

Glass Density Effects in Glass-To-Metal Sealing

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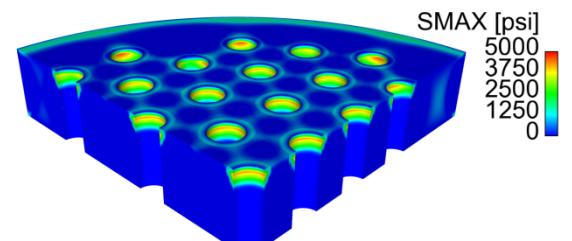
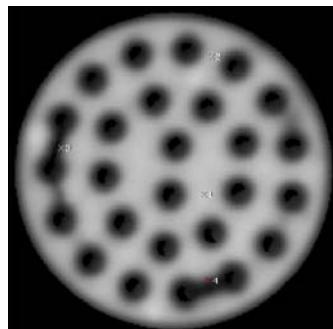
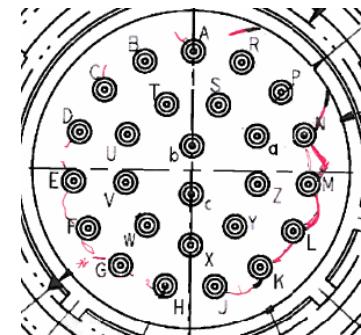
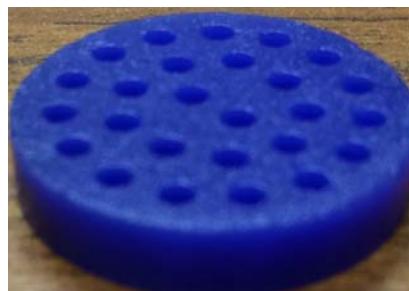
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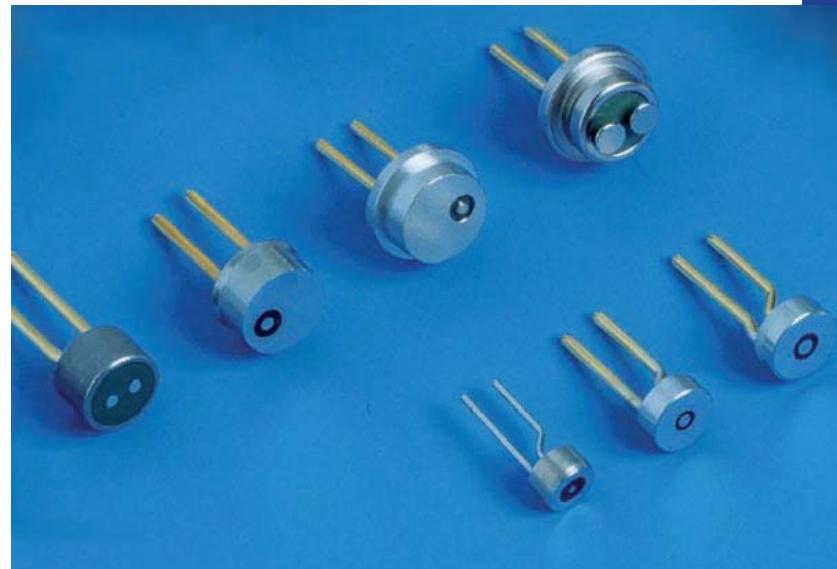


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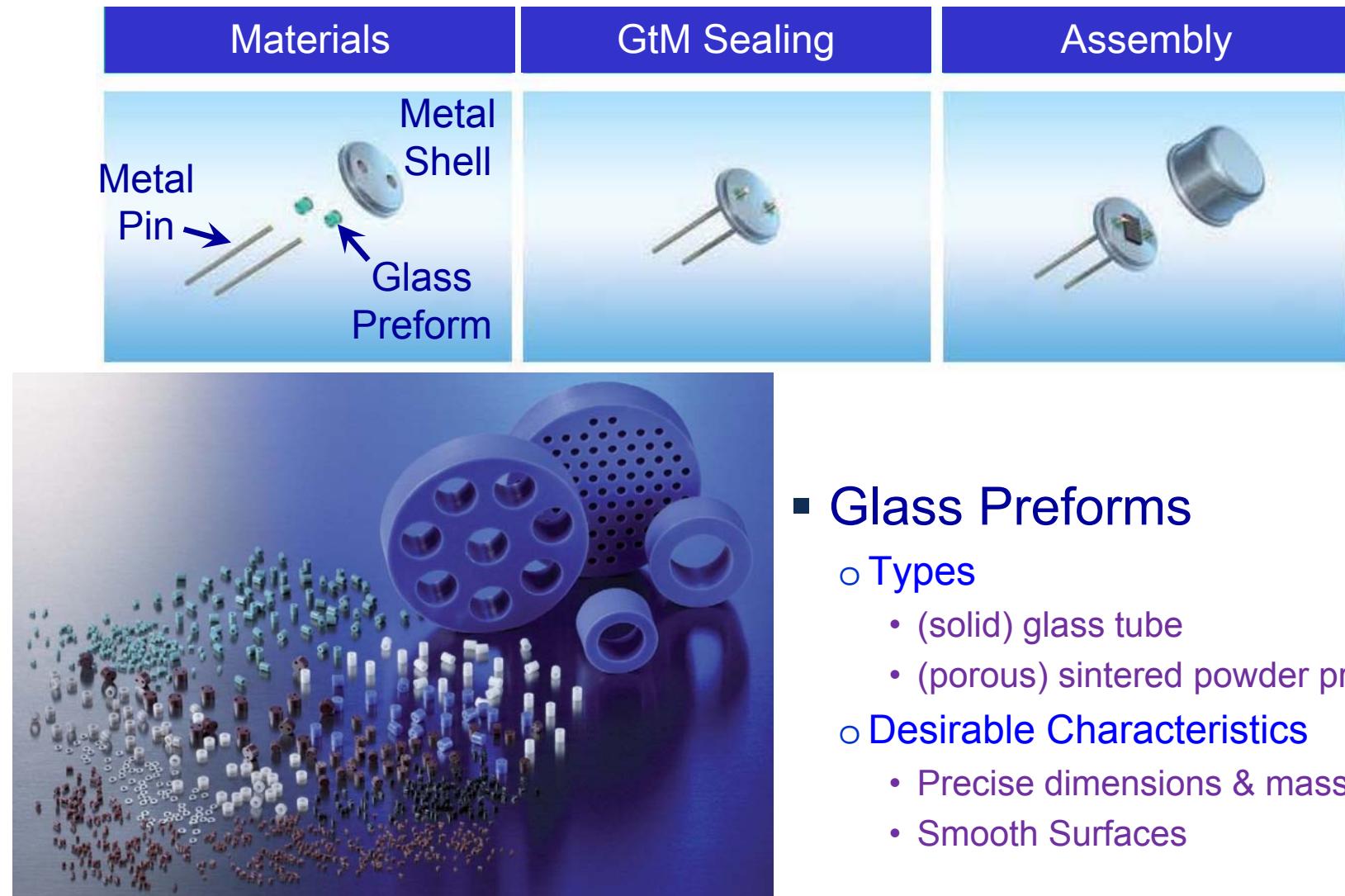
Glass to Metal (GtM) Seals Are Used To Make Hermetic Electrical Feed-Throughs



- GtM Seal Applications
 - Automotive
 - Aviation
 - Telecommunications
 - Medical
 - Energy (Fuel Cells)



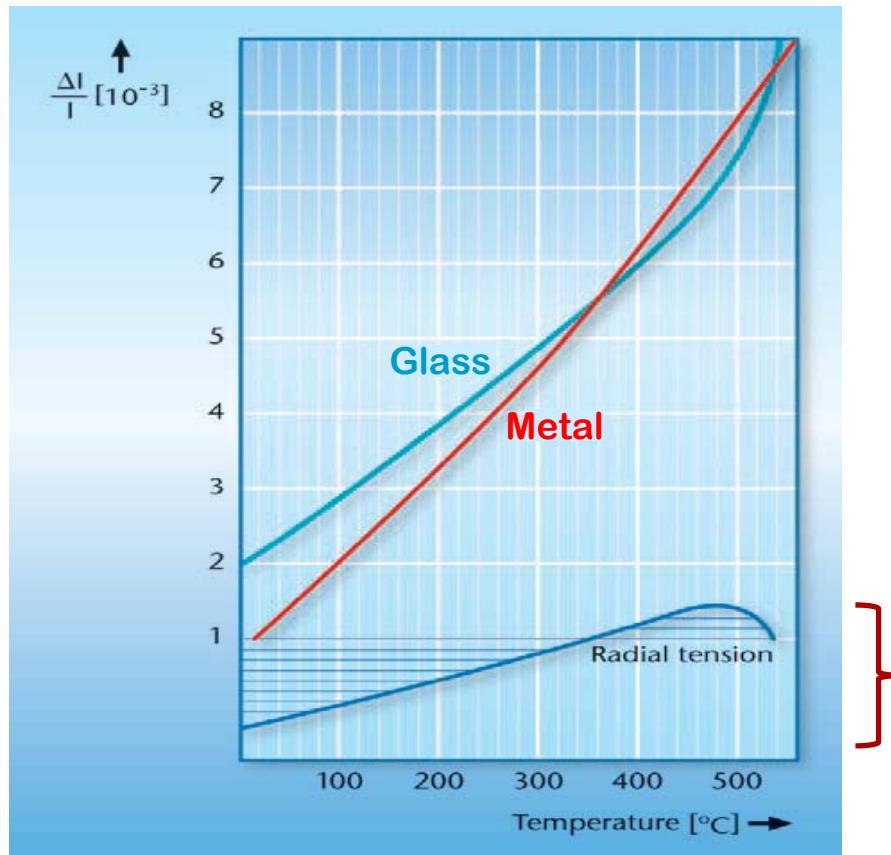
Glass Preforms Are Fabricated, Assembled, And Reflowed To Produce A GtM Seal



