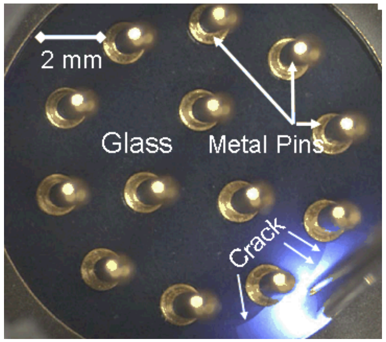
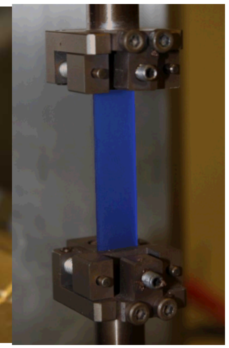
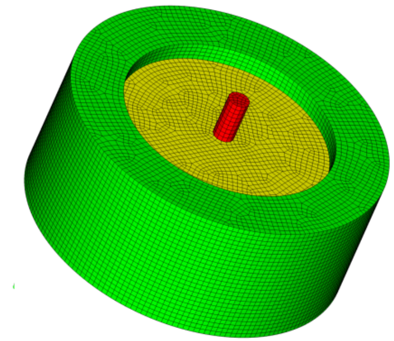
SAND2016-4917C

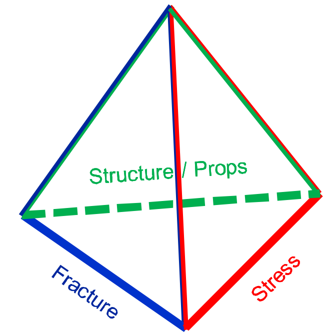
*Exceptional service in the national interest*

Sandia National Laboratories








# Characterizing and Predicting Stress and Structural Relaxation in Glass

[a]Kevin T. Strong Jr, [b]Brenton Elisberg, [b]Ryan D Jamison, and [c]Kevin G Ewsuk

Glass and Optical Materials Division Meeting

May 24, 2016

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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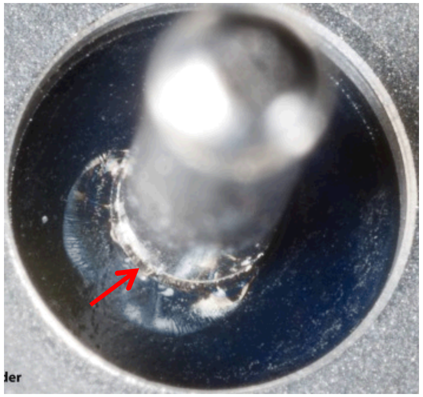
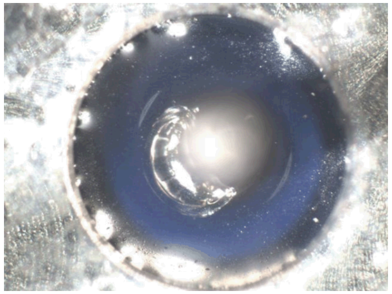
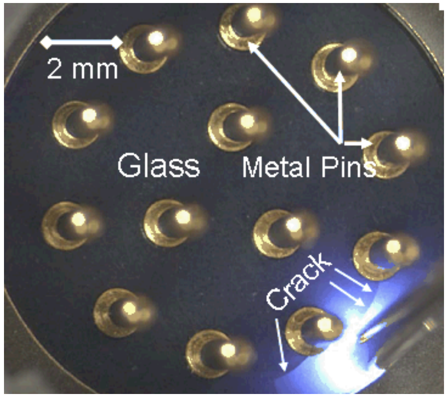
# Outline

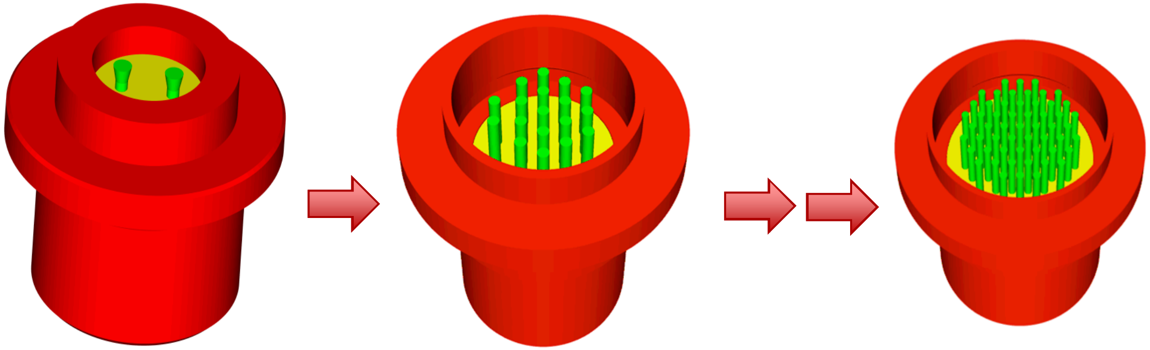
- Motivation
- Approach
- Model Calibration Experiments
- Model Validation
- Current Applications
- Conclusions

# Motivation – Glass to Metal Seals



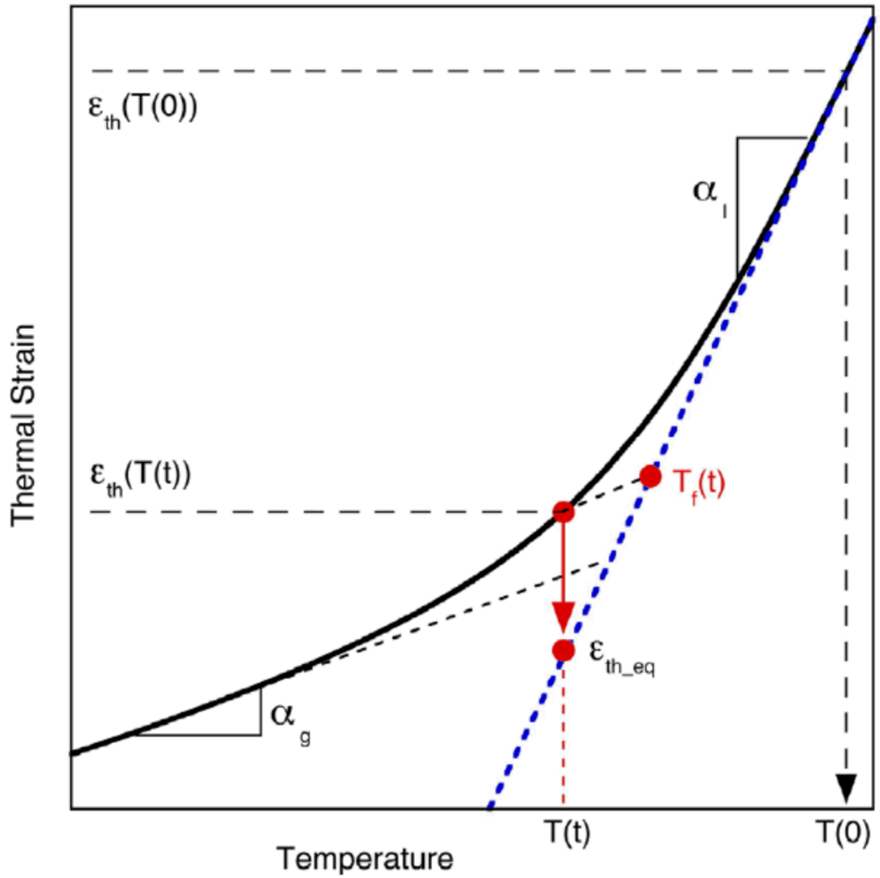




*Higher fidelity stress modeling is needed to address shrinking performance margin in more complex designs*

