Processing and Properties of Ion Exchanged Glasses

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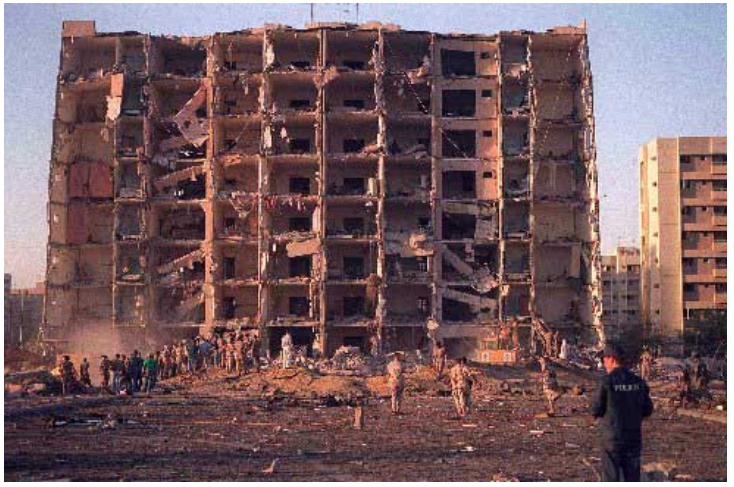
Recent Severe Hailstorm in New Mexico


HONDA
CIVIC


CHEVROLET
XT4807

Truck Bomb Attacks on Federal Buildings Have Focused Attention on Glass Behavior

1995- Murrah Building,
Oklahoma City, OK



1996- Khobar Towers, Saudi Arabia

Embassy in Nairobi
August 7, 1998 Truck Bomb

Embassy in Dar Es Salaam
August 7, 1998 Truck Bomb

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Glass Fragment Character and Size, and Glass Strength Depend on Processing

Plate Glass- 5 kg Indent

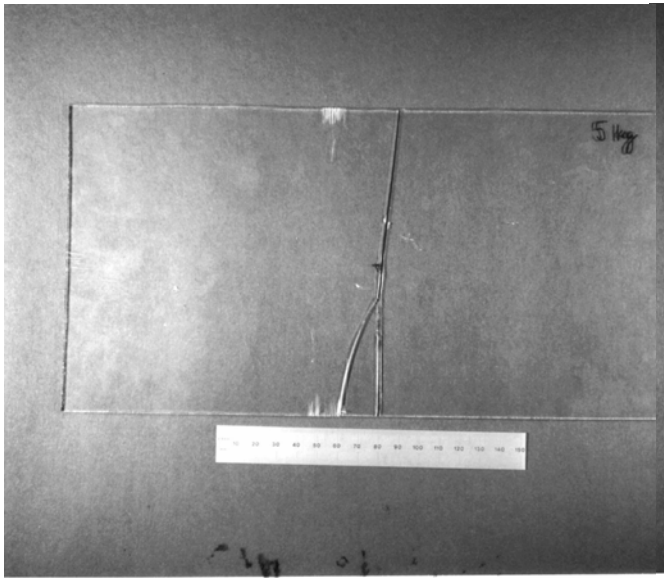
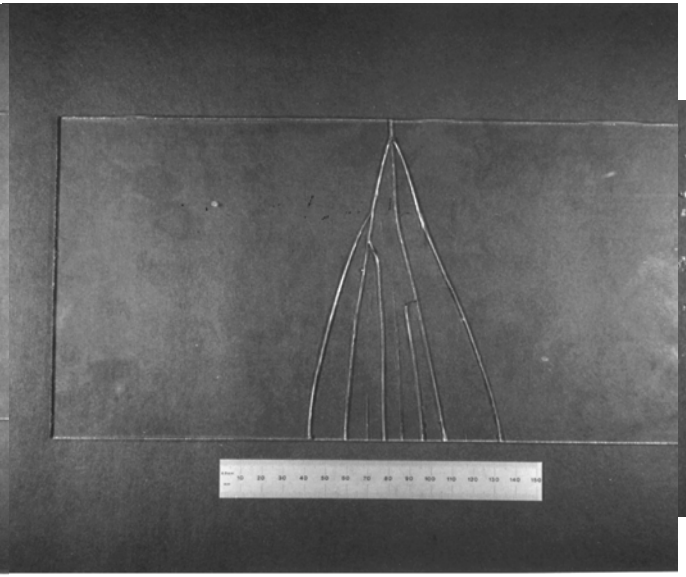
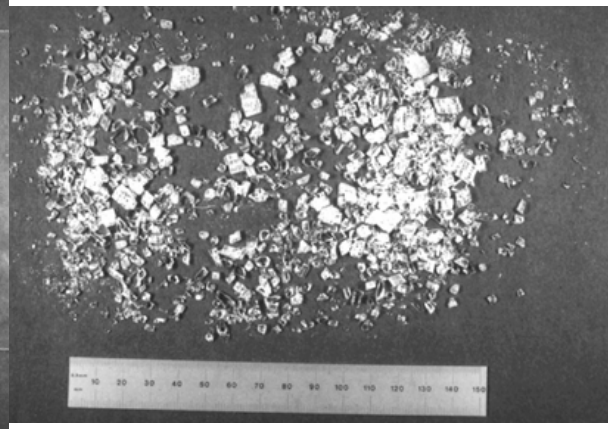


