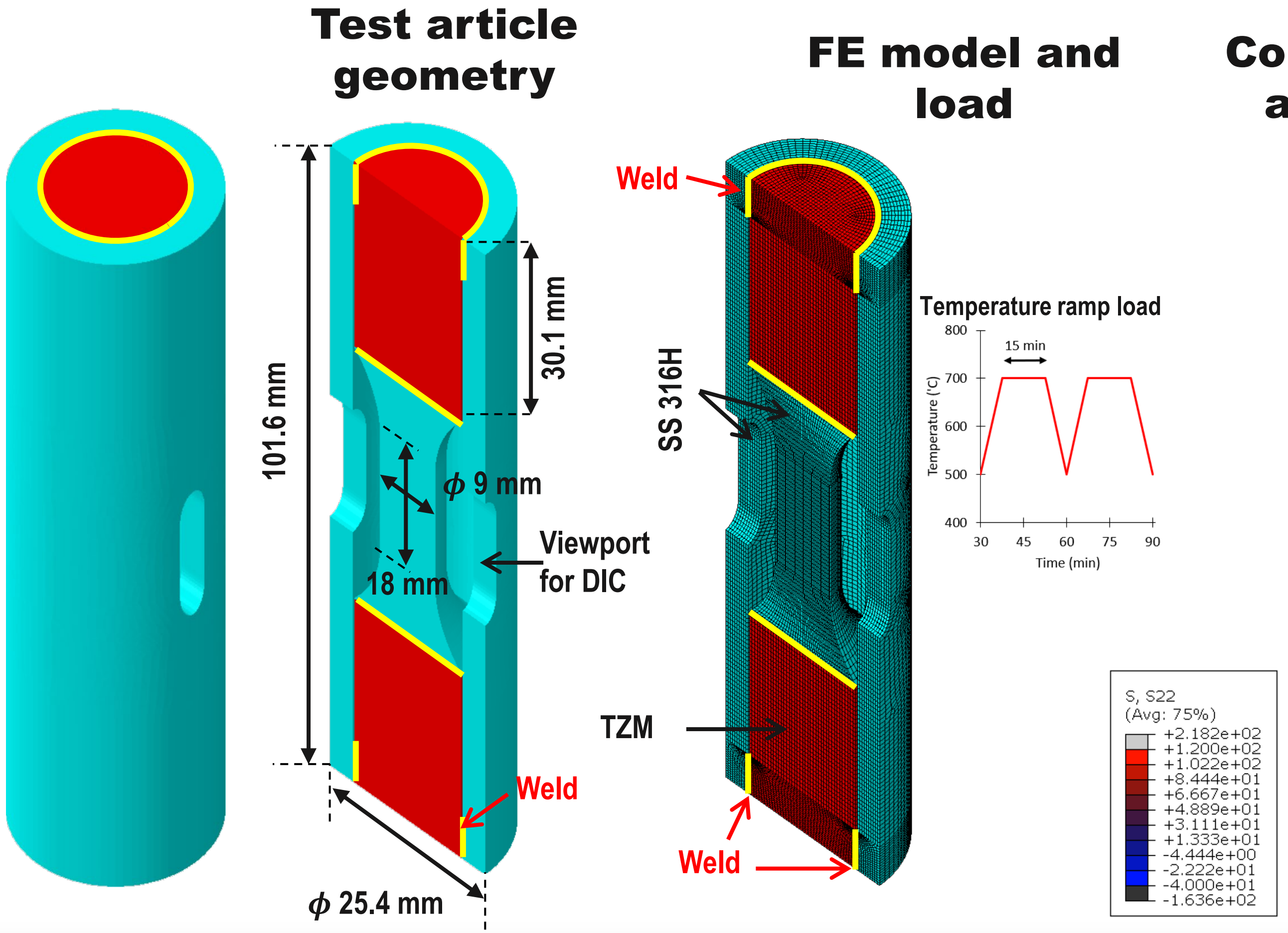
Electron beam: not yet successful, but less time to iterate with vendor