- Glass Preforms
 - Types
 - (solid) glass tube
 - (porous) sintered powder preforms
 - Desirable Characteristics
 - Precise dimensions & mass
 - Smooth Surfaces

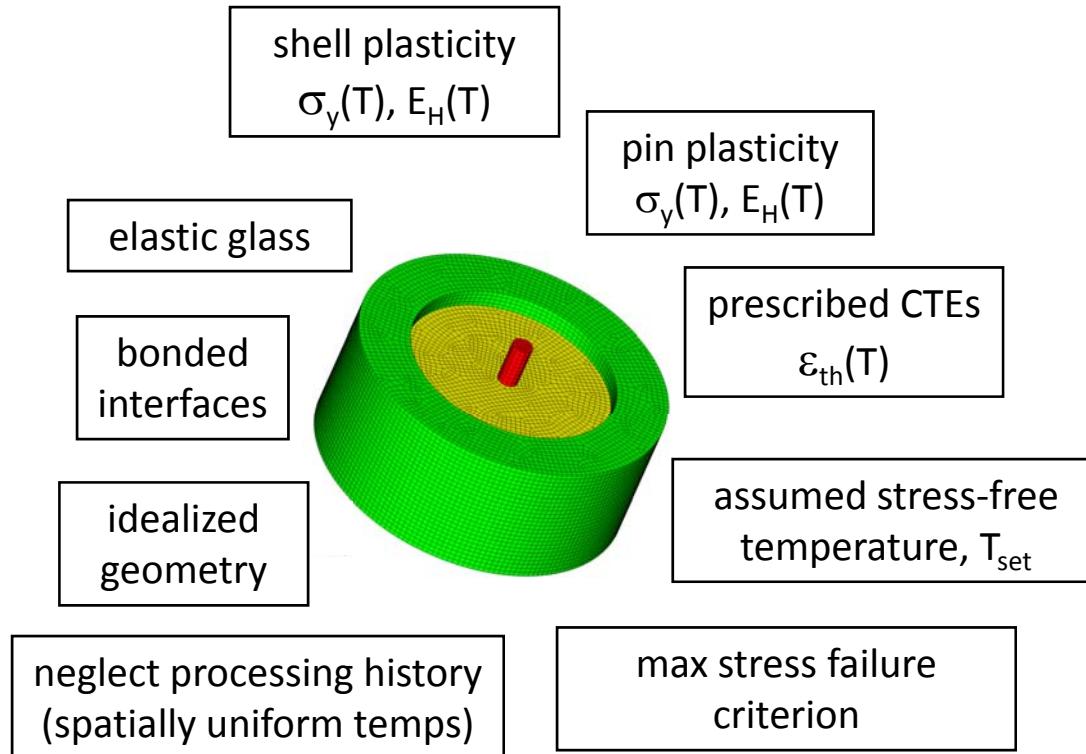
A Compression Seal Is Produced When The $CTE_{\text{metal}} > CTE_{\text{glass}}$

- Compression GtM Seal
 - Corrosion & Pressure Tolerant



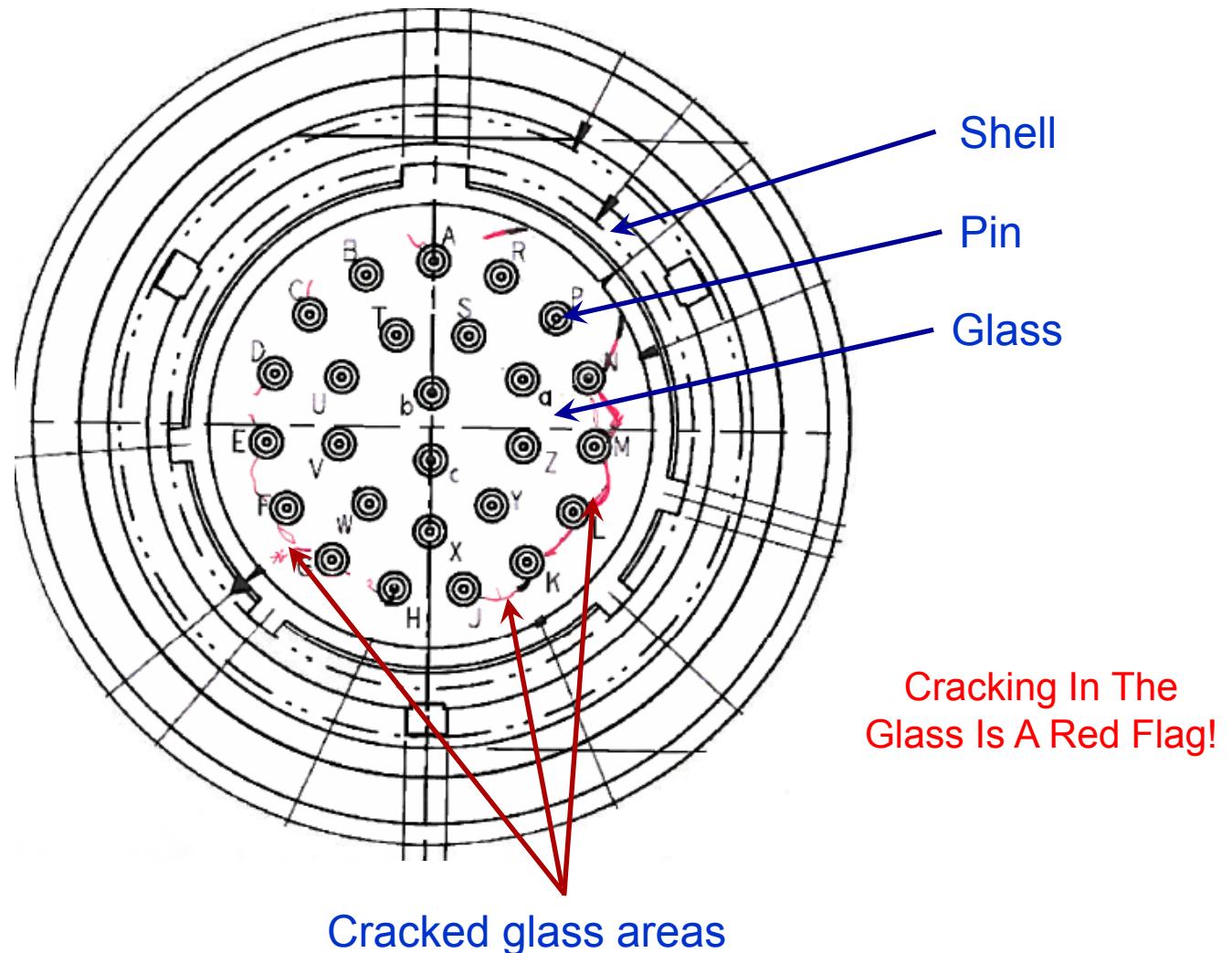
Heating/Cooling
Changes The
Stress In The
Glass Seal

Finite Element (FE) Stress Predictions Are Used To Assess GtM Seal Performance & Reliability