Plate Glass - As-Rec'd



Ion Exchanged



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Video

To view the video showing the breaking glass sheet for

standard glass compared to ion exchanged glass

use the link on the IMI-NFG website or

http://rm1.cc.lehigh.edu:8080/dept/IMI/EdVideo/RealTime&SloMoGlassBreakage.mpg

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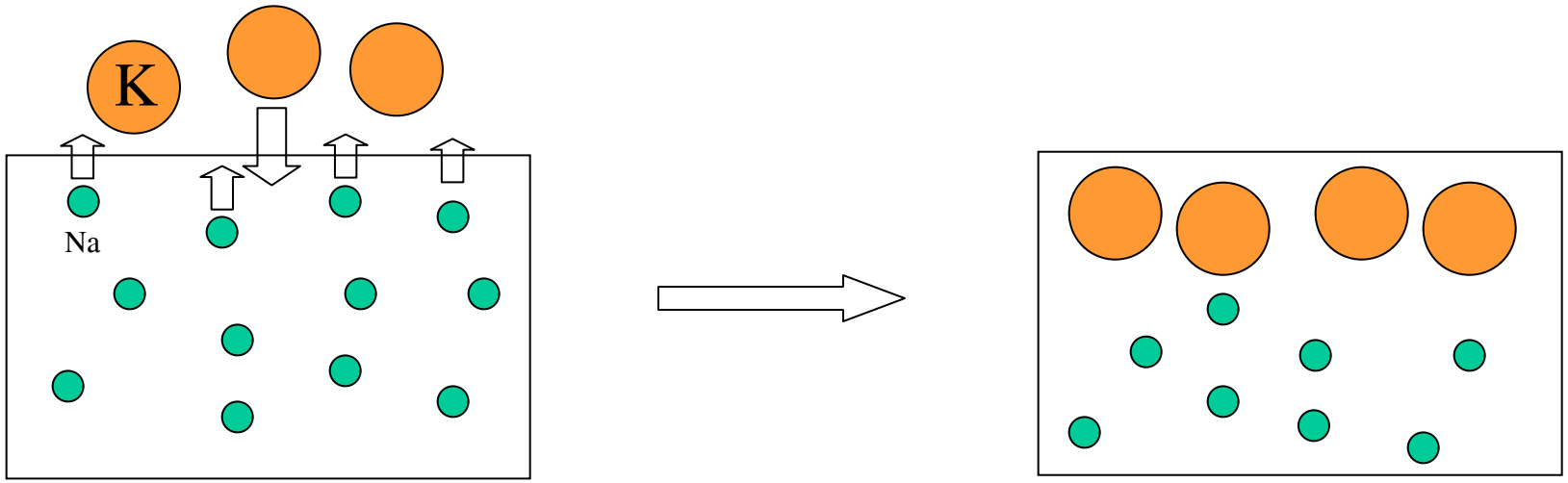
Ion Exchange Process Replaces Small Ions in Glass Surface with Large Ions



Exchange of a Na-containing glass in a bath of molten KNO_3 salt

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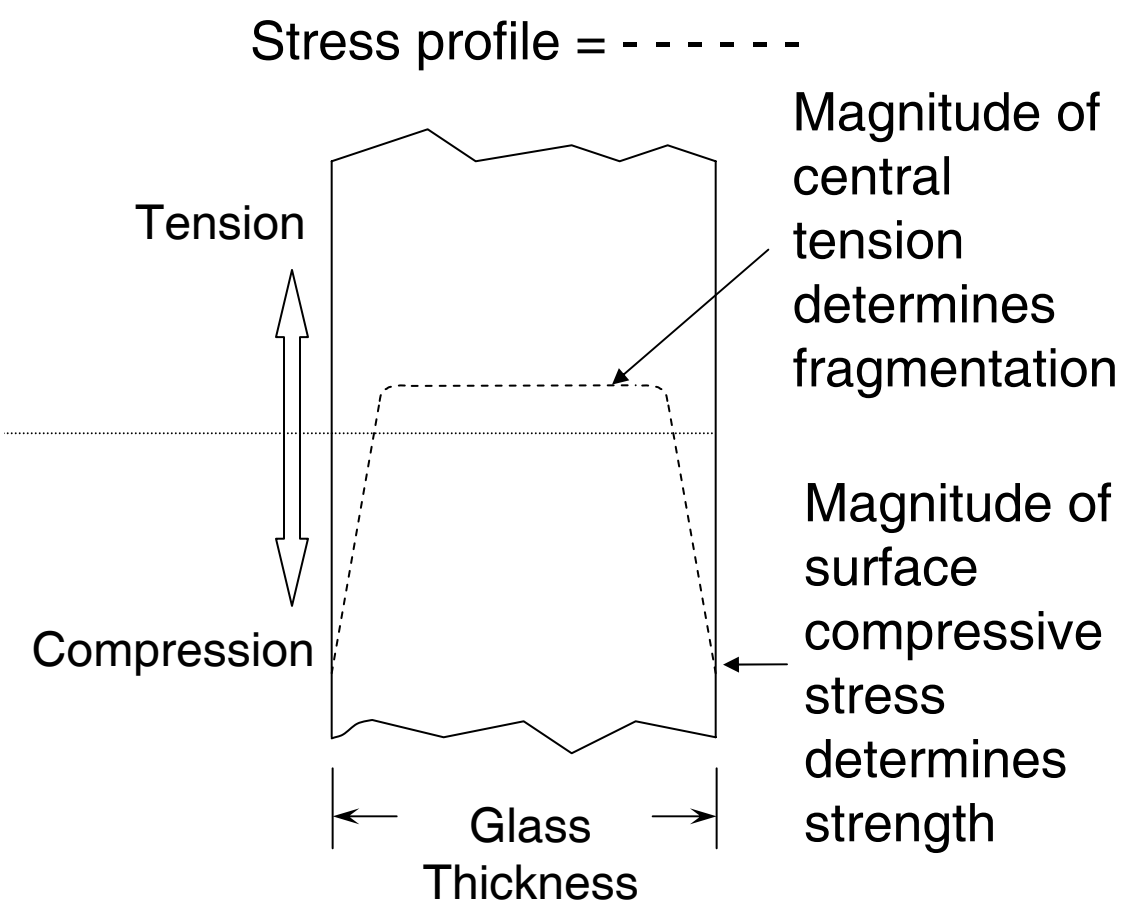
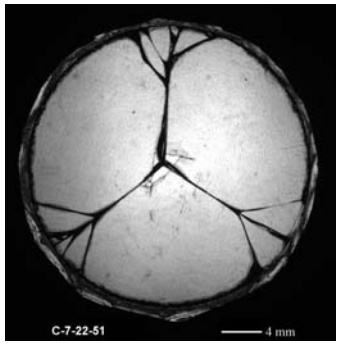
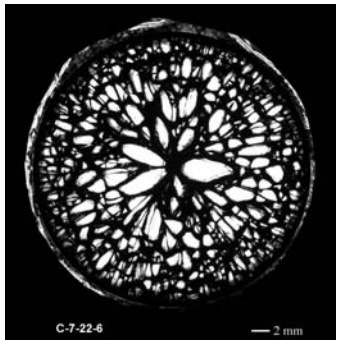
Ion Exchange Stress Profile Increases Glass Strength and Fragmentation



Disk diameter=1 inch



12 hr exchange
Strength = 759 MPa



48 hr exchange
Strength = 706 MPa

The more a crack **branches** as it propagates the greater the degree of **fragmentation**.

