SAND2017-4573C

Photos placed in horizontal position with even amount of white space between photos and header

Stress Mapping in Glass-to-Metal Seals using Indentation Crack Length Measurements

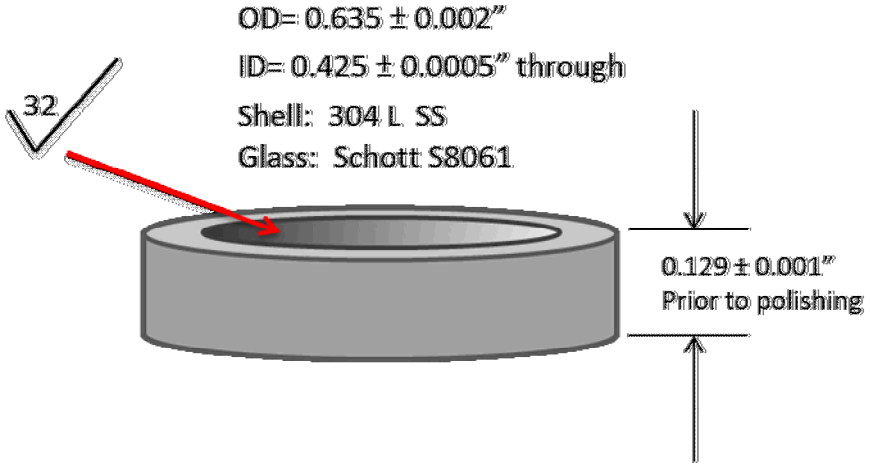
T.E. Buchheit, M.C. Teague, R.D. Jamison, T. Diebold, C. Newton, K.T. Strong

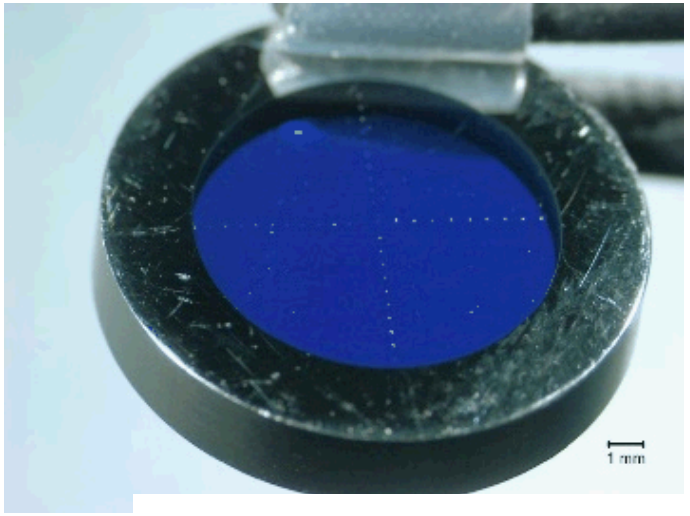
Sandia National Laboratories is a multi-mission laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. SAND NO. 2011-XXXXP

Introduction

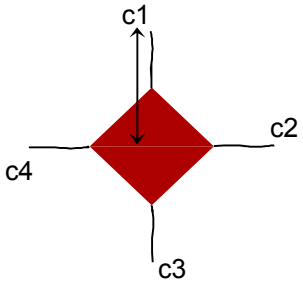
- Review of Indentation method for measuring stress in brittle materials.
- Application of method to ‘map’ residual stress in a glass captured within a short cylindrical geometry
- A more practical application in a SB glass/Inconel shell glass-to-metal seal with interconnect pins.
- Size scale effects observed in indentation of brittle materials

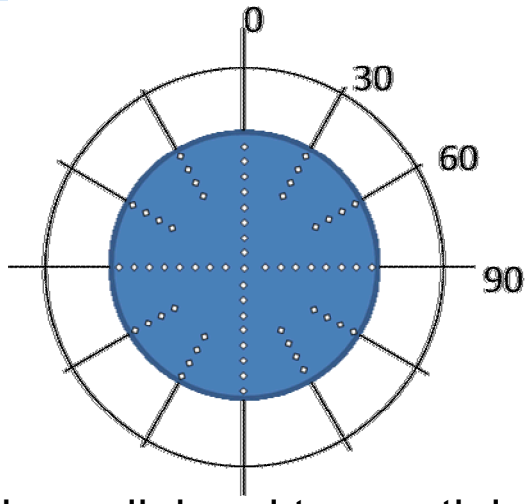
Measuring radial cracks in ‘Short cylinder’ compression seal geometry





Radial stress component is taken from c2 & c4 crack lengths and Tangential stress component is c1 & c3 crack lengths



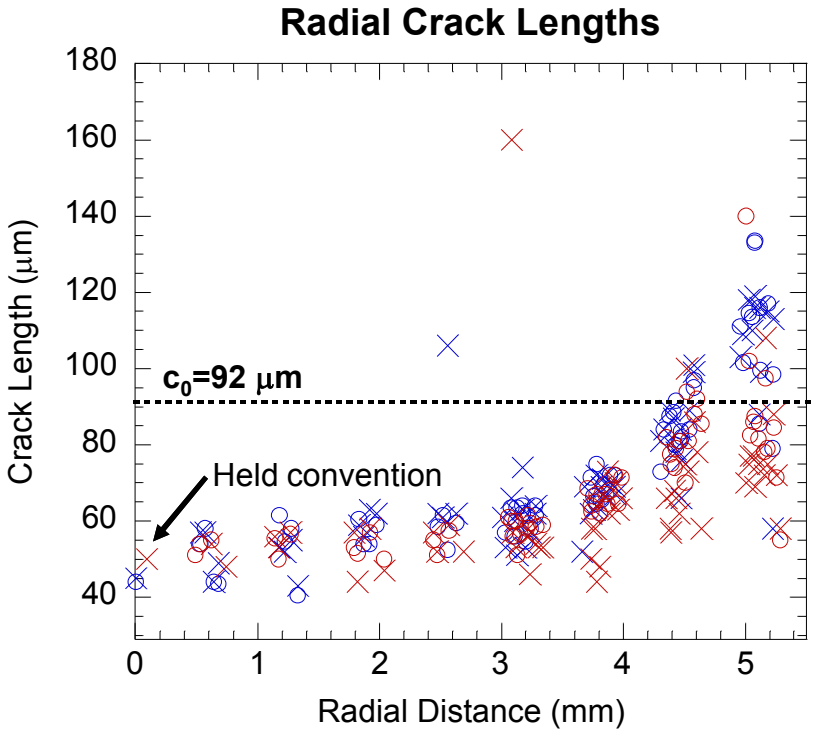


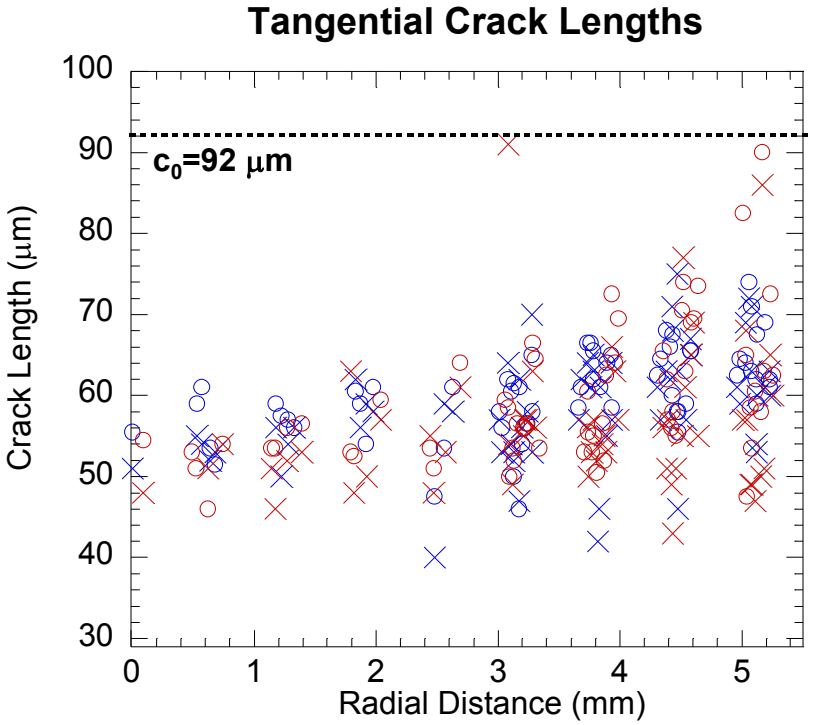
Goal: Use the crack length measurement to infer the radial and tangential stress components at the indent locations in the captured glass

