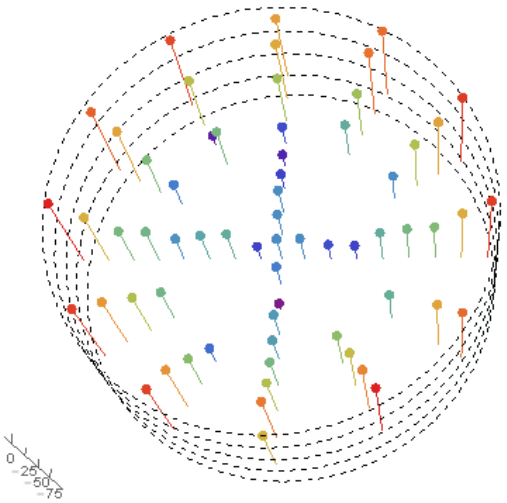
EXPERIMENTAL DATA UNCERTAINTY, CALIBRATION AND VALIDATION OF A VISCOELASTIC POTENTIAL ENERGY CLOCK MODEL FOR INORGANIC SEALING GLASSES

SAND2016-4635C



Ryan Jamison, Vicente Romero, Mark Stavig, Thomas Buchheit, & Clay Newton

Wednesday, May 18, 2016

ASME Verification & Validation Symposium

Las Vegas, NV, May 18-20, 2016

Sandia National Laboratories

Exceptional service in the national interest

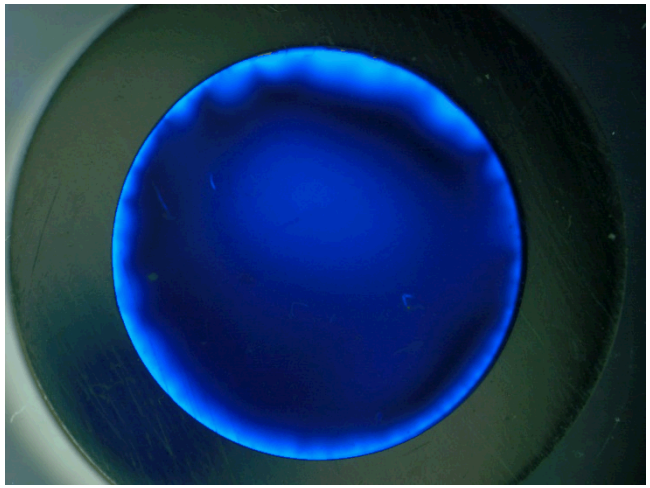
U.S. DEPARTMENT OF ENERGY

NNSA 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

Sealing Glass Introduction

- Uses
  - Hermeticity ➡ hermetic connectors
  - Insulation
- Important properties
  - Bulk & shear moduli
  - Glass transition ➡ CTE
  - Material history
  - Relaxation functions
- Why?
  - Residual stress
  - Structural relaxation

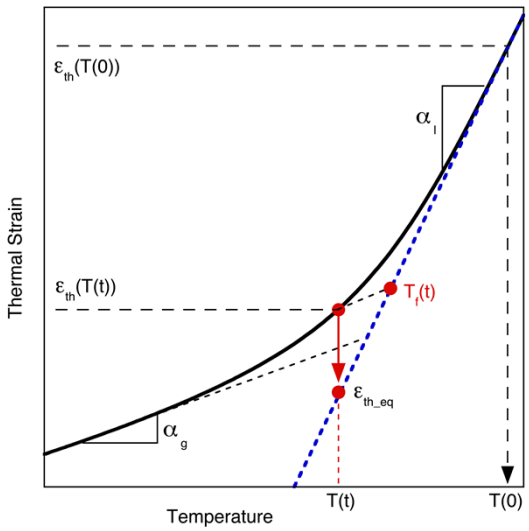


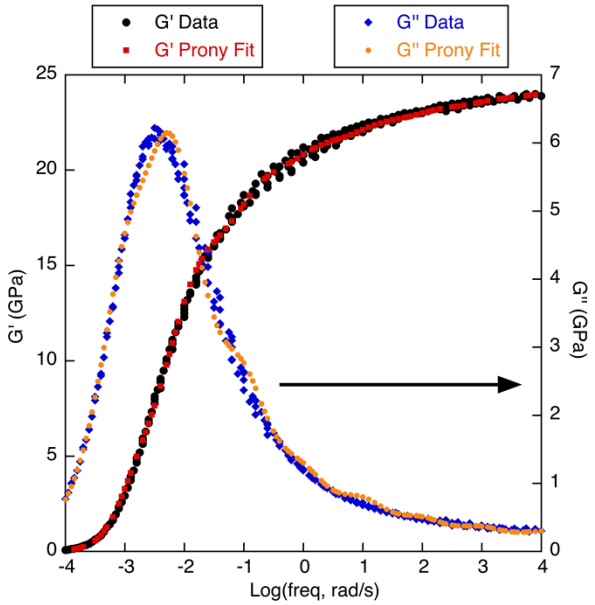
The SPEC Model

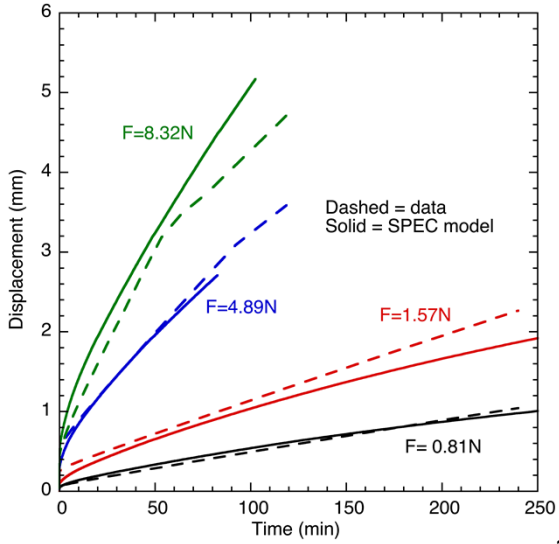
The Simplified Potential Energy Clock Model[1] allows for:

- Stress/strain during cooldown
- Structural relaxation
- Creep

The SPEC model was calibrated for Schott 8061 sealing glass[2]