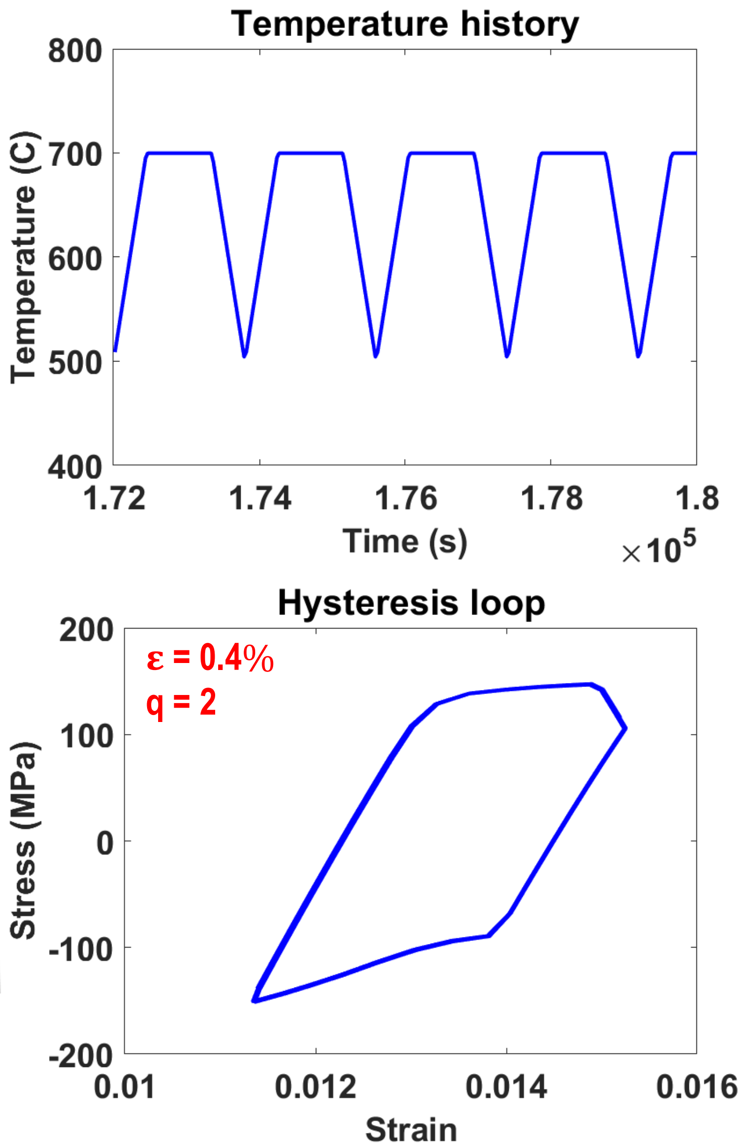


- Benefits of refractory alloys
  - Very low CTEs
  - Very good strength – induce failure in the test material
- Challenges
  - Joining a refractory driver to the test material
  - Brittle failure in the refractory material (at low temperatures [i.e., outages])
- Weld parameter optimization in progress

Messner, Mark C., Momozaki, Yoichi, and Boron, Ed. 2022. "Report on Thermal Cycling Testing and Bimaterial Weld Development for a Passively Actuated Materials Surveillance Test Article". United States. https://doi.org/10.2172/1846247. https://www.osti.gov/servlets/purl/1846247.