Indentation crack length measurements show consistent trends

Sandia National Laboratories

Blind measurements → Measurement #1 3/2015
Measurement #2 6/2016

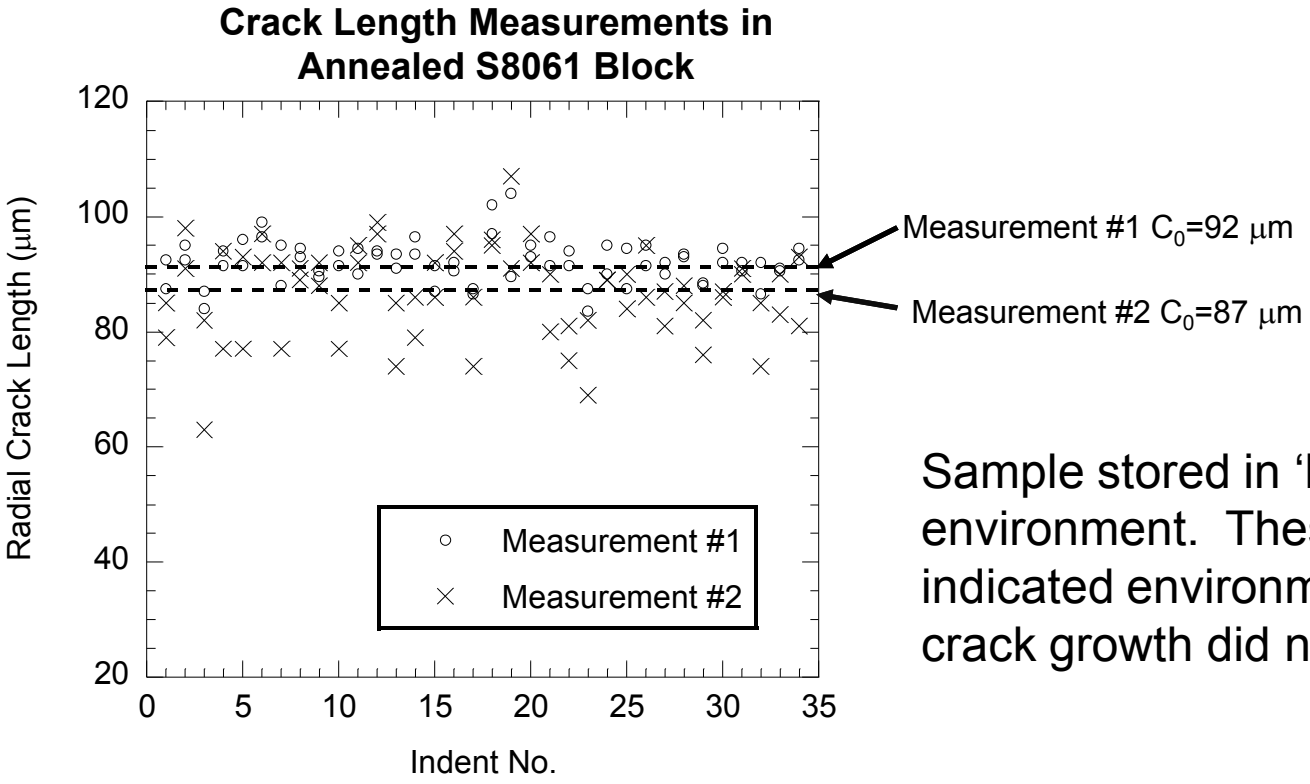




Measurement #1 (oxidized)
Measurement #2 (oxidized)
Measurement #1 (no oxide)
Measurement #2 (no oxide)

Measurement #1 (oxidized)
Measurement #2 (oxidized)
Measurement #1 (no-oxide)
Measurement #2 (no-oxide)

Annealed Block used as a zero stress reference measurement



Sample stored in 'low' humidity lab environment. These results indicated environmentally assisted crack growth did not occur

Principle of superposition used to measure stress normal to indentation crack growth direction

- Uniformly loaded half-penny crack in a semi-infinite body

$$K_a = 2\sigma\sqrt{\frac{c}{\pi}}\,F$$ (Stress analysis of cracks handbook, Tada, Paris, Irwin, 2000)

- Center loaded penny crack used for indentation medial-radial crack system

$$K_r = \chi\left(\frac{P}{c^{3/2}}\right) \qquad \chi = 0.02\left(\frac{E}{H}\right)^{1/2}$$

Anstis et al., JACS, 1981
Morris, Cook, JACS, 2004

$$K_{Ic} = \left(\frac{P}{c^{3/2}}\right) + 2\sigma\sqrt{\frac{c}{\pi}}$$

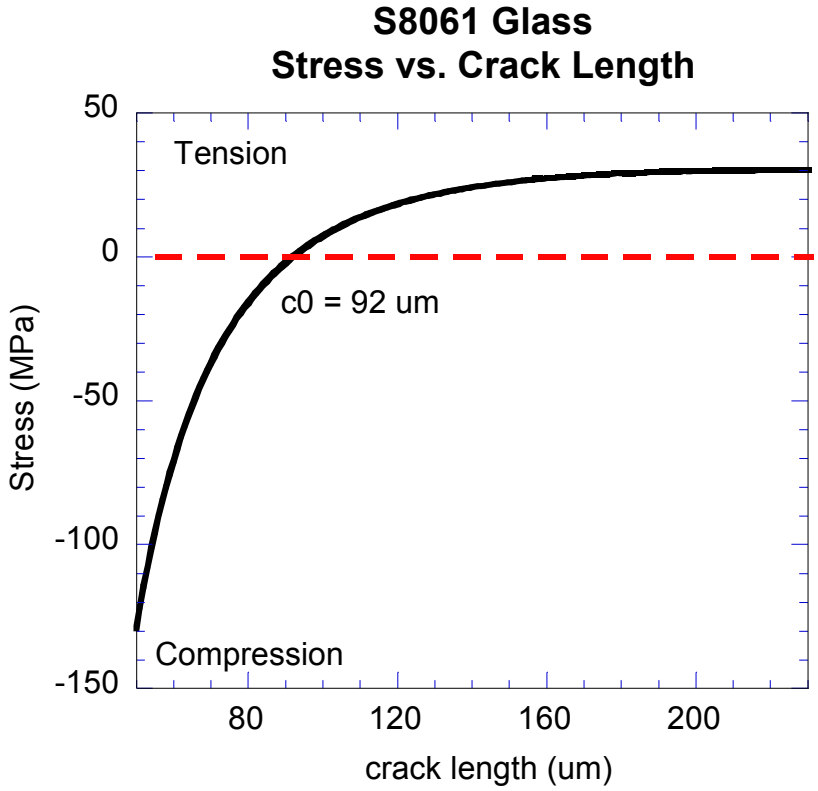
Measure K_{Ic} on unstressed material

Marshall, Lawn, JACS, 1976
Lawn, 'Fracture of Brittle Solids', Chp. 8.
Anunmana, Anusavice, Mecholsky, Dental Materials, 2009.

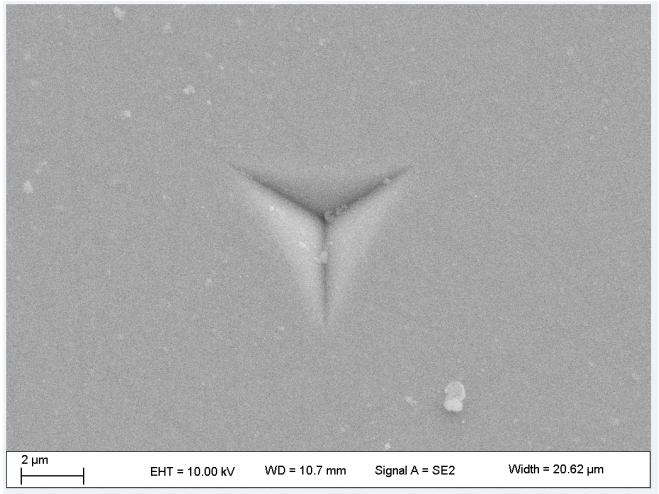
This model for measuring stress is stiff in compression and forgiving in tension

$$\sigma = \frac{\left(K_{Ic} - \chi\left(P/c^{3/2}\right)\right)}{2\sqrt{c/\pi}}$$