# Background – Structural Relaxation



# Finite Element (FE) Modeling Predicts Residual Stress In Glass-to-Metal Seals

— routine
— missing

crack initiation

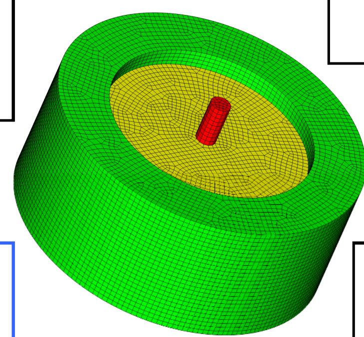
pin plasticity $\sigma_y(T)$, $E_H(T)$

SS small strain

shell plasticity $\sigma_y(T)$, $E_H(T)$

idealized geometry

maximum stress failure criterion



elastic glass

glass transition

bonded interfaces

viscoelastic glass

assumed stress-free temperature, $T_{set}$

prescribed CTE $\varepsilon_{th}(T)$

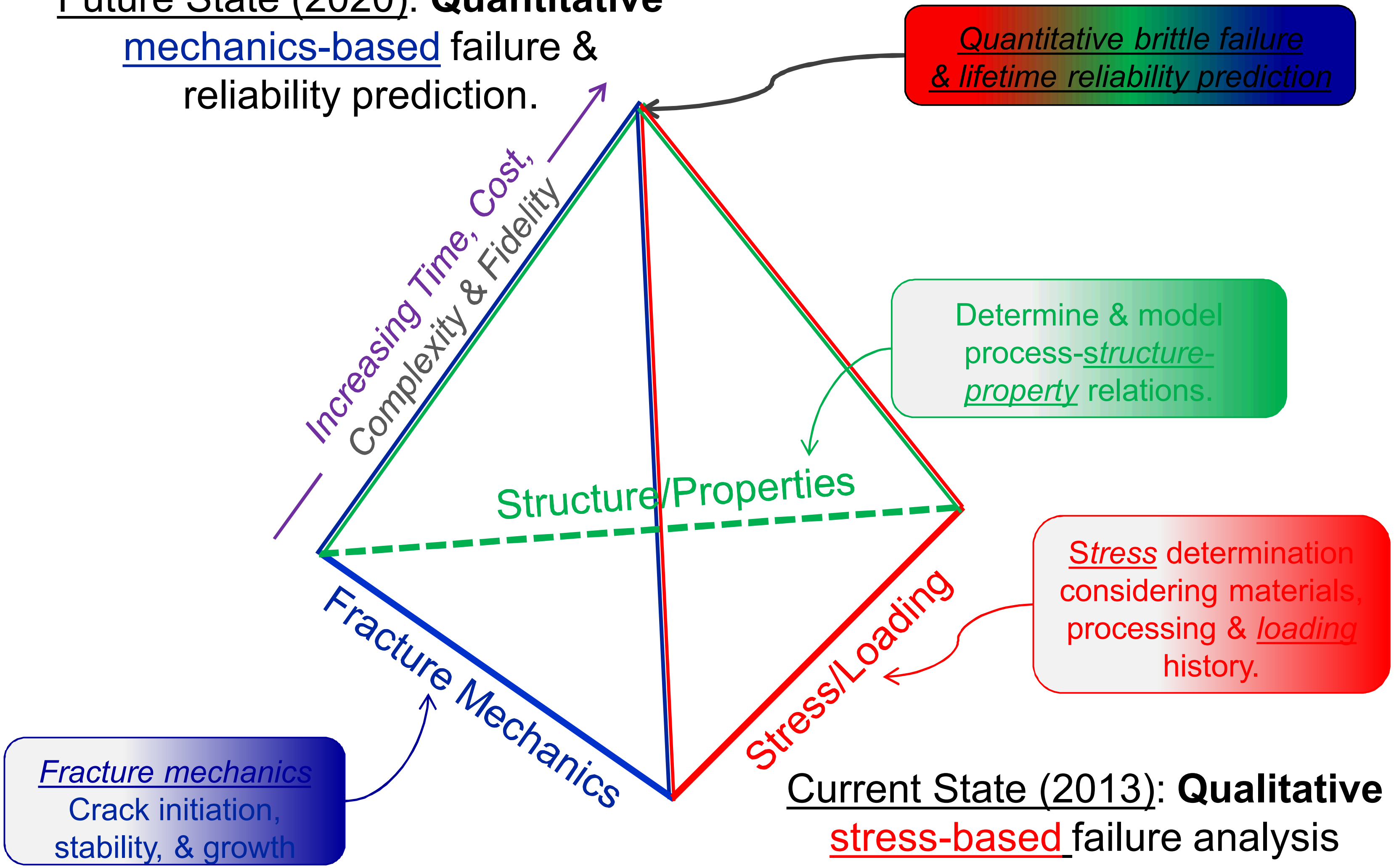
history dependent thermal strain

fracture mechanics

***Higher fidelity stress modeling is possible with improved materials behavior models***

# BrittMAPP – Brittle Materials Assurance Predictability Program

Future State (2020): **Quantitative** mechanics-based failure & reliability prediction.




Current State (2013): **Qualitative** stress-based failure analysis (i.e., engineering judgment).

# Simplified Potential Energy Clock (SPEC) Model

Journal of Non-Crystalline Solids 432 (2016) 545–555

Contents lists available at ScienceDirect

Journal of Non-Crystalline Solids

journal homepage: www.elsevier.com/ locate/ jnoncrysol


## Characterization and calibration of a viscoelastic simplified potential energy clock model for inorganic glasses

Robert S. Chambers [a,*], Rajan Tandon [b], Mark E. Stavig [c]

