SAND2012-9837C

Glass-To-Metal (GTM) Seals

Phase I Research & Development Program

To Improve & Validate Residual Stress Predictions for GTM Seals

Jointly Funded by

Weapons Systems Engineering Assessment Technology (WSEAT) – FY12 $132k
Robert S. Chambers, 1526 (PI)
Raj Tandon, 1825
Mark Stavig 1833
Bonnie Antoun, 8256

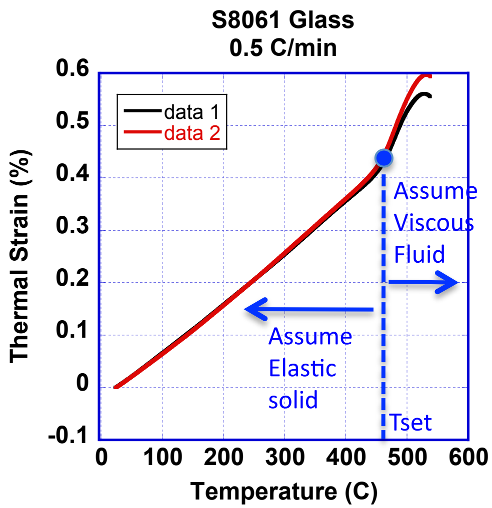
ASC Verification & Validation (V&V) of Materials – FY12 $150k
John Emery, 1524 (PI)
Robert S. Chambers, 1526

November 1, 2012 Status

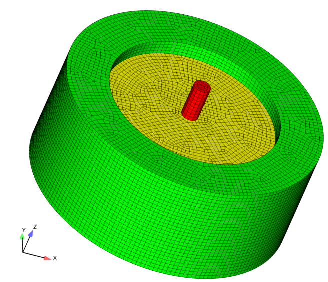
Motivation

- GTM seal designs are pushing the frontiers with
  - irregular geometries (lack of symmetry)
  - more pins in less real estate
- Despite years of experience – we still struggle with glass cracking (SFN MC4713)
- Unexpected glass cracking, produces many concerns:
  - loss of hermeticity
  - foreign debris (e.g., glass chips)
  - diminished mechanical integrity allowing pins to shift or short out
- Past studies have identified discrepancies between model predictions and indentation results but root cause has not been identified
  - Models make assumptions about: geometry, materials, processing
  - Experiments lack ability to make direct stress measurements
- Faced with B61-LEP and W88-ALT demands for GTM seals, time is right to:
  - Incorporate missing physics: glass viscoelasticity for process modeling (history)
  - More fully characterize materials: glasses, metals for small strain plasticity at temperature
  - Perform extensive model validation: materials 1st, then the structure
  - Assess modeling assumptions/sensitivities: wetting, uniform cooling, etc
  - Explore the glass sealing process: coupled thermo-mechanical analyses

Current State of Material Modeling



Advances in material modeling have not kept pace with advances in computing

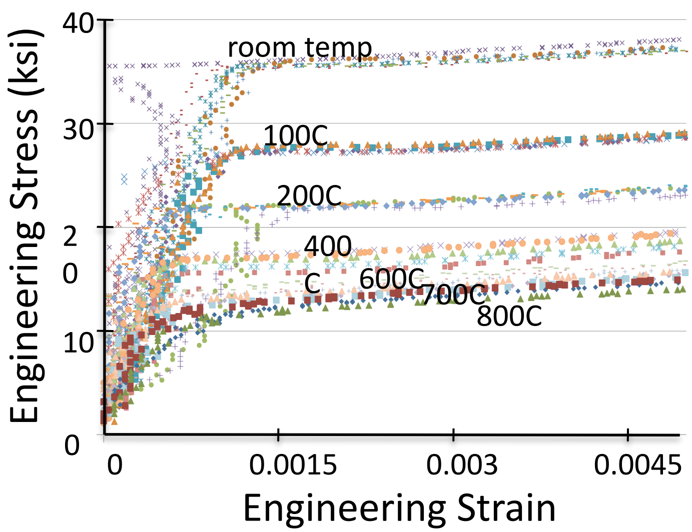


Glass Modeling

- Assume Tset
- Assume elastic behavior below Tset
- Compute stresses based on net CTE mismatch from Tset
- Neglect all history: time & temperature