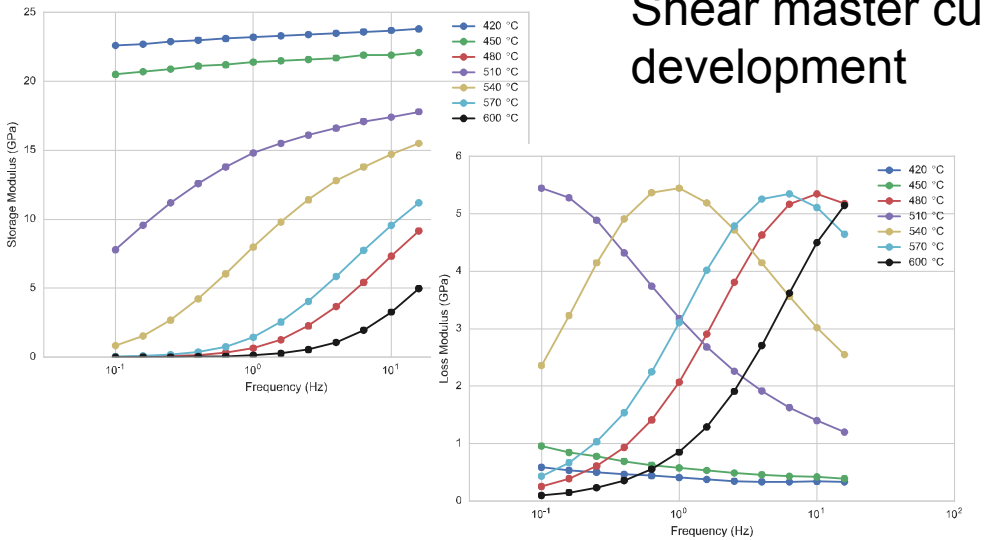


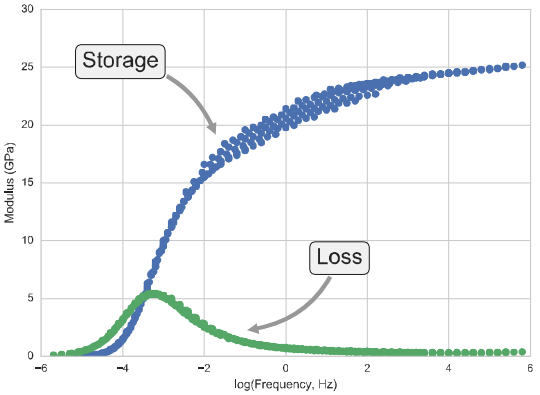


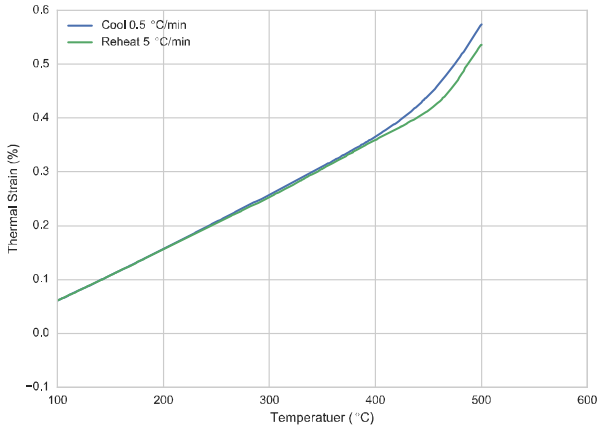


SPEC Calibration

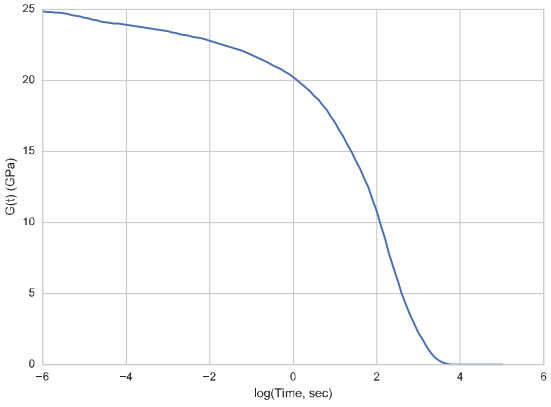
Shear master curve development



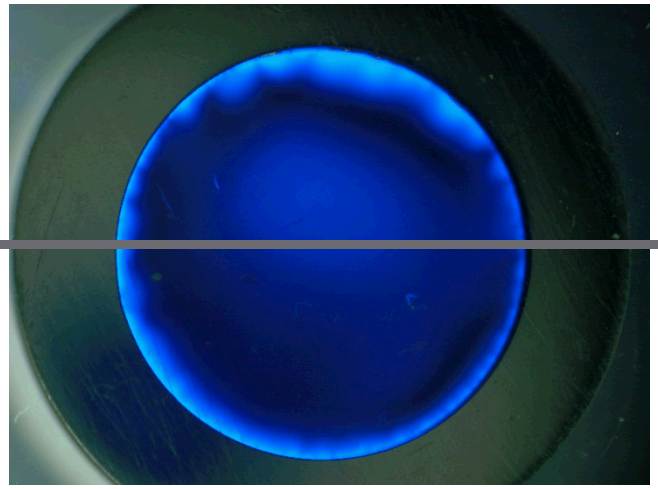




William Watts Prony series calibration



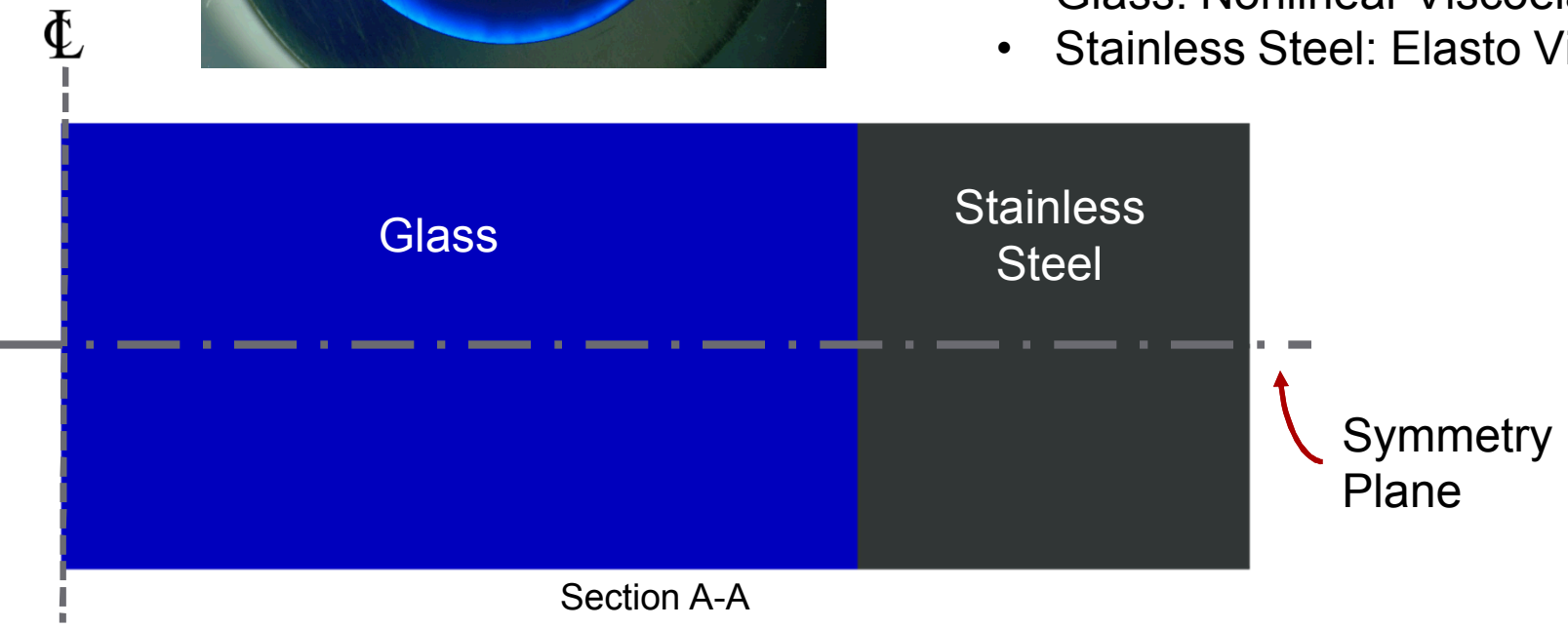
FE Model of Simplified GTMS



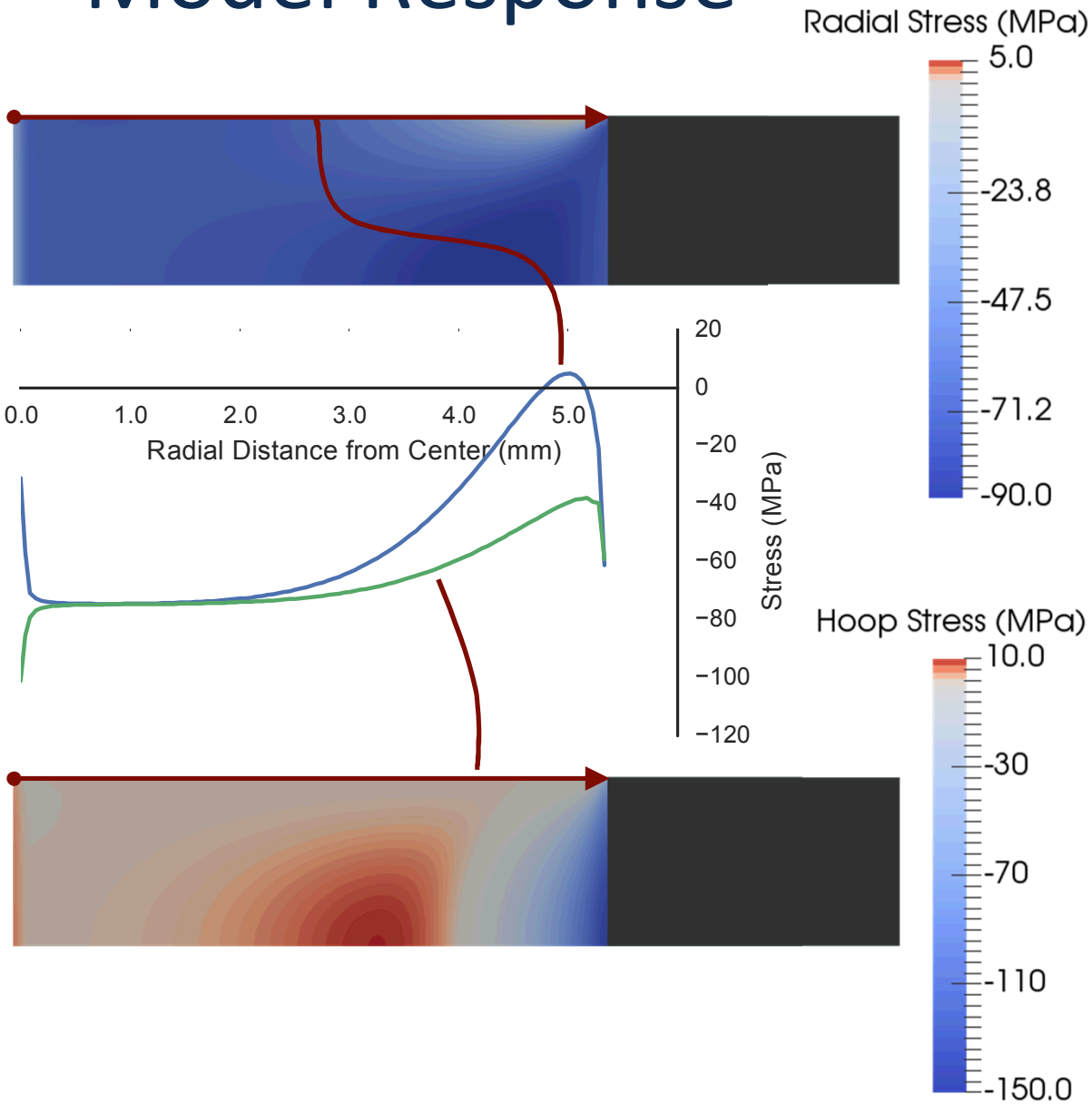
Concentric seal geometry
- Outer diameter = 16.1 mm
- Inner diameter = 10.8 mm
- Glass thickness = 3.1 mm

Processing
- Cool from 600 ºC to 20 ºC

Materials
- Glass: Nonlinear Viscoelastic
- Stainless Steel: Elasto Viscoplastic



Model Response



Radial Stress

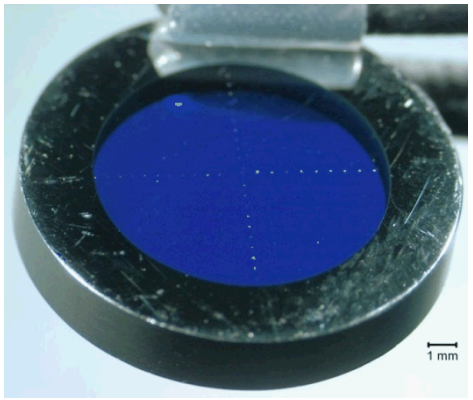
- Glass is largely in compression
- A region of tensile stress exists on surface of glass

