SAND2016-4683C

Identifying Uncertainty in Material Model Selection for Finite Element Analysis of a Hermetic Connector

Brenton Elisberg

May 18th, 2016

ASME Verification and Validation Symposium
Las Vegas, NV, May 18-20th, 2016

Sandia National Laboratories

Exceptional service in the national interest

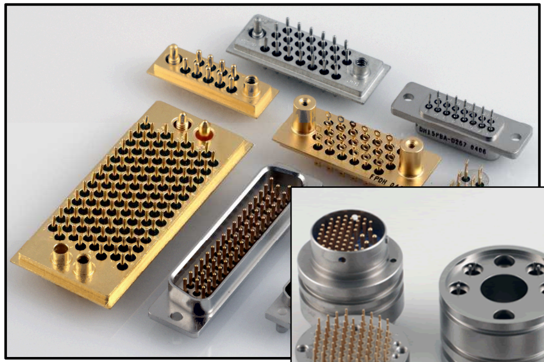
U.S. DEPARTMENT OF ENERGY

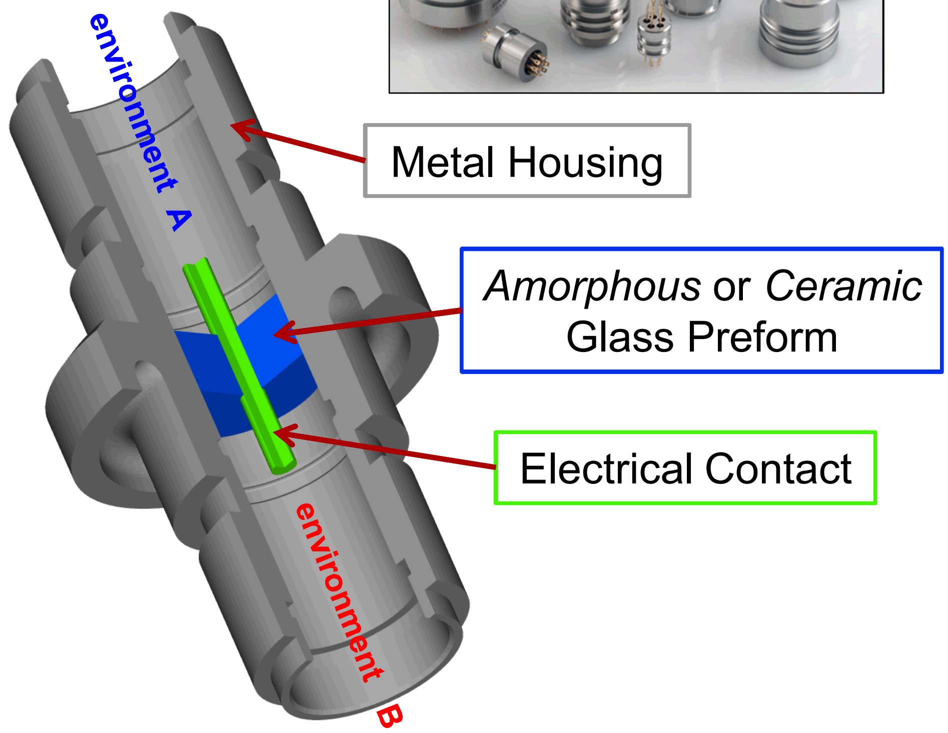
National Nuclear Security Administration

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. SAND NO. 2011-XXXXP

What is a hermetic connector?

- Barrier to gas/liquid transfer between environments.
  - Allow electrical transmission
- Designed for extreme conditions
  - Thermal
  - Pressure
  - Shock/vibration
- Many applications:
  - Satellites, submarine vehicles, medical, telecommunications, etc.
- Types of hermetic connectors
  - Matched seals
  - Compression seals

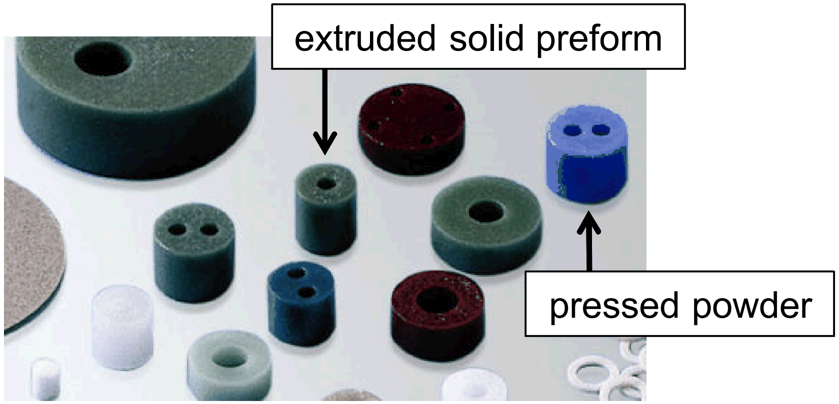


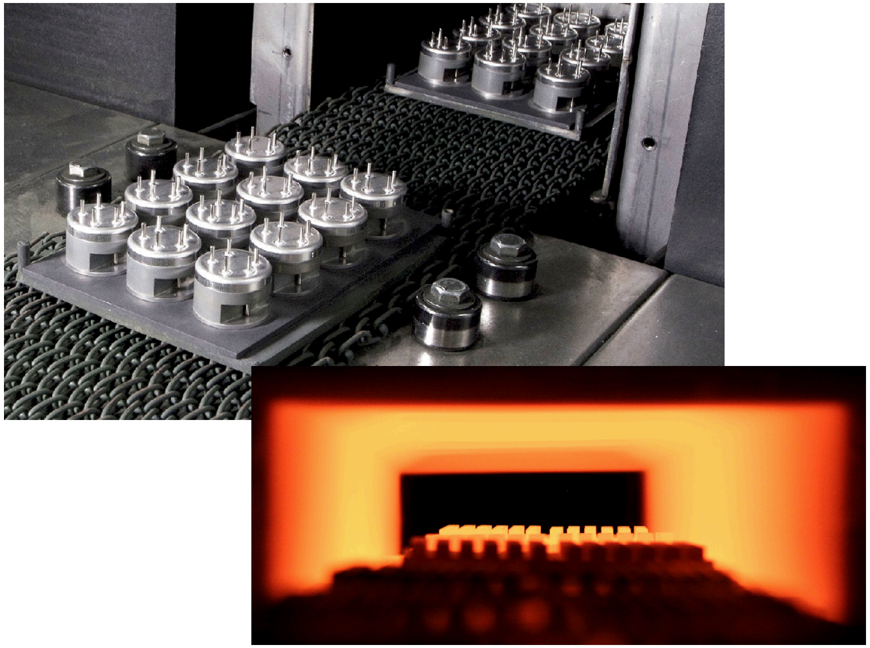


Creating a Hermetic Seal

Sandia National Laboratories

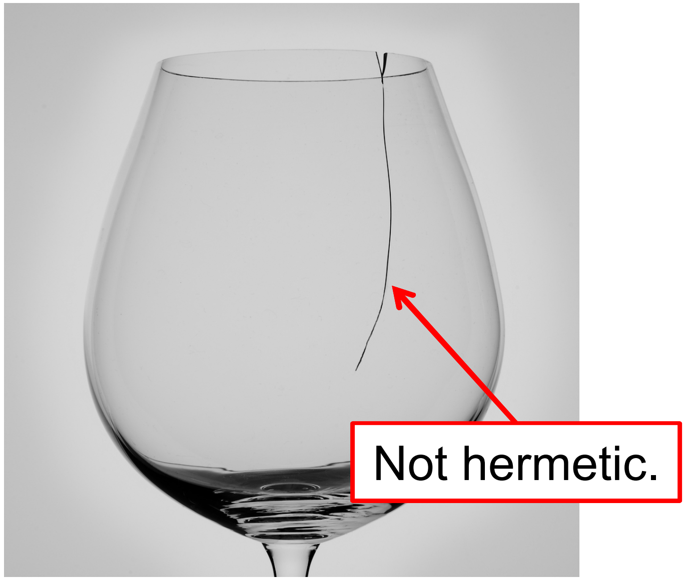
- Piece-part assembly
  - Fixture holds preform and contact(s) in shell
- Glass melt and flow
  - Belt fed furnace w/ multiple chambers
  - Exceed melt temp
- Compression from shell as connector cools
  - $304L_{CTE} \approx 17$ ppm/^{o}C
  - $GLASS_{CTE} \approx 10$ ppm/^{o}C





So what's the problem?

processing…
…testing



Visual, x-ray, CT, ultrasonic, etc.