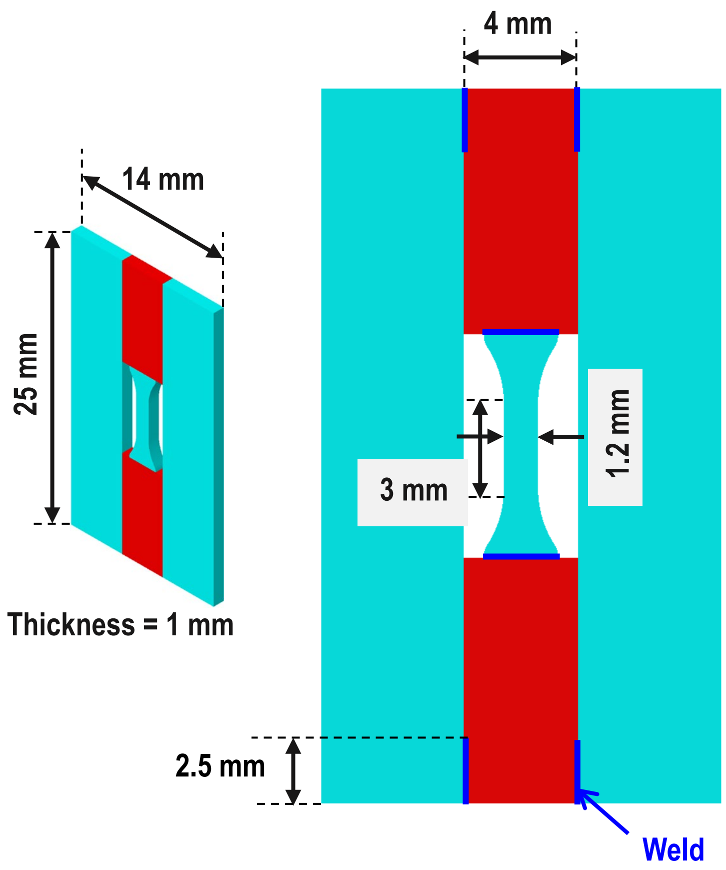
Circular Surveillance Test Article





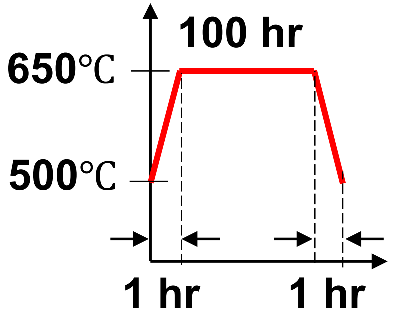
New Surveillance Test Article

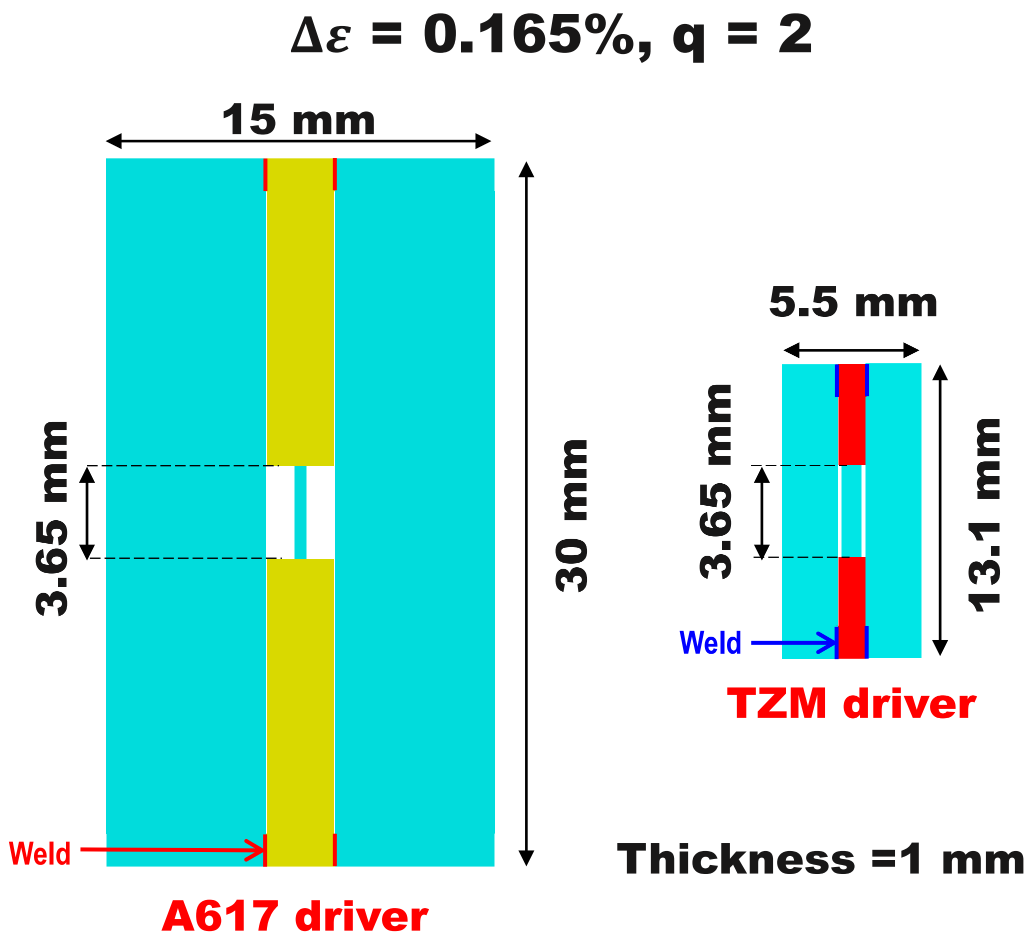
- Easier to manufacture
- Easier to instrument and monitor during the validation of the technical basis
- Smaller and less disruptive to fluid flow/plant operation
- Design is more accessible for evaluation and mechanical testing after the test articles are removed from the reactor; also, smaller activated volume