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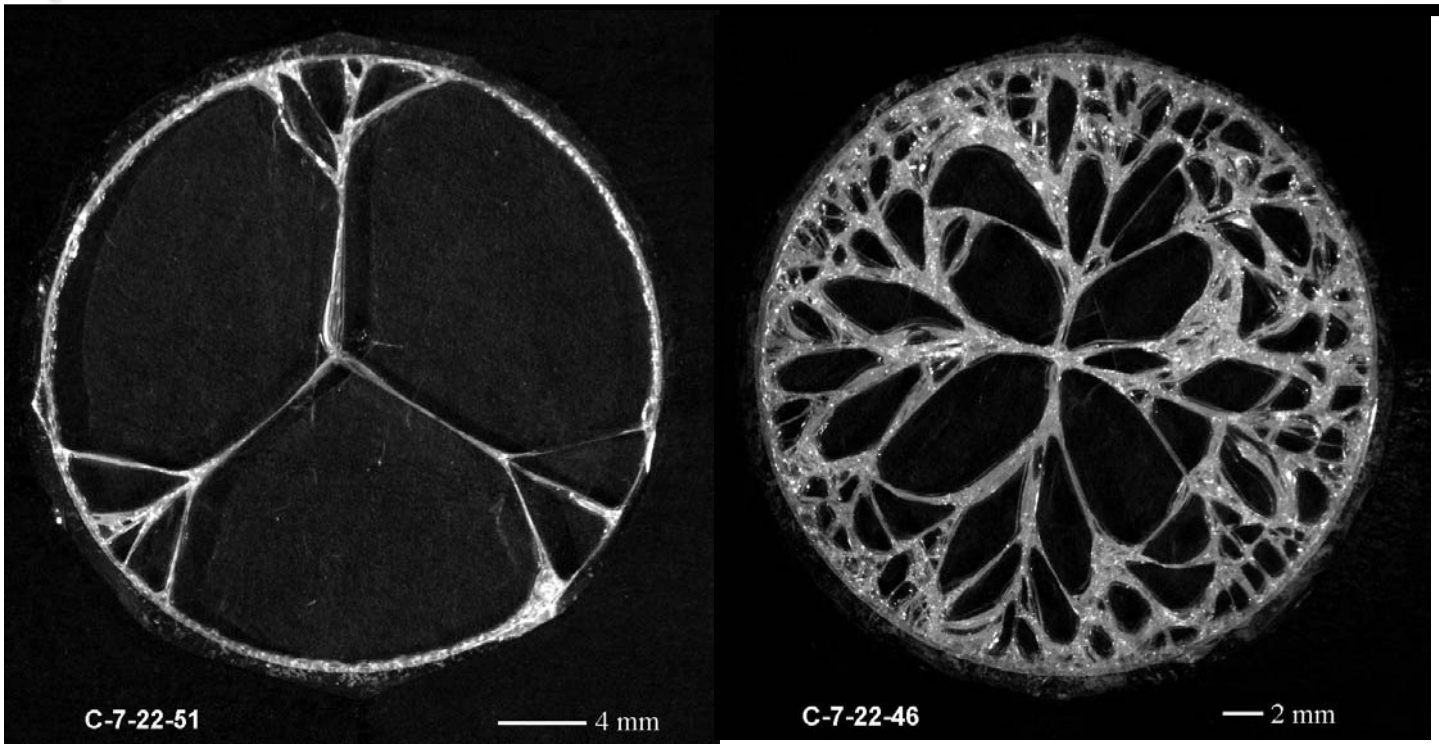
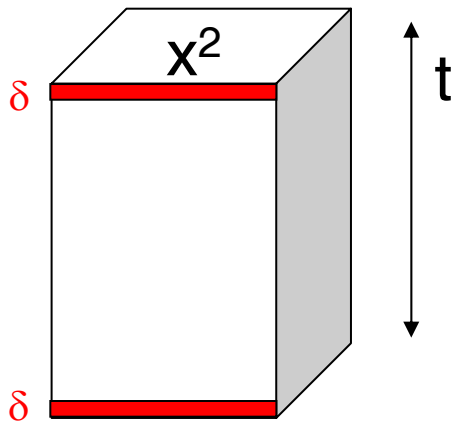
Fragment Size Largely Determined by Central Tension, σ_t and Crack Branching Behavior





Fragment size, $$x = \frac{K_{1c}^2}{\sigma_t^2}(1+\nu)\frac{t}{(0.5t-\delta)}$$

K_{IC}=toughness, t=thickness, δ=ion exchange depth

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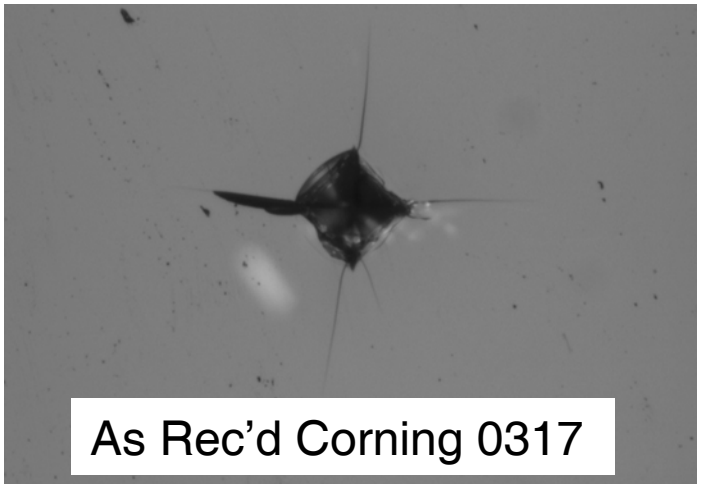
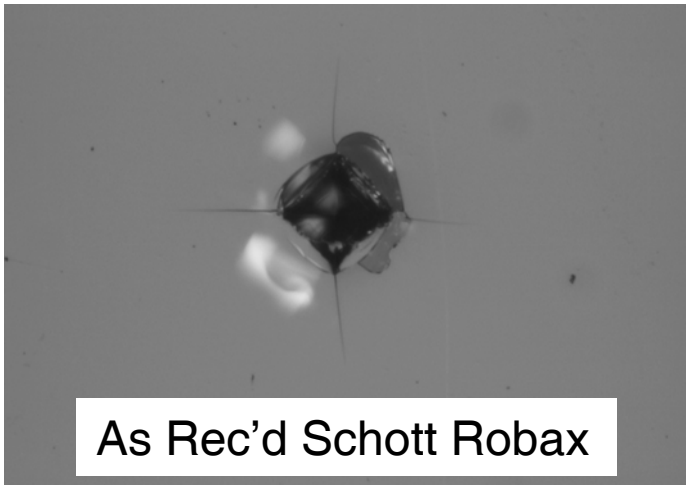
Schott Robax and Corning 0317 Glass Exchanged at 450 & 500C for Different Times