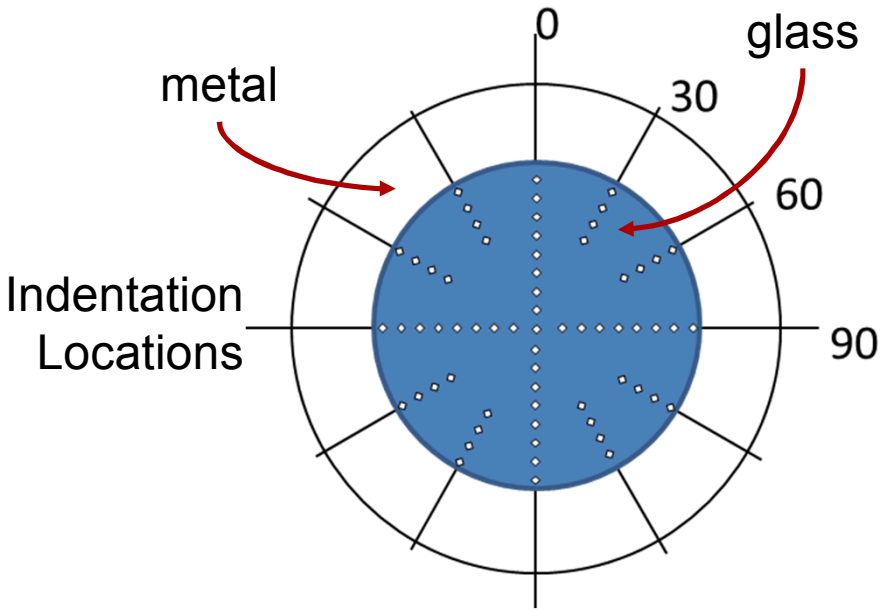
Hoop Stress

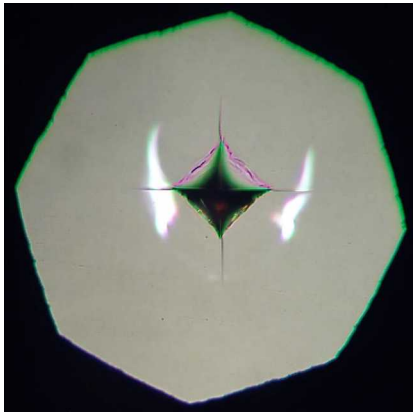
- Low stress on the surface of the glass
- Region of tensile stress in the center of the glass

Indentation Technique

Simplified Glass-to-Metal Seal







K_I Stress Intensity Factor

K'_{Ic} Stress Free Fracture Toughness

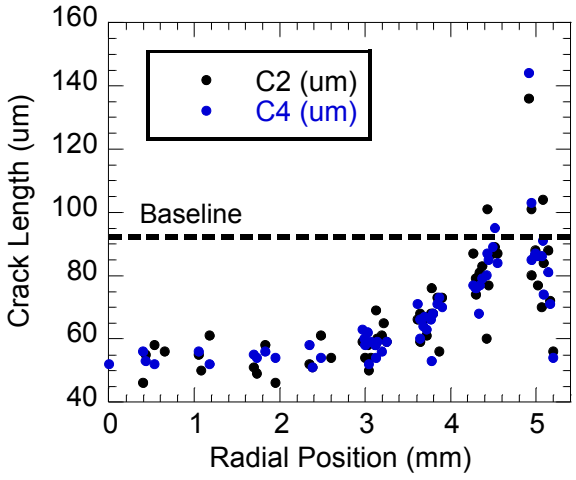
c Crack Length

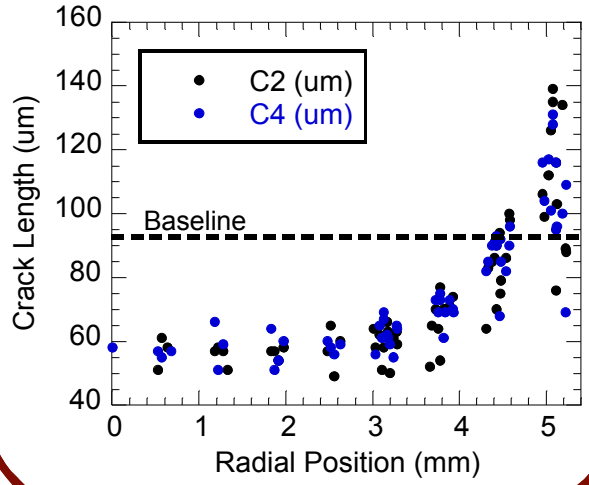
$$\sigma = \frac{-(K_I - K'_{Ic})}{1.12(\pi c)^{1/2}}$$