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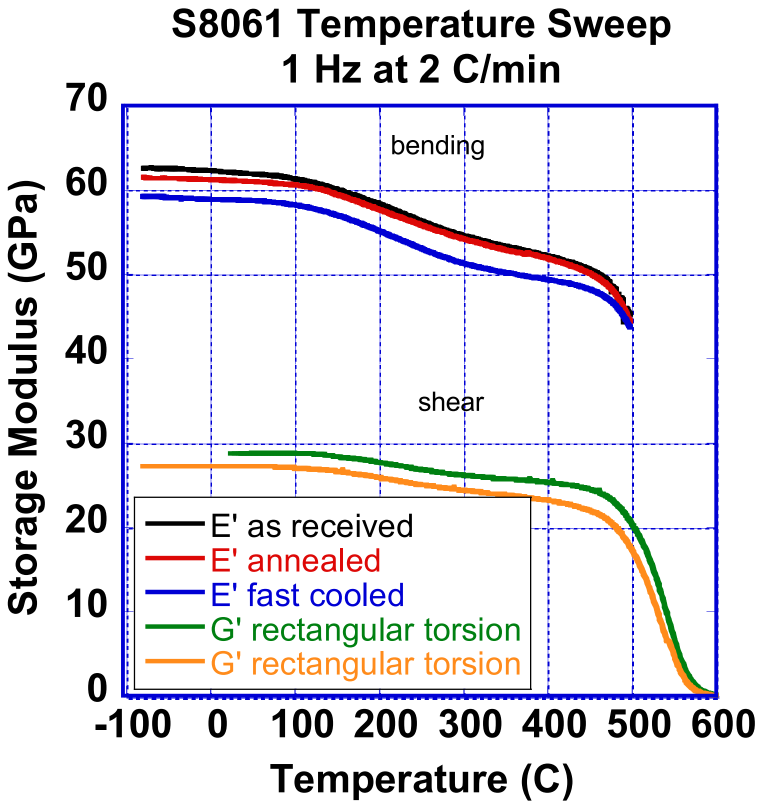
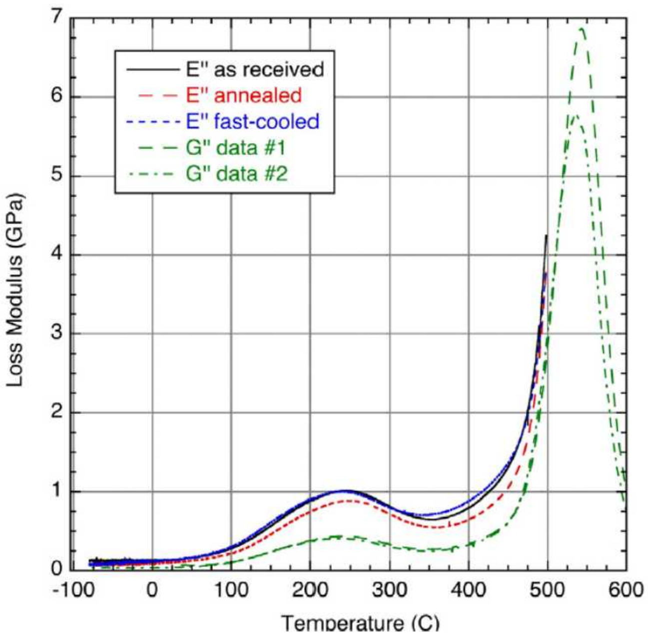
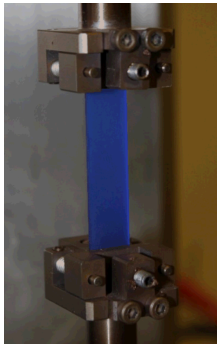
[c] *Materials Science and Engineering Center, Sandia National Laboratories, Albuquerque, NM 87185–0958*