Wt% of oxides	Corning 0317	Schott Robax
SiO_2	62.3	67.2
Na_2O	12.8	0.4
K_2O	3.5	0.23
CaO	0.3	0.05
MgO	3.3	1.1
Al_2O_3	16.4	20.1
Fe_2O_3	0.24	
TiO_2	0.75	2.7
SnO_2	0.04	
Li_2O		3.2
BaO		0.9
As_2O_3		0.9
ZrO_2		1.7
ZnO		1.7
Total	99.53	99.92



H_V=5.95±0.19 GPa
K_{IC}=0.82±0.03 MPa$\sqrt{m}$



H_V=6.44±0.19 GPa
K_{IC}=1.09±0.03 MPa$\sqrt{m}$

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Comparison of Amount of Ion Being Exchanged

Corning Constituents	Wt%	Mol%
SiO_2	61.96	65.33
Na_2O	11.88	12.14
K_2O	3.41	2.29
CaO	0.41	0.46
MgO	3.34	5.24
Al_2O_3	16.50	10.25
Fe_2O_3	0.08	0.03
TiO_2	0.67	0.53
Li_2O	1.75	3.71
Total	100.00	100.00

Robax Constituents	Wt%	Mol%
SiO_2	67.20	72.92
Na_2O	0.35	0.37
K_2O	0.23	0.16
CaO	0.05	0.06
MgO	1.06	1.71
Al_2O_3	20.10	12.85
TiO_2	2.65	2.16
Li_2O	3.15	6.87
BaO	0.88	0.37
As_2O_3	0.87	0.29
ZrO_2	1.73	0.92
ZnO	1.65	1.32
Total	99.9	100.0

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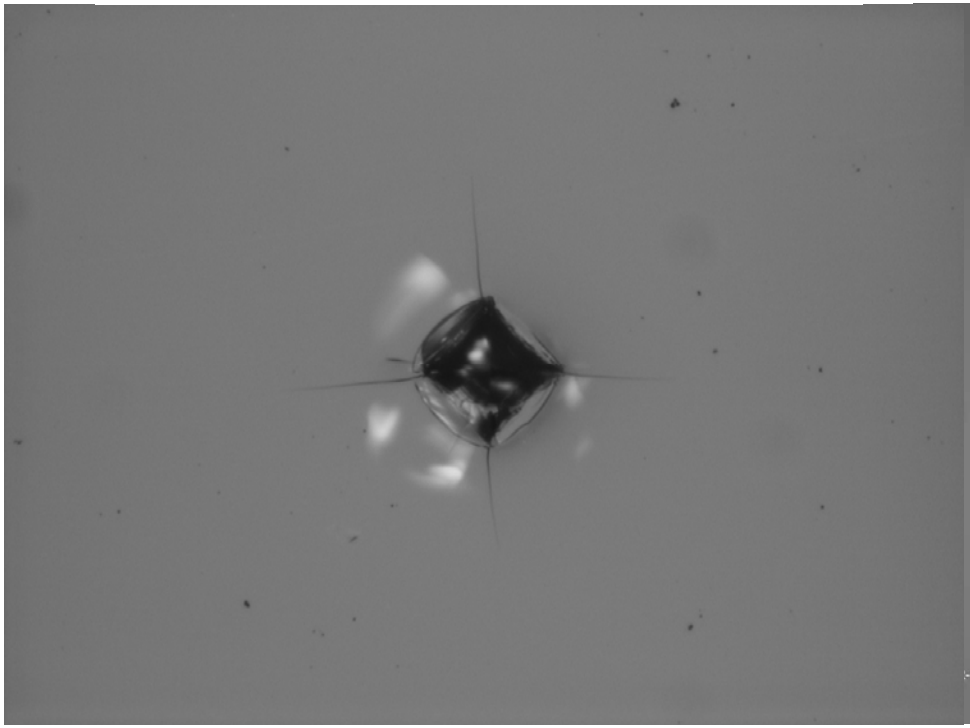
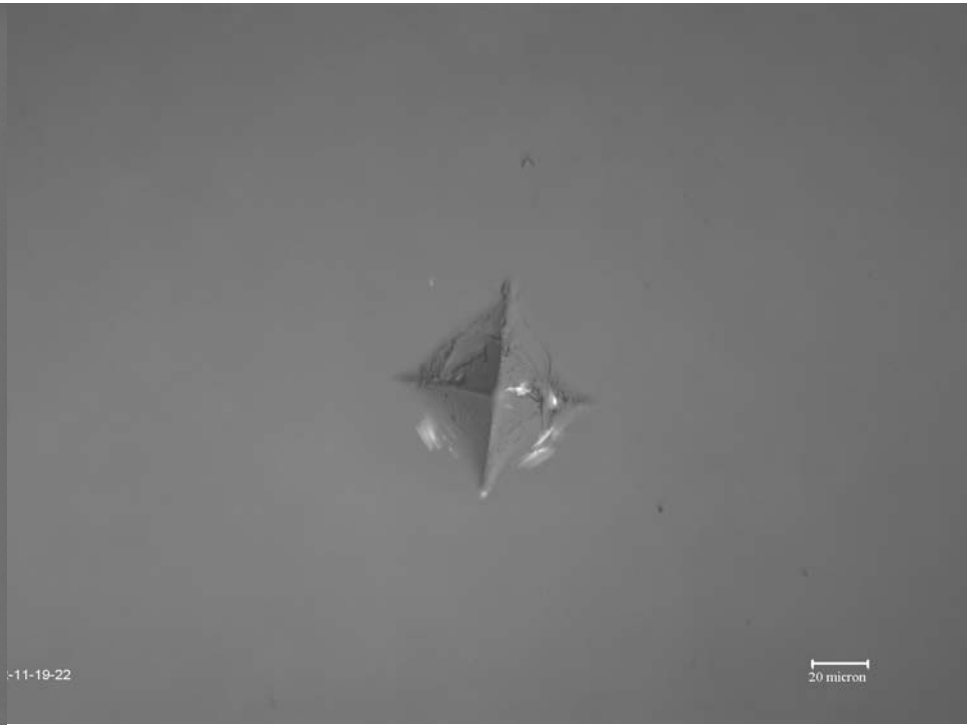
Indentation Behavior of Exchanged Schott Glass Show Improved Damage Tolerance