Comparison of Different Drivers in New Test Article

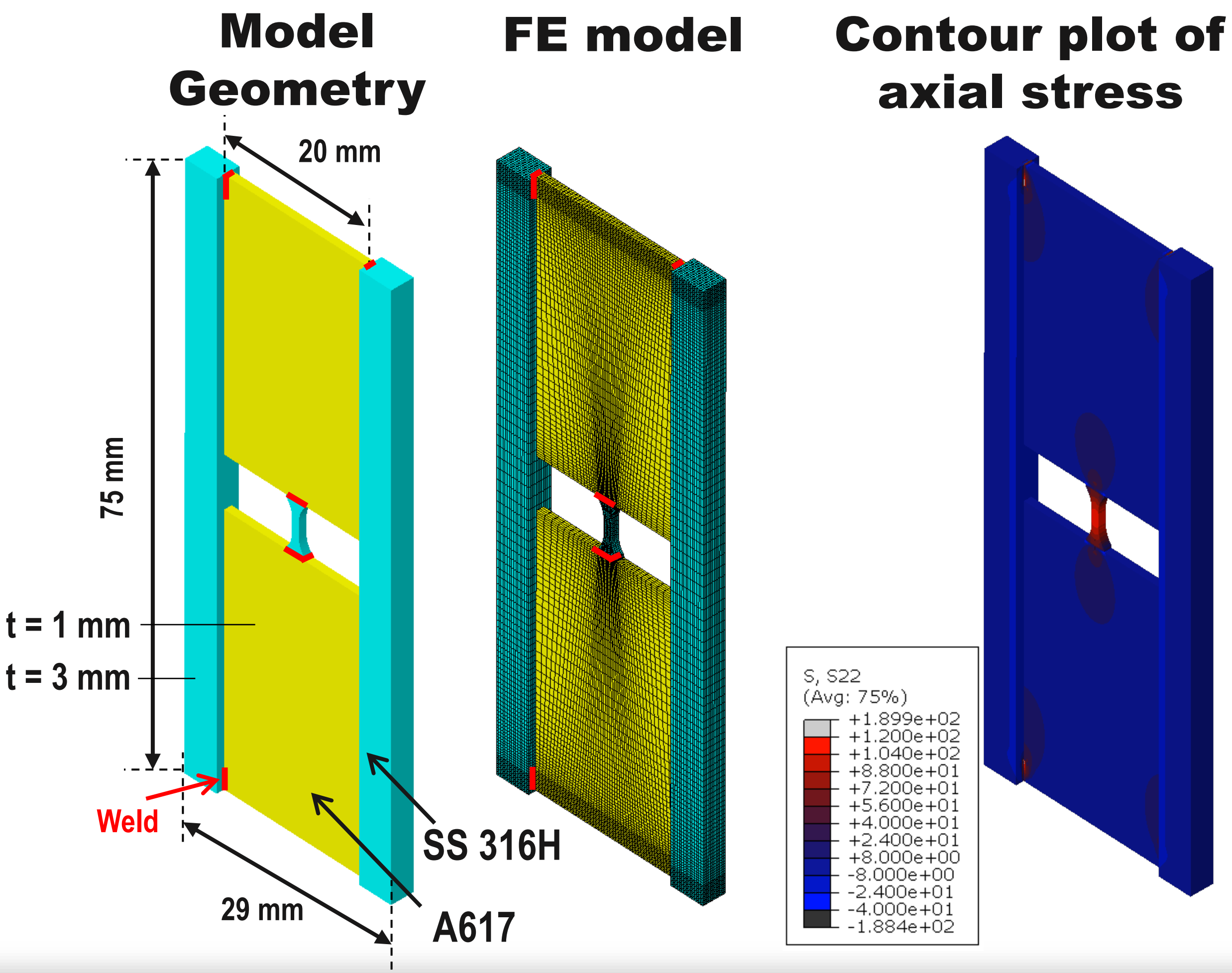
- Same gauge length with different driver materials
- Test article design parameters:
  1. $\Delta\varepsilon = 0.165\%$
  2. q = 2
  3. Temperature cycle
  4. Dwell time = 100 hr
- Higher CTE mismatch results in smaller surveillance test article size for given design parameters