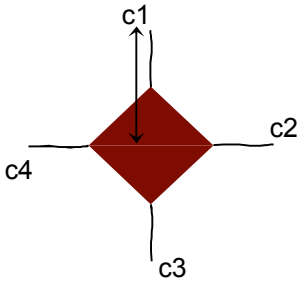
Measured Crack Lengths

Sandia National Laboratories

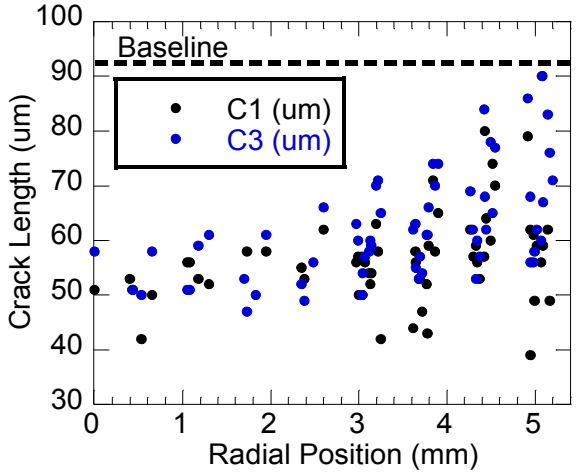
Radial Direction

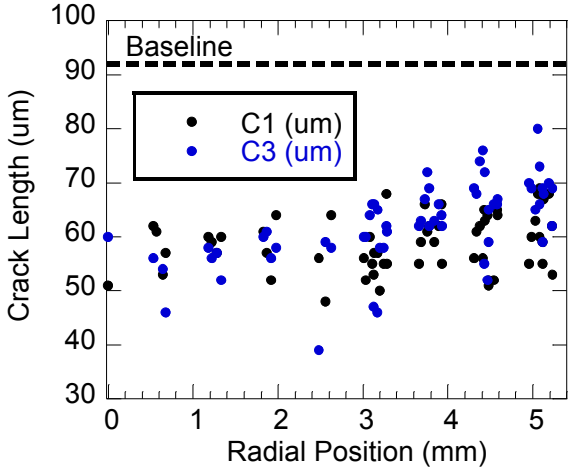




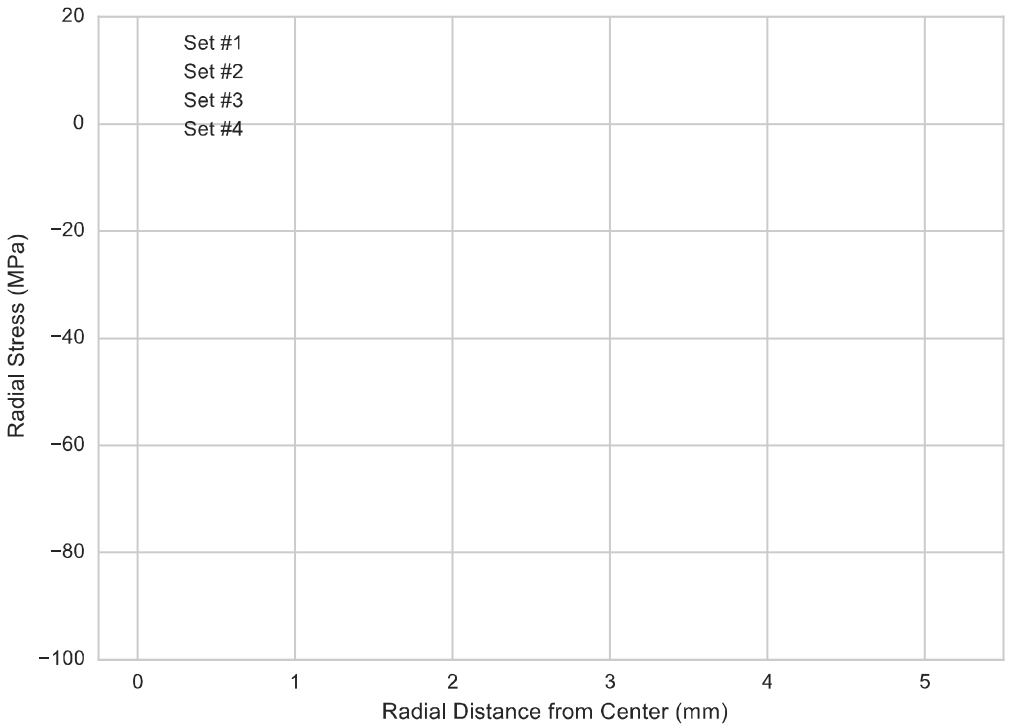


Tangential Direction





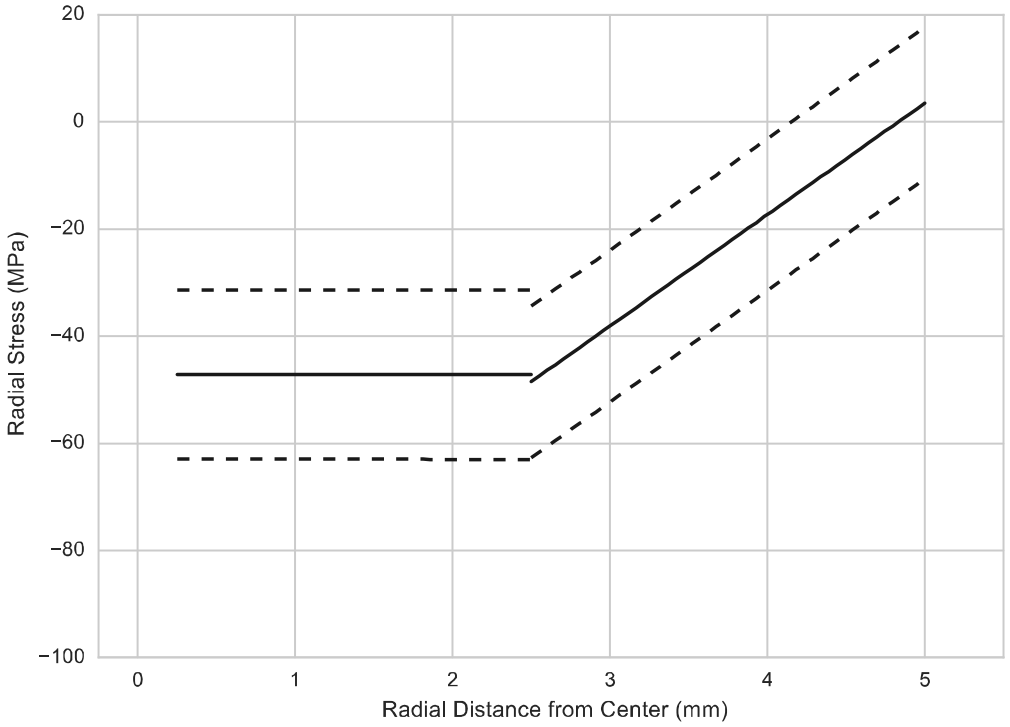
Calculated Radial Stress



Set	Polished	Oxide
#1	Yes	Yes
#2	Yes	No
#3	Yes	Yes
#4	No	Yes

Crack lengths measured on four samples

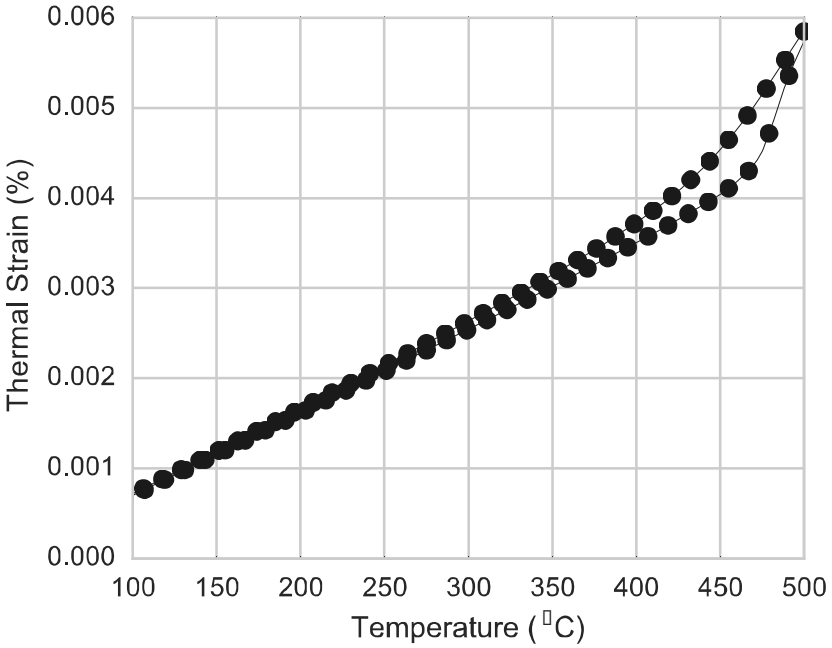
Analysis of Radial Stress Data



Data analysis process

- Only considered data from polished samples
- Data in the range of $0.25 > x > 5.0$ considered outliers