R-11-19-11



As received, 2000 g indent

R-11-19-22



Exchanged at 500C, 6 hr, 2000 g

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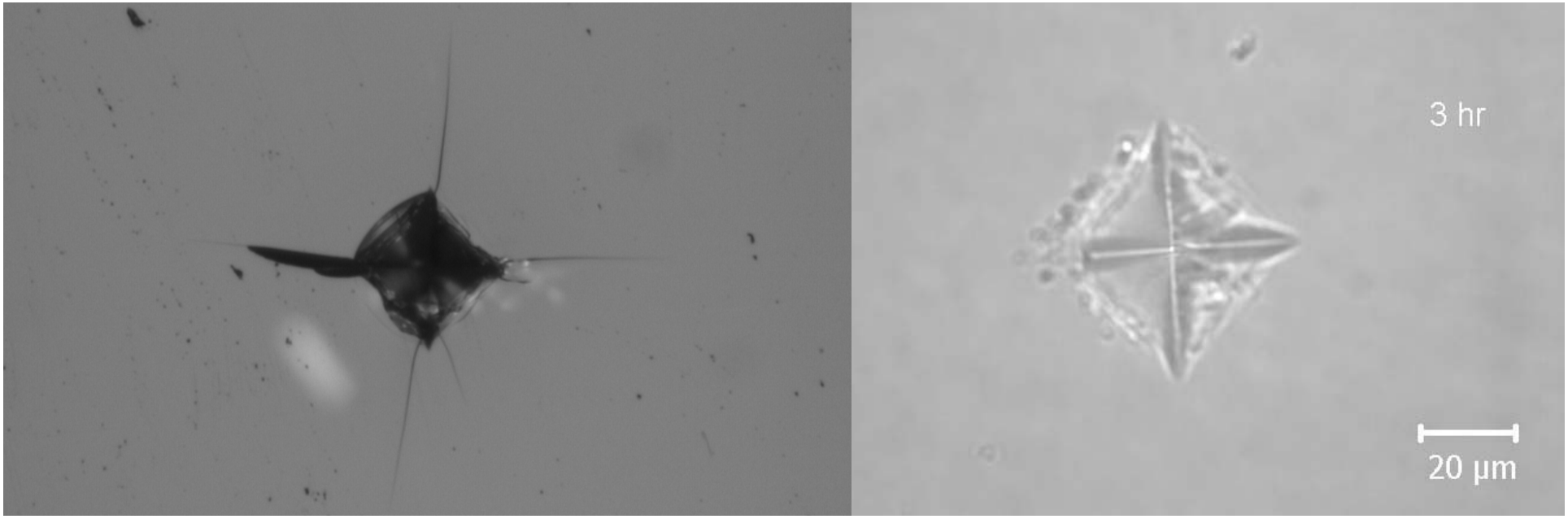
Indentation Behavior of Exchanged Corning 0317 Glass Shows Improved Damage Tolerance



As-Rec'd

Exchanged at 450°C/3 hr

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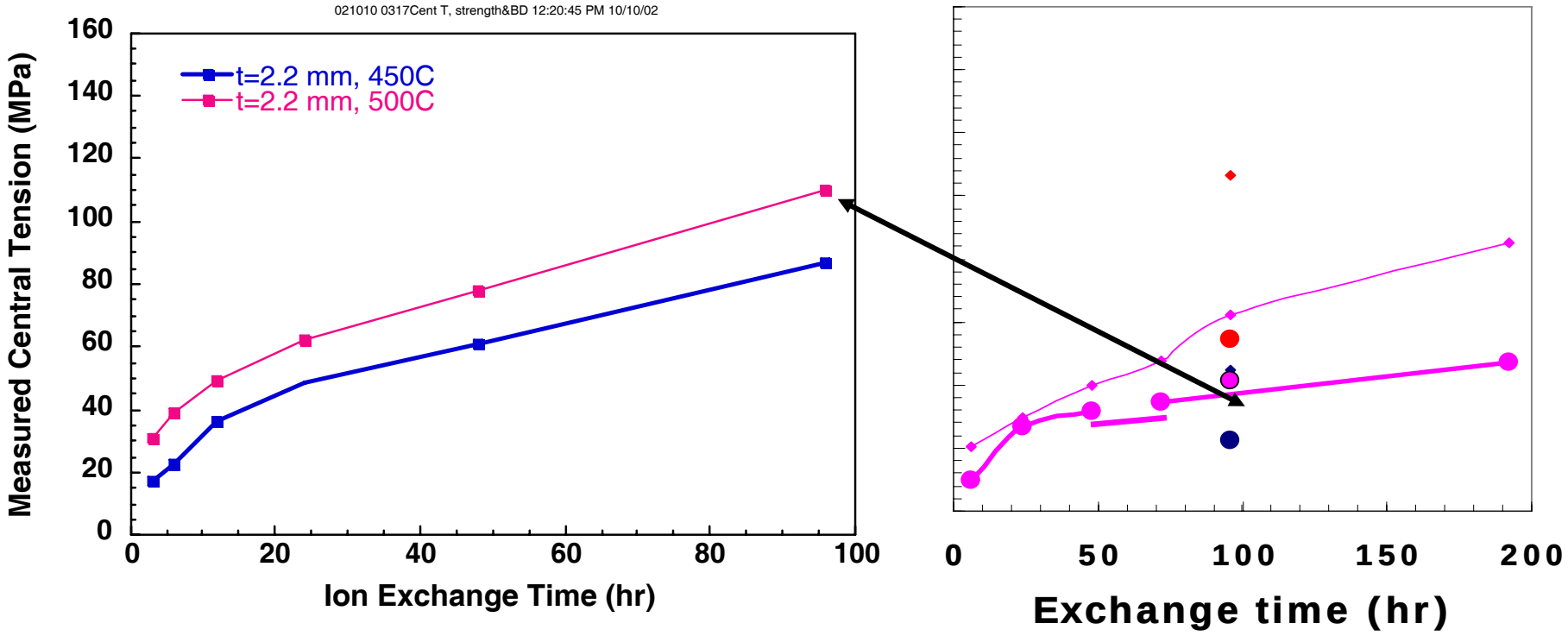
Central Tension as a Function of Ion Exchange Temperature and Glass Thickness

Corning 0317

Schott Robax



Arrow joins same ion exchange conditions (t & T) and glass thickness. 110 MPa vs. 42 MPa.