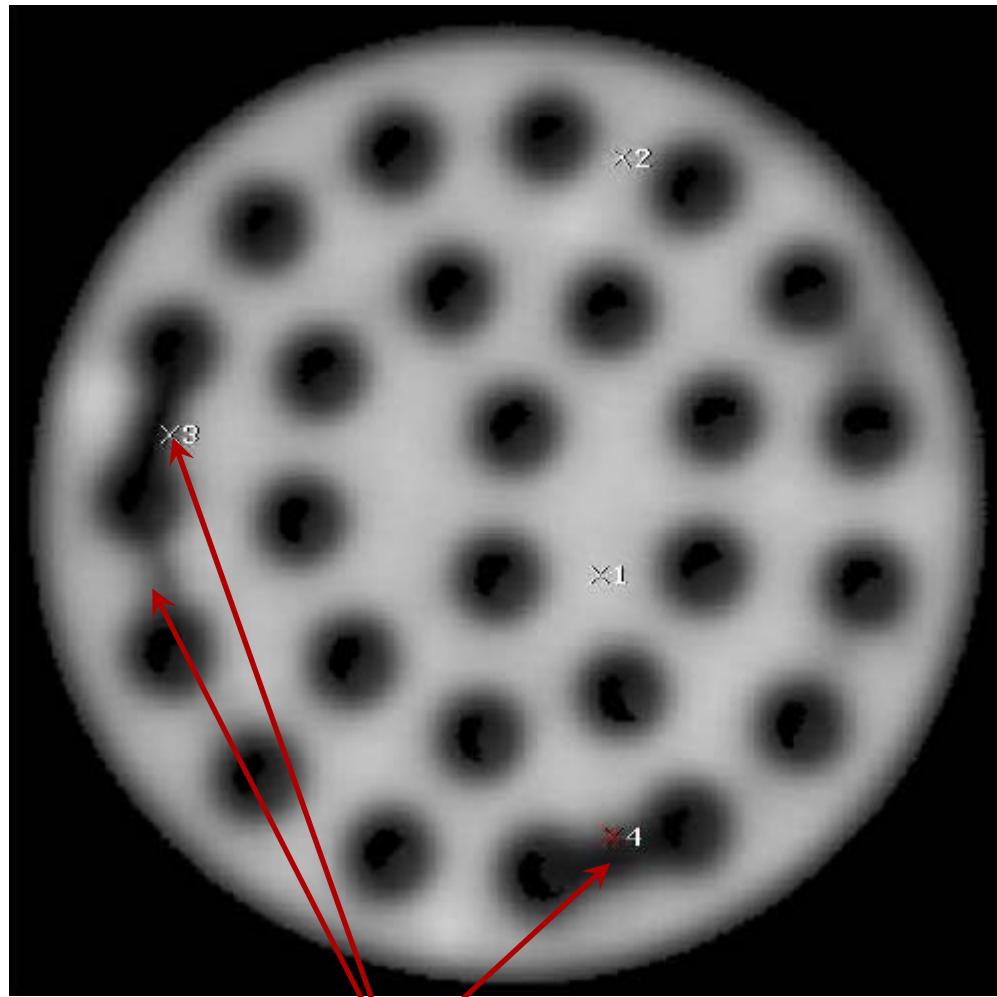


Materials/Modeling Assumptions Determine The Fidelity Of FE Stress Predictions

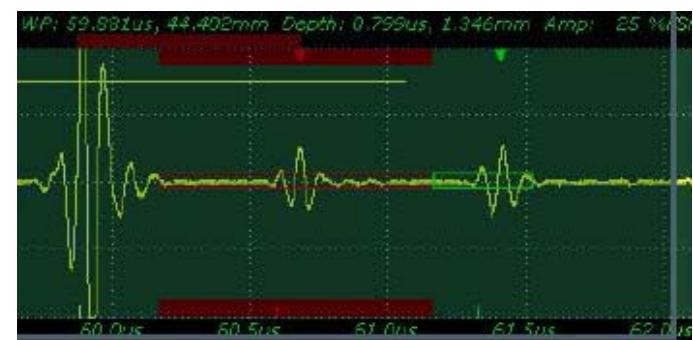
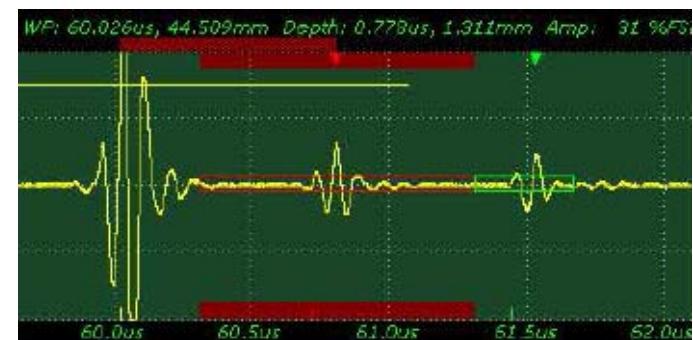
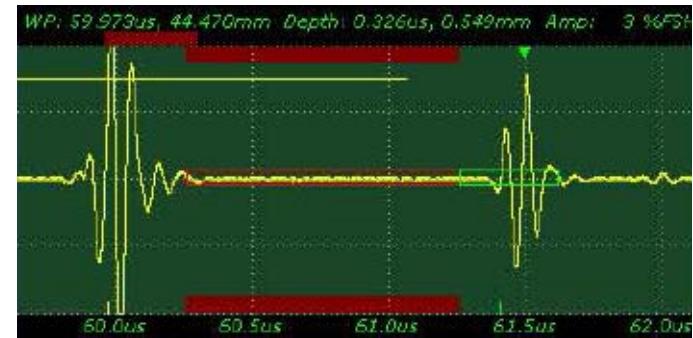
Post Stress Test Visual Inspection Identified Cracks Between The Outer Pins



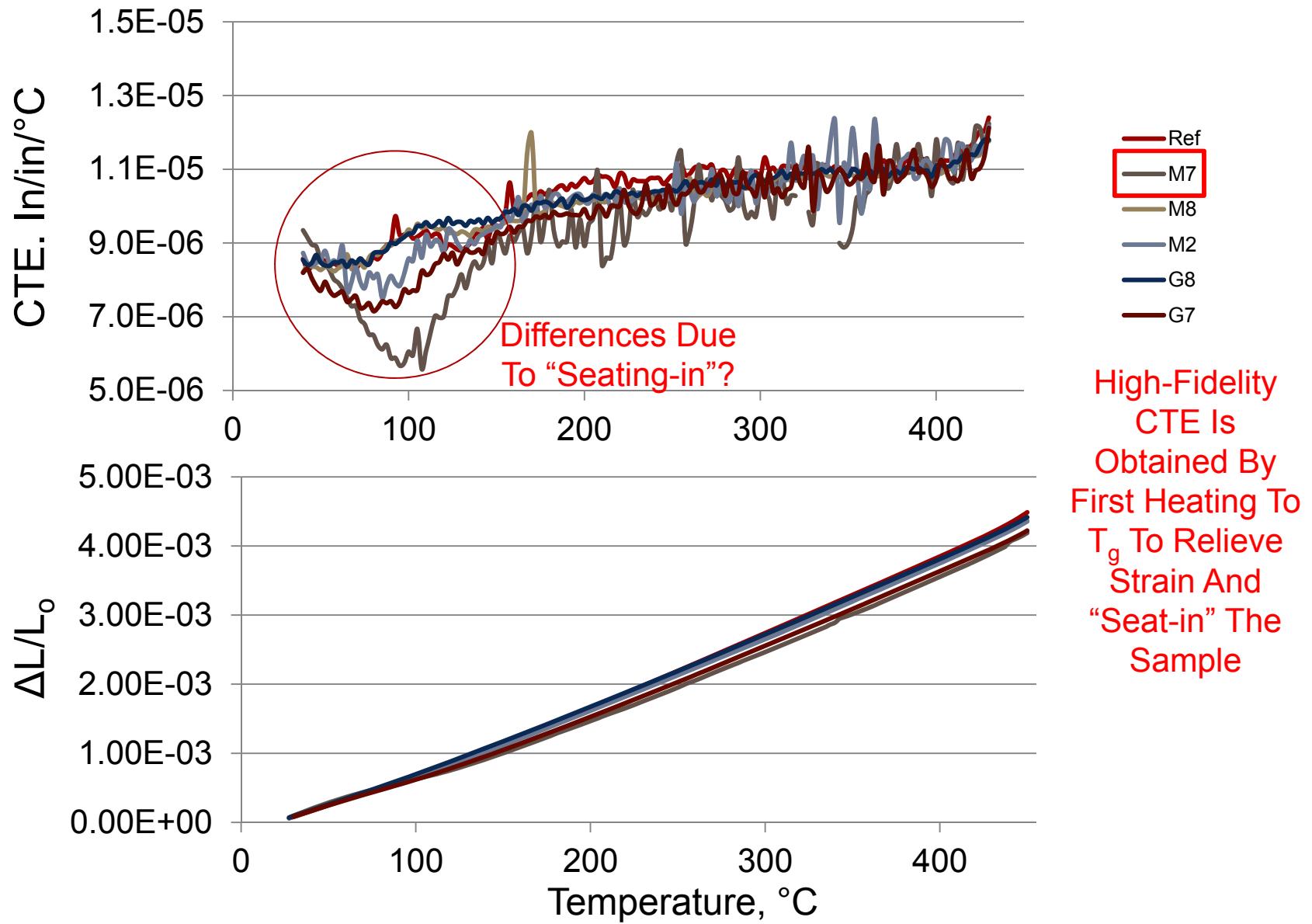
Post Stress Test Ultrasound Imaging Revealed Low Density Areas Between The Outer Pins