- Processing, testing, and fielding causes short and/or long term residual stress.
- Difficult to identify and visualize cracks due to size of connectors.
- <u>Very</u> difficult to measure stress in the glass of a hermetic connector.

WE MUST RELY ON MODELING!

So what's the BIGGER problem?

Assumptions and approximations lead to uncertainties in model predictions.

- Real Geometry → Modeled Geometry
  - Drawing does not match processed form (not just tolerances).
  - Menisci vary and may be neglected in the model.
  - Shell details may be neglected which affects modeled shell volume.
- FEA Assumptions
  - Material model selection for pin, glass, and shell (chosen based on available data or limited computational resources).
  - Set temperature (T_{set})
  - Glass transition (T_g) is dependent on processing history

Simulating the Sealing Process

Old way…

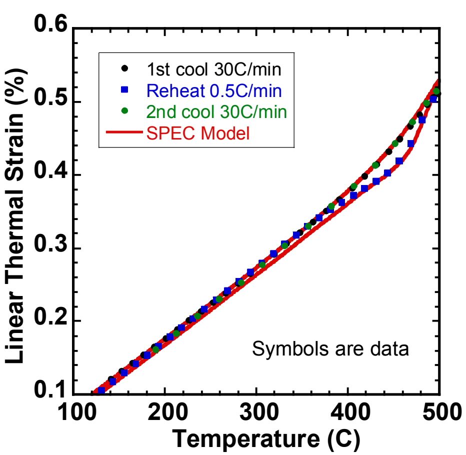
- Choose constitutive models:
  - Elastic for glass
  - Elastic-plastic for metals
- **Assume** T_{set}
  - T_{set} → Room Temp
  - Rate independent
- **Less** information about processing is needed
- **Qualitative** predictions
  - Lead design process
  - Determine features that greatly affect stress

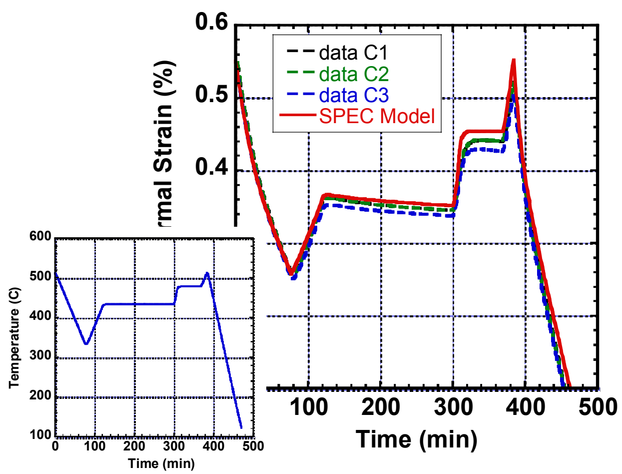
New Way!

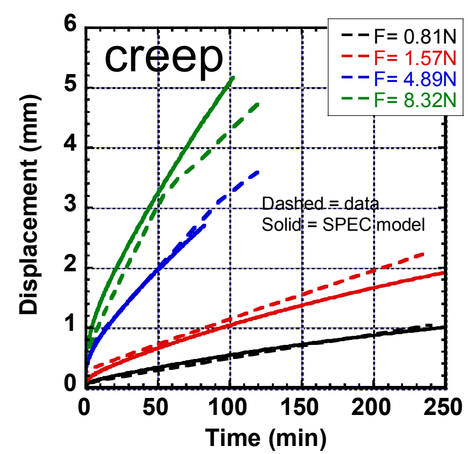
- Choose constitutive models:
  - Viscoelastic for glass
  - Viscoelastic-plastic for metals
- **Predicted** T_g
  - $>T_g$ → Room Temp
  - Rate dependent
- **Detailed** information about processing is needed
- **Quantitative** predictions
  - Predict evolution of residual stress and structural relaxation over time.

Viscoelastic Glass Predictions

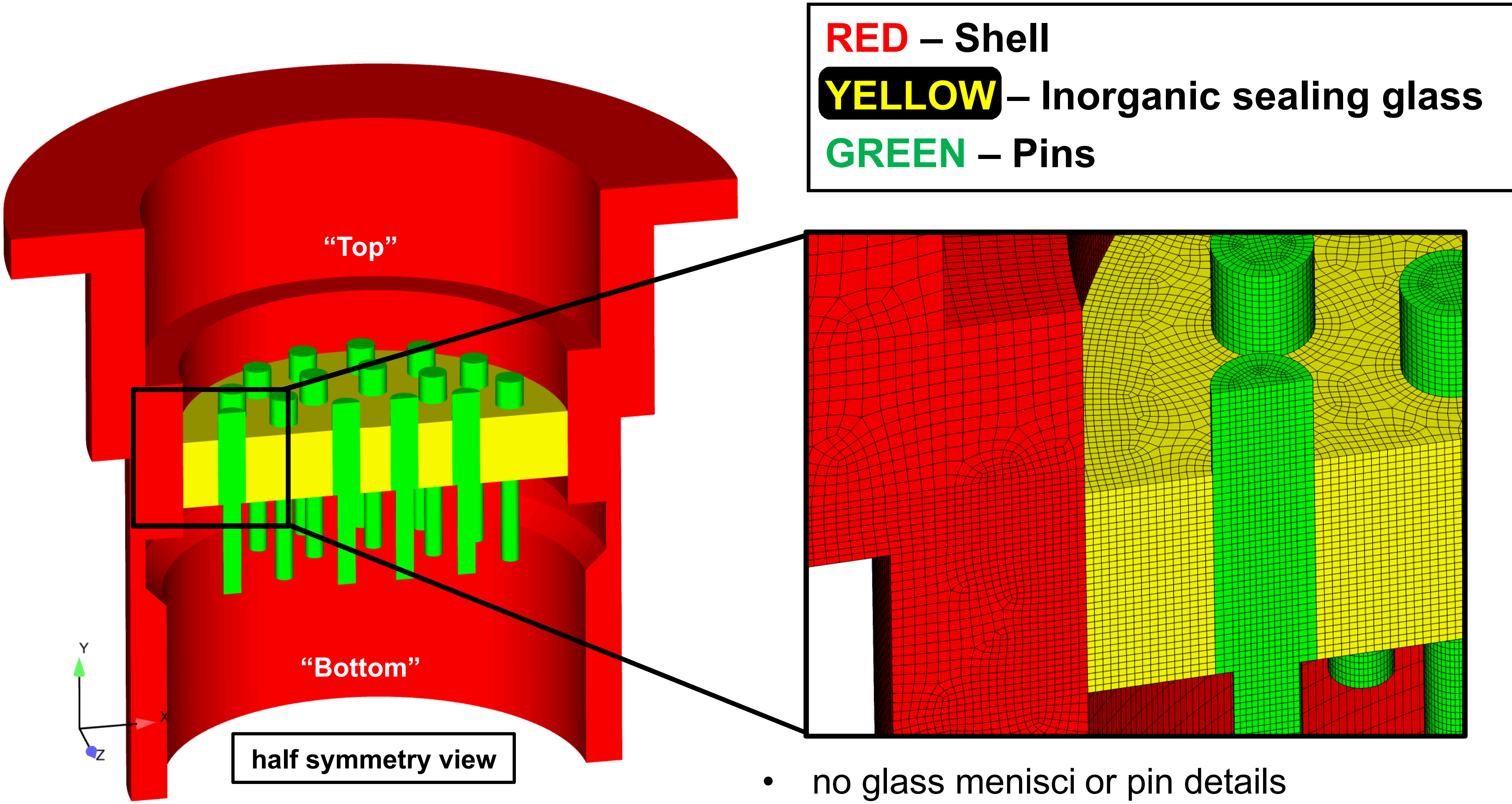
- Simplified Potential Energy Clock (SPEC) Model [1]
  - Predicts behavior of thermorheologically simple materials [2]
    - thermosets, thermoplastics, elastomers, and inorganic glasses
  - Based on the Potential Energy Clock (PEC) model which is derived using the Helmholtz free energy and a material clock through which potential energy accelerates relaxation. [3,4]
    - SPEC easier to calibrate and requires less data to parameterize.
    - stress relaxation, physical aging, creep, and "yield"
    - time and temperature history dependent