# Dynamic Mechanical Analysis Temperature Sweep

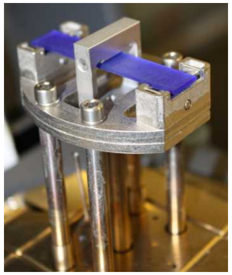


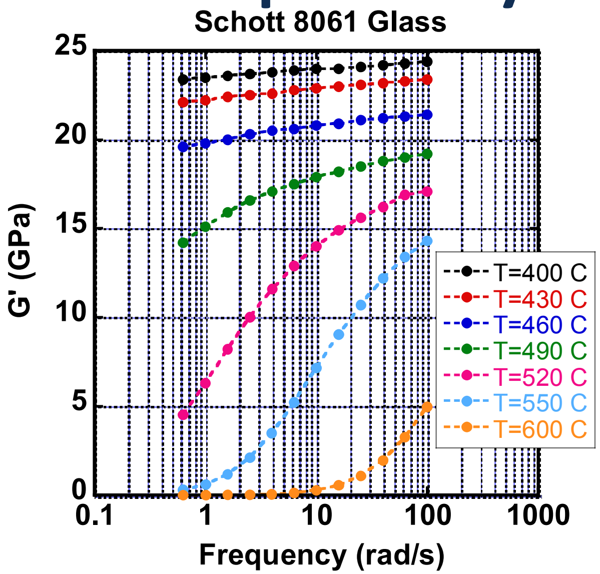

TA ARES Rheometer

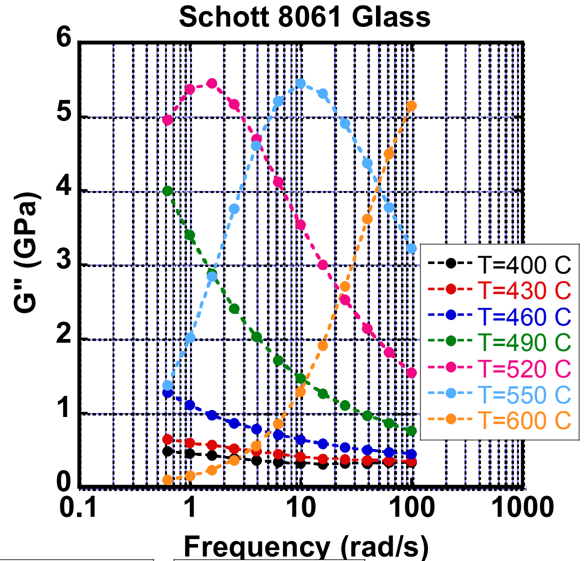


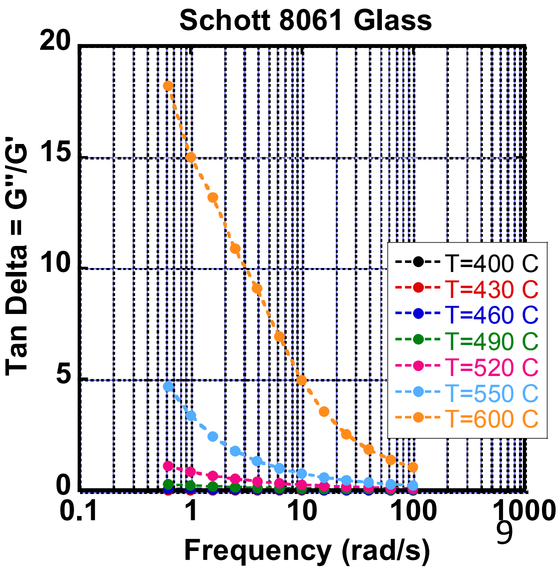
TA Q800 DMA

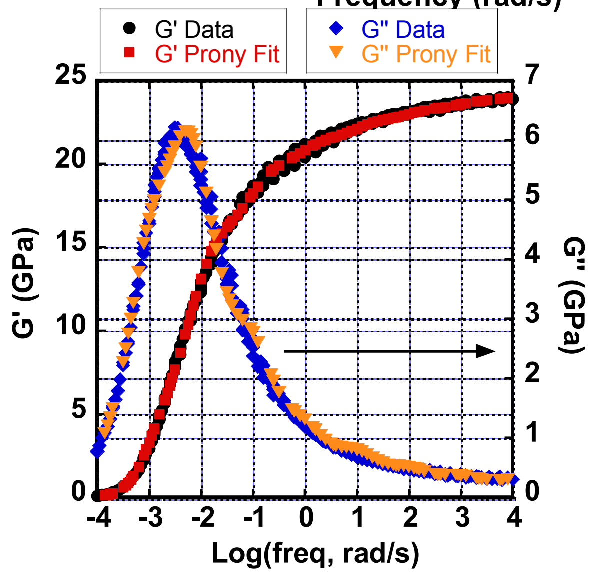


# Dynamic Mechanical Analysis Frequency Sweep

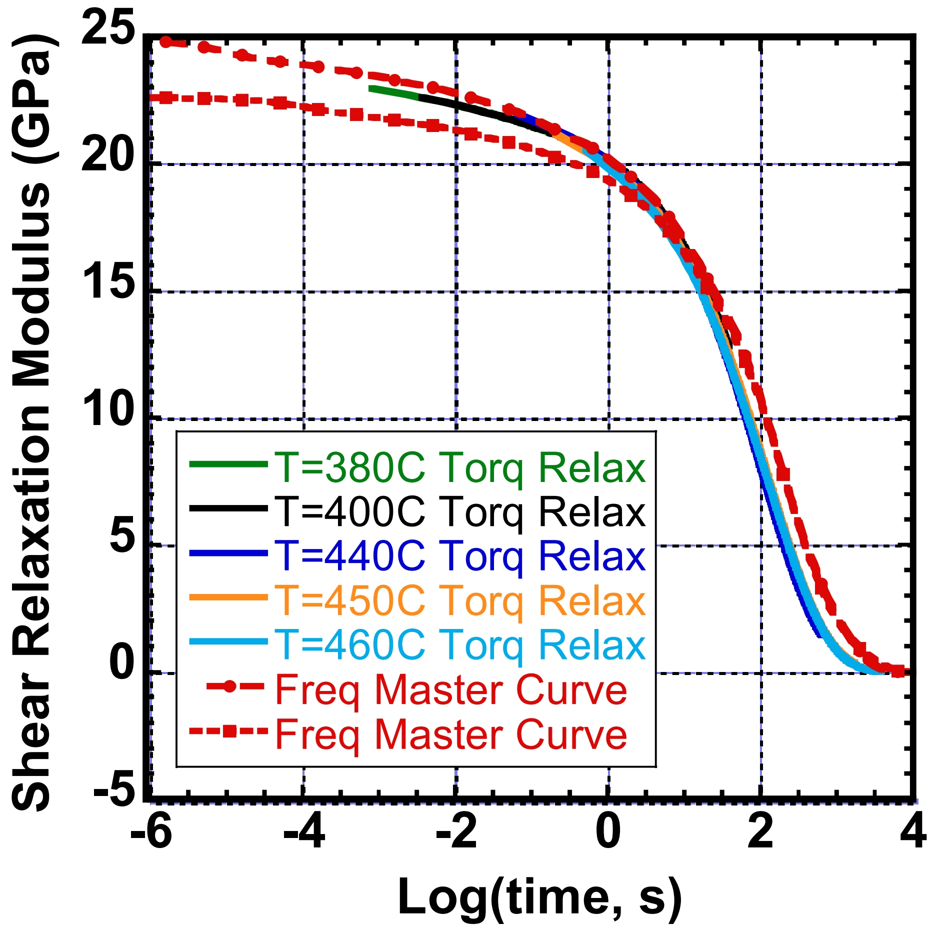