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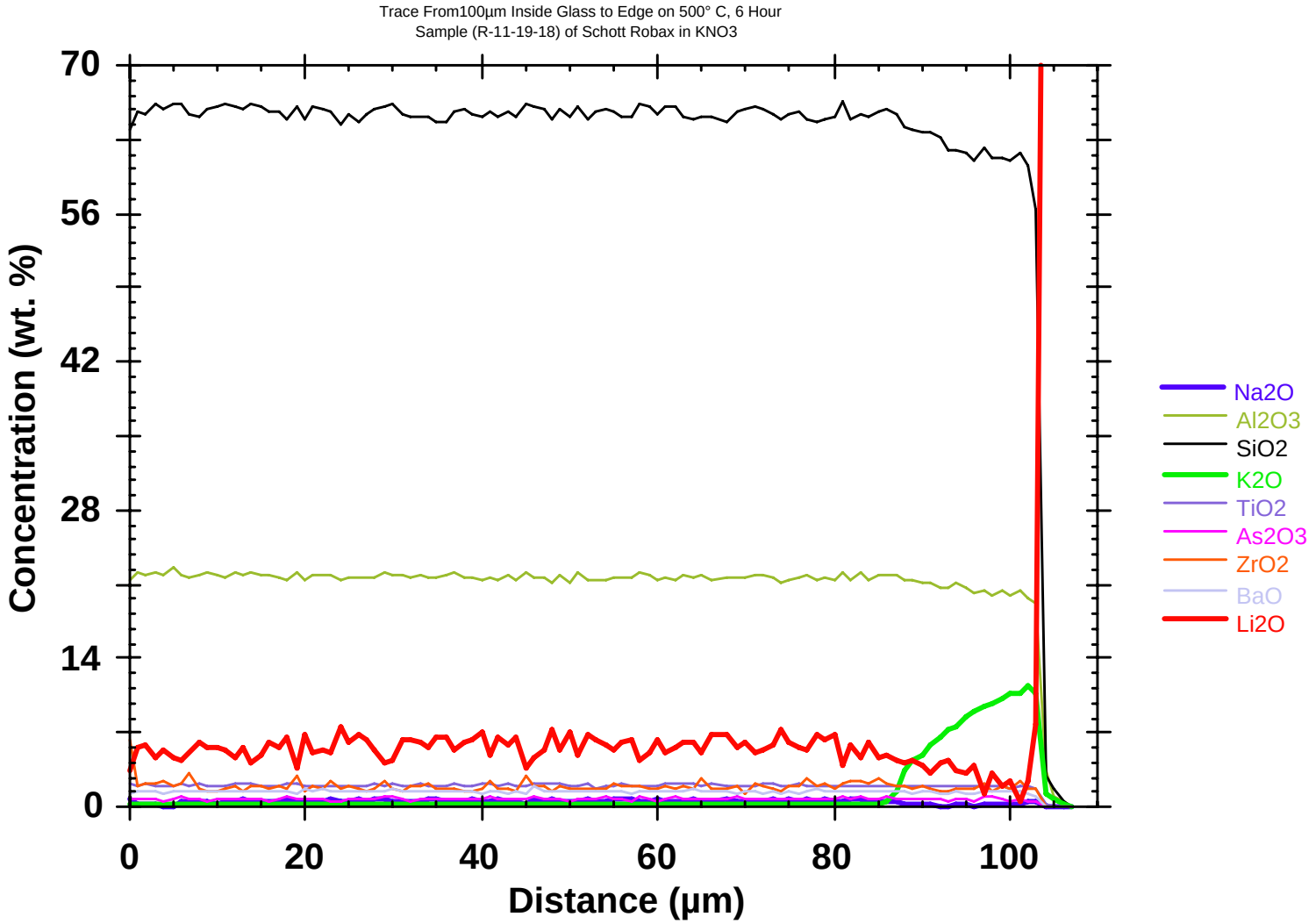
K Ion Exchange Depth for Schott Robax- 6 hr @500C



K penetration depth ~ 20 microns.

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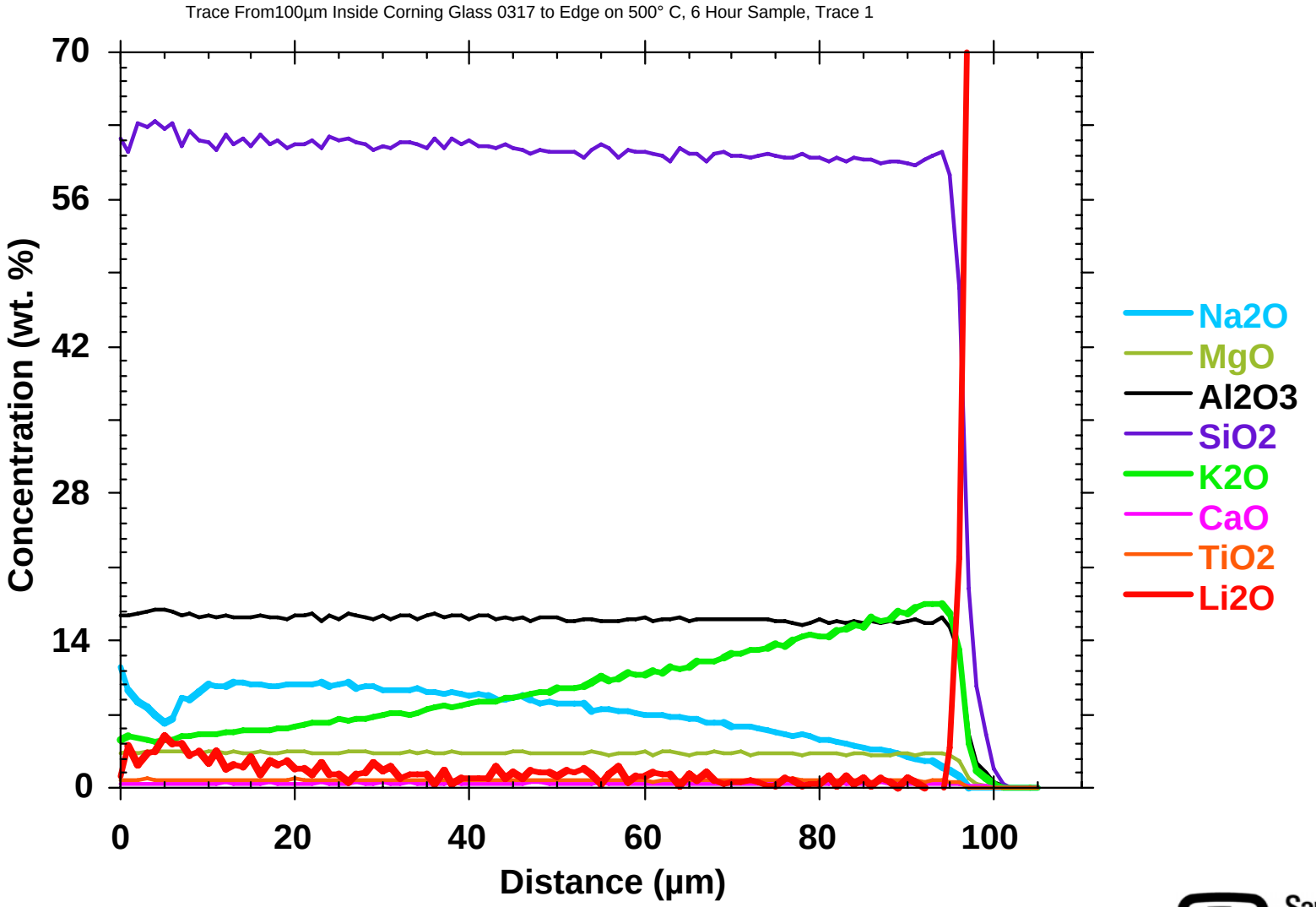
K Ion Exchange Depth for Corning 0317- 6 hr @500C



K penetration depth ~ 90 microns.