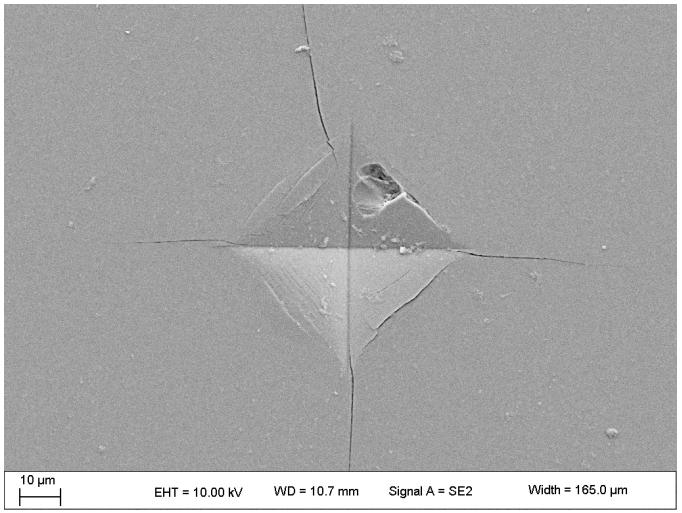
Table I – S8061 Experimental Parameters	
Parameter	**Value**
Young's Modulus (E)	73 GPa
Hardness (H)	7.7 GPa
$\chi = 0.02\ (E/H)^{1/2}$	0.062
Indentation Load (P)	9.807 N
Avg. crack length, annealed S8061 (c_0)	92 μm
Reference Fracture Toughness (T_0)	0.69 MPa · $m^{1/2}$



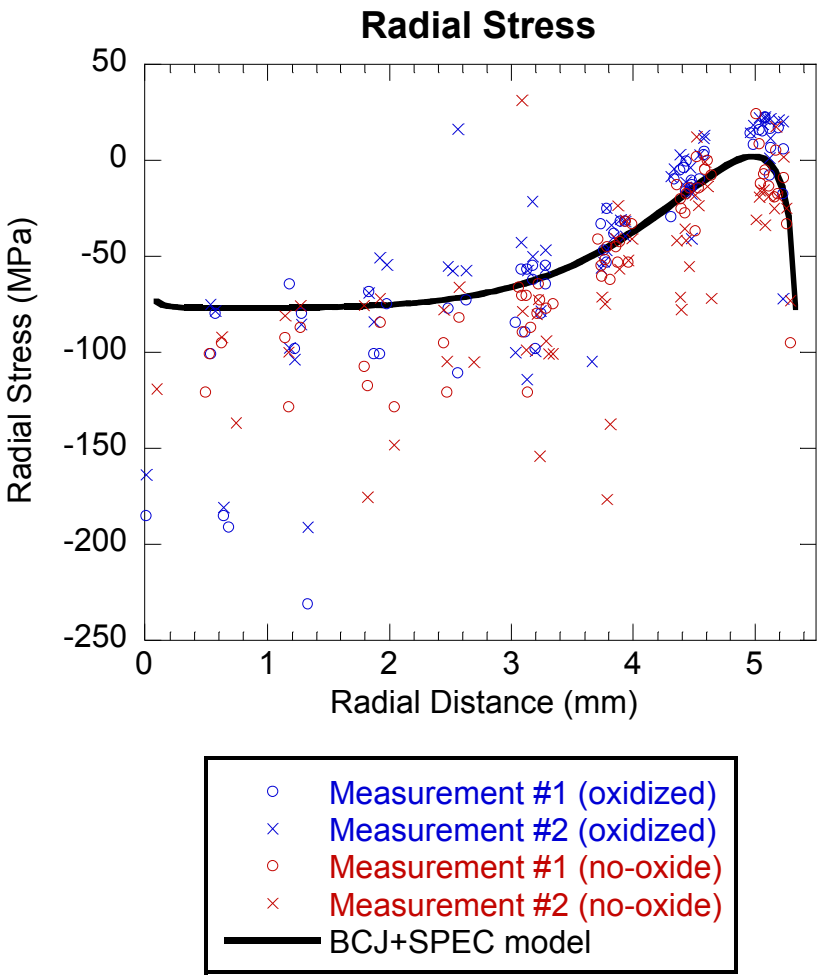
Evaluating Hardness in S8061 glass

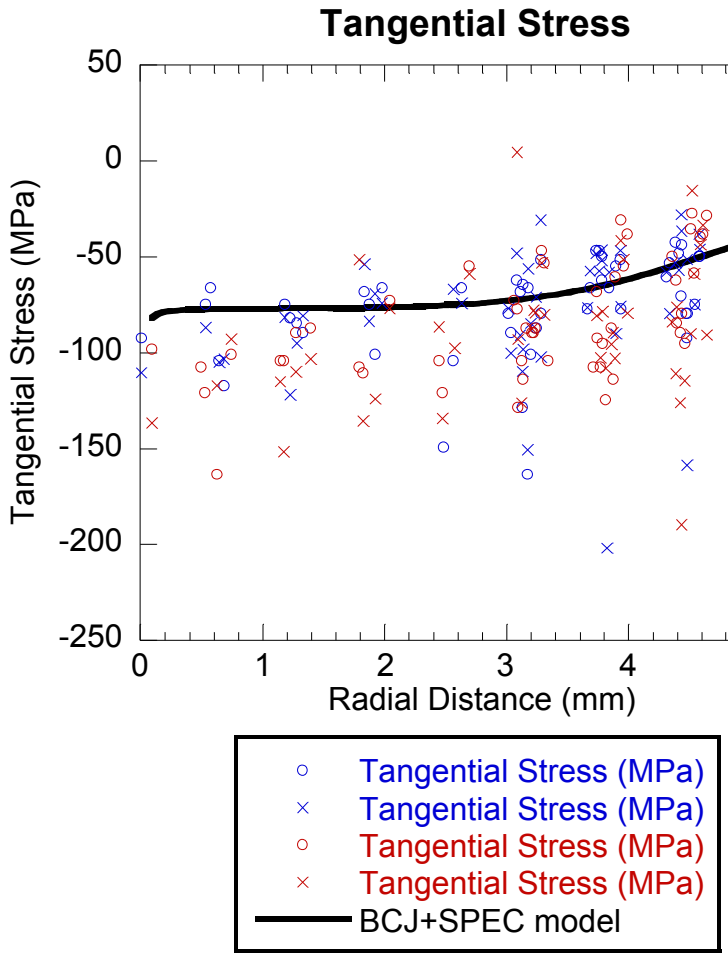


S8061 berkovich tip impression
1 um experiment – instrumented
H=7.7 GPa

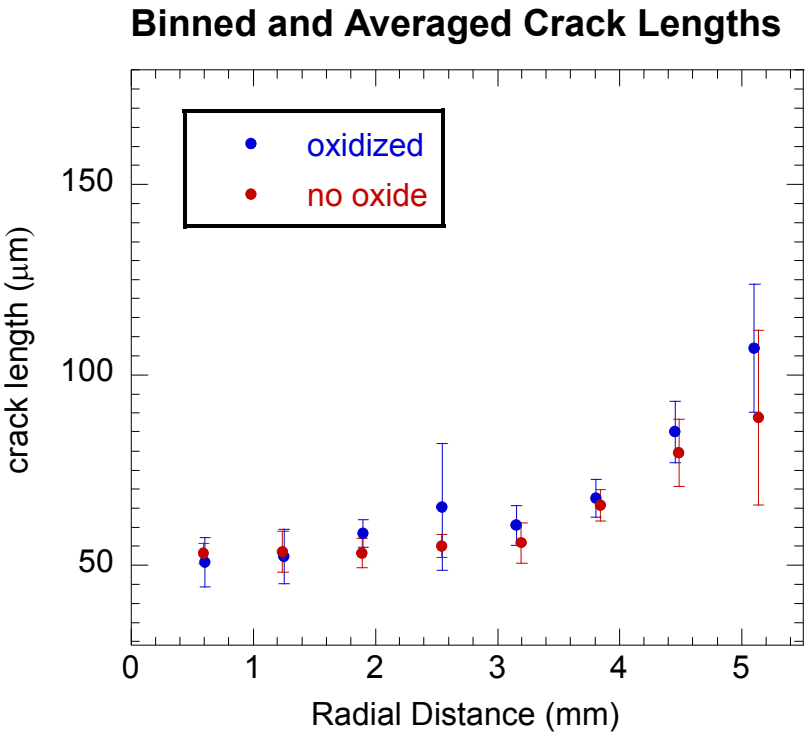


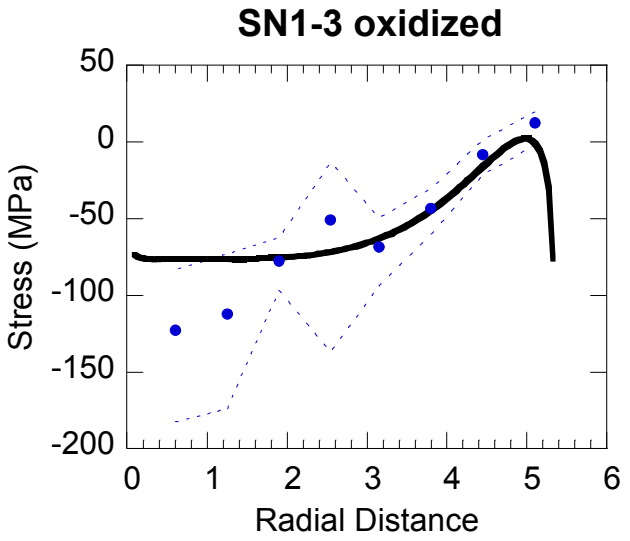
S8061 1 Kg Vickers Tip Impression
H= 551 VHN ≈ 5.7 GPa