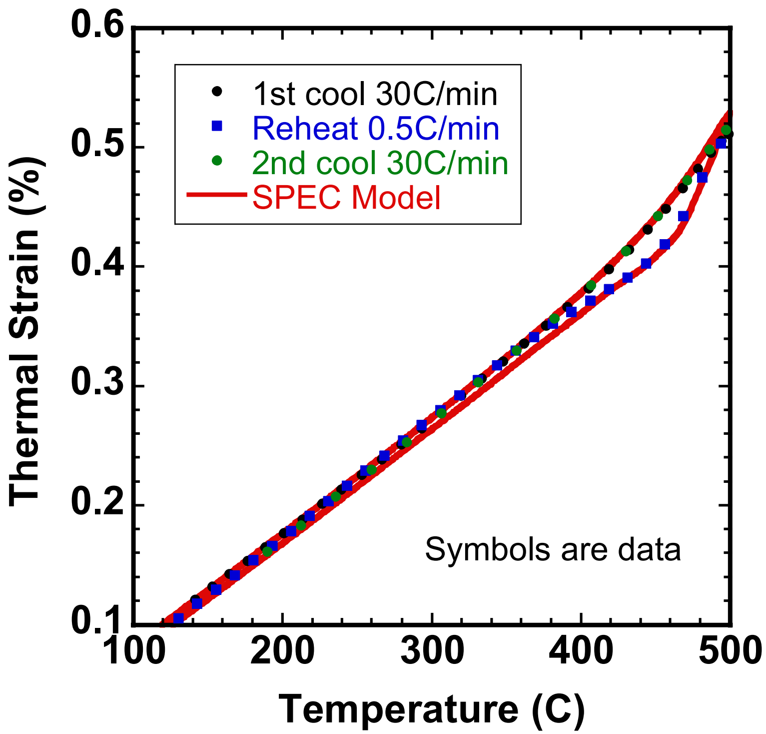



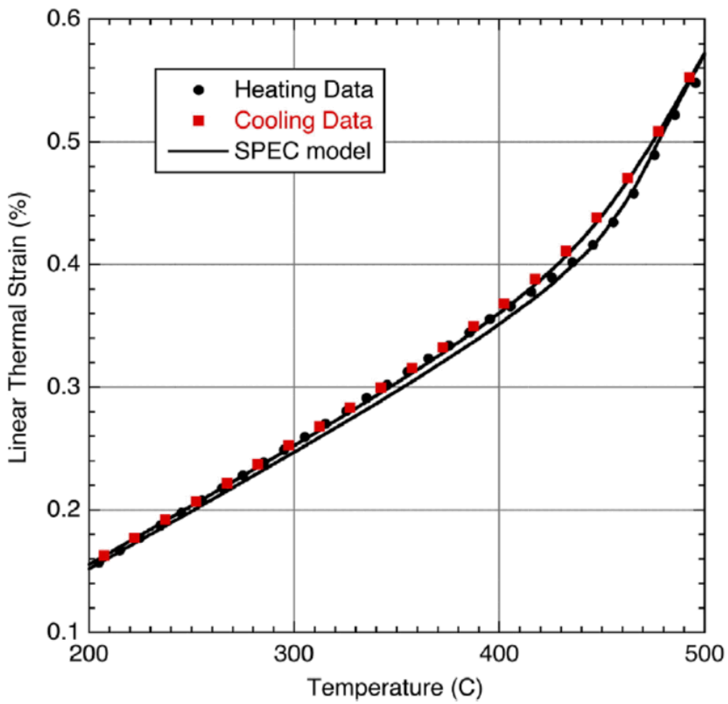



# Constructing time based master curve



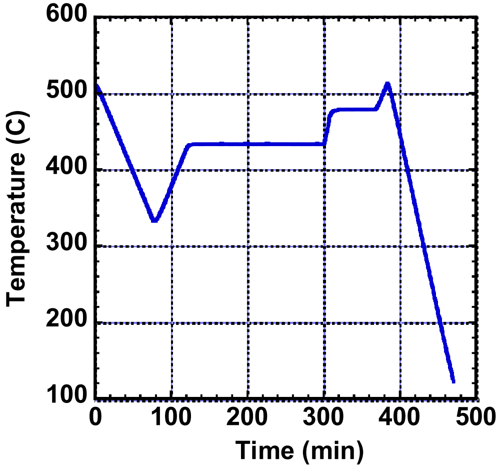
# Model Calibration

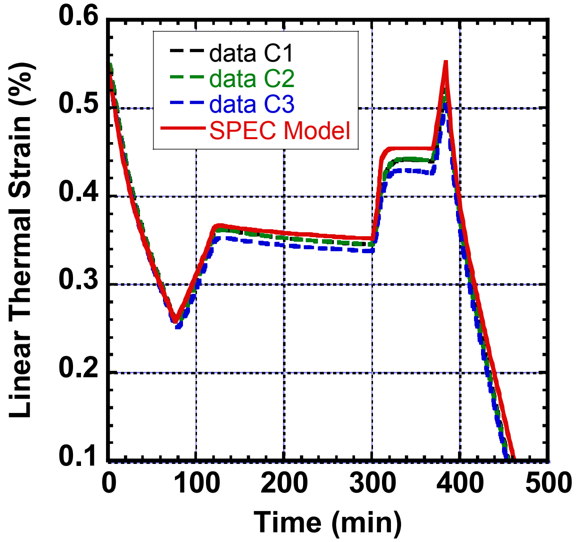


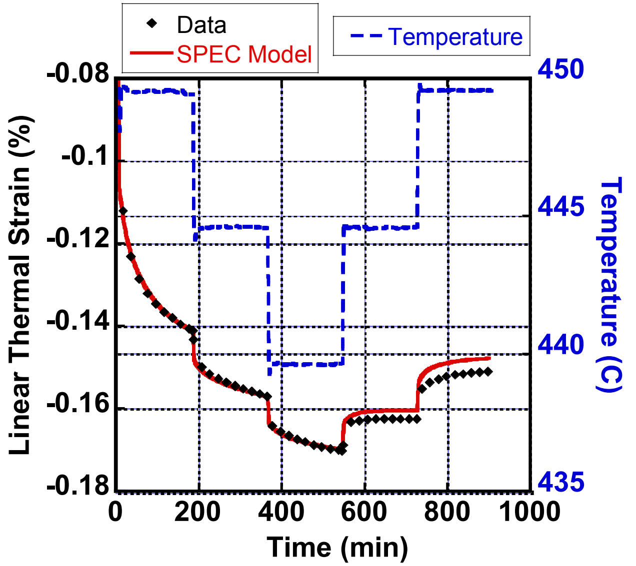



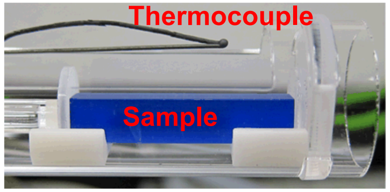

SPEC Model volume response adapted and calibrated to measure glass thermal strain