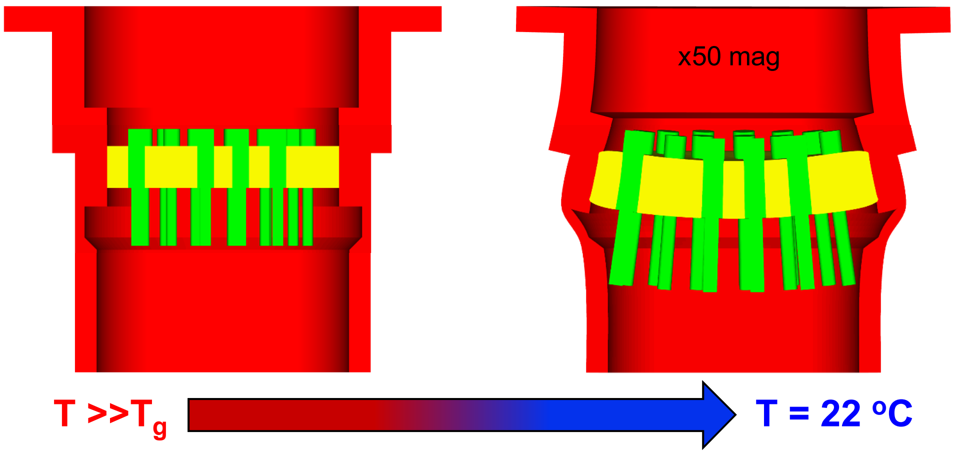
Hermetic Seal Model



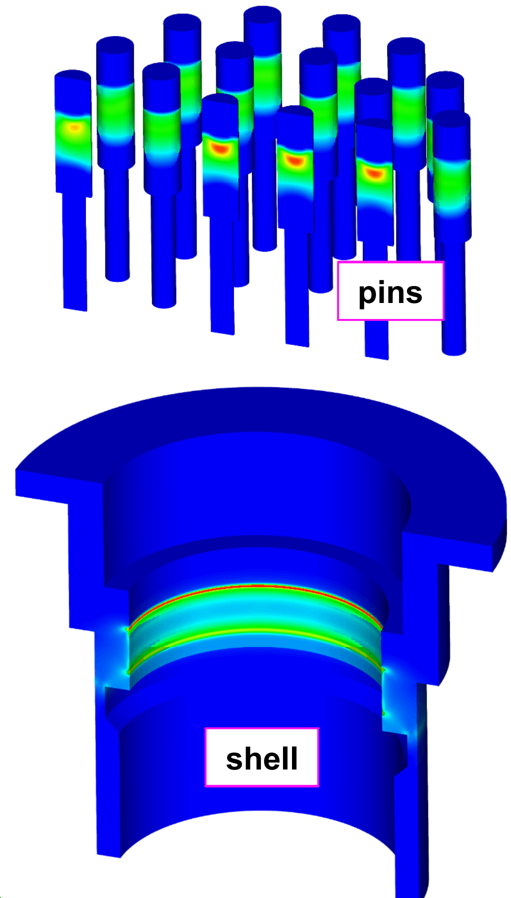
- no glass menisci or pin details
- simplified shell (no threads, rounds, chamfers)
- contiguously meshed interfaces