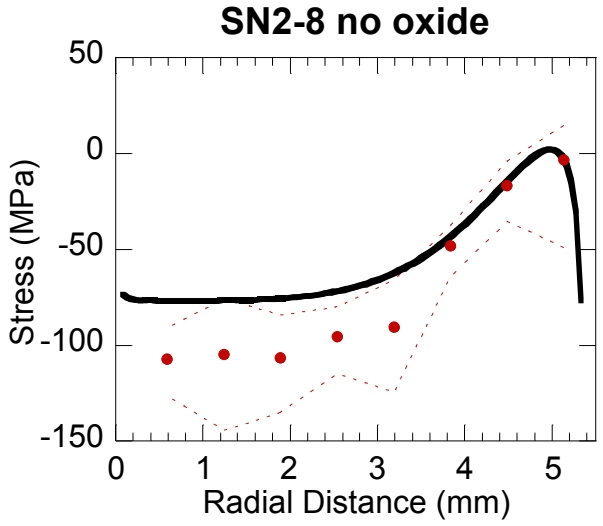




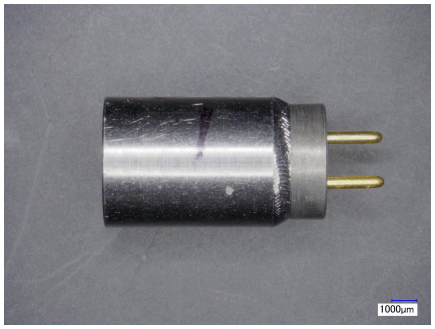
R.S.Chambers,*et al.*, Characterization and calibration of a viscoelastic simplified potential energy clock model for inorganic glasses, *J. Non. Cryst. Solids* (2015)


Binned and Averaged Crack Lengths
oxidized
no oxide
crack length (μm)
150
100
50
0
1
2
3
4
5
Radial Distance (mm)

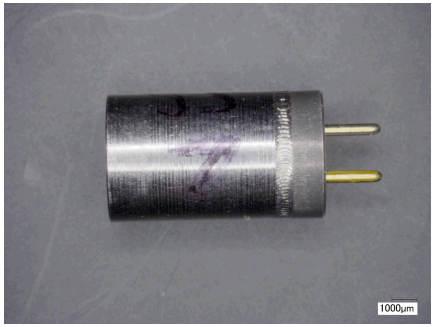

SN1-3 oxidized
Stress (MPa)
50
0
-50
-100
-150
-200
0
1
2
3
4
5
6
Radial Distance


SN2-8 no oxide
Stress (MPa)
50
0
-50
-100
-150
0
1
2
3
4
5
Radial Distance (mm)

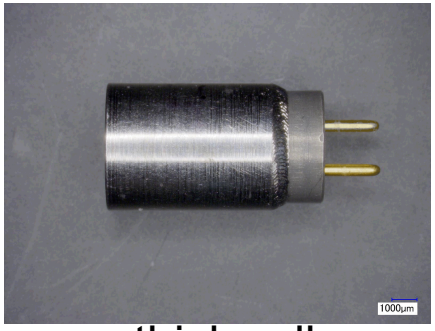
SB14-Inconel Glass-to-Metal Seal Interconnects