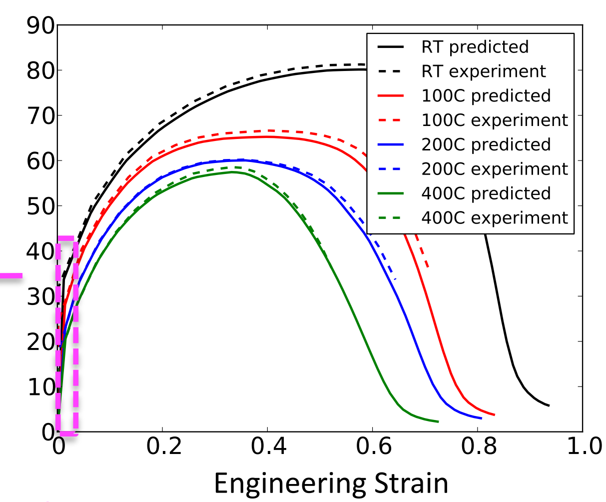
Metal Plasticity

Temperature dependent plasticity: $\sigma_y(T), E_H(T)$



data collected from ductile failure testing to very large strains

GTM seal strains are ~1%

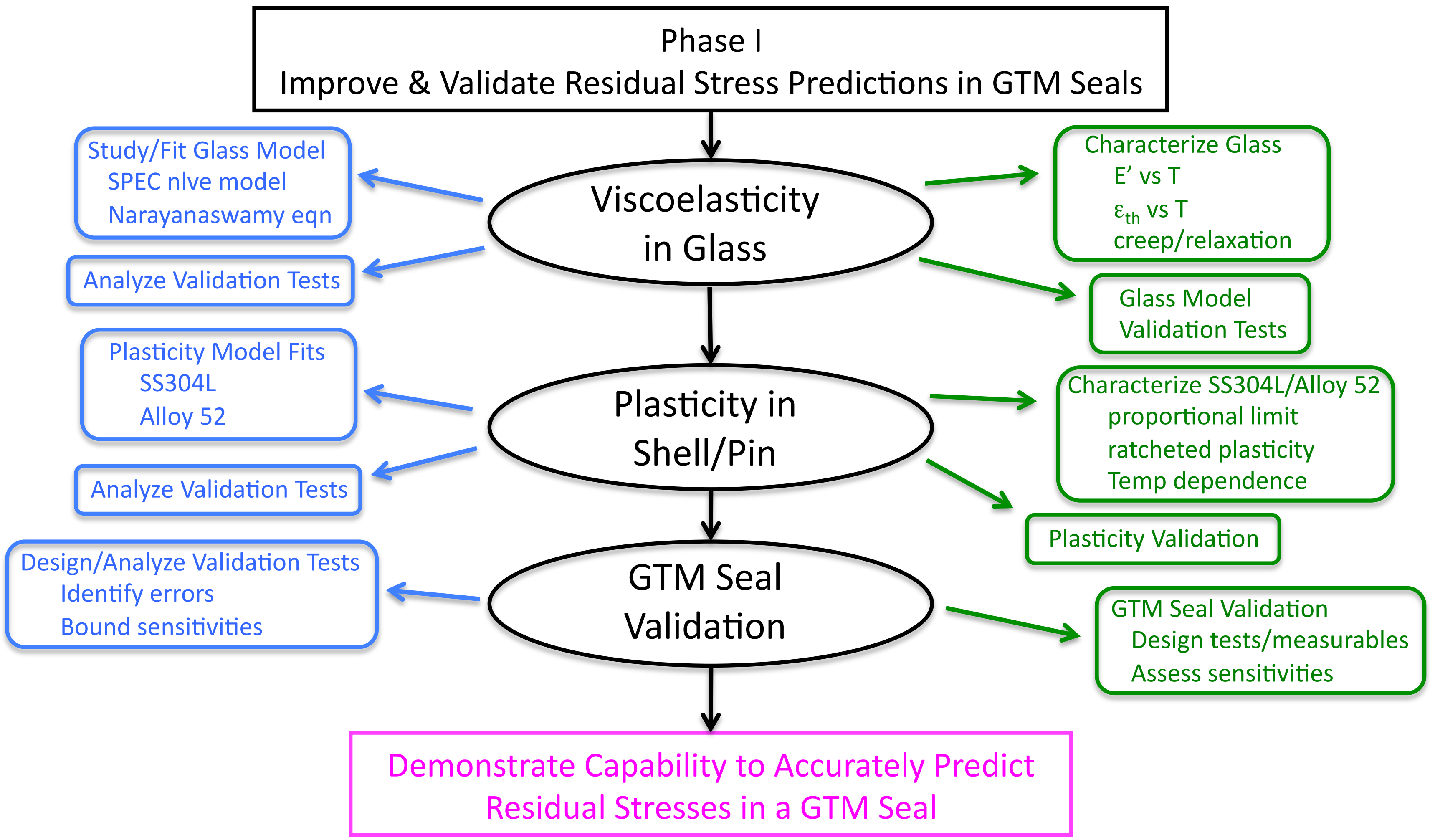


We Can Do Better!