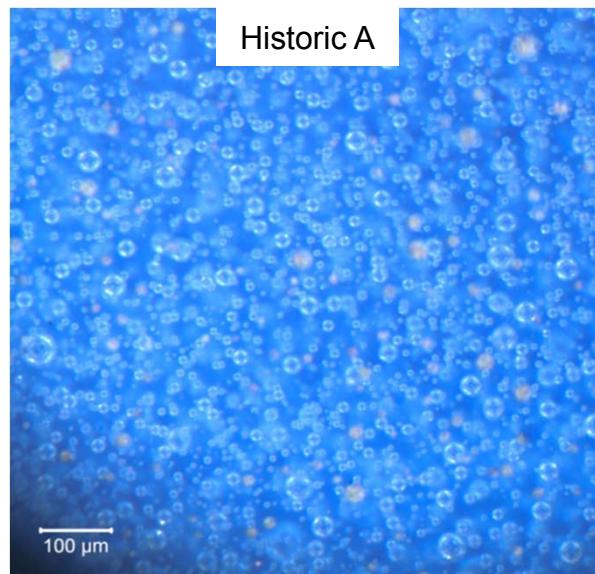
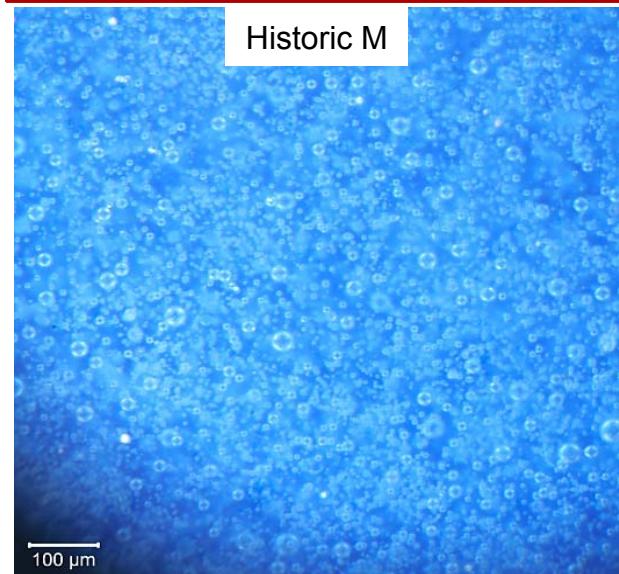
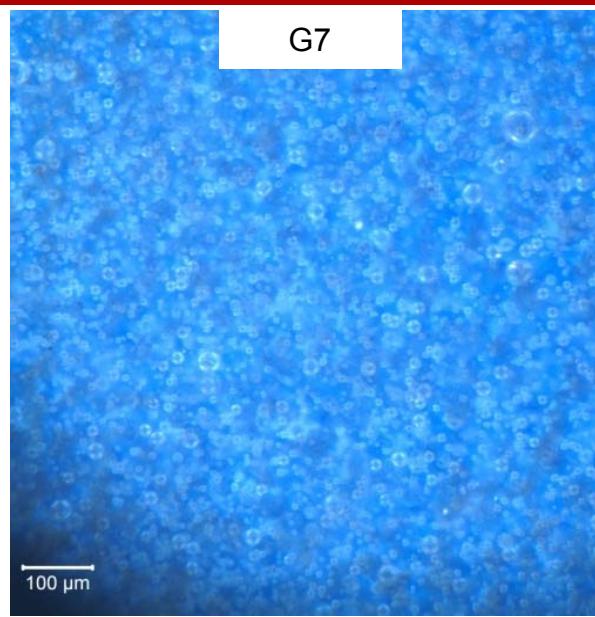
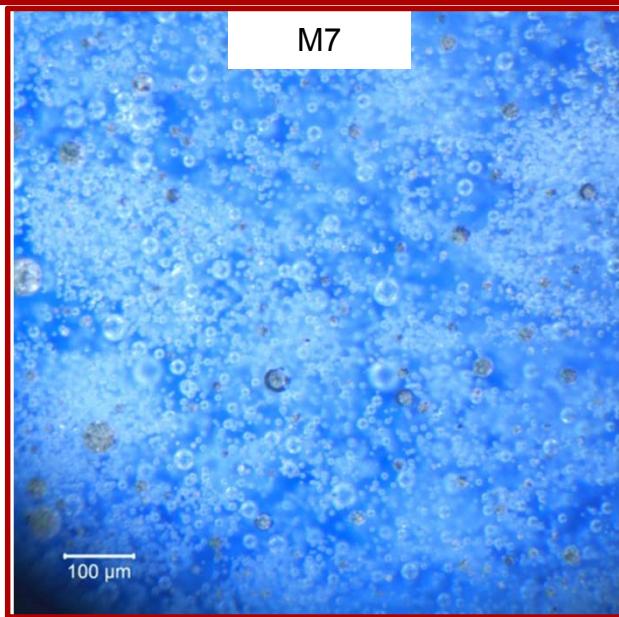
Low-density regions



Heating Coefficient Of Thermal Expansion Curves Show No Significant Differences

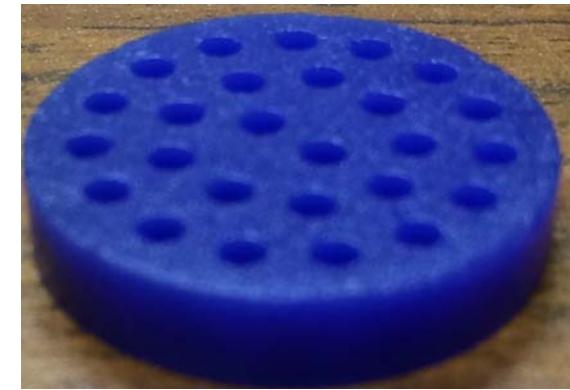


The M4047 Glass Looks Heterogeneous & “Cloudy” After Sealing

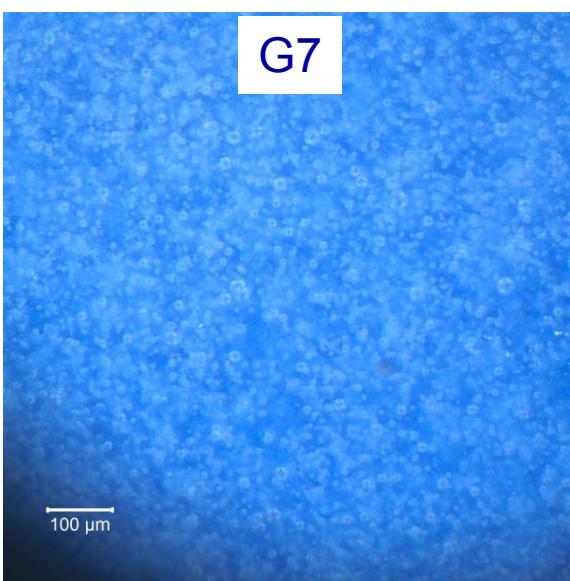
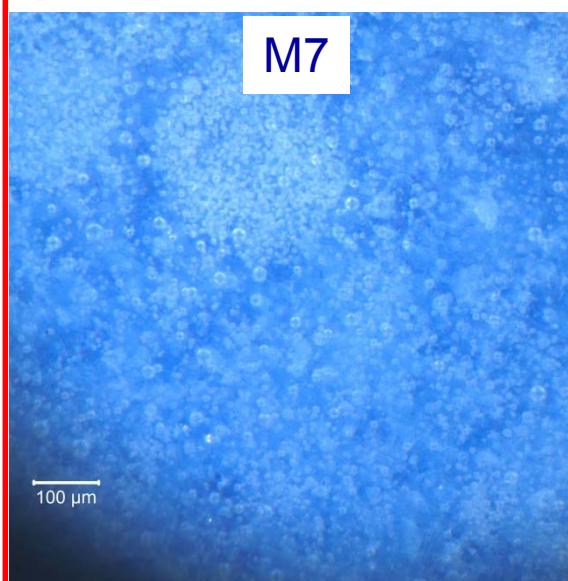