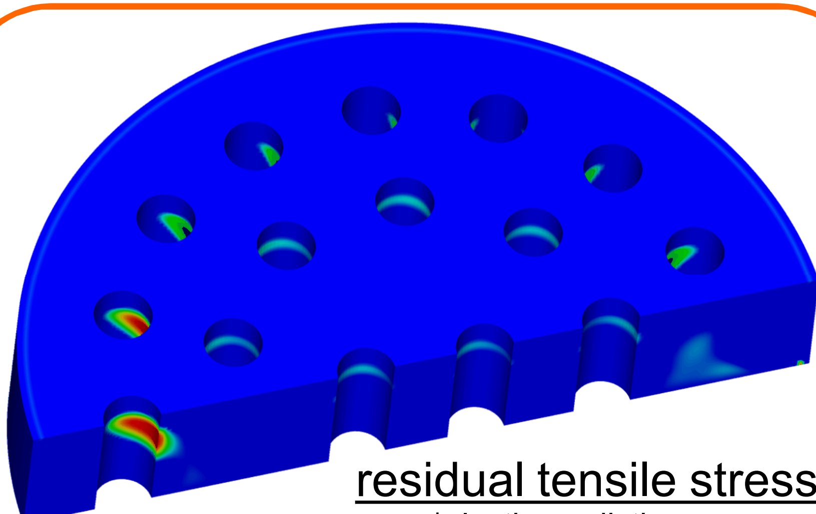
Residual Stress from Sealing Process

compression during cool down



plastic strain in metals



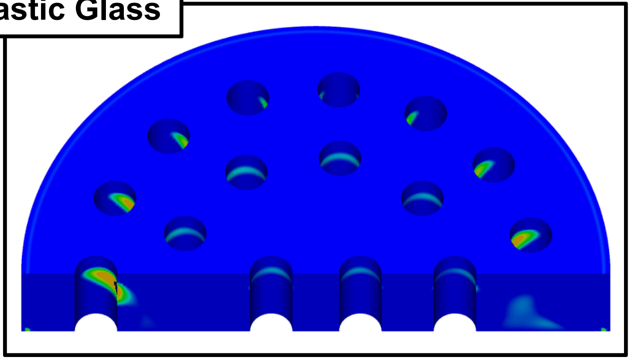


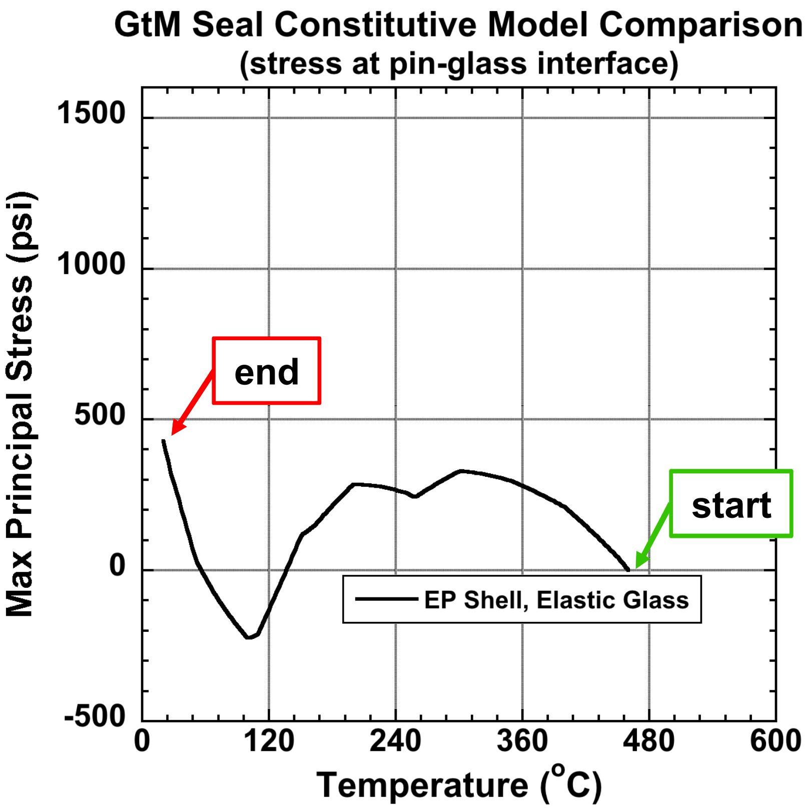
residual tensile stress

*elastic predictions

Constitutive Model Comparison

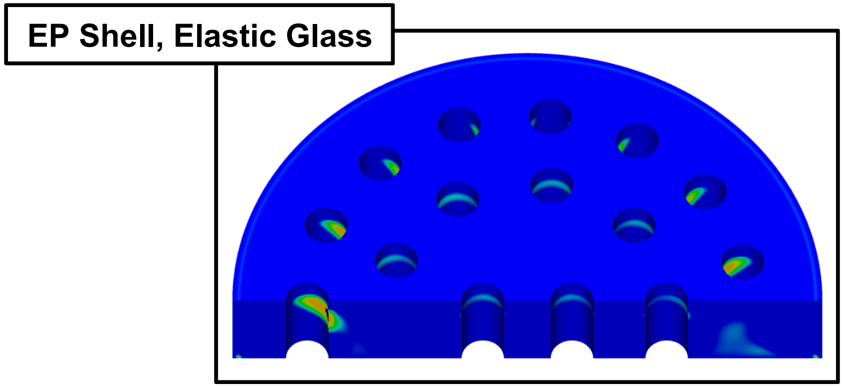
EP Shell, Elastic Glass

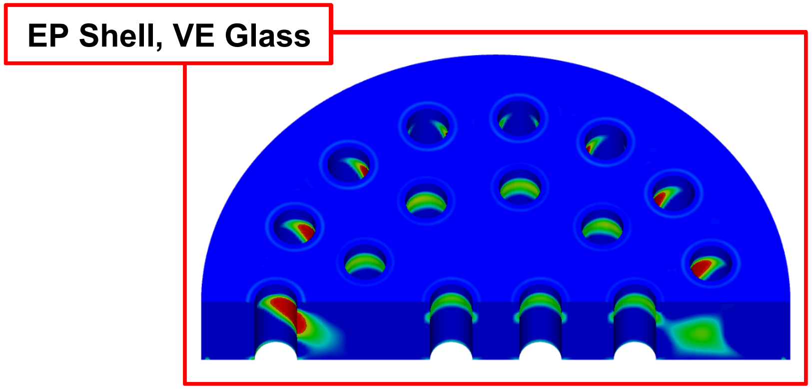


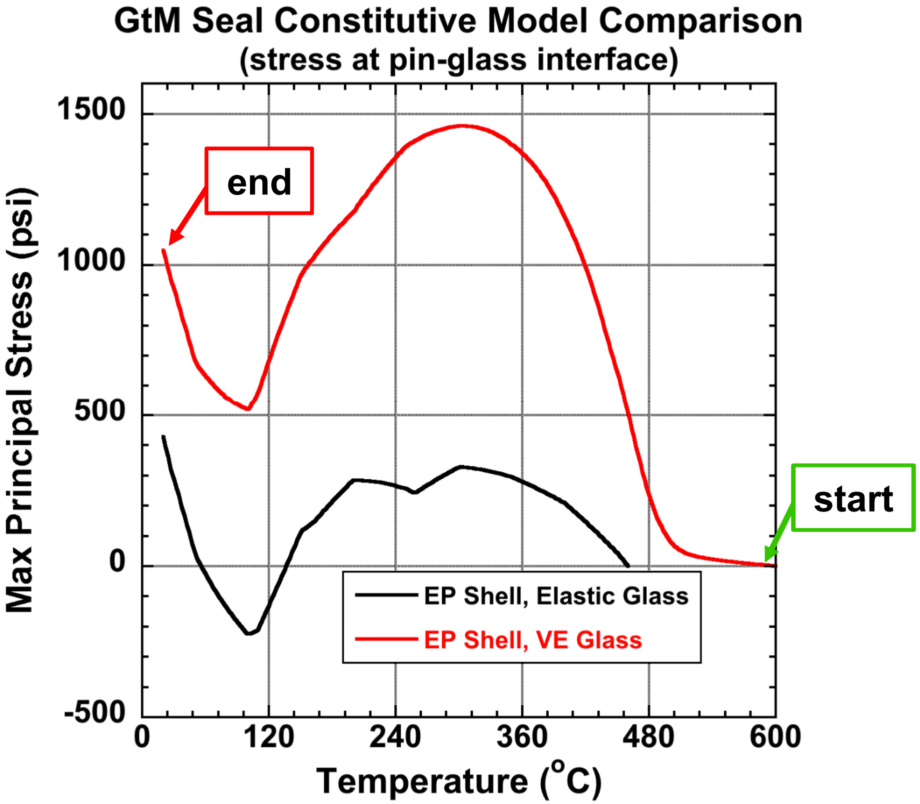


*assumed failure at 5000 psi

Constitutive Model Comparison





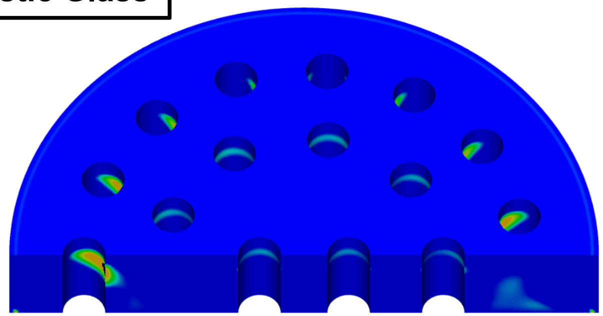


***1 °C/min cooling rate**
***assumed failure at 5000 psi**

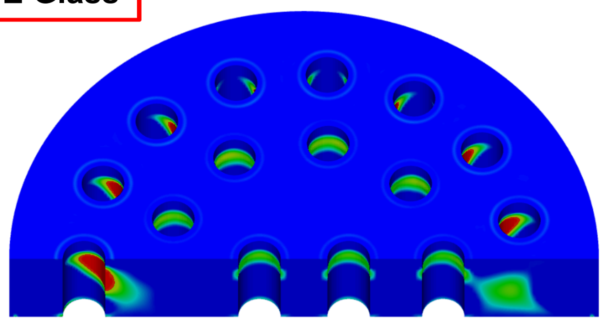
Constitutive Model Comparison

Sandia National Laboratories

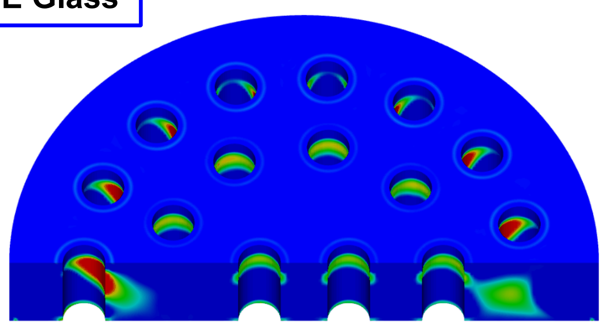
EP Shell, Elastic Glass

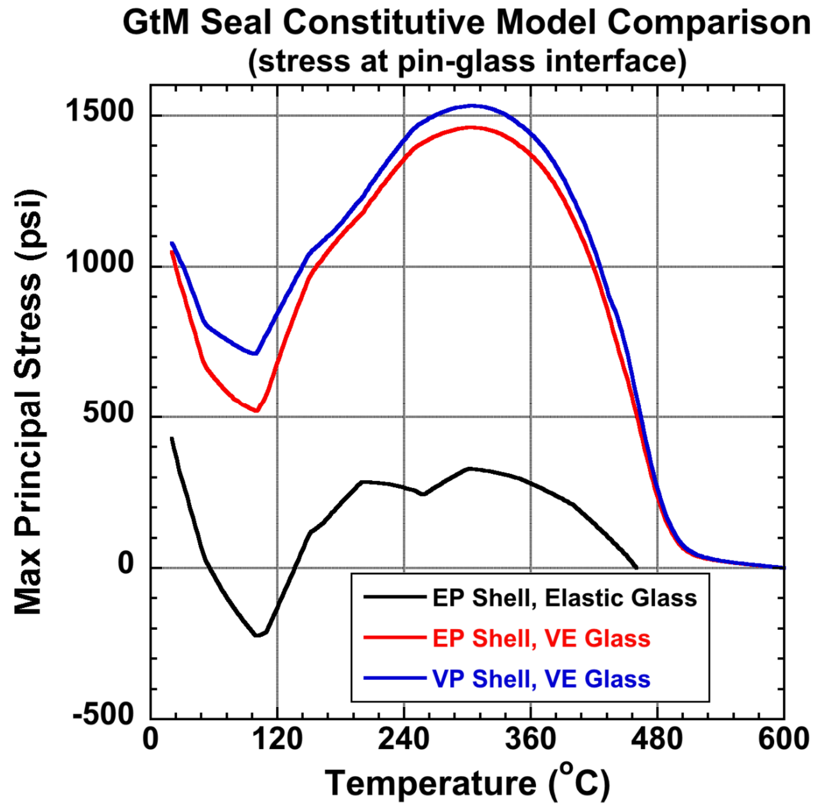