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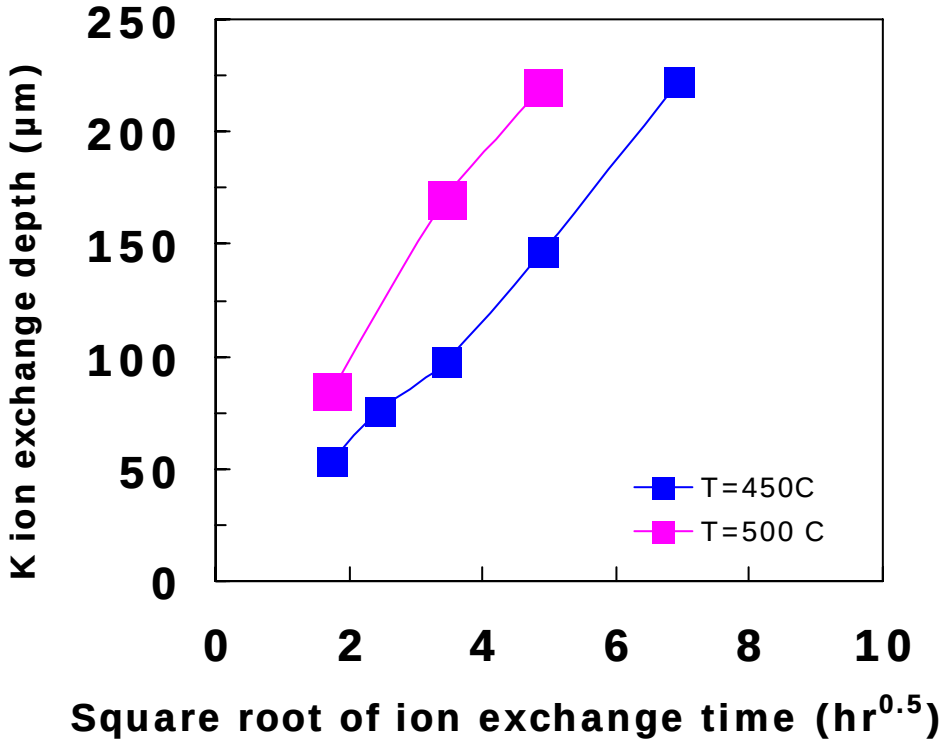
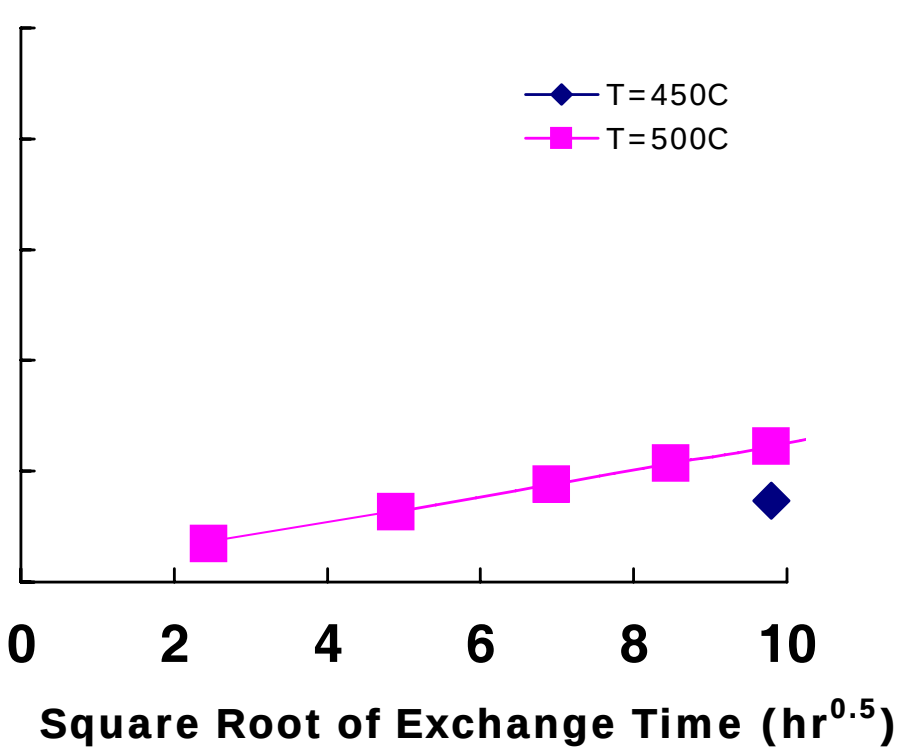
Schott Robax Has a Much Smaller Ion Exchange Depth than Corning 0317 for the Same T and t

Corning 0317



Schott Robax



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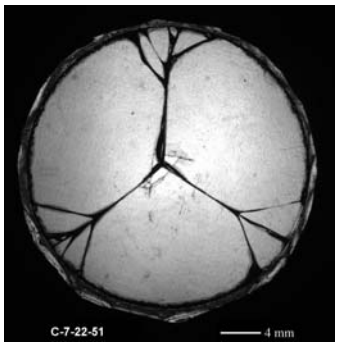
Comparison of Critical Central Tensions for Crack Branching in 1” Diameter Disk

	Measured Values for Critical Central Tensions (MPa) for Branching in 1” Disks				K_{IC} (MPa$\sqrt{m}$) (Indentation)
Thick.▶ Glass ▼	t=1.0	t=1.2	t=1.8	t=2.2	
Corning 0317	42		40	34	0.82
Schott Robax		~ < 47		~ <47	1.09