# Model Validation – Complex Thermal History



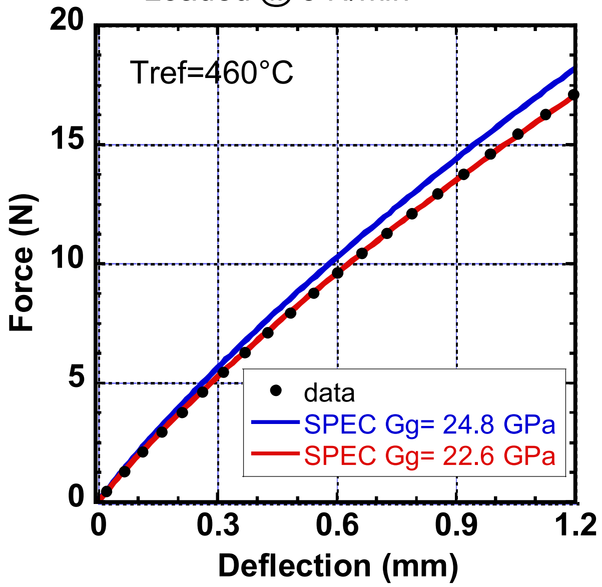




Netzsch Dilatometer

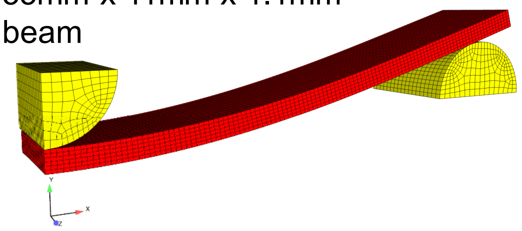
# Model Validation – 3 – point bending

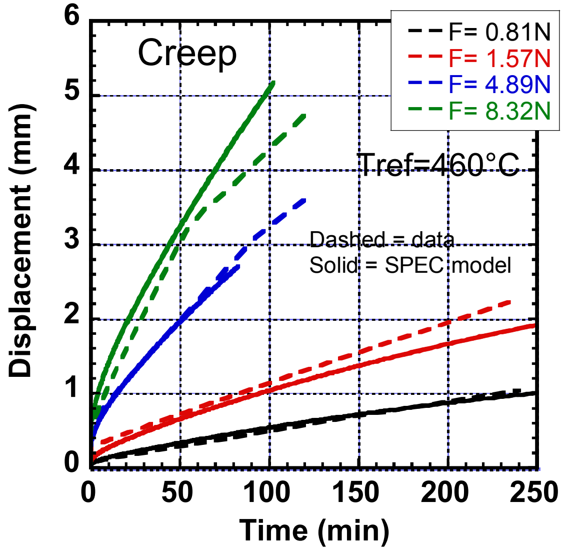
Ramp
Loaded @ 5 N/min




3-Pnt Bending Tests at Tg

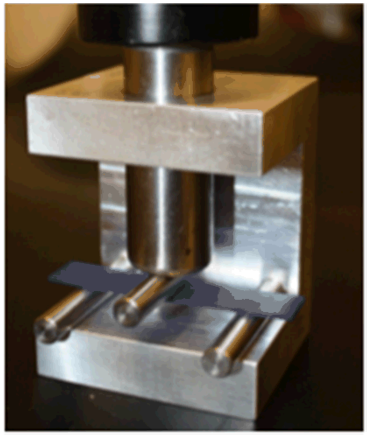
55mm x 11mm x 1.1mm beam



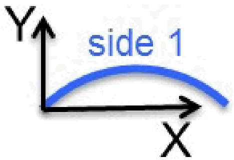


# Characterizing Low Temp Creep

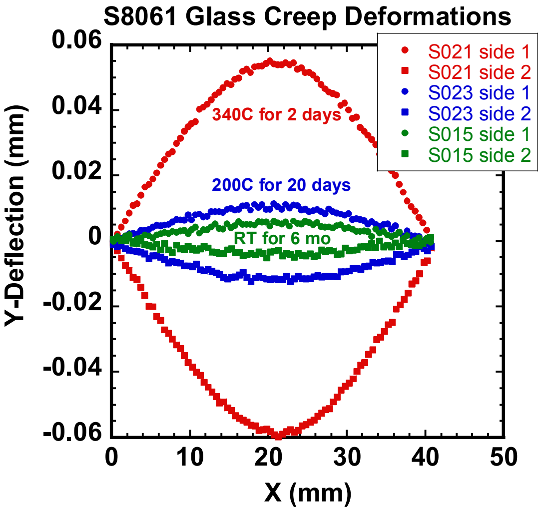
### *Three-point bend testing*



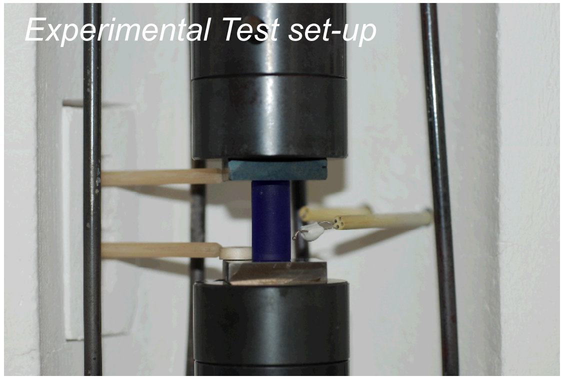
| T (°C) | Stress (psi) |
|---|---|
| 340 | 4220 |
| 200 | 4220 |
| 20 | 4720 |

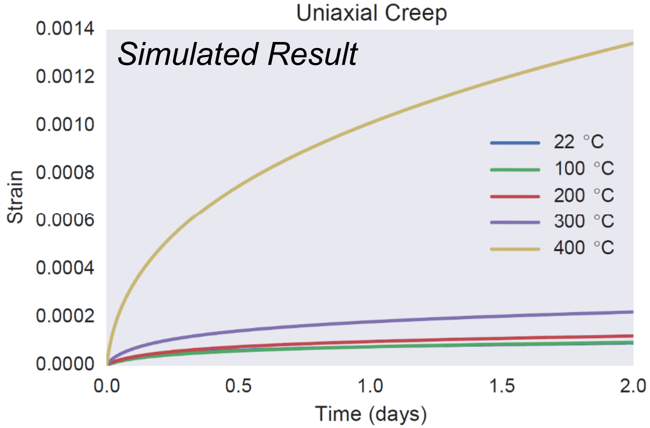



**. . . Measurable creep 440°C below Glass Transition**




### *Compression creep testing*

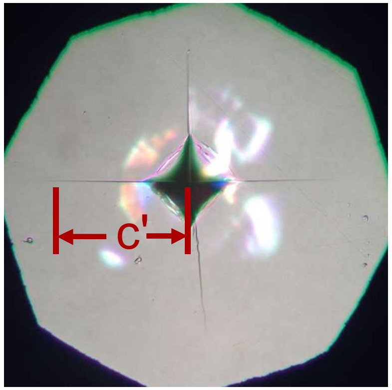


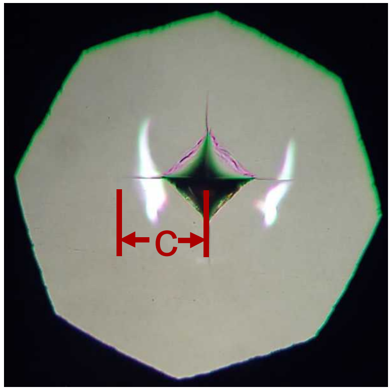

30 MPa

# Model Validation: stress mapping by indentation crack measurements


*GtoM seal test geometry*




Polished Annealed Block
avg. c ≈ 92 um




Indent on test geometry glass (not near SS shell)
avg. c ≈ 55 um

$$K_{Ic}' = \chi P / c^{3/2}$$

stressed glass

unstressed glass

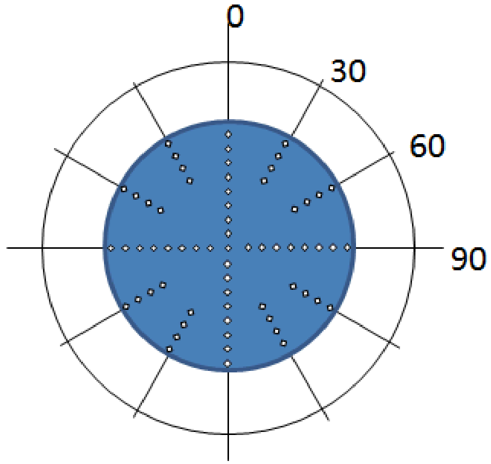
$$\sigma_r = \frac{-(K_I - K_{Ic}')}{1.12\,\pi\, c^{1/2}}$$

*Derived from indentation fracture mechanics concepts*

*e.g. Lawn Fracture of Brittle Solids (1993)*

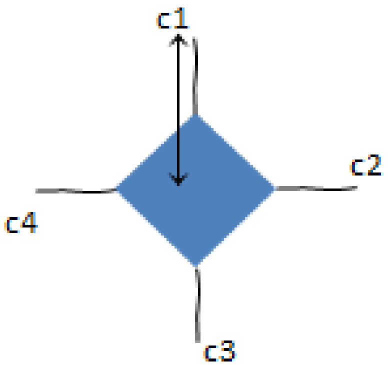
# Model Validation: stress mapping by indentation crack measurements