EP Shell, VE Glass



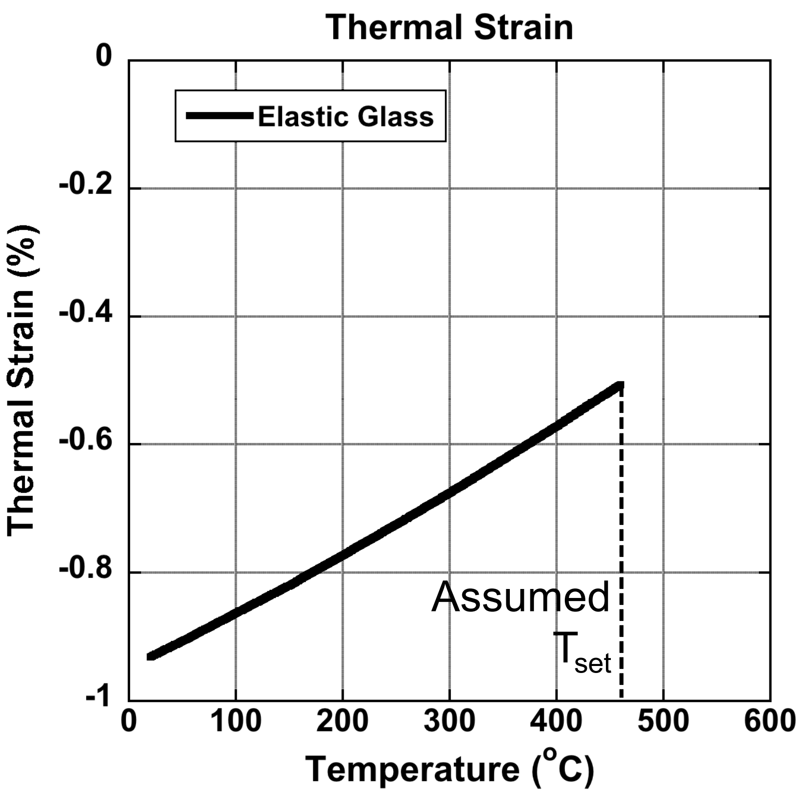
VP Shell, VE Glass

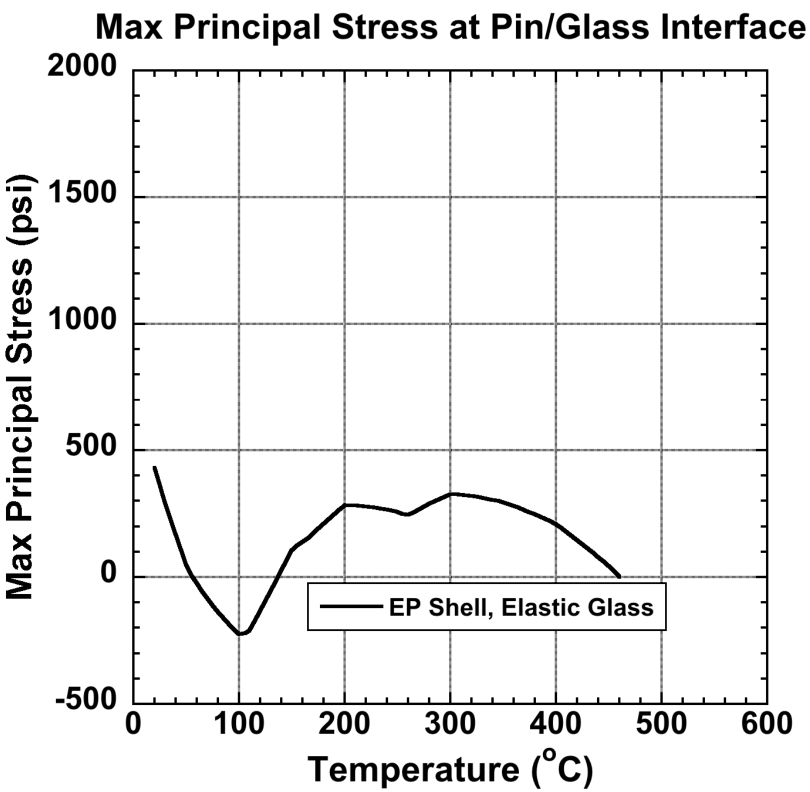




*1 °C/min cooling rate
*assumed failure at 5000 psi

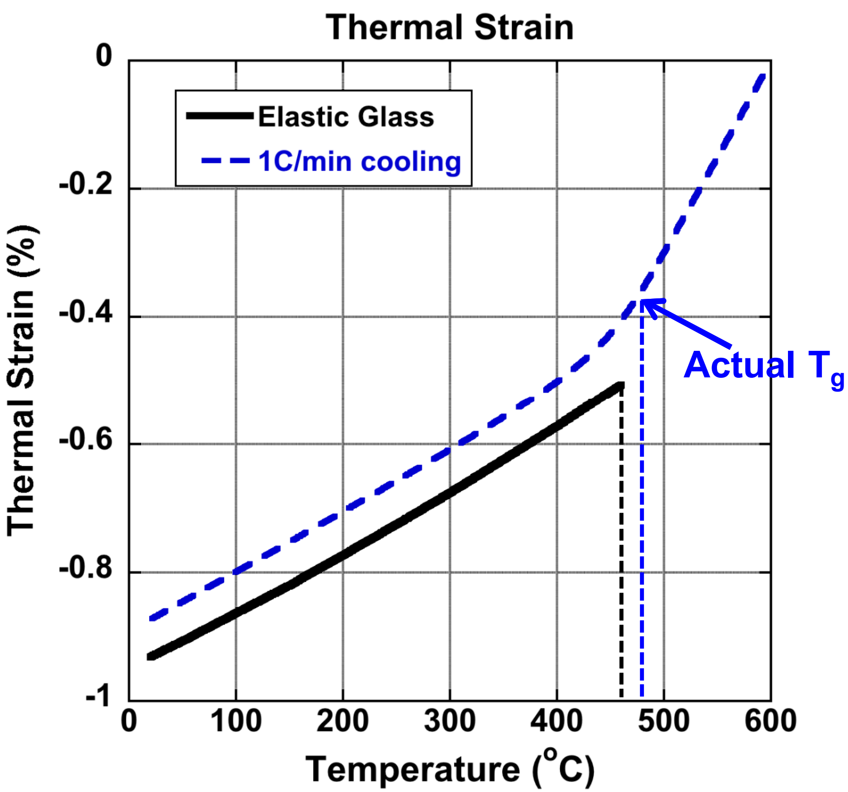
History Dependent Predictions

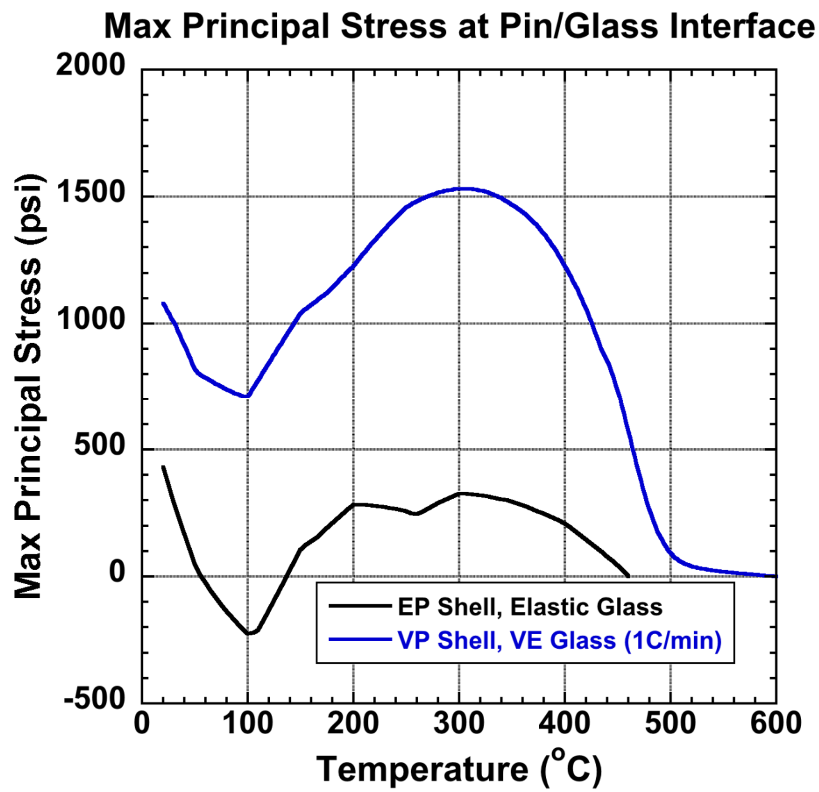




***assumed failure at 5000 psi**

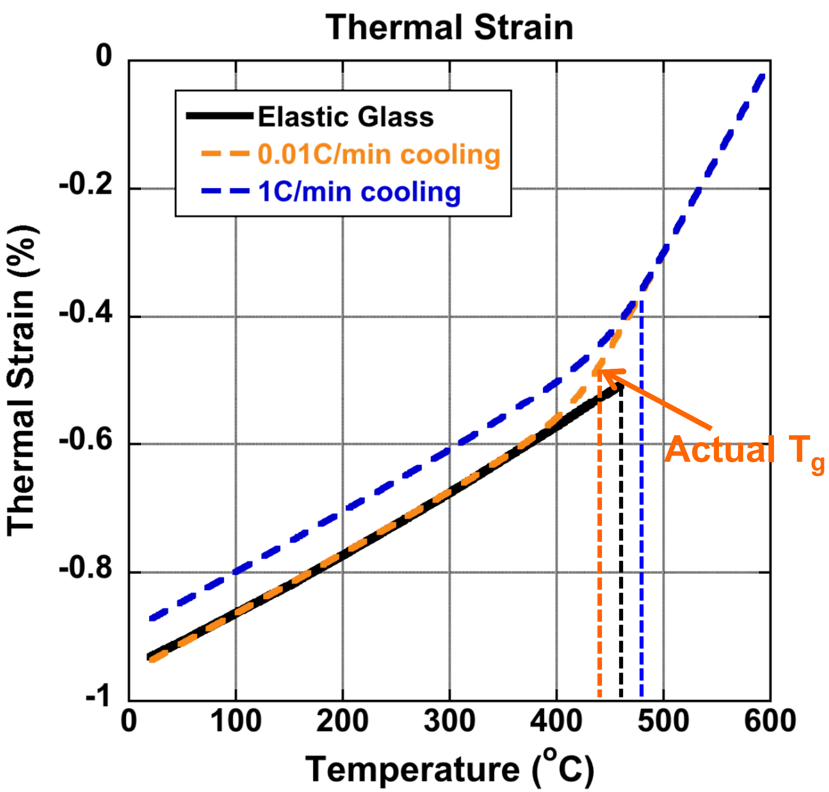
History Dependent Predictions

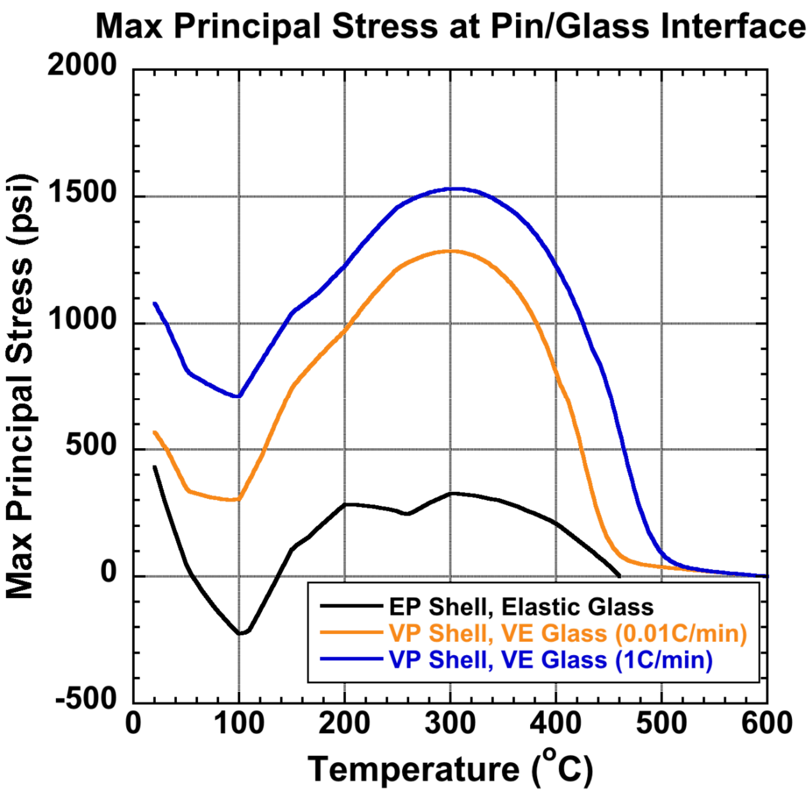




*assumed failure at 5000 psi

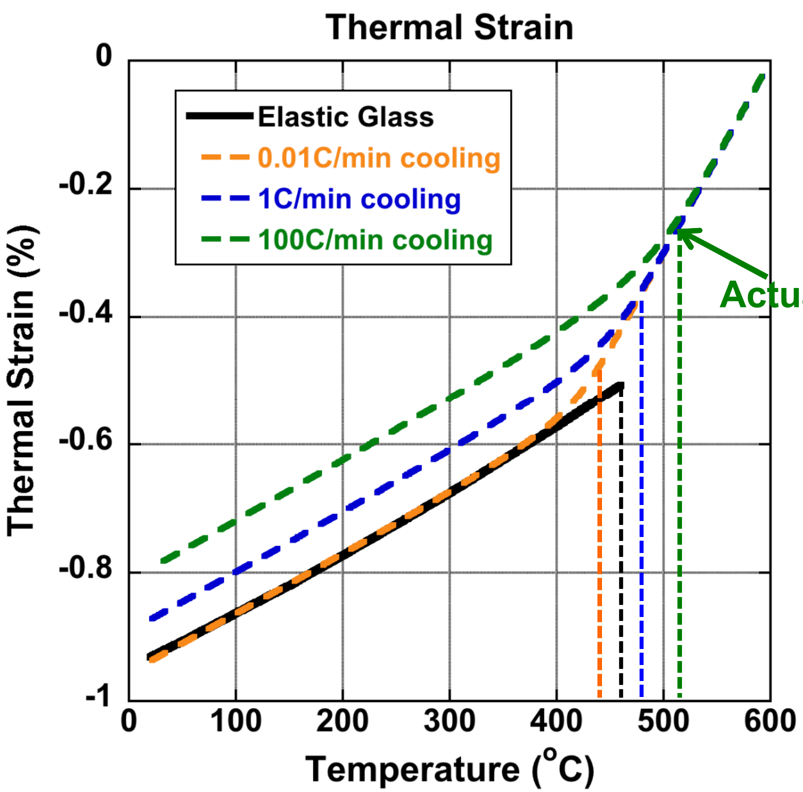
History Dependent Predictions

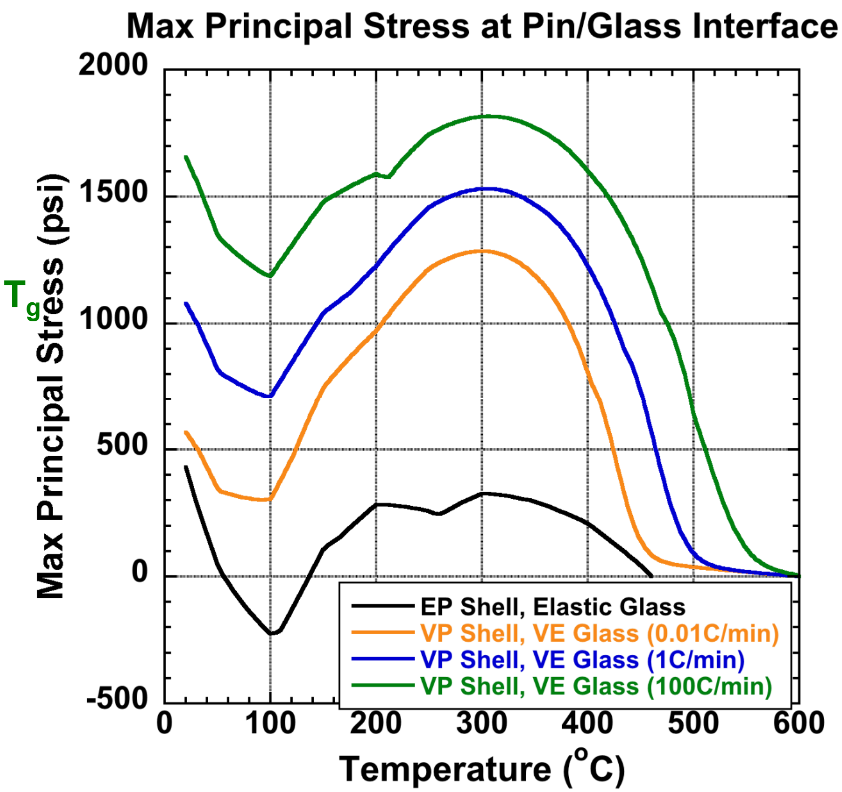




*assumed failure at 5000 psi

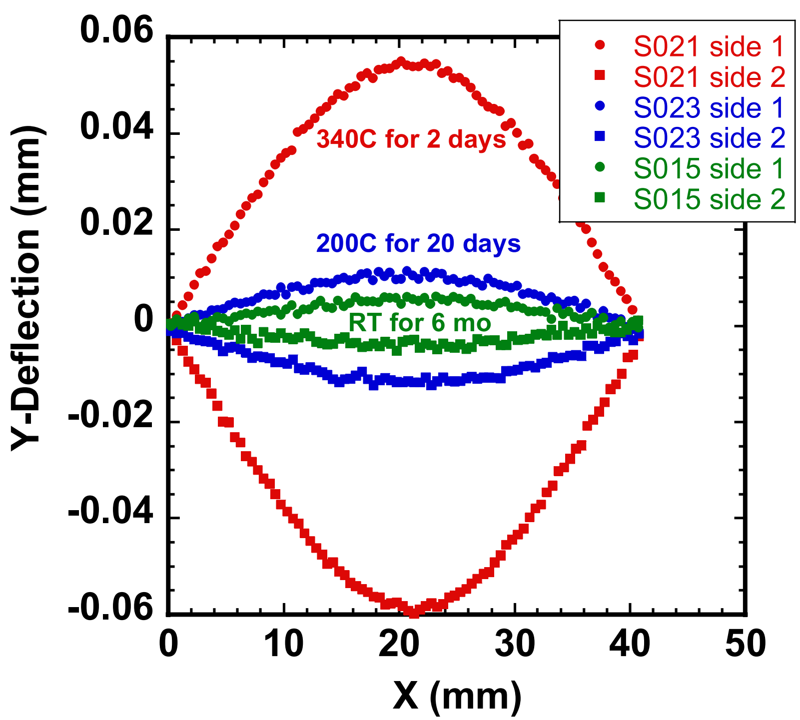
History Dependent Predictions

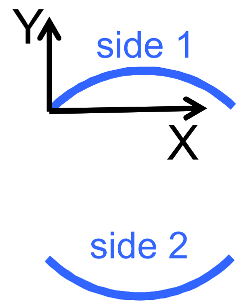




***assumed failure at 5000 psi**

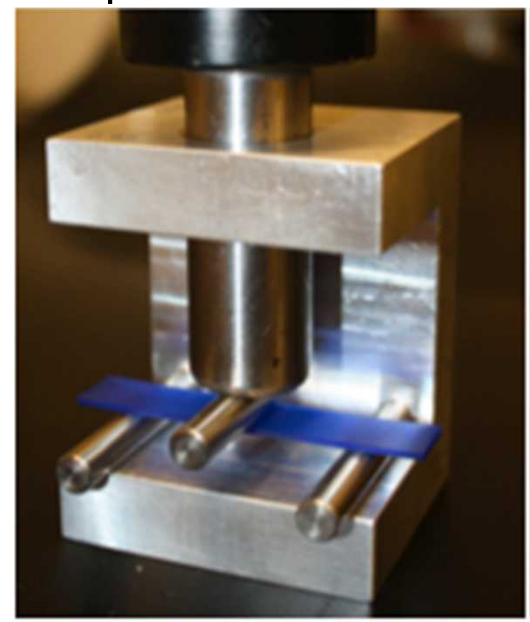