Program Goal & Approach

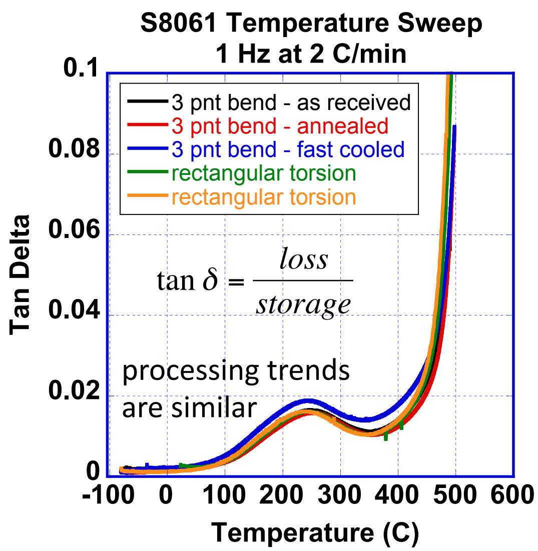
ASC V&V Project
FY12-$150k, FY13-$150k
J. Emery (PI), R. Chambers

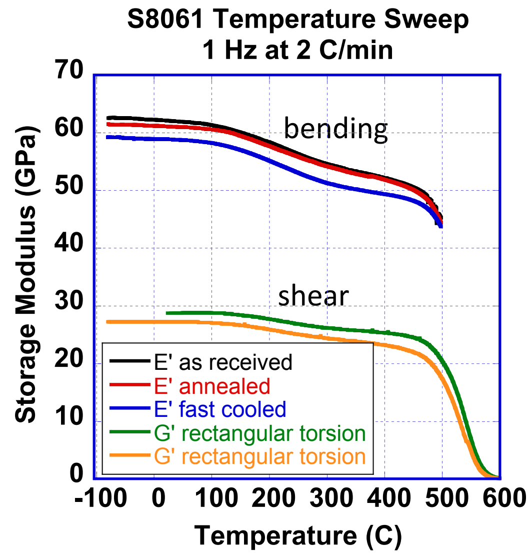
WSEAT Project
FY12-$132k, FY13-$225k
R. Chambers (PI), R. Tandon, B. Antoun, M. Stavig