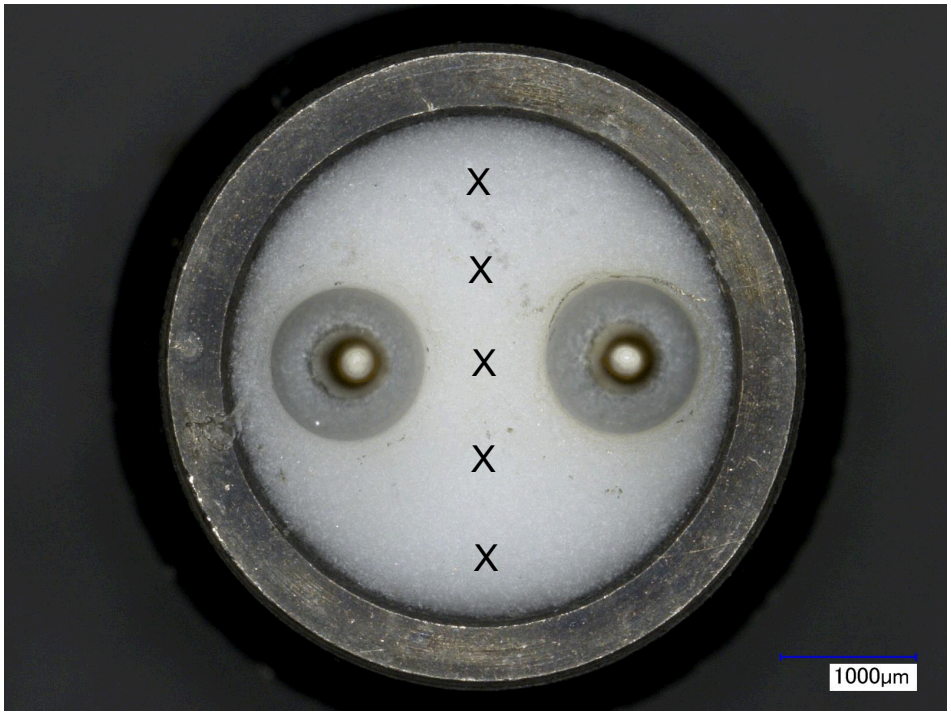
baseline



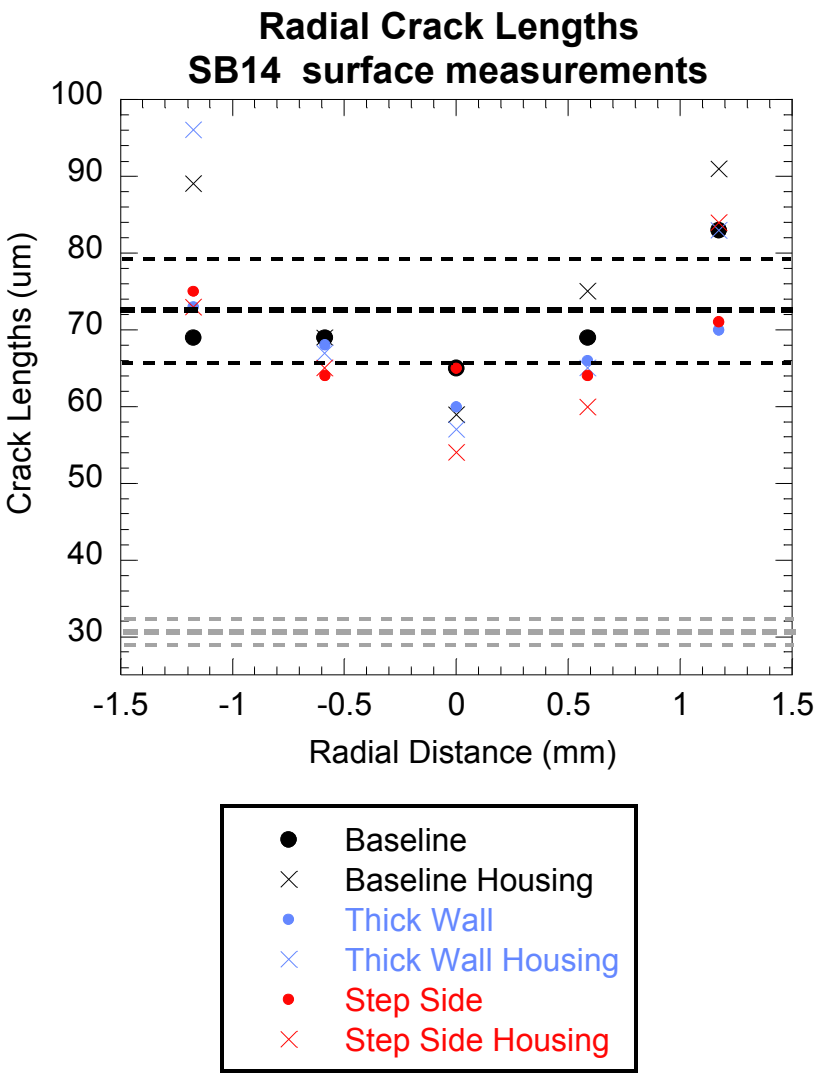
stepside

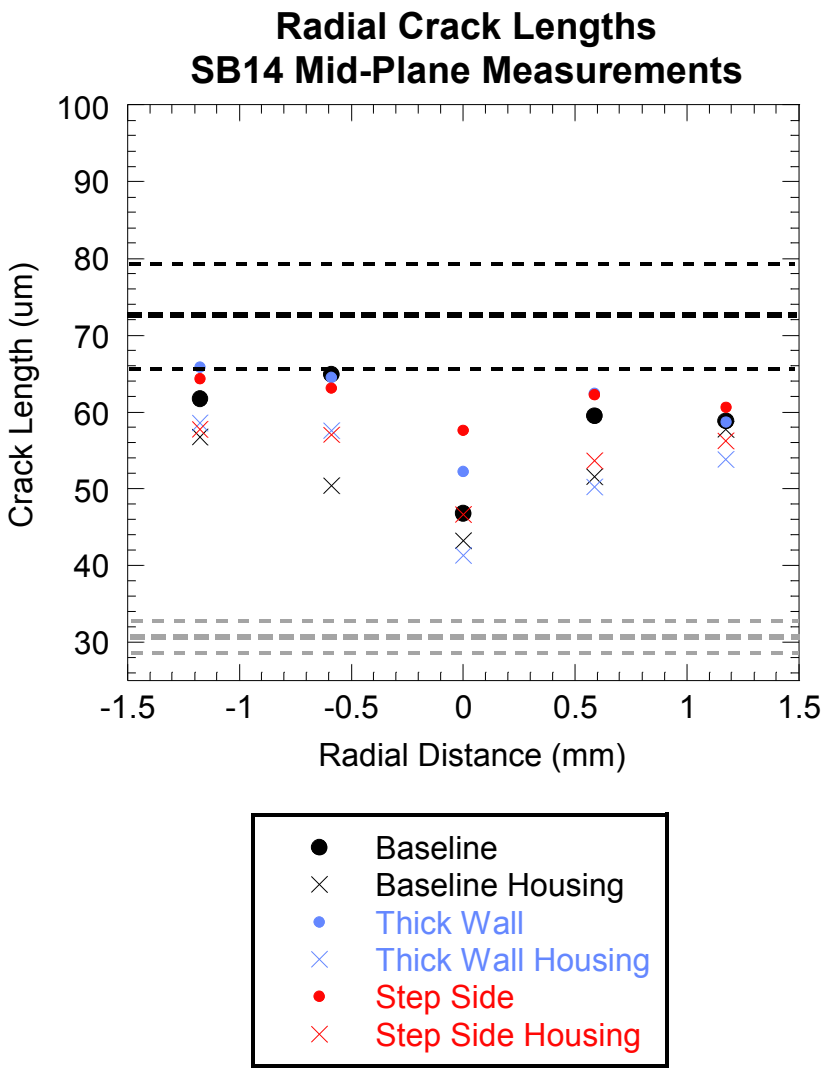


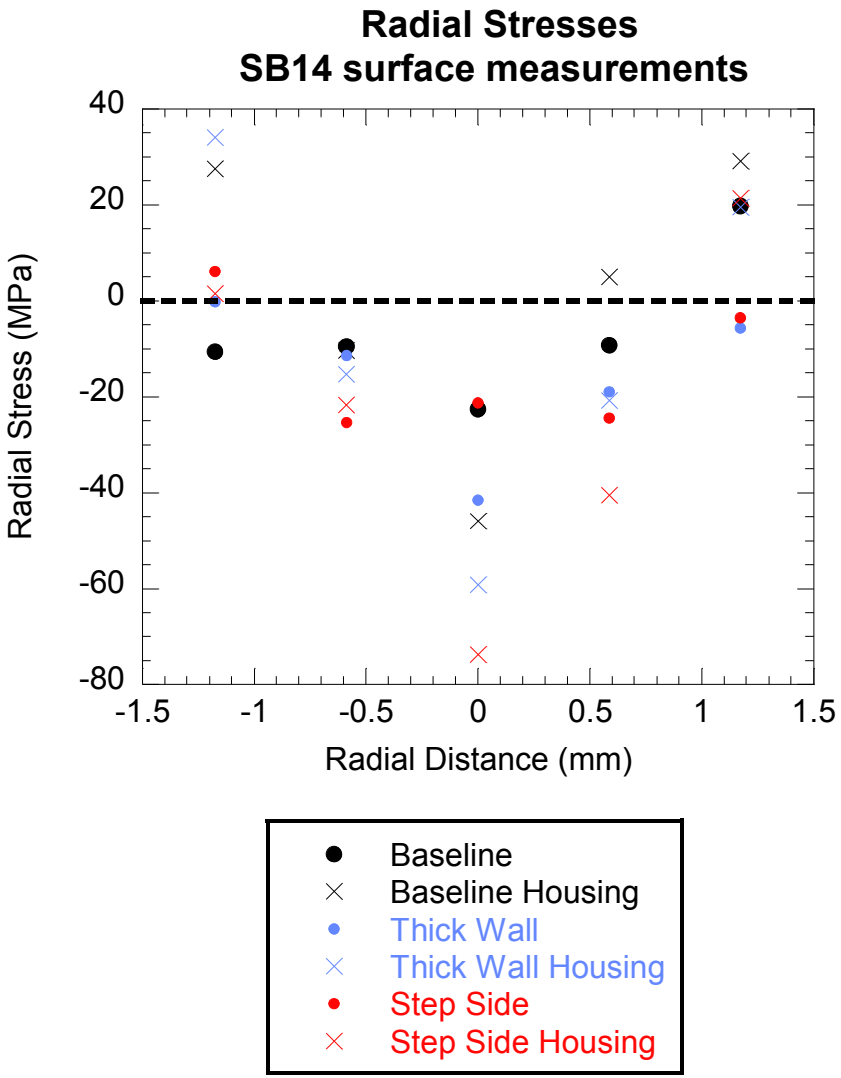
thickwall

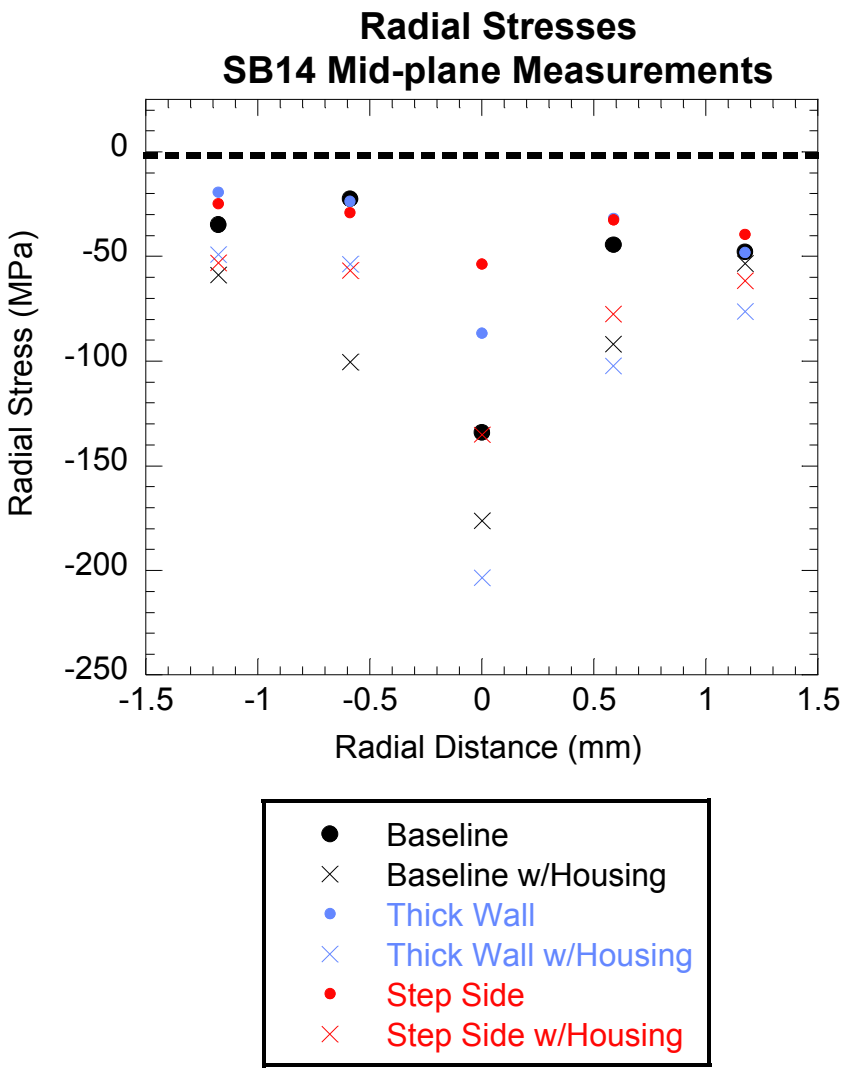


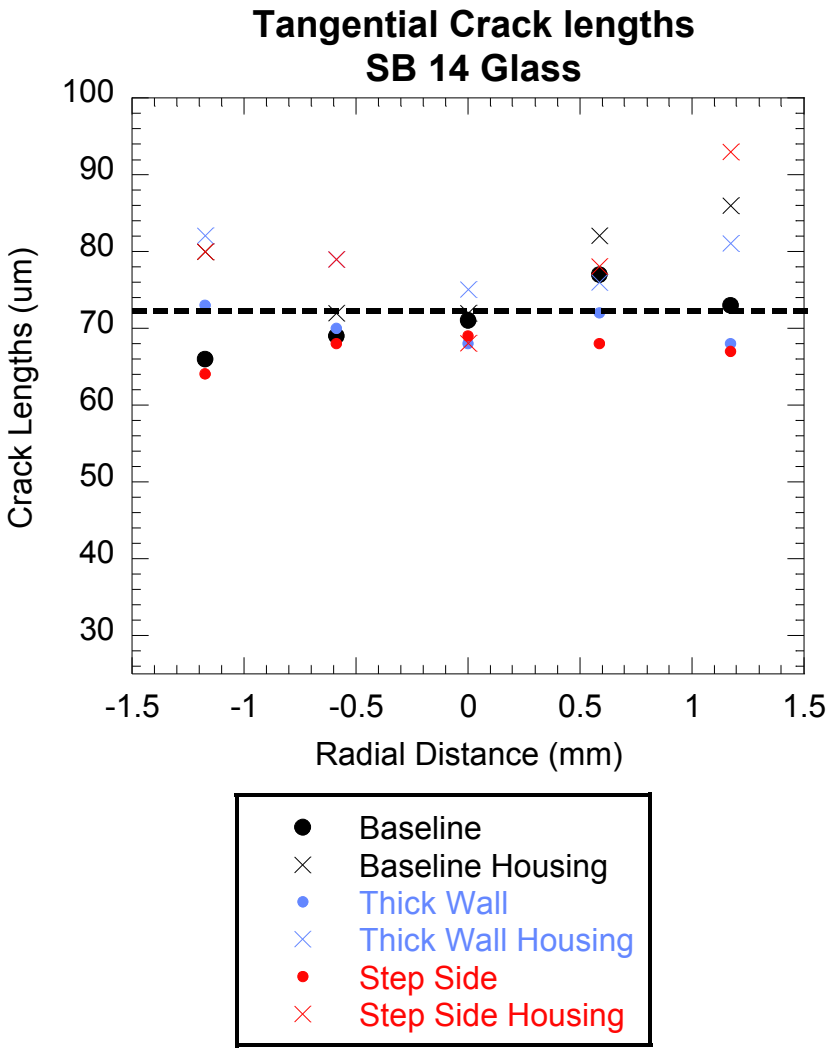