Preform Processing Affects The Look Of The Glass Before & After Sealing

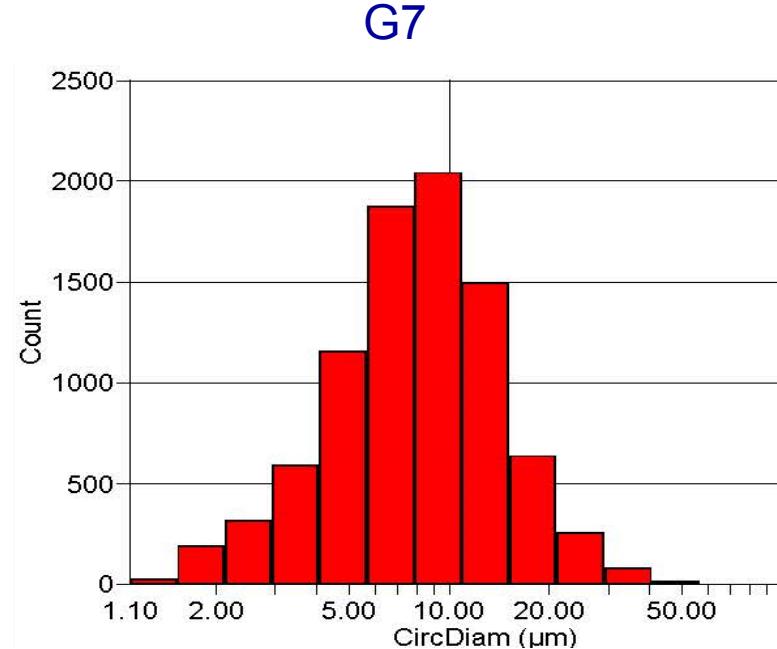
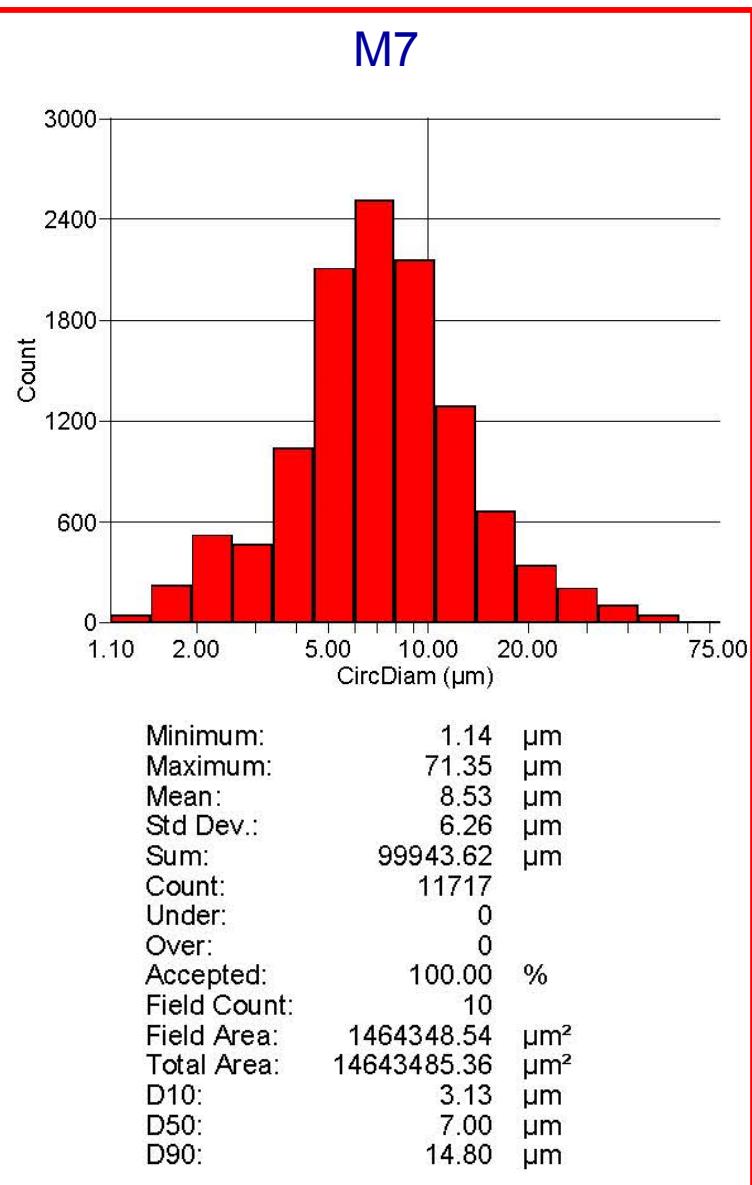
Preform →