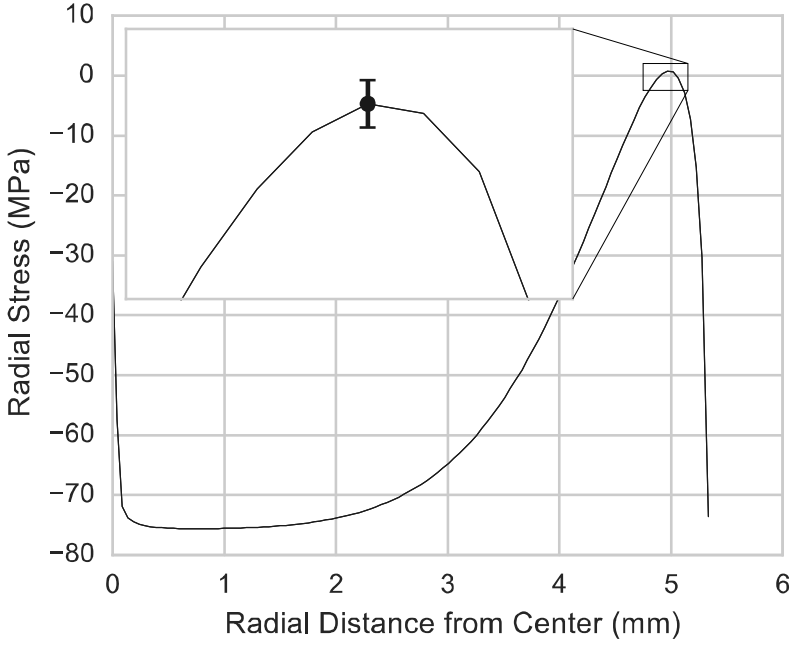
Thermal Strain Uncertainty



Uncertainty exists in the calibration of the prony series representing the thermal strain:

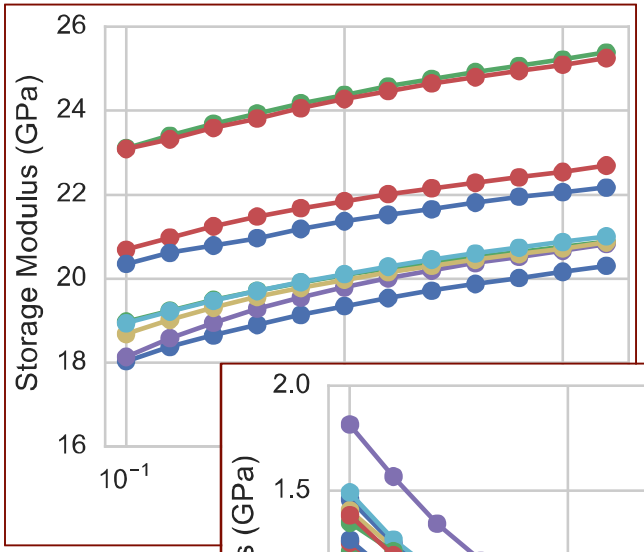
- $\tau \pm 10\%$
- $\beta \pm 10\%$

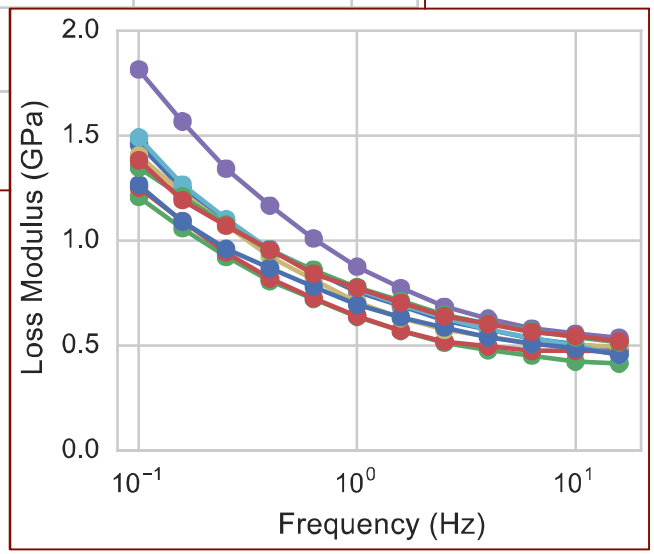
The mean of the maximum radial stress is 0.73 MPa with a standard deviation of 0.40 MPa