Pins up – Indent locations

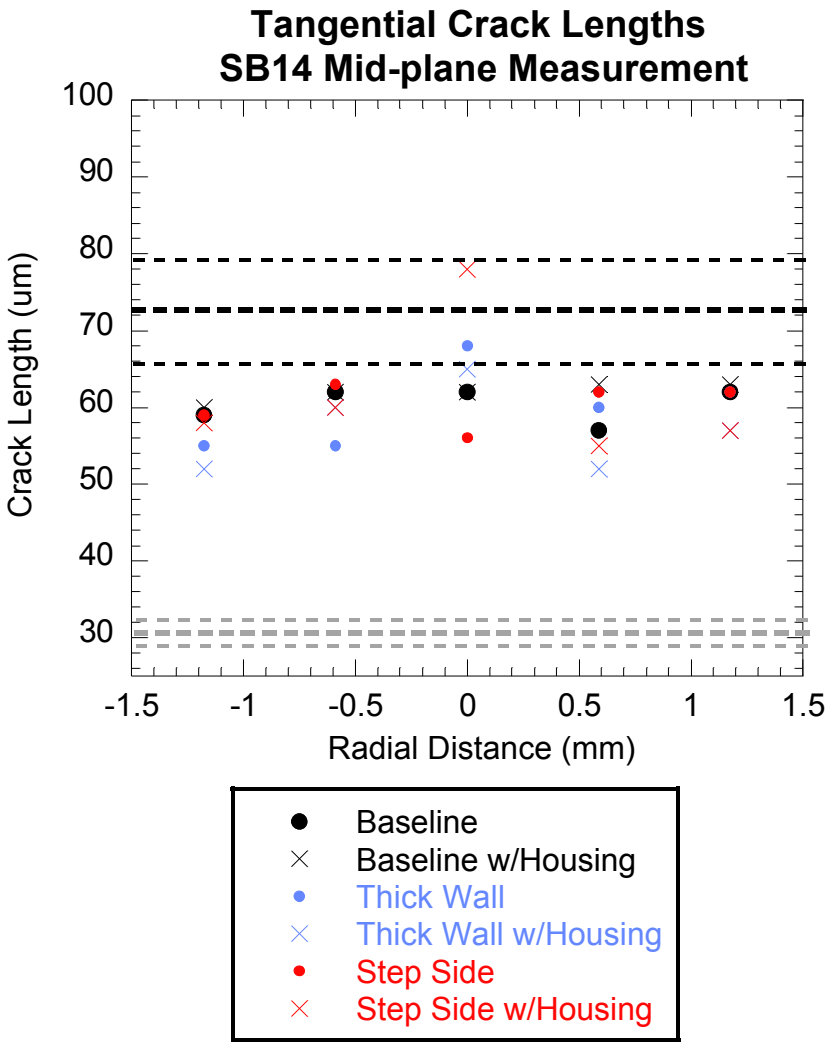

Radial Crack Lengths
SB14 surface measurements
Crack Lengths (um)
100
90
80
70
60
50
40
30
-1.5
-1
-0.5
0
0.5
1
1.5
Radial Distance (mm)
Baseline
Baseline Housing
Thick Wall
Thick Wall Housing
Step Side
Step Side Housing