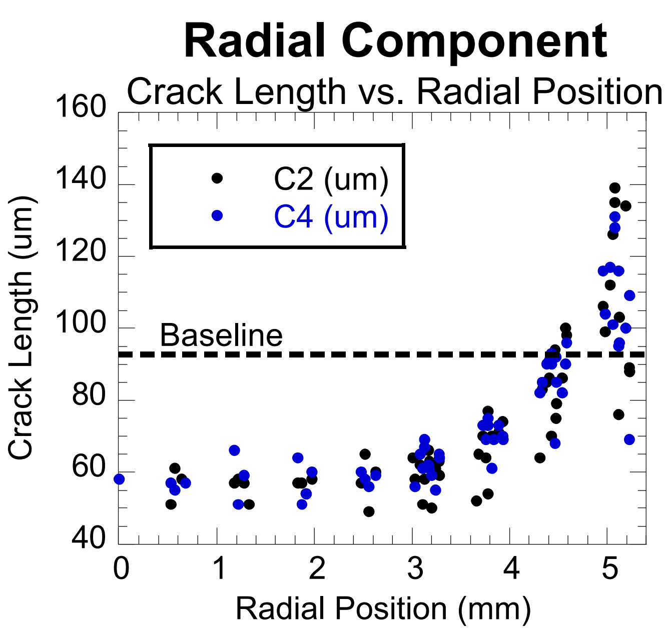
Indentation locations

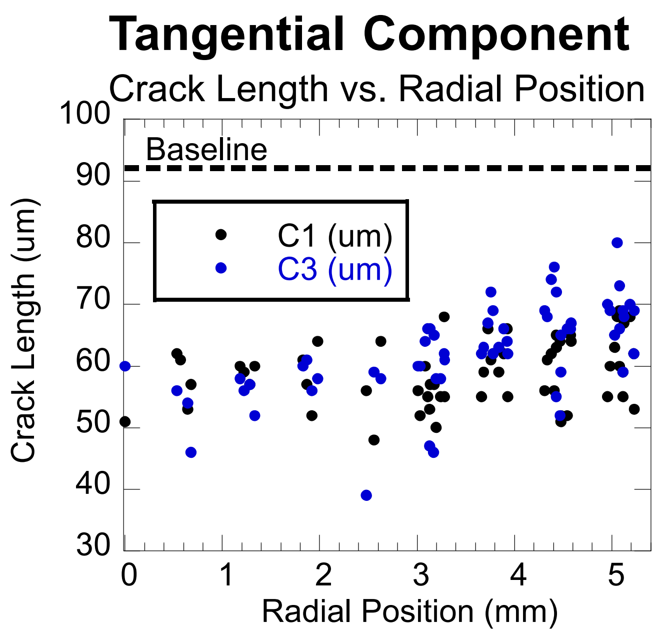



Radial Component
c1 and c3

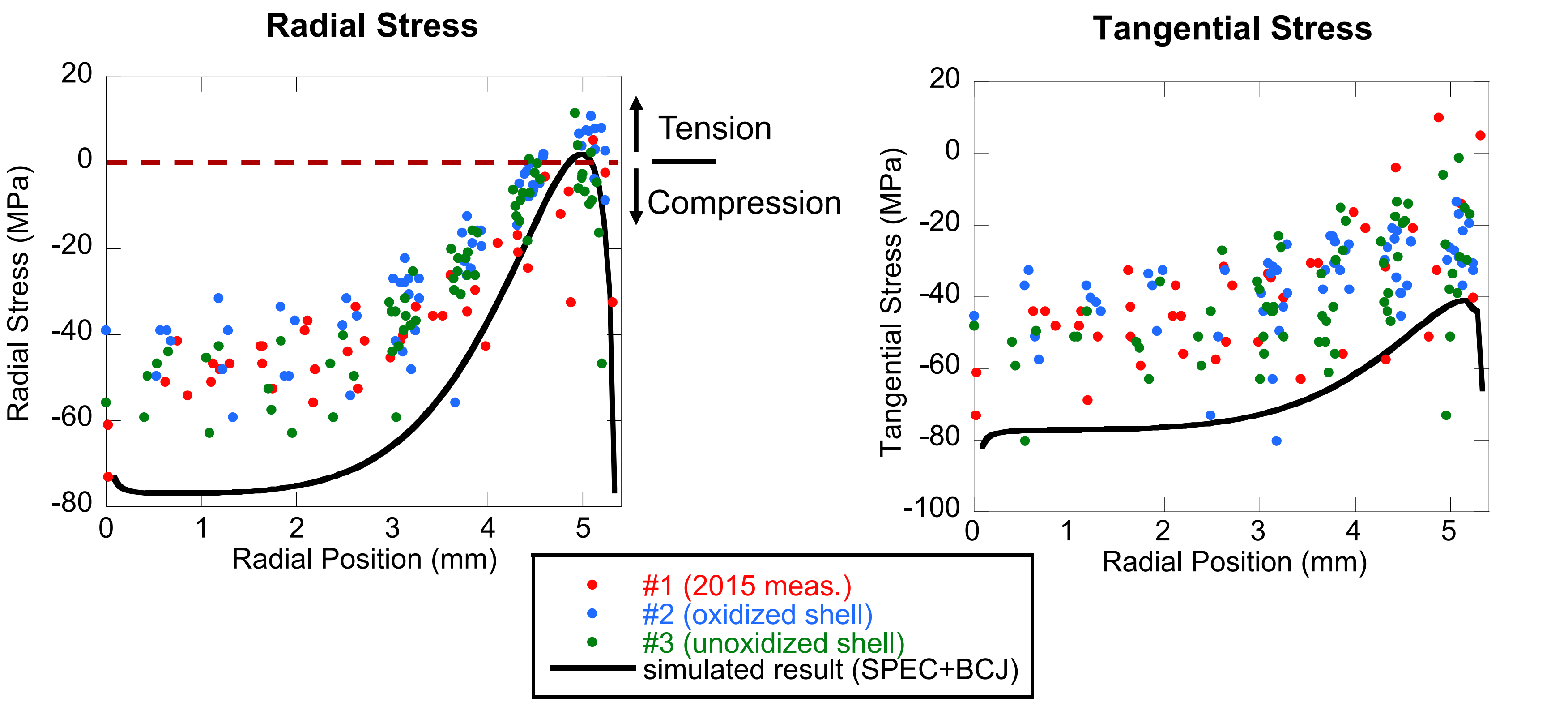
Tangential Component
c2 and c4



# Model Validation: stress mapping by indentation crack measurements

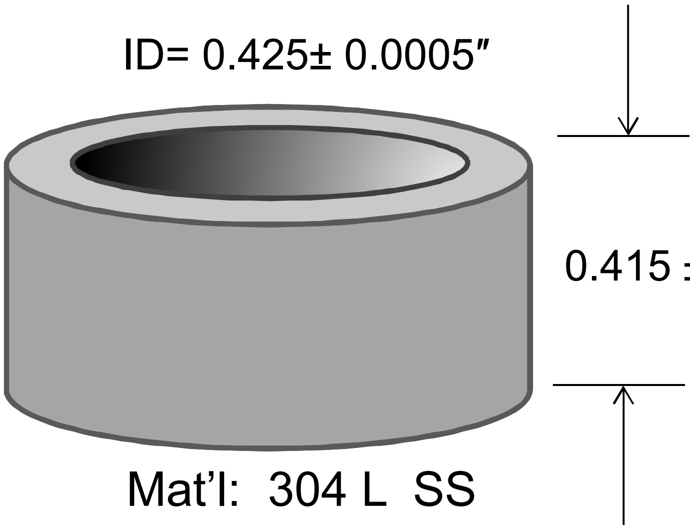


# Model Validation: capturing dimensional changes in a glass to metal seal geometry

## *Tall cylinder geometry*

OD= 0.635± 0.002”

ID= 0.425± 0.0005”



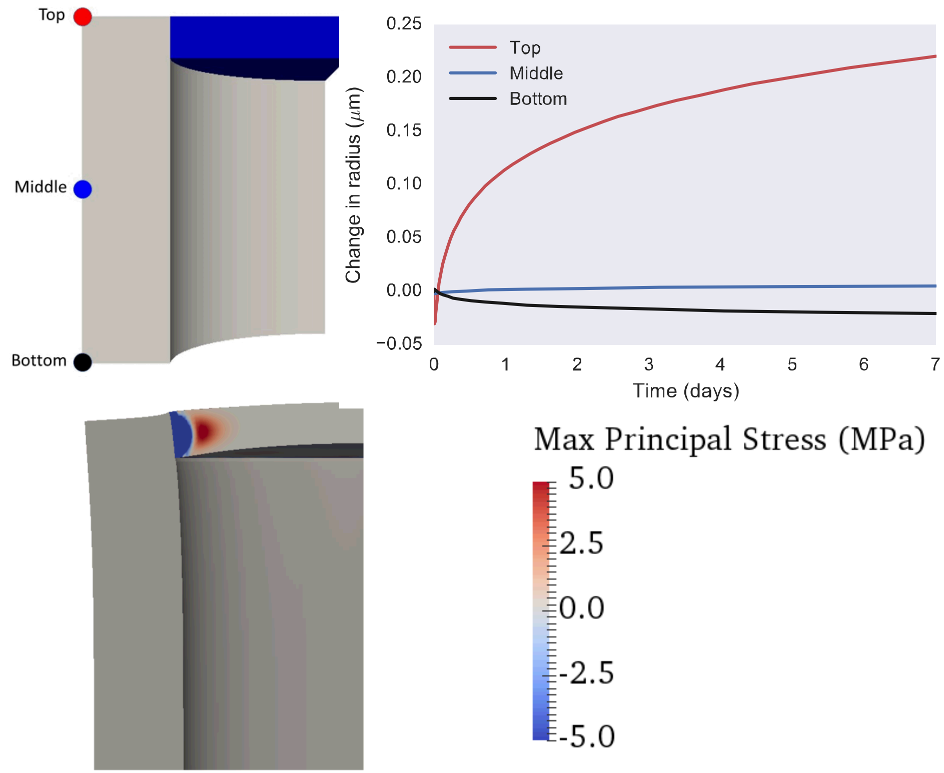

Mat’l: 304 L SS

0.050 ± 0.0005”