After Sealing →

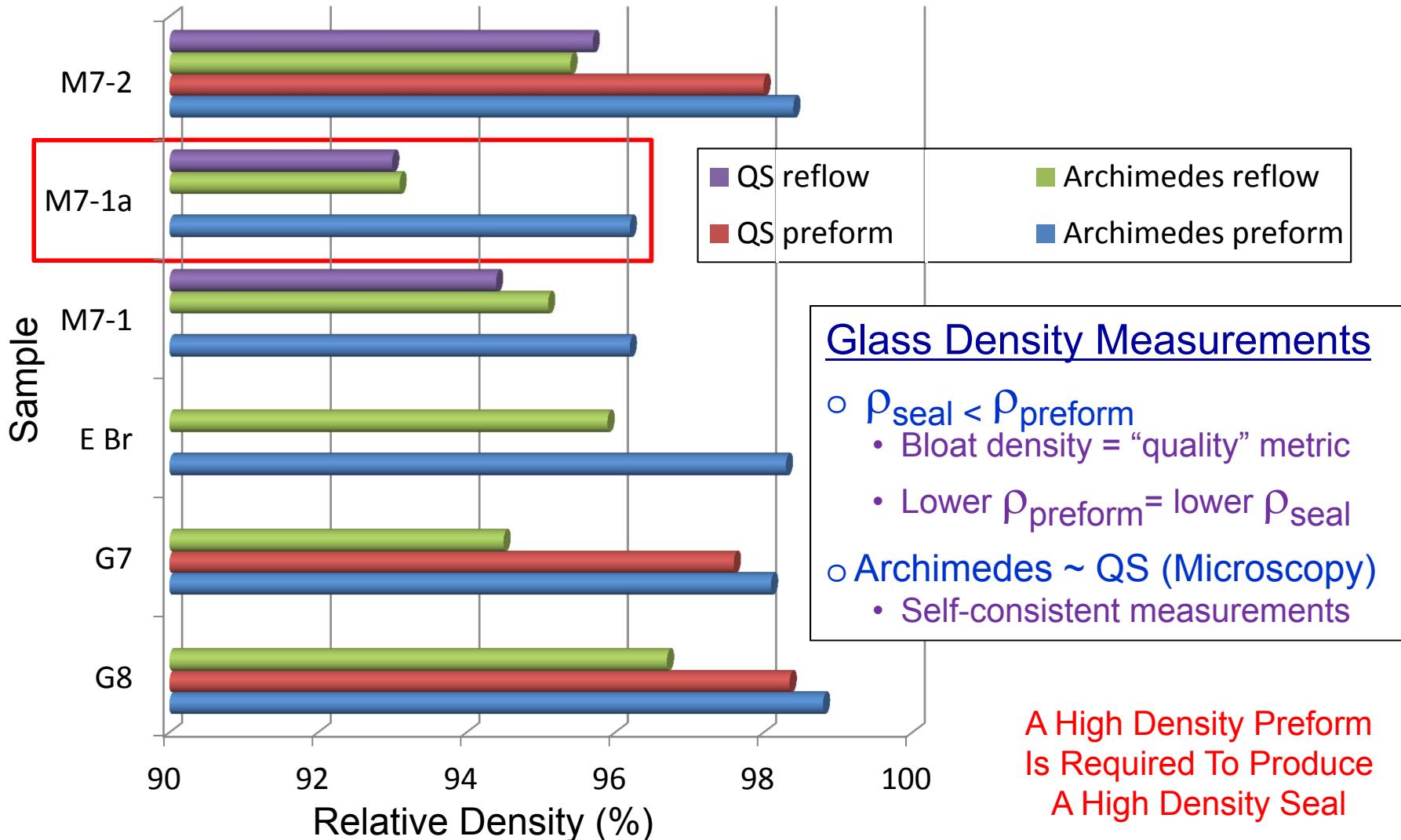


Quantitative Stereology Shows Only Minor Differences in Pore Size/Distribution

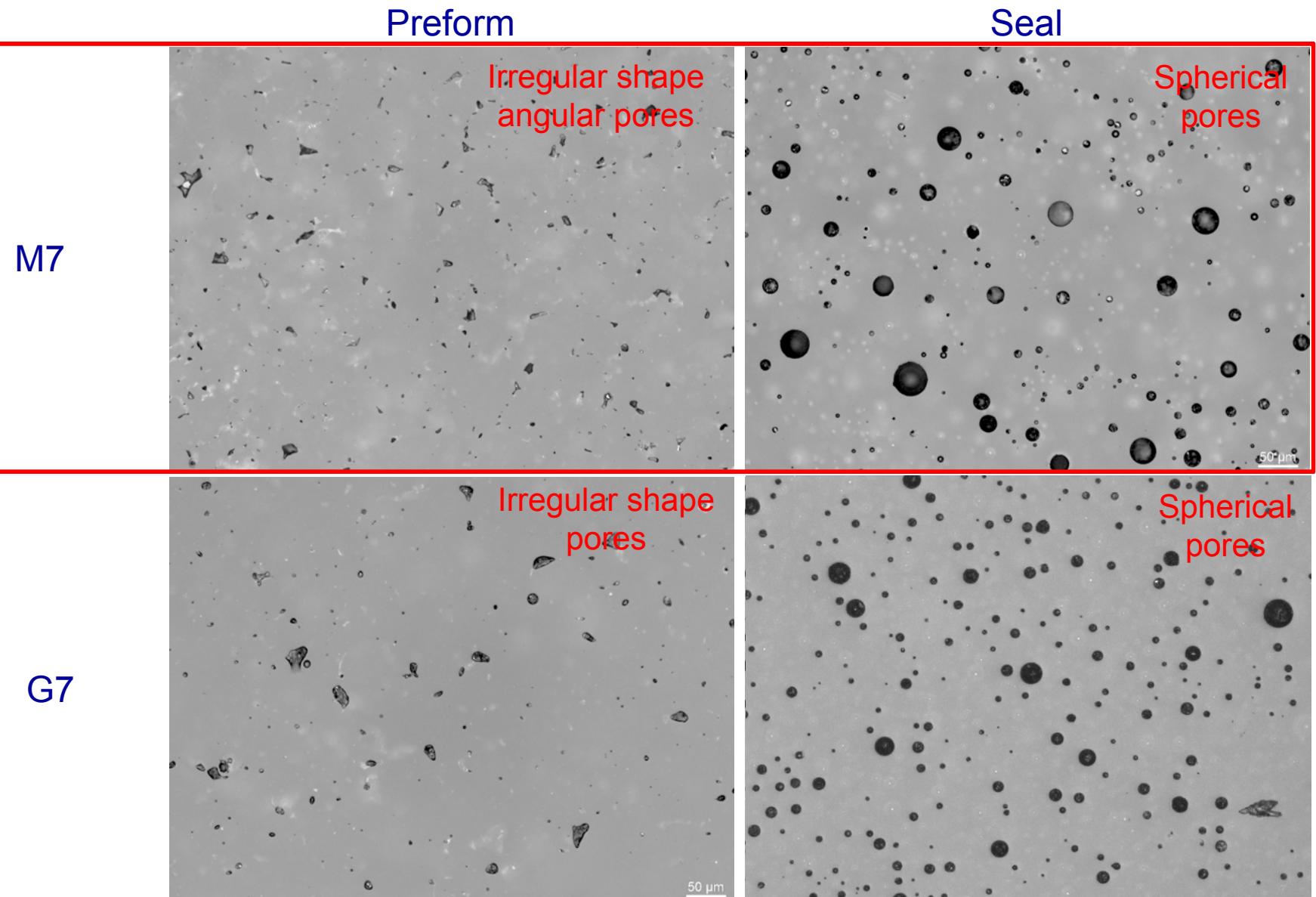


QS Does
Not
Discern
The
Differences
Seen By
Eye

Cracked Parts Have Lower Preform And Glass Seal Density



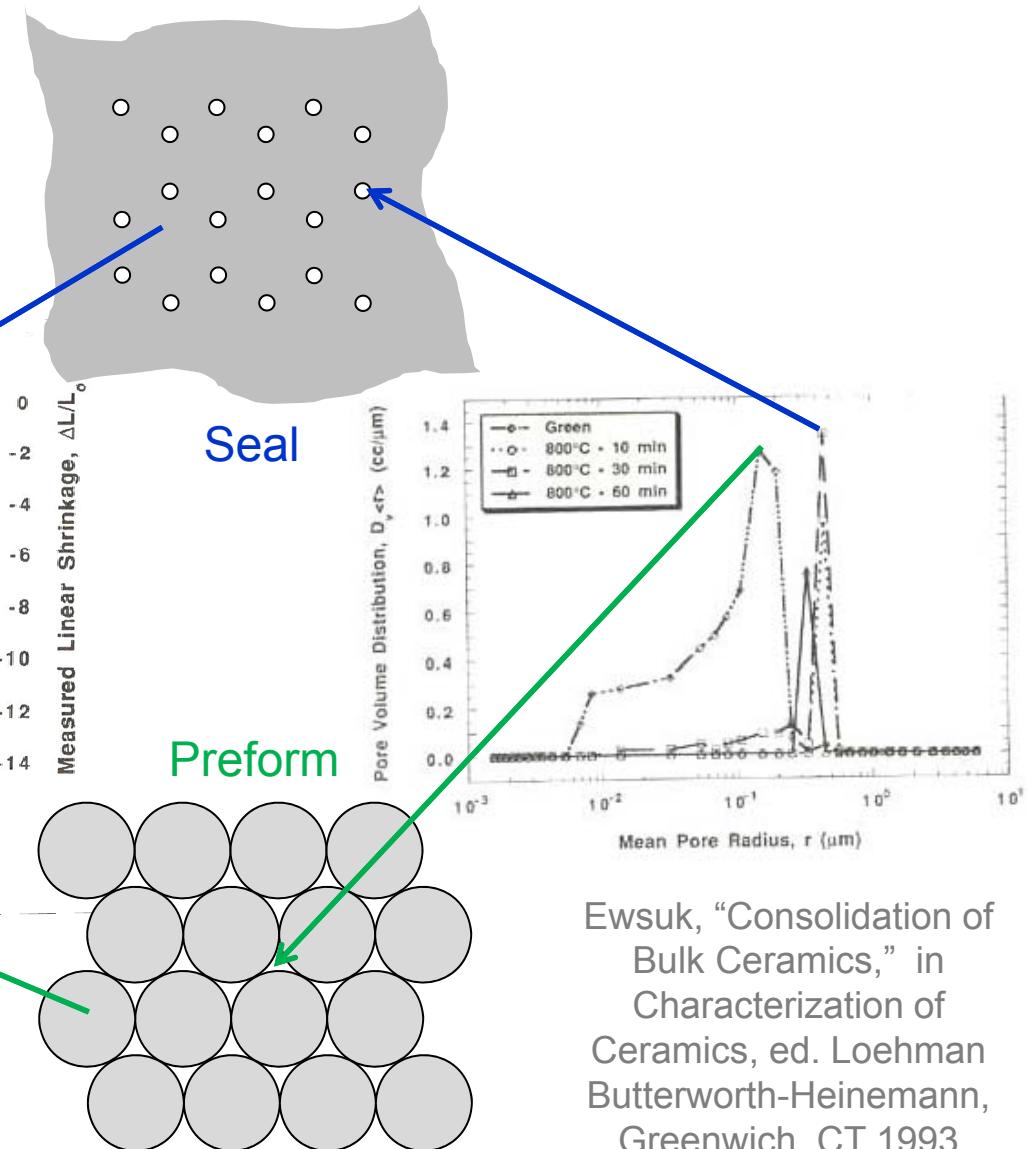
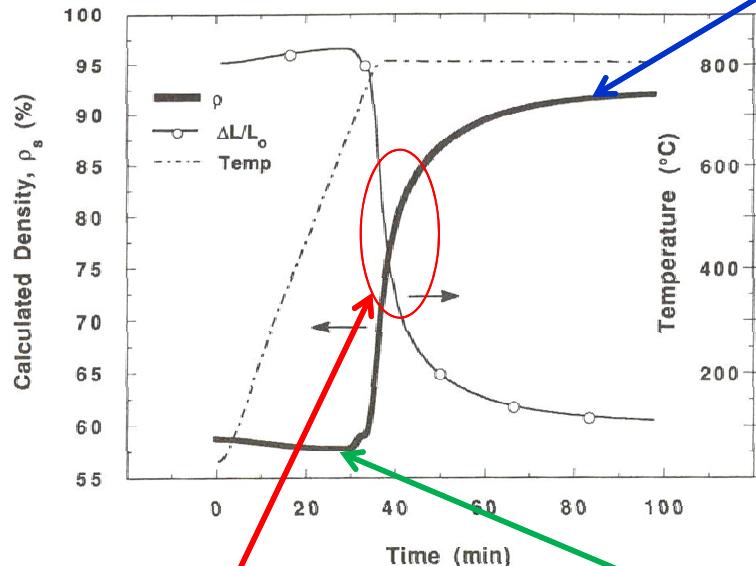
Glass Microstructure/Pore Shape Change During Sealing