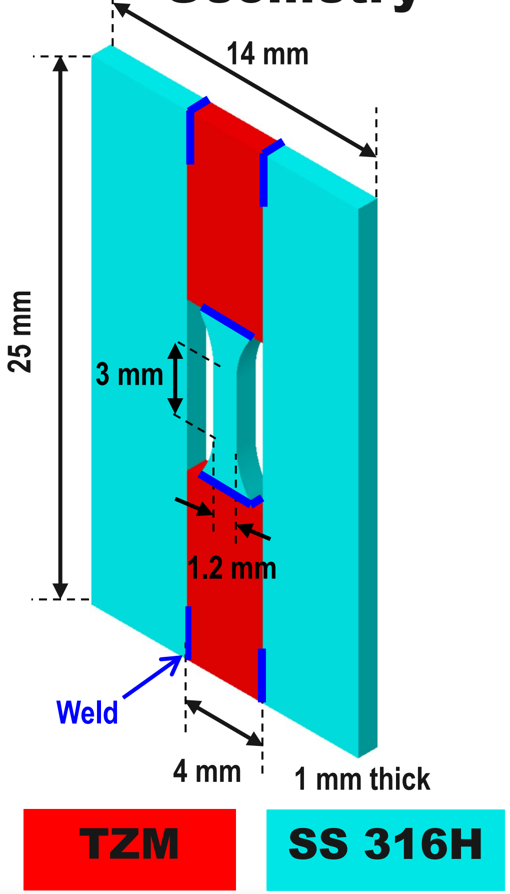
Flat Surveillance Test Article Design – A617 Driver

- Goal – Design a flat surveillance test article to attain the strain range and elastic follow-up similar to the previously tested 12” long test article
- Initial optimization through test article sizing app followed by finite element analysis