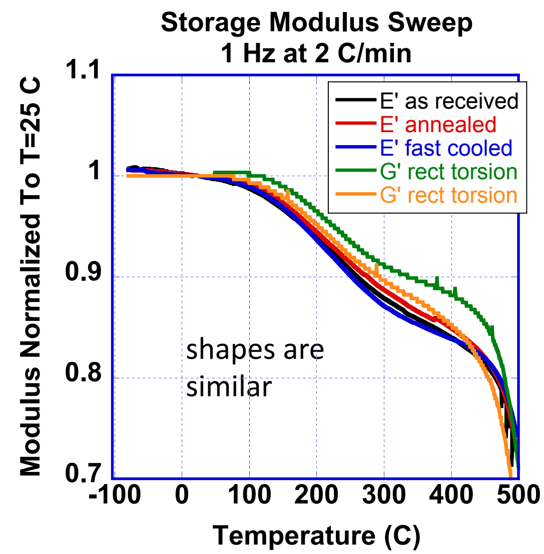


S8061 Glass Storage Modulus Tests

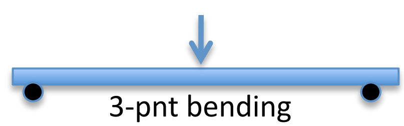
Temperature Sweep at Fixed Frequency





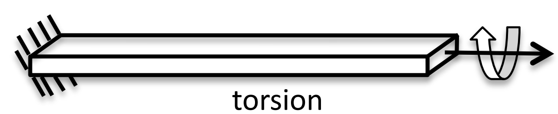


- Storage moduli were measured:
  - to define temperature dependence
  - to assess sensitivity to processing history
- Samples conditioned differently:
  - as-received
  - annealed (slow cooled)
  - fast cooled (quenched)
- Both E' (bending) and G' (shear) were measured
- Tan delta bump at 250 C is reproduced consistently



Dynamic Tests:
- impose oscillating deformation while ramping temperature
- measure in-phase (E', G') storage response
- measure out-of-phase (E'', G'') loss response

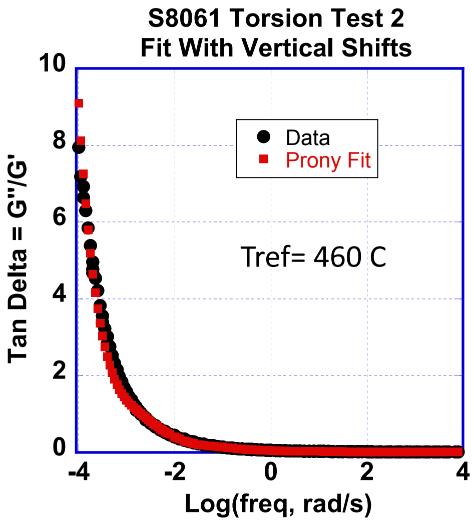
Defines temperature dependence of shear modulus

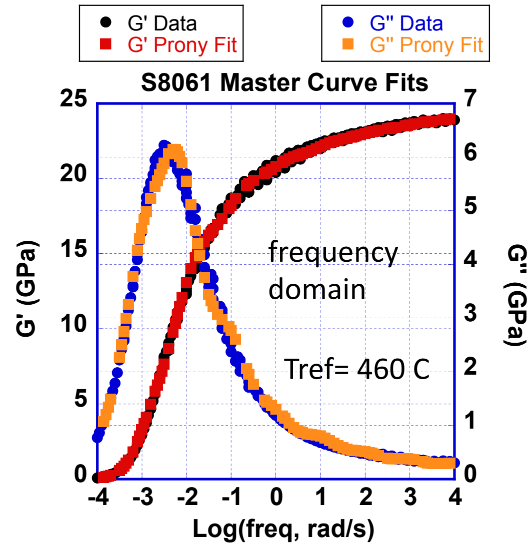


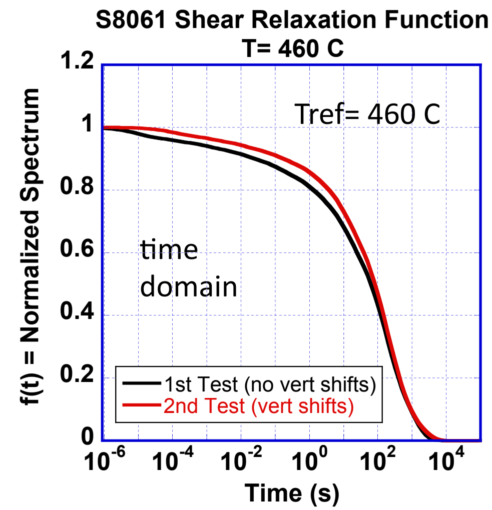
Experiments conducted by Mark Stavig, 1833