Material: Schott 8061 Glass

Seal at top of cylinder

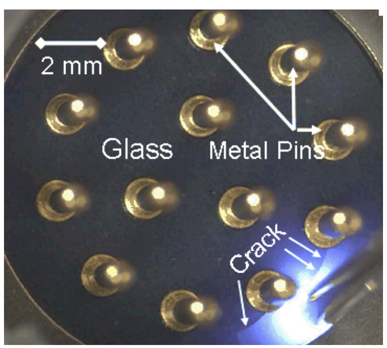
## *A simulated result*

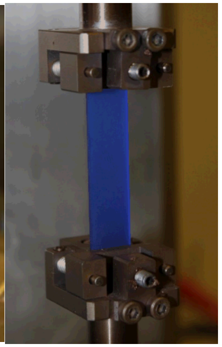


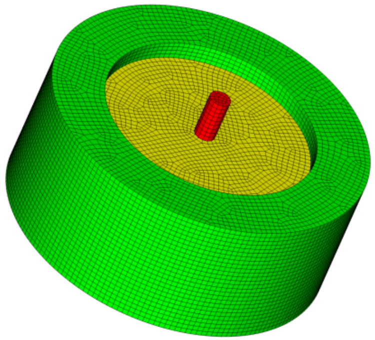

*A geometry which can exaggerate dimensional changes due to the sealing process*

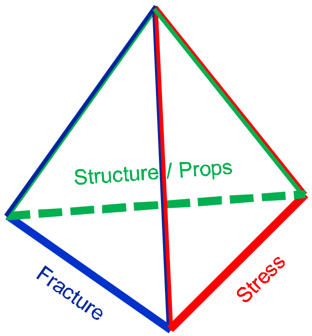
# Conclusions

- SPEC model can predict glass response with engineering accuracy
- Currently applying the model to realistic components to predict long term reliability



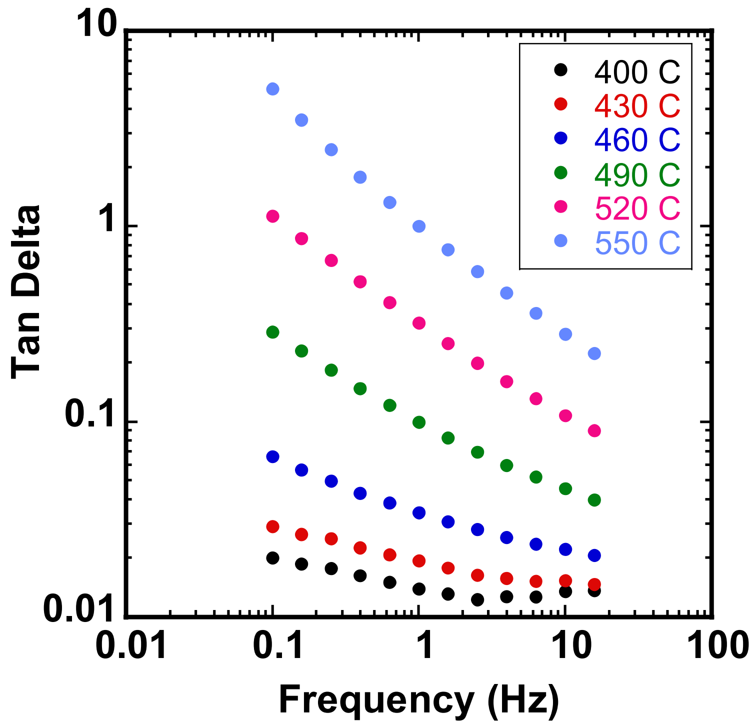





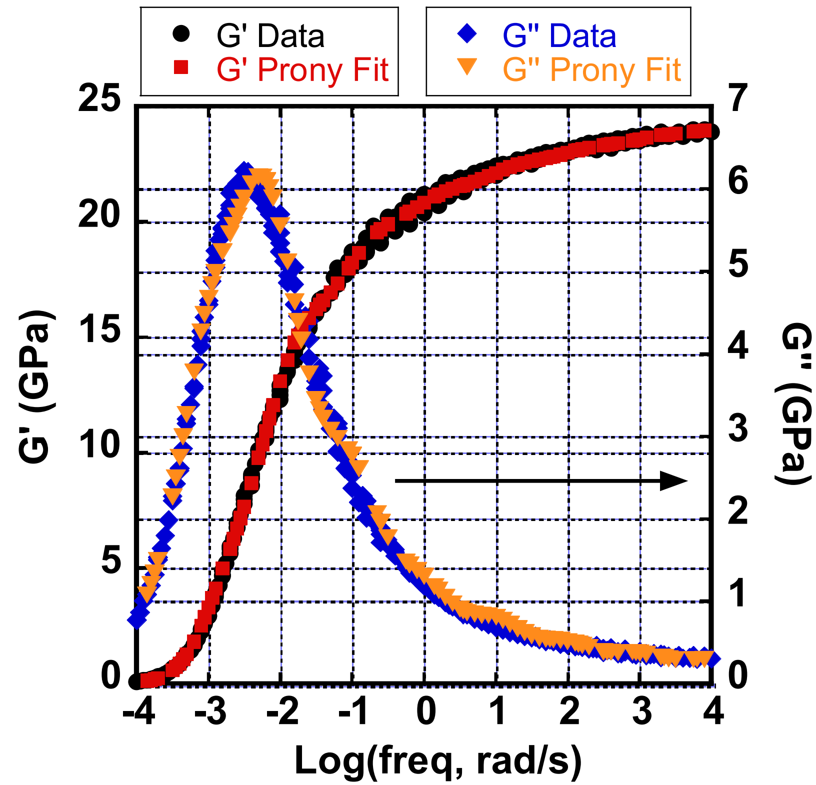


# Acknoledgements


- Thomas Buchheit
- Clay Newton
- Raj Tandon
- Bob Chambers
- Mark Stavig
- Scott Reedy



Tan Delta
Frequency (Hz)
400 C
430 C
460 C
490 C
520 C
550 C
10
1
0.1
0.01
0.01
0.1
1
10
100

G' Data
G' Prony Fit
G" Data
G" Prony Fit
G' (GPa)
G" (GPa)
Log(freq, rad/s)
25
20
15
10
5
0
7
6
5
4
3
2
1
0
-4
-3
-2
-1
0
1
2
3
4