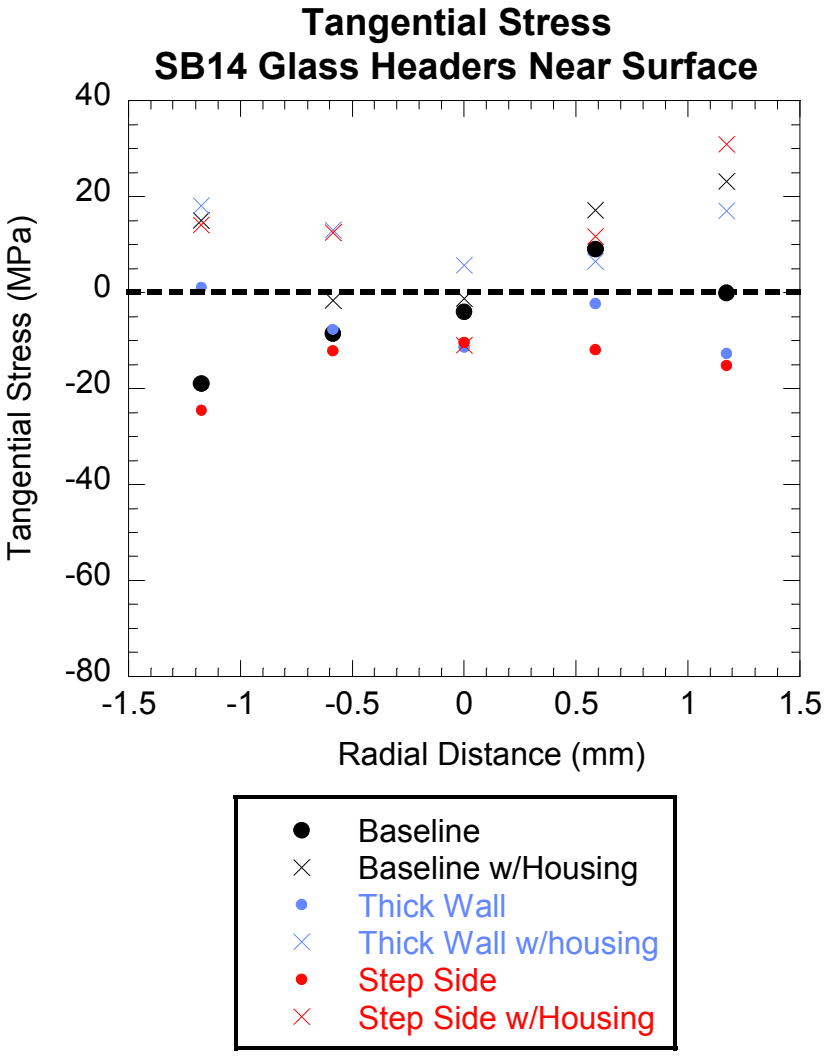

Radial Crack Lengths
SB14 Mid-Plane Measurements
Crack Length (um)
100
90
80
70
60
50
40
30
-1.5
-1
-0.5
0
0.5
1
1.5
Radial Distance (mm)
Baseline
Baseline Housing
Thick Wall
Thick Wall Housing
Step Side
Step Side Housing

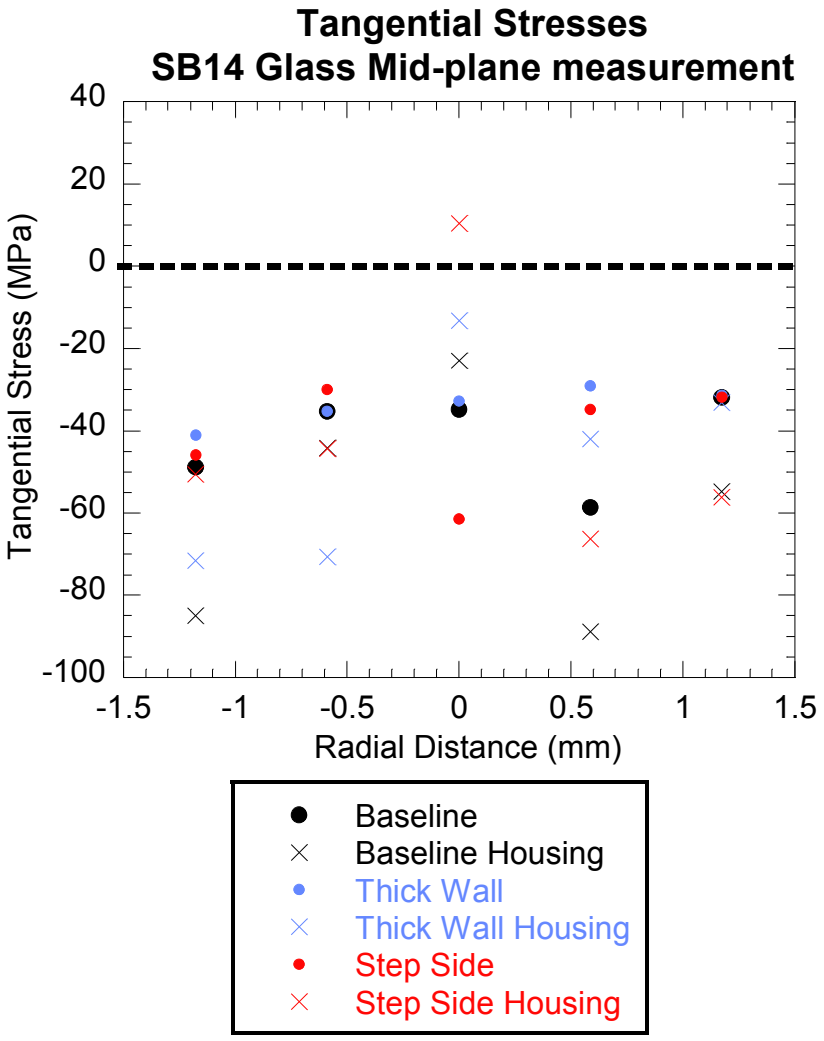

Radial Stresses
SB14 surface measurements
Radial Stress (MPa)
40
20
0
-20
-40
-60
-80
-1.5
-1
-0.5
0
0.5
1
1.5
Radial Distance (mm)
Baseline
Baseline Housing
Thick Wall
Thick Wall Housing
Step Side
Step Side Housing


Radial Stresses
SB14 Mid-plane Measurements
Radial Stress (MPa)
0
-50
-100
-150
-200
-250
-1.5
-1
-0.5
0
0.5
1
1.5
Radial Distance (mm)
Baseline
Baseline w/Housing
Thick Wall
Thick Wall w/Housing
Step Side
Step Side w/Housing

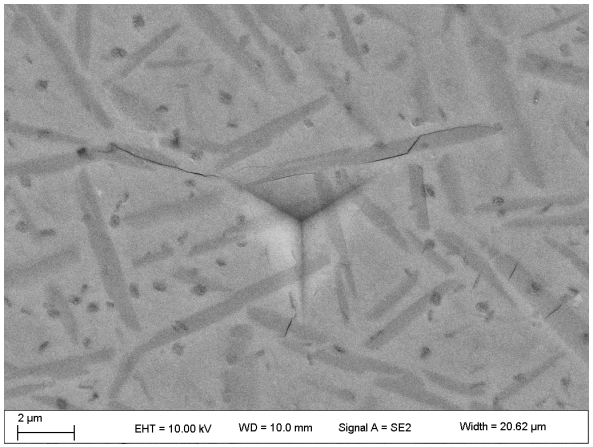

Tangential Crack lengths
SB 14 Glass
Crack Lengths (um)
100
90
80
70
60
50
40
30
-1.5
-1
-0.5
0
0.5
1
1.5
Radial Distance (mm)
Baseline
Baseline Housing
Thick Wall
Thick Wall Housing
Step Side
Step Side Housing


Tangential Crack Lengths
SB14 Mid-plane Measurement
Crack Length (um)
100
90
80
70
60
50
40
30
-1.5
-1
-0.5
0
0.5
1
1.5
Radial Distance (mm)
Baseline
Baseline w/Housing
Thick Wall
Thick Wall w/Housing
Step Side
Step Side w/Housing

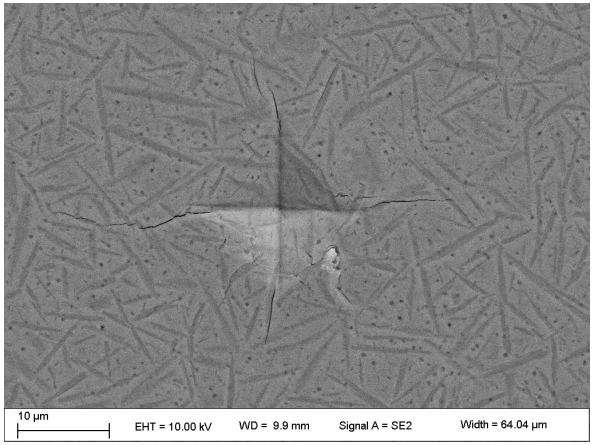

Tangential Stress
SB14 Glass Headers Near Surface
Tangential Stress (MPa)
40
20
0
-20
-40
-60
-80
-1.5
-1
-0.5
0
0.5
1
1.5
Radial Distance (mm)
Baseline
Baseline w/Housing
Thick Wall
Thick Wall w/housing
Step Side
Step Side w/Housing


Tangential Stresses
SB14 Glass Mid-plane measurement
Tangential Stress (MPa)
40
20
0
-20
-40
-60
-80
-100
-1.5
-1
-0.5
0
0.5
1
1.5
Radial Distance (mm)
Baseline
Baseline Housing
Thick Wall
Thick Wall Housing
Step Side
Step Side Housing