S8061 Master Curve Construction

Frequency Sweep at Stepped Temperatures







- For viscoelastic materials, shear modulus is a function of time/frequency
- Define frequency dependence of dynamic moduli assuming thermorheological simplicity → time/temperature superposition
- Convert from frequency to time domain → G(t,Tref)
- Response functions are defined as an exponential (Prony) series

$$G(t,T) = G_0(T)\ f(t^*,T_{ref})$$

$$f(t^*,T_{ref}) = \sum_{i=1}^{N} f_i \exp(-t^*/\tau_i) \qquad where \ \sum_{i=1}^{N} f_i = 1$$

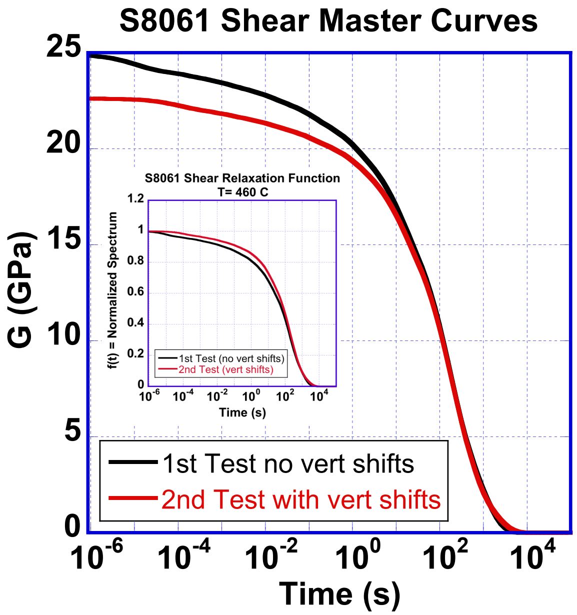
Defines shear relaxation modulus at any temperature

Dynamic Tests:

- impose oscillating deformation sweeping frequency (f=0.1 to 10 Hz)
- measure moduli (G’, G’’)
- increment temperature
- repeat frequency sweep from Temp= 400-600C in 10 C increments
- shift tan δ curves in log f to generate Master Curves

Experiments conducted by Mark Stavig, 1833

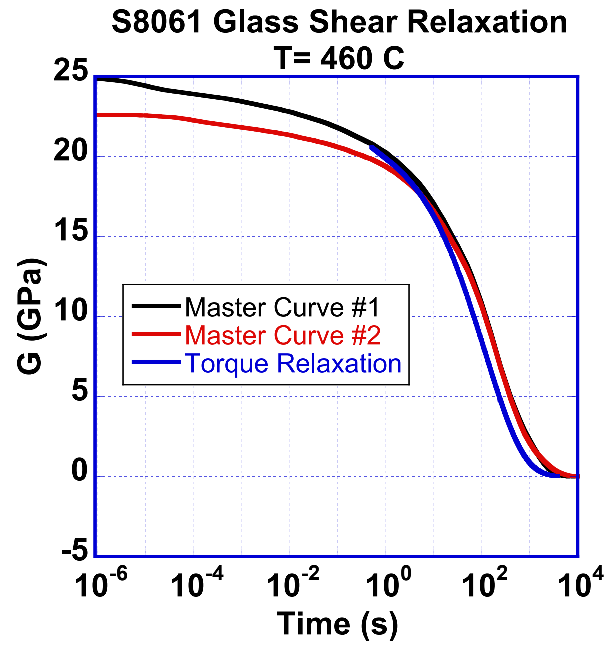
Schott 8061 Shear Relaxation Master Curve at T=460 C



$$G(t,T) = G_0(T)\, f(t^*, T_{ref})$$

$$f(t^*, T_{ref}) = \sum_{i=1}^{N} f_i \exp(-t^*/\tau_i)$$

$$\text{where} \quad \sum_{i=1}^{N} f_i = 1$$



<u>Master curves generated from 2 tests</u>

- DMA – dynamic oscillation
- frequency sweep at different temperatures
- shift tan delta, G'' and G''
- transfer from frequency to time domain to get G(t)

<u>Measure shear relaxation modulus directly</u>

- conduct torsional relaxation test at T=460 C
- compare to shear master curves from dynamic experiments

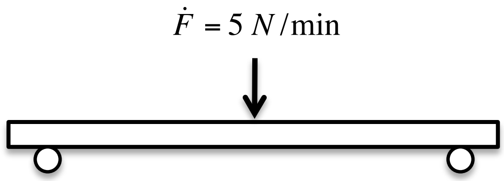
This is an independent test – and it compares exceptionally well !