Pore Size & Shape Change During Sintering, And Indicate Microstructure Maturity

▪ Typical Sintering

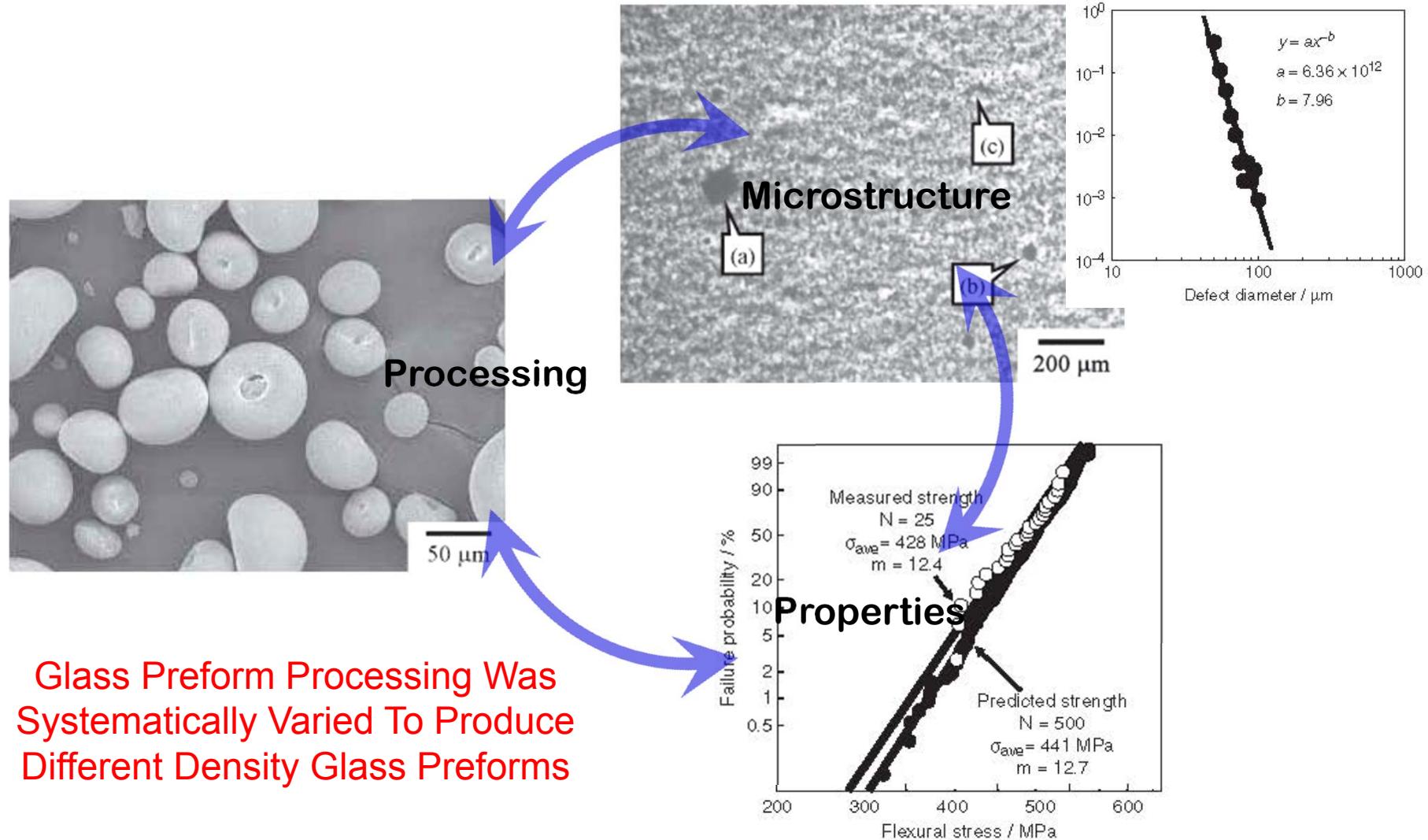
- Angular pores spheroidize
- Shrinkage of part & pores
 - Fine pores eliminate preferentially
 - Closed pores swell
- Densification



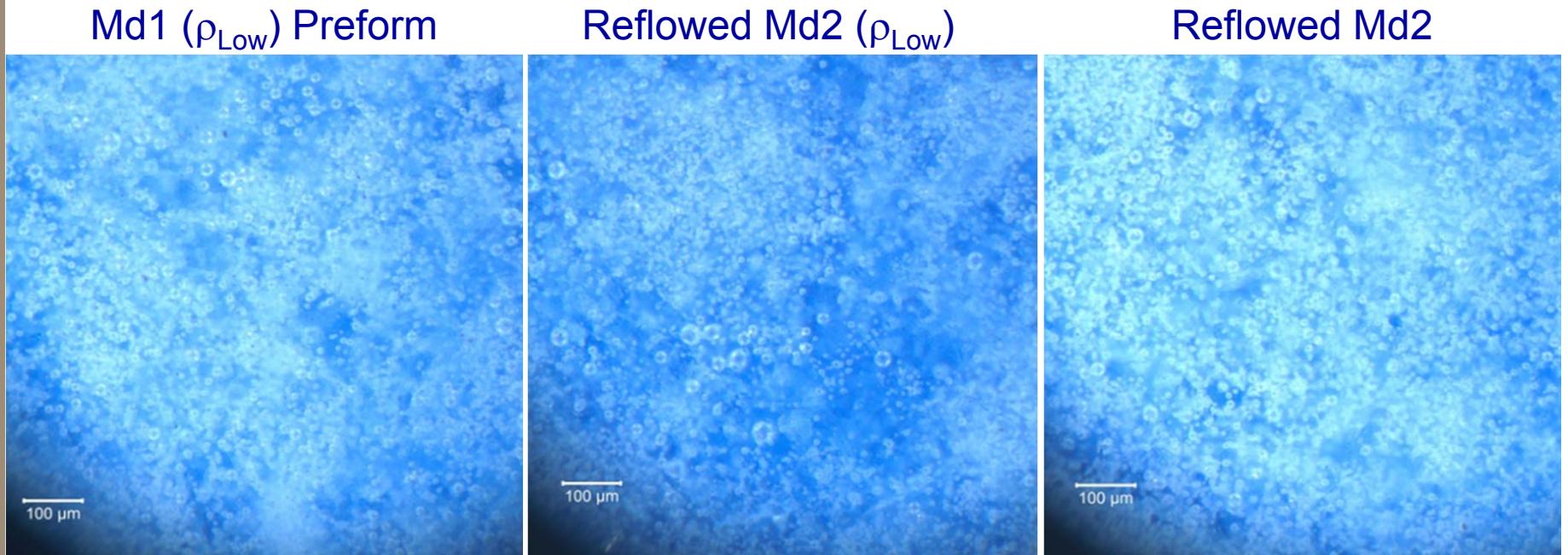
Angular Porosity Indicates An Immature Microstructure And High Manufacturing Variability

Ewsuk, "Consolidation of Bulk Ceramics," in Characterization of Ceramics, ed. Loehman Butterworth-Heinemann, Greenwich, CT 1993

Process-Structure-Property Understanding & Control Are Critical To Performance & Reliability