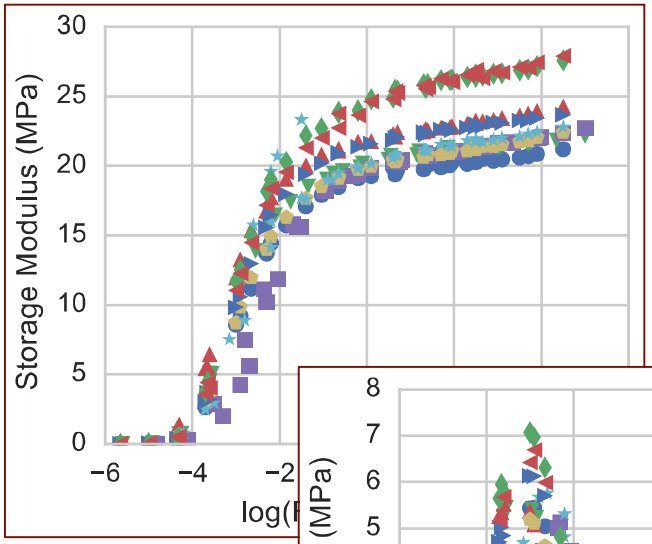


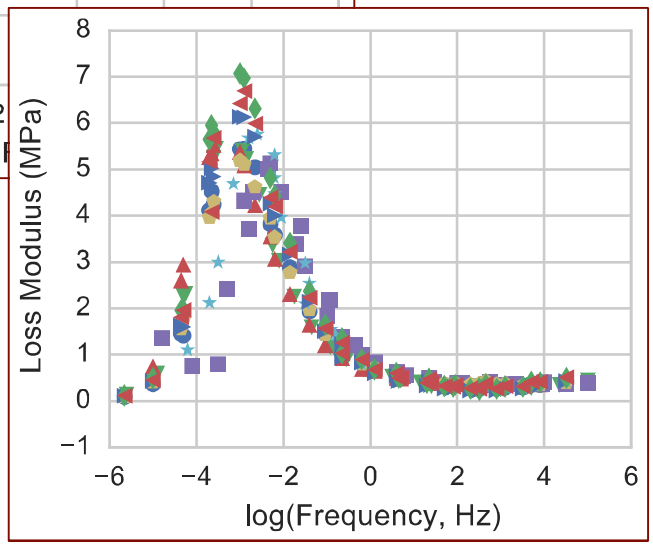
Shear Master Curve Data

Storage and loss moduli for 10 samples at 460 ºC



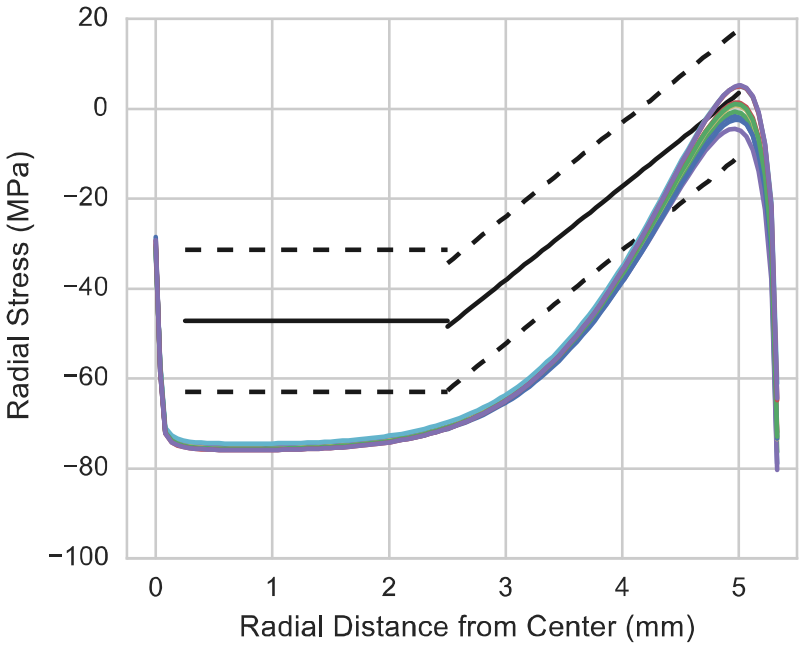






Shifted storage and loss modulus

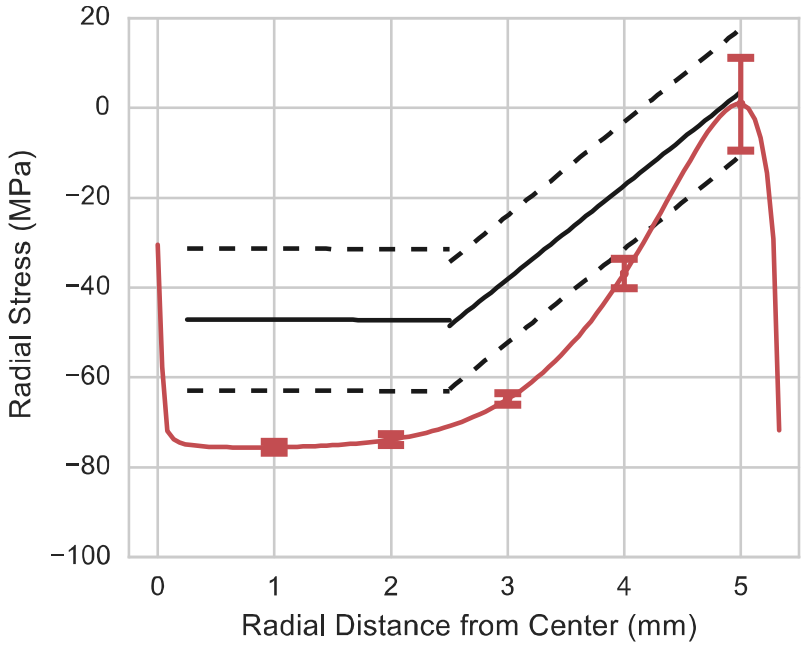
Shear Master Curve Uncertainty



- Mean model response over predicts compression → limitation of experimental method?
- At location of highest stress, model and experimental results exhibit similar level of confidence

- Results of 10 simulations compared to the indentation residual stress measurements
- Experimental results bound model results at highest stress