Glass Creep at Room Temperature





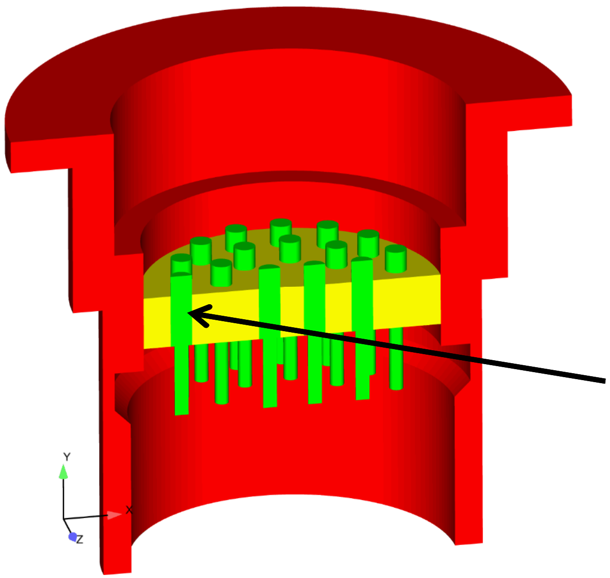
T (°C)	Stress (psi)
340	3500
200	3500
20	4000

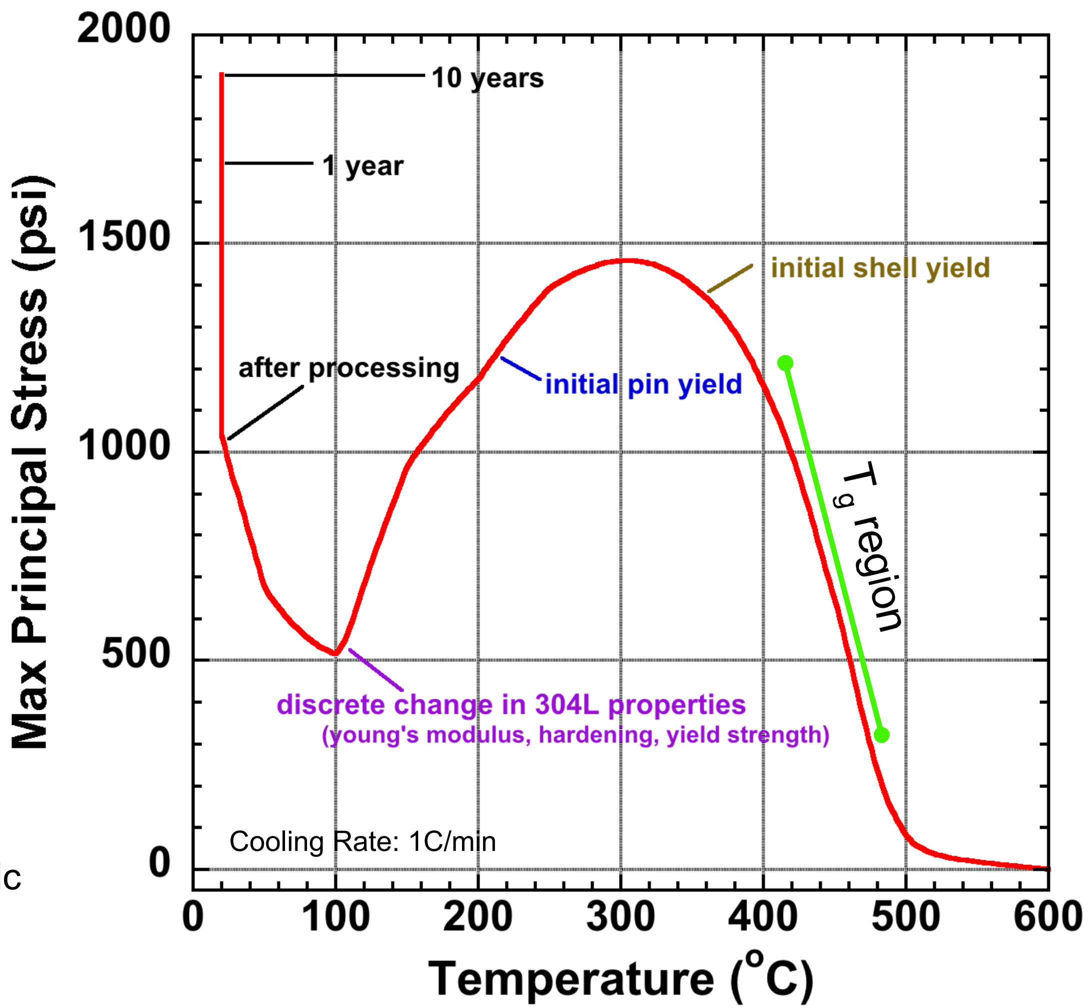
3-Pnt Bending Test
Creep Under Dead Load



. . . . Measurable creep 440°C below glass transition…
So what happens over long periods of time?

Aging of Compression Seal





- 304L Shell: thermoelastic-plastic
- Alloy 52 Pin: thermoelastic-plastic
- Glass: viscoelastic (SPEC)

Back to uncertainties…

- Geometry
  - **5-10%** error within tolerances
  - Glass thickness/position, pin diameter, and various shell features.
- Material properties
  - **150% error** of room temperature predicted tensile stress.
    - Based on elastic → 1 ^{o}C/min viscoelastic
    - Difference in predicted stress depends on temperature examined.
- Cooling rate dependence