Next steps: Repeat T=460 C torsion relaxation test

Conduct similar tests at T=450, 440, 430, ... to generate a master curve directly from relaxation data in time domain

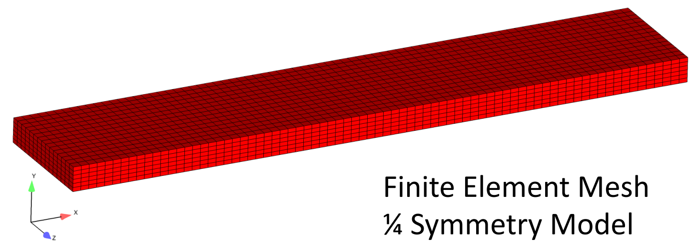
(Test data generated by Mark Stavig, 1835)

Linear Viscoelastic Analysis of 3-Pnt Bending at T=460 C

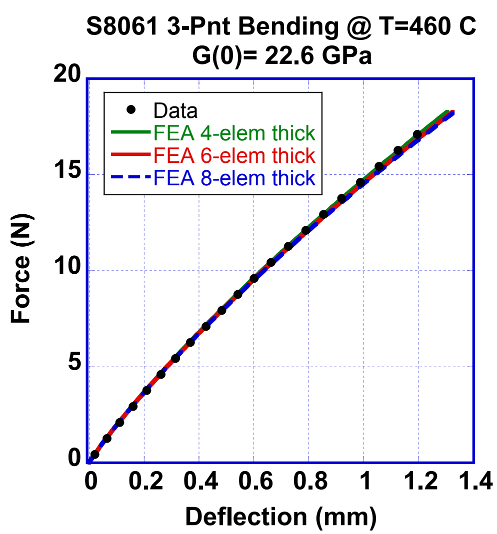


Nominal 3-pnt bending sample dimensions:
(50 mm long x 10.9 mm wide x 1.1 mm thick)

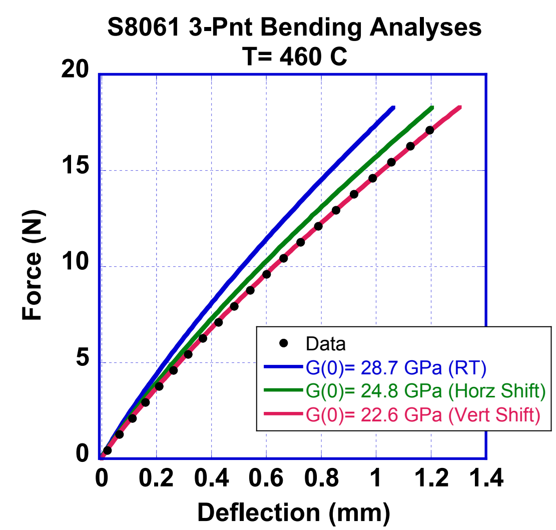
Experiments conducted by
Mark Stavig, 1833



Finite Element Mesh
¼ Symmetry Model

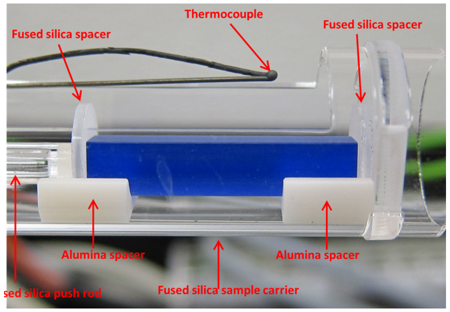


- Load Sample @ 5 N/min at Tref=460 C
- Measure Force vs Deflection
- Perform Linear Viscoelastic Analysis of test
  - Use G(t,Tref) defined from master curve
  - Assess sensitivities to:
    - mesh
    - glassy modulus, G(0,Tref)
- Results insensitive to mesh
- Data & Prediction compare well
- Shear master curve looks good!