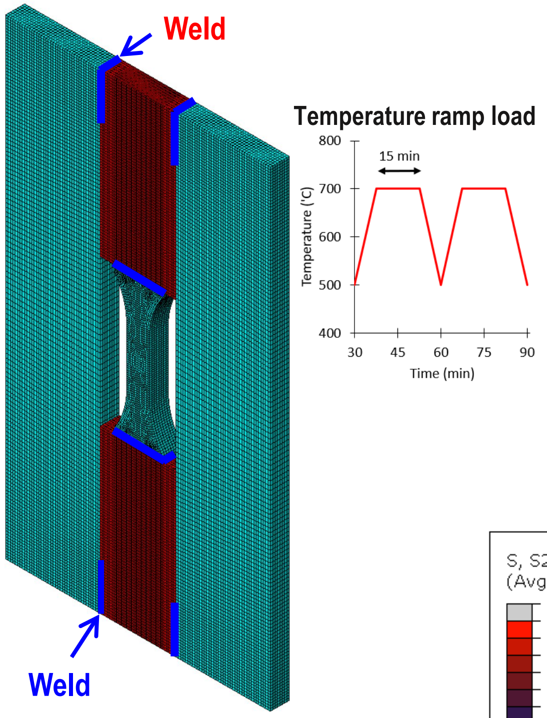


Flat Surveillance Test Article Design – TZM Driver

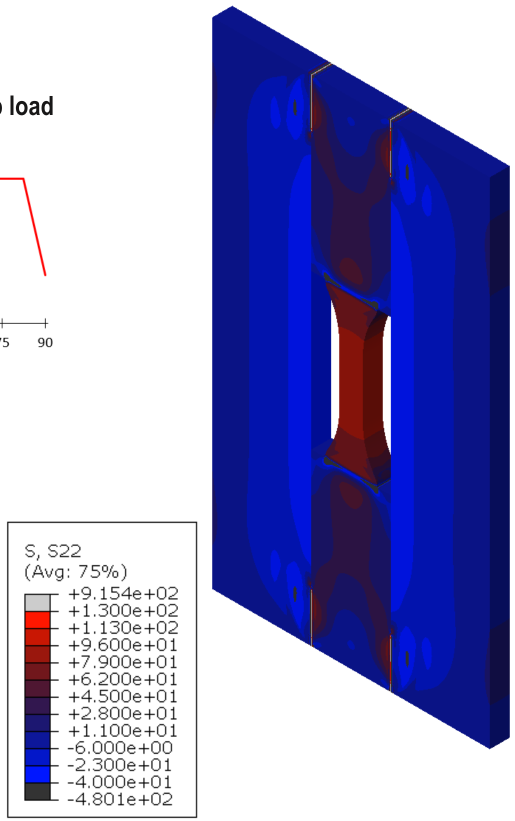
Model Geometry

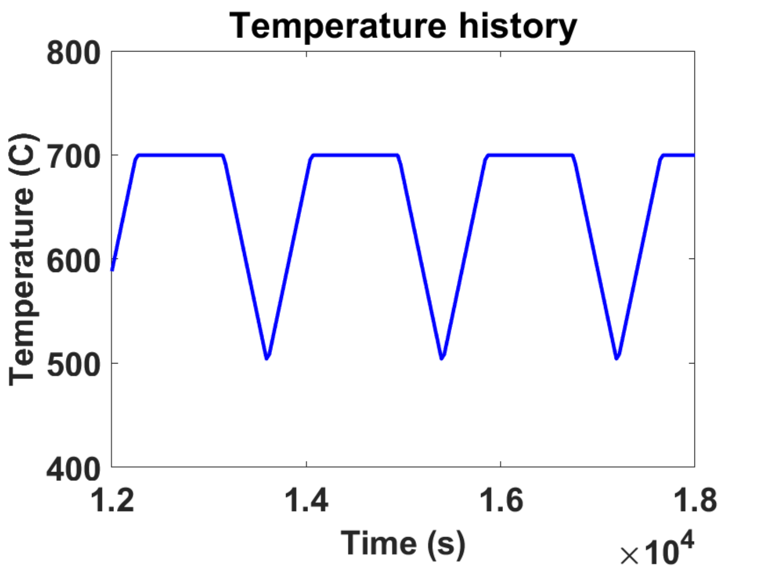


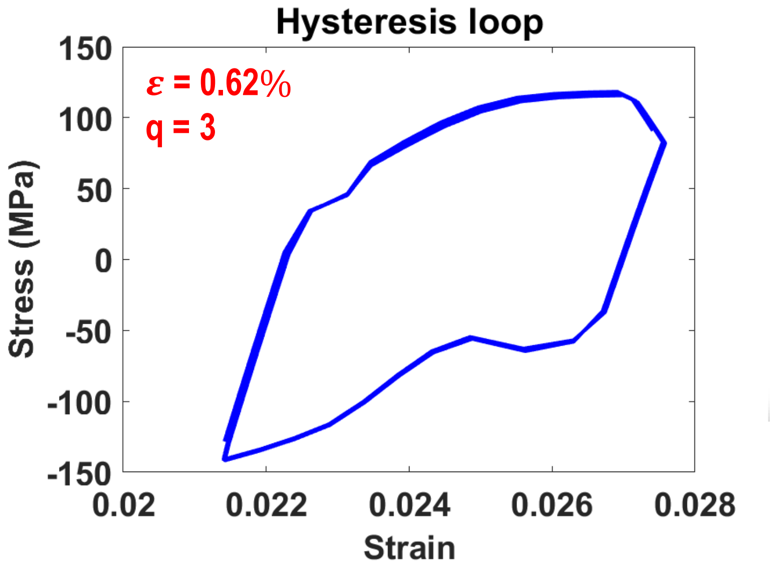
FE model and load



Contour plot of axial stress







Ongoing and Future Work

- Continue development of smaller test article
- Continue work on test setup - induction heating, DIC setup tuning
- Printed strain gauge (in development under the Advanced Sensors and Instrumentation Program) on the inside gauge
- Complete induction heating testing of the initial test article designs (617/316H)
- Complete induction heating testing of the redesigned smaller circular test articles (TZM/316H)
- Complete induction heating testing of the new test articles (TZM/316H)

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