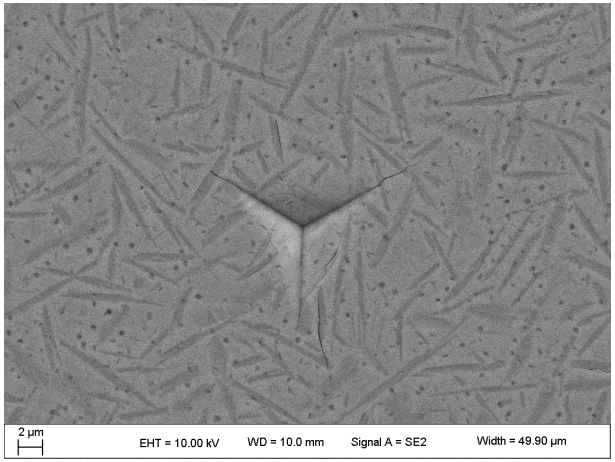
Indentation size effect in SB Glass



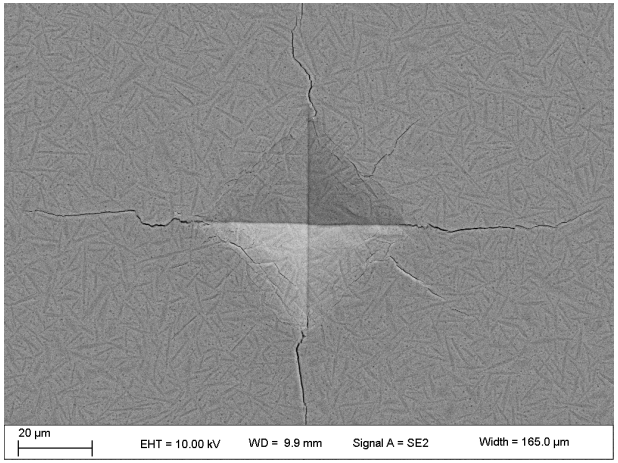
1000 nm deep berkovich impression



0.1 Kgf Vickers impression

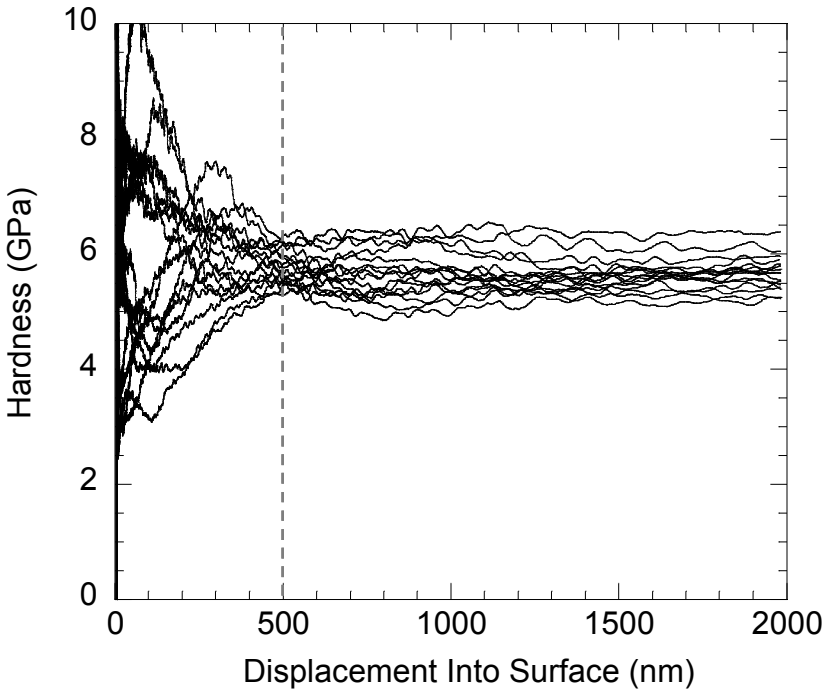


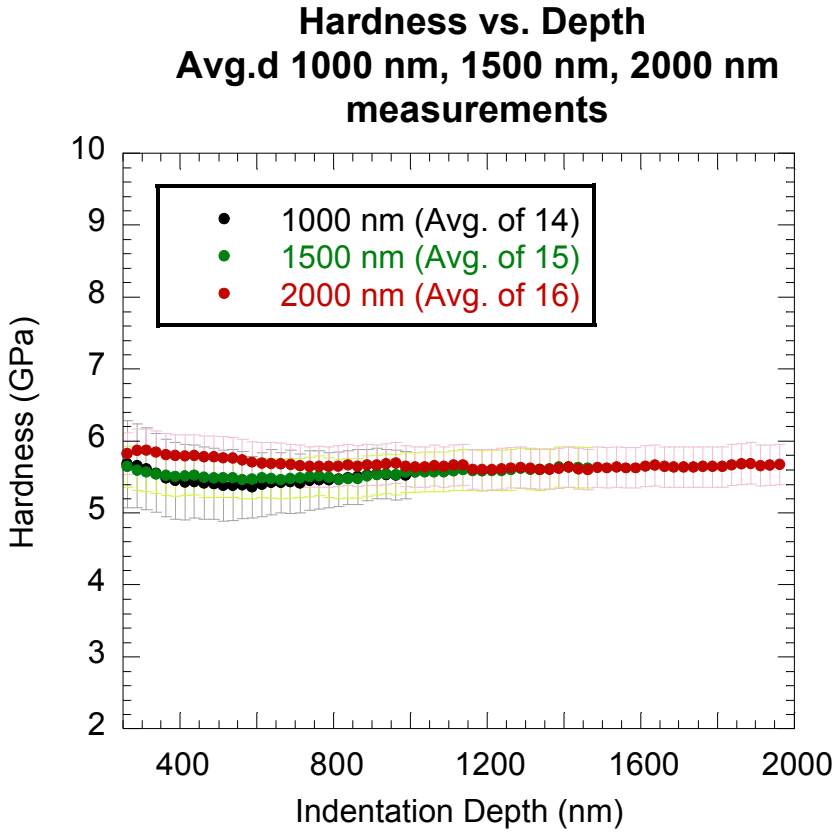
2000 nm deep berkovich impression



1 Kgf Vickers impression

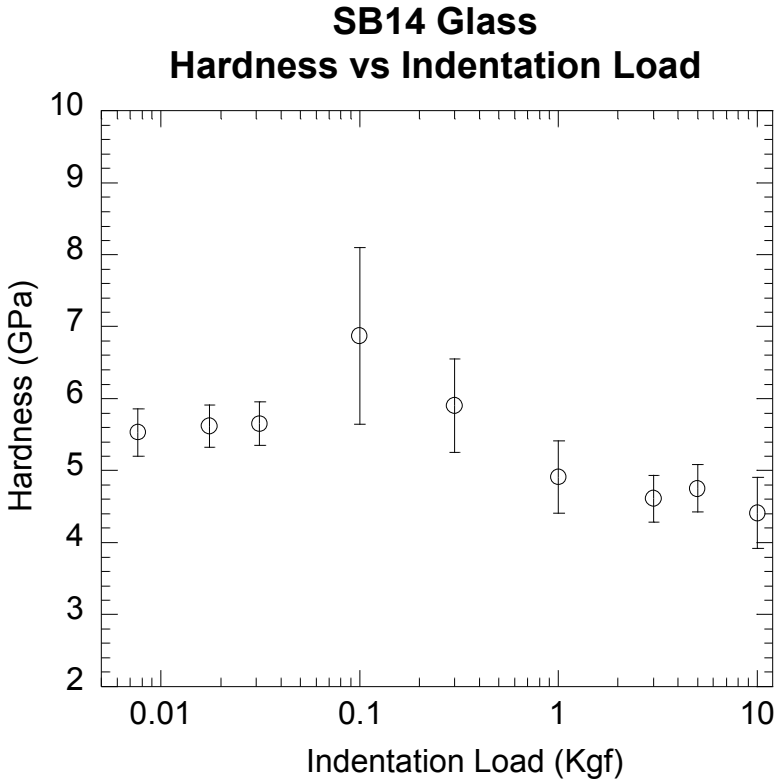
Consistent measure of hardness achieved by 500 nm depth





E=68 +/- 2 GPa
H=5.6 +/- 0.3 GPa

Indentation Size Effect in SB14 Glass driven by precision of measurement



Summary

- Mapping stress using an indentation crack measurement method in a reduced dimensional geometry.

- Performed mapping experiments on a short cylinder compression seal geometry where S8061 glass was captured with 304L stainless steel.