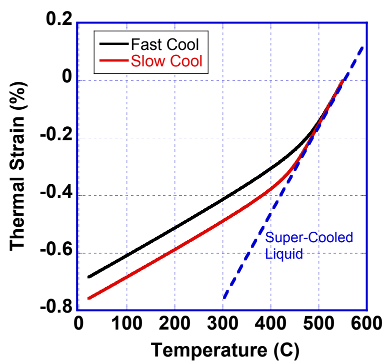


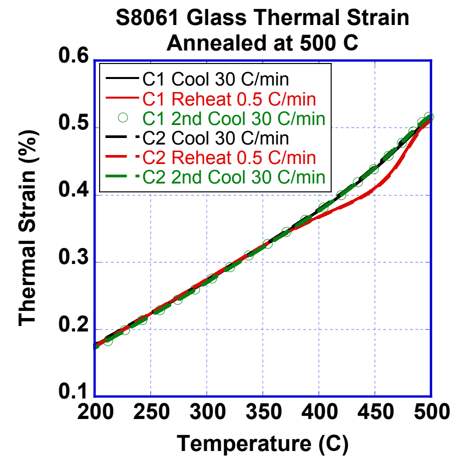
S8061 Glass Structural/Volume Relaxation

Netzsch Dilatometer DIL 402 C



Raj Tandon, Clay Newton, 1825, & Chris Diantonio, 1833, are characterizing thermal strain histories

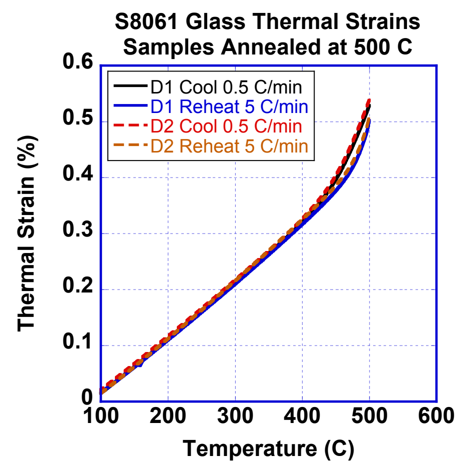




Anneal glass at 500 C,

- cool @ 30 C/min
- reheat @ 0.5 C/min
- 2nd cool at 30 C/min

Glass structurally relaxes on reheat producing hysteresis in strain curve



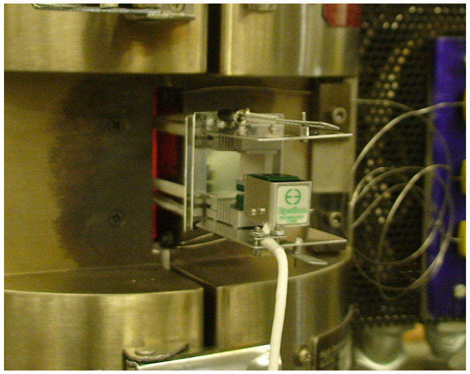
Anneal glass at 500 C,

- cool @ 0.5C/min
- reheat @ 5 C/min

Thermal strain is different passing through Tg (400-500 C)

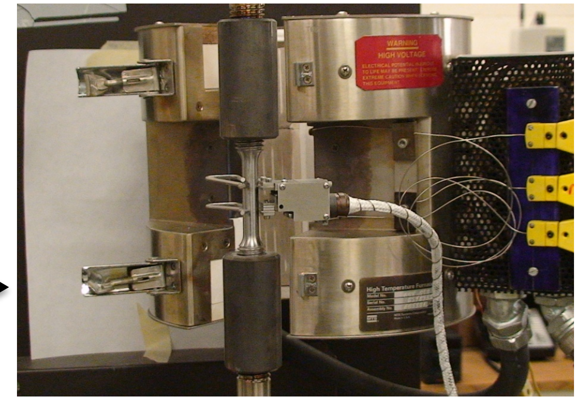
- Thermal strain is not defined by a material parameter, i.e., CTE
  - It is a function of glass structure and all prior history (need data to characterize)
  - Must be predicted by a viscoelastic constitutive equation
  - Can vary from point to point if thermal history is spatially non-uniform