Systematic Process Changes Did Not Significantly Affect Bubble Size/Distribution

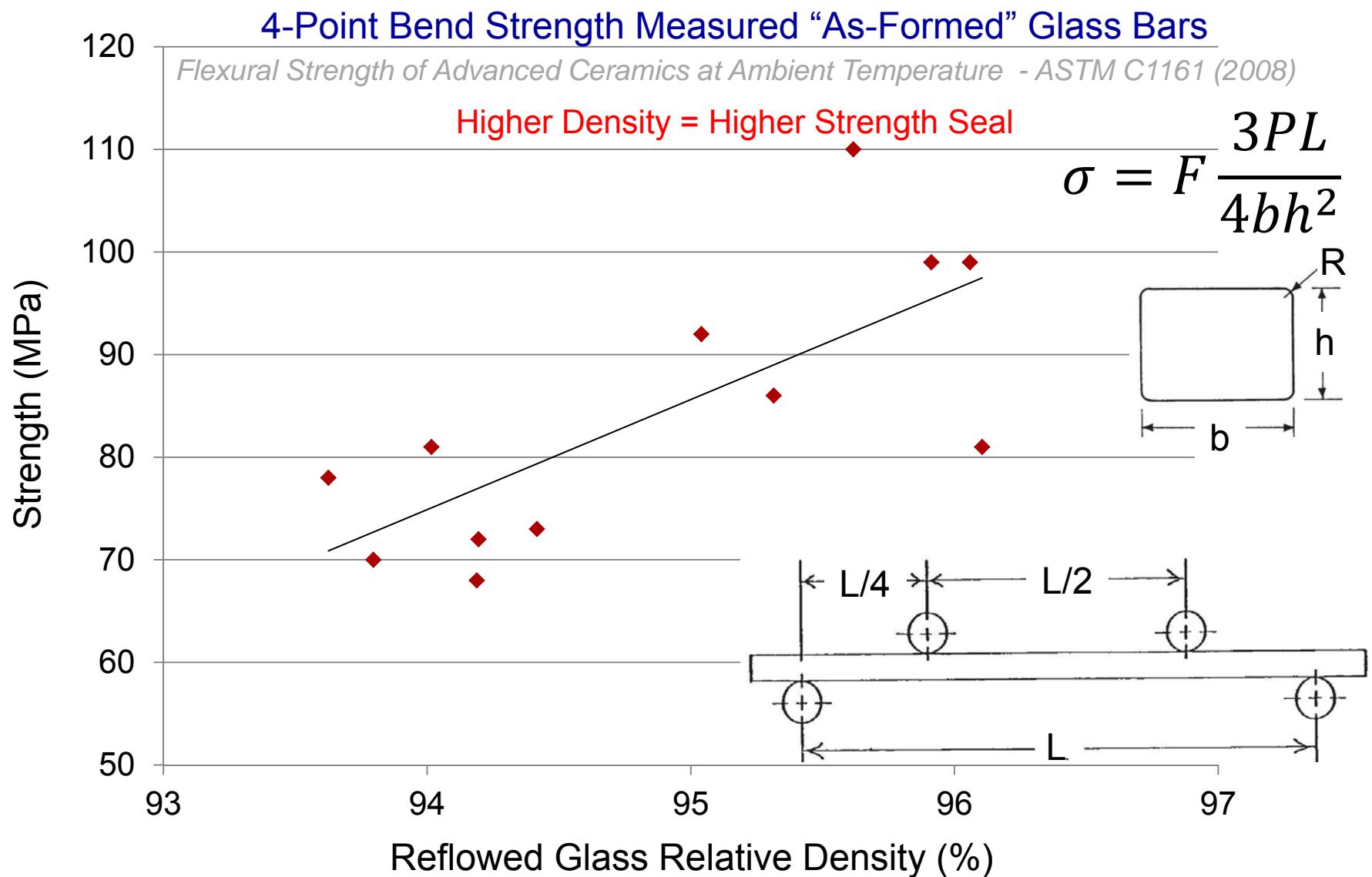


Potential Supply Chain Issues

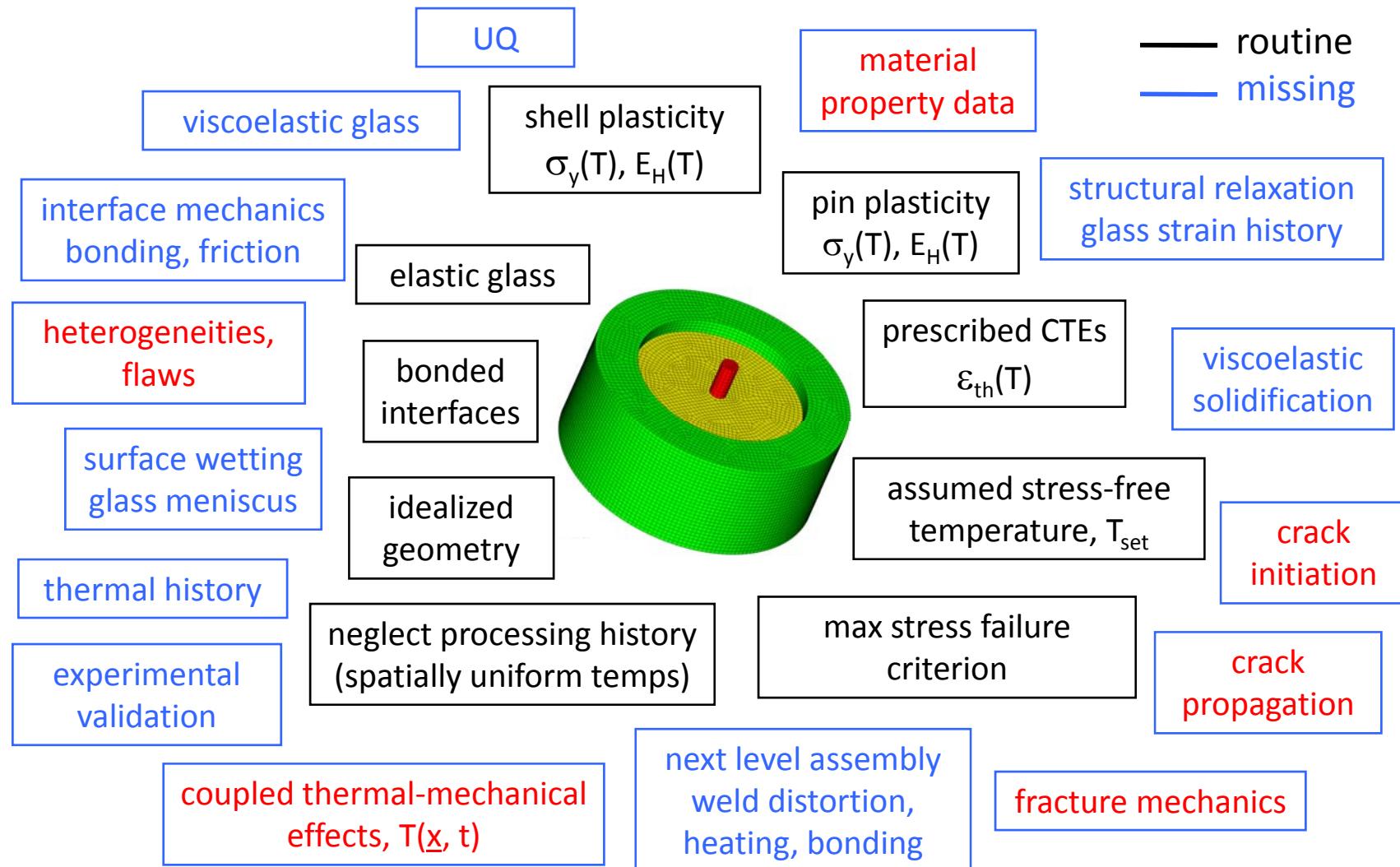
- Lot-to-Lot Process Variability
- Limited Process Understanding & Control

(it was not possible to replicate the low preform density)

Reflowed/Sealed Glass Strength Trends Up With Density



Residual Stress & Cracking Will Be Affected By Thermo-Mechanical, & Structure-Properties



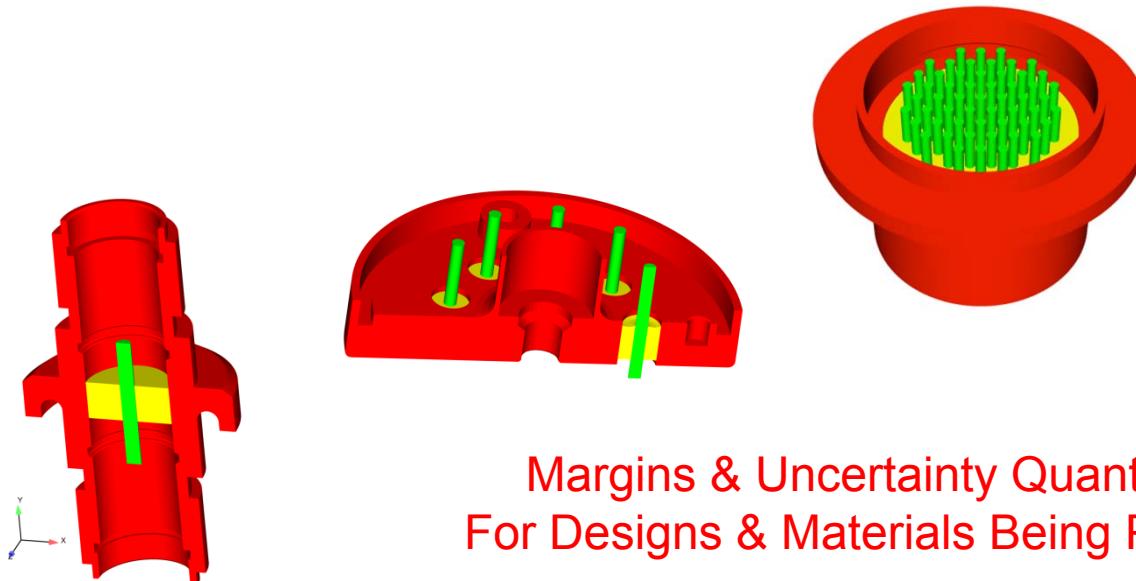
The Seal Geometry, Materials, Processing, & Model Details Are Critical
For High-Fidelity Stress, Performance, & Reliability Predictions

GtM Sealing/Manufacturability Improves With Glass Preform Consistency/Quality



▪ What's Different With GtM Seals Today?

- More complex designs/geometries
 - more pins & tighter spacing
- More demanding requirements
 - Higher stress, longer lifetime
- Approaching materials & processing limits



Margins & Uncertainty Quantification Are Critical
For Designs & Materials Being Pushed To Their Limits

Summary & Conclusions



▪ Summary

- Stress-Testing resulted in glass seal cracking – a **Red Flag**
- No materials differences indicated by CTE measurements
- Process differences indicated by density & microstructure measurements
 - Preform variability due to insufficient process understanding/control
- Seal density < preform density
 - Bloat density is a “quality” metric
 - Self-consistent results (Archimedes and QS)
- Strength increases with glass seal density

▪ Conclusions

- Pre-heating to T_g is recommended for high-fidelity CTE measurements
 - Quick measurements are subject to errors.
- QS cannot discern the differences (heterogeneity) seen by eye.
 - Meso-structure characterization techniques may be needed (e.g., tessellation)
- Consistent, high density preforms = high quality
 - Preform quality = GtM seal manufacturing yield & quality