Error bars: 90% conf. w/ 95% coverage



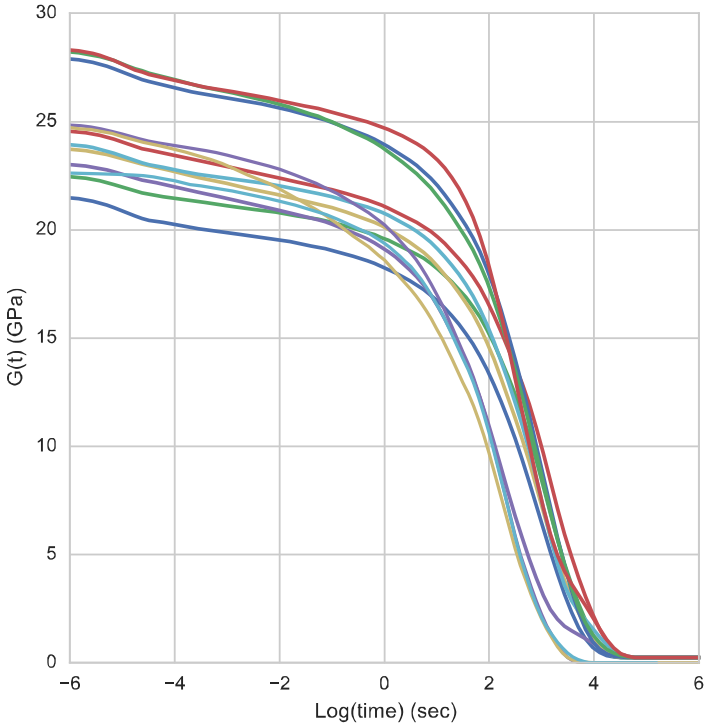
Conclusions

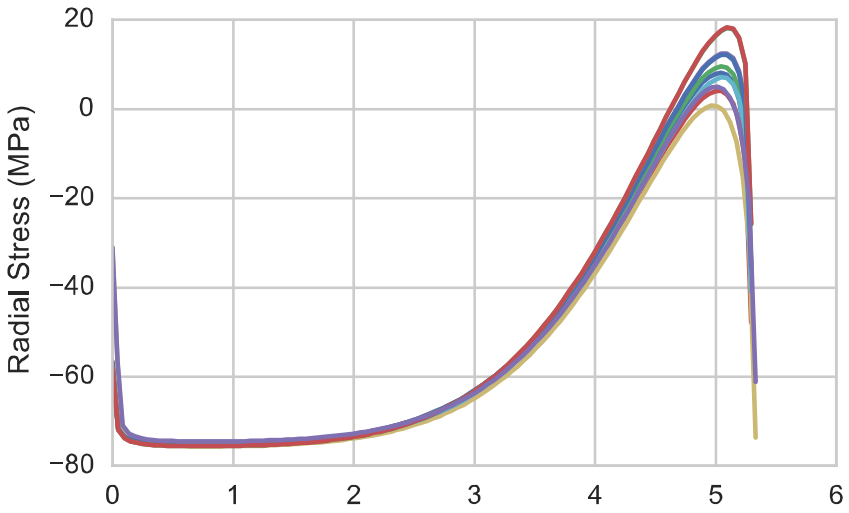
- Uncertainty in model inputs of nonlinear viscoelastic properties for sealing glass evaluated
- Indentation technique used to infer residual stress in simple glass-to-metal seal (GTMS)
- Residual radial stress on surface of GTMS showed little sensitivity to prony series calibration terms (τ & β)
- 10 shear master curve measurements completed, models calibrated, and uncertainty propagated through model
- The variation in the model response at the peak stress captured 95% of experimental data with 90% confidence
- Need to further investigate behavior towards the center of GTMS

References

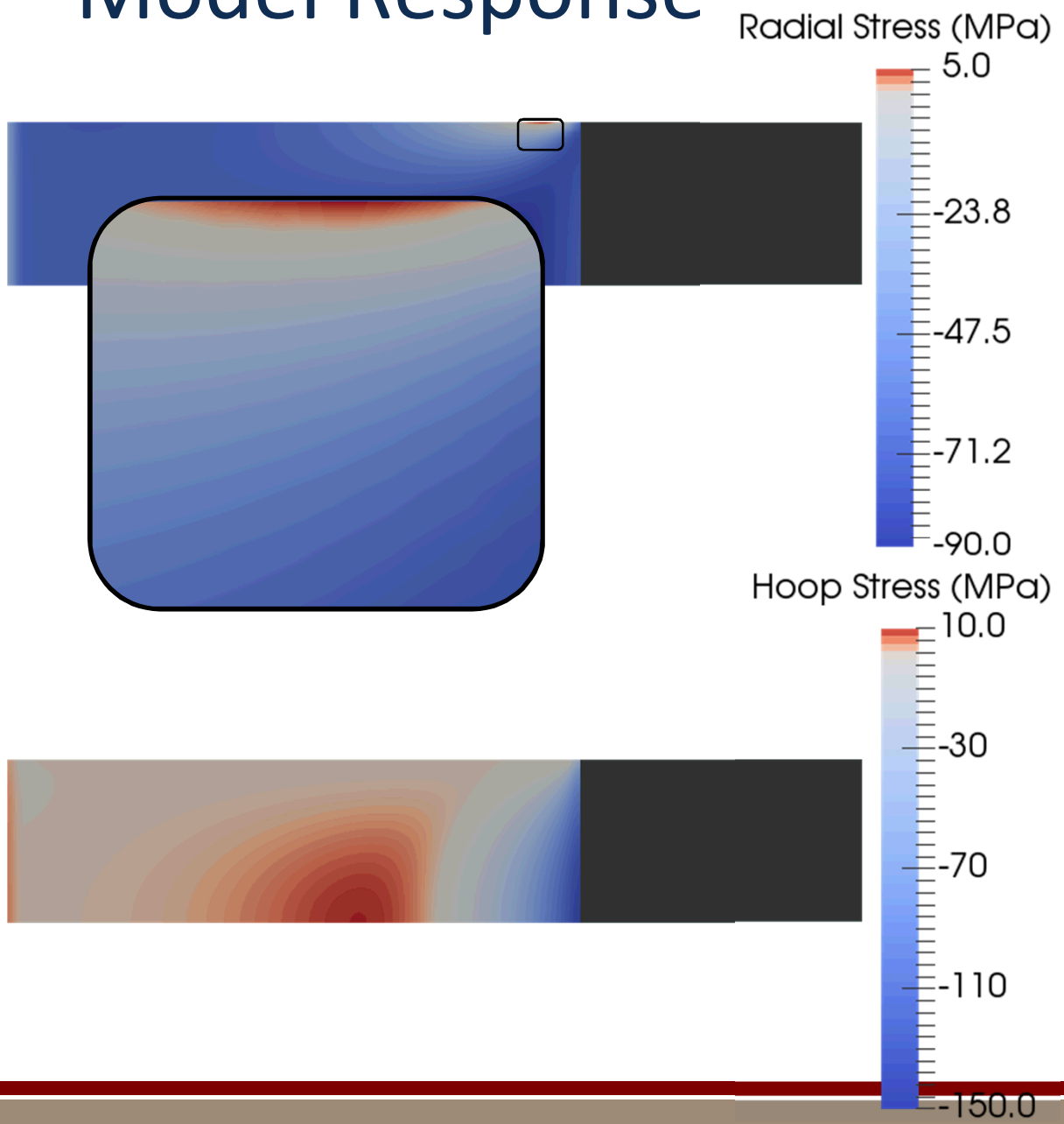
1. D.B. Adolf, *et al.*, A simplified potential energy clock model for glassy polymers, *Polymer*, Volume 50, Issue 17, 12 August 2009, Pages 4257-4269, ISSN 0032-3861, http://dx.doi.org/10.1016/j.polymer.2009.06.068.
2. R.S. Chambers, *et al.,* Characterization and calibration of a viscoelastic simplified potential energy clock model for inorganic glasses, *J. Non-Cryst. Solids* (2015), http://dx.doi.org/10.1016/j.jnoncrysol.2015.06.005

Shear Master Curve Uncertainty





Model Response



Radial Stress

- Glass is largely in compression
- A region of tensile stress exists on surface of glass

Hoop Stress

- Low stress on the surface of the glass
- Region of tensile stress in the center of the glass

FE Model of Simplified GTMS