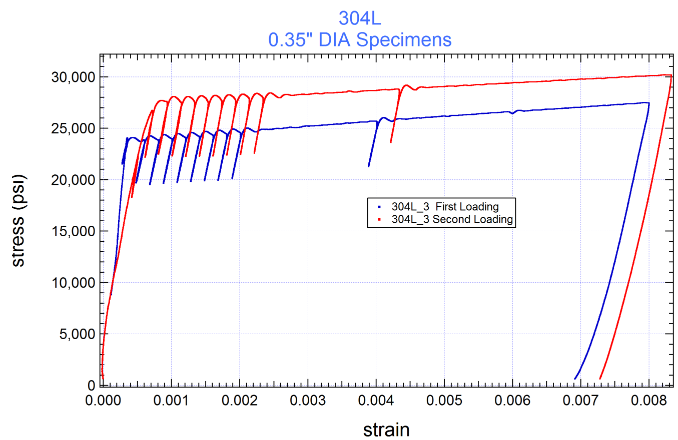
Small Strain Plasticity Measurements at Temperature



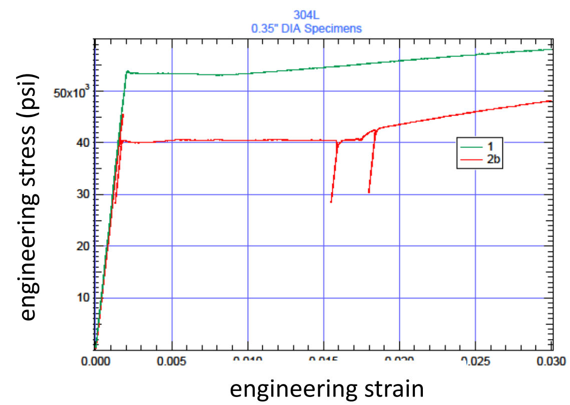
New test setup developed for higher fidelity small strain plasticity data

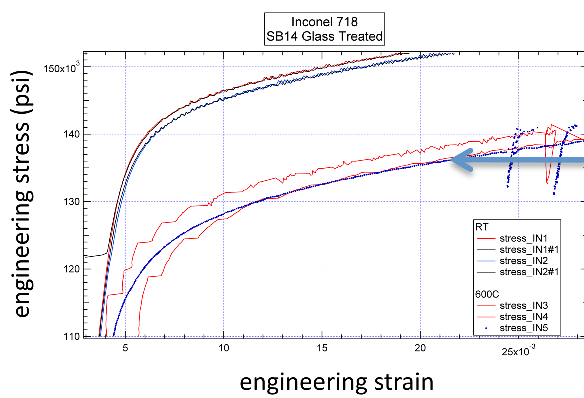
- New extensometer in small furnace with cutout
- Small strain capacitive extensometer in furnace





- ratcheting experiments imposed with strain control
- design conversion kit being developed for small strain excursions





improved high temperature data (blue vs red curves)

Experiments conducted by Bonnie Antoun, 8256

Summary

- In our first year, we can claim several novel accomplishments:
  1) Designed samples and test to measure shear stress relaxation master curve for an inorganic glass (S8061)
     - this is a 1st for Sandia
     - defines solidification on cooling
  2) Measured the temperature dependence of S8061 glass moduli
     - 3 pnt bending (E) and torsion (G) from -80 C to 500 C
     - assessed sensitivity to glass structure and processing history
  3) Measured the S8061 thermal strain behavior under several temperature histories to characterize structural relaxation
  4) Developed new experimental apparatus to measure small plastic strains in metals as a function of temperature
     - Previous measurements have focused on large strains to failure
     - Glass-to-metal compression seals experience 1-2% strains
- Began the process of calibrating and validating higher fidelity glass models that incorporate time/temperature relaxations (i.e., not just elastic approximations)
- Through this work, we have developed a methodology for characterizing and comparing “equivalent” glasses → These tests are affordable