  - **50% error** of room temperature predicted tensile stress.
    - 1 ^{o}C/min → 0.1 ^{o}C/min OR 1 ^{o}C/min → 100 ^{o}C/min
    - Difference in predicted stress depends on temperature examined.
- History dependence (aging)
  - 55% increase in tensile stress after 1 year.
  - Additional testing needed to validate aging predictions…

Conclusion

- FEA models can lack geometry and material model detail and still predict qualitative trends to direct the design process.
- Predicted tensile stress when using viscoelastic glass is significantly higher than assuming elastic properties.
- Actual history (processing, aging) makes a difference.
- Quantitative predictions will require physically based models.
- Uncertainty in model predictions are difficult to quantify, but easy to identify! 👍

QUESTIONS?

References

1. Adolf, Douglas B., Chambers, Robert S., Neidigk, Matthew A., "A simplified potential energy clock model for glassy polymers." *Elsevier Polymer* 50 (2009): 4257-4269.
2. Chambers, Robert S., Tandon, Rajan, Stavig, Mark E., "Characterization and calibration of a viscoelastic simplified potential energy clock model for inorganic glasses." *Elsevier Journal of Non-Crystalline Solids* 432 (2016): 545-555.
3. Caruthers, James M., Adolf, Douglas B., Chambers, Robert S., Shrikhande, Prashant, "A thermodynamically consistent, nonlinear viscoelastic approach for modeling glassy polymers." *Elsevier Polymer* 45 (2004): 4577-4597.
4. Adolf, Douglas B., Chambers, Robert S., Caruthers, James M., "Extensive validation of a thermodynamically consistent, nonlinear viscoelastic model for glassy polymers." *Elsevier Polymer* 45 (2004): 4599-4621.