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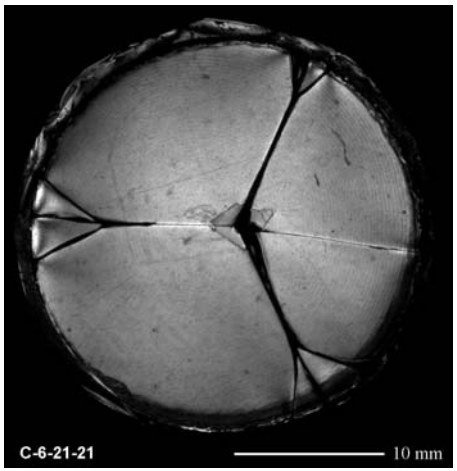
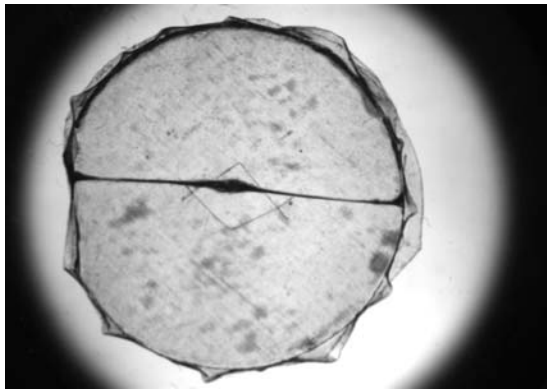
Fragment Size Comparisons for Two Glasses with Equivalent t's and σ_t's

Corning 0317



C-6-21-21
t=0.085"=2.2 mm
500C/6 hr
σ_t=38.7 MPa

Schott Robax



R-11-20-6
t=0.085"=2.2 mm
500C/96 hr
σ_t=41 MPa

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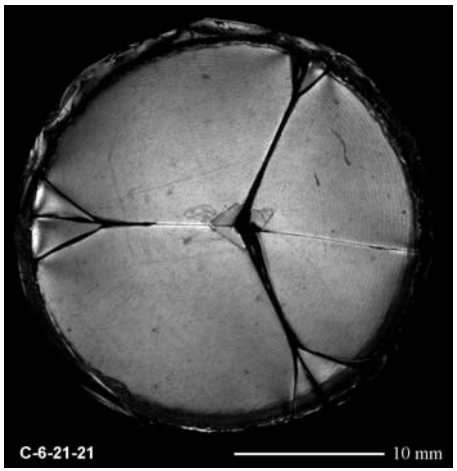
Fragment Size Comparisons for Two Glasses with Equivalent t's and σ_t's

Corning 0317



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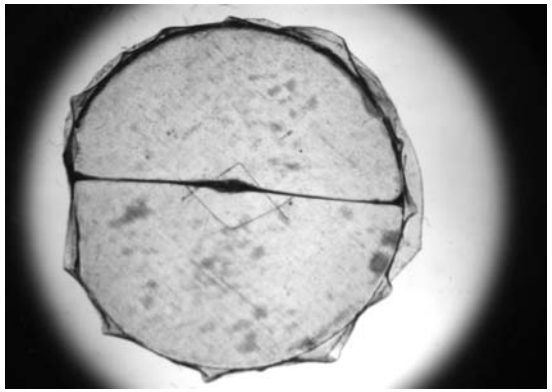

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t=0.085"=2.2 mm
500C/96 hr
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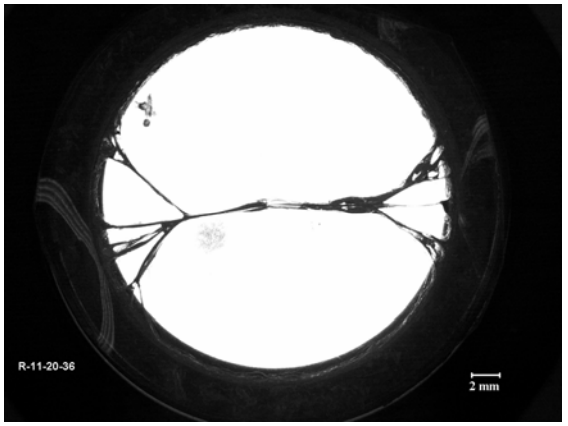
Schott Robax



R-11-20-36
t=0.085"=2.2 mm
500C/192 hr
σ_t=47 MPa

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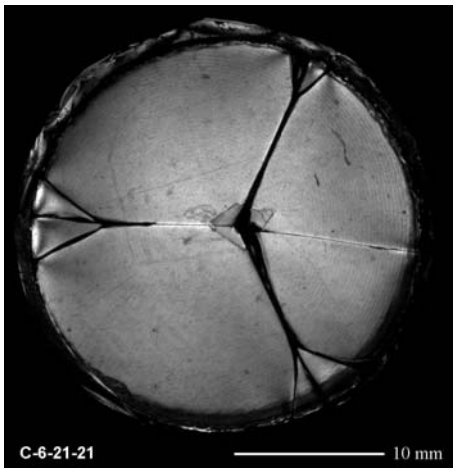
Fragment Size Comparisons for Two Glasses with Equivalent t's and σ_t's

Corning 0317



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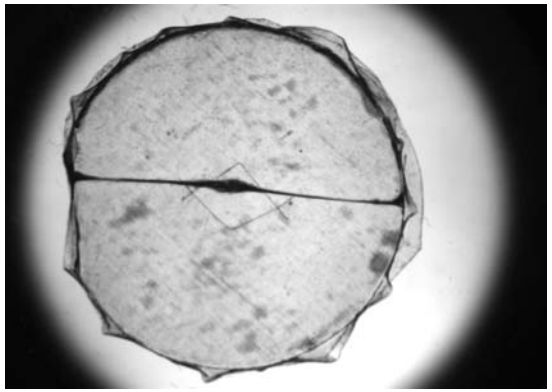

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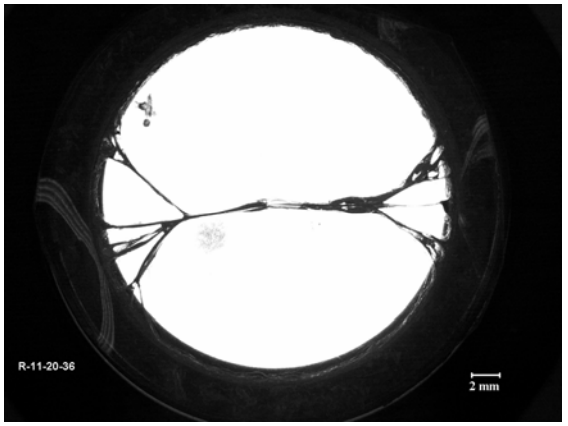

R-11-20-36
t=0.085"=2.2 mm
500C/192 hr
σ_t=47 MPa

$$x = \frac{K_{1c}^2}{\sigma_t^2}(1+\nu)\frac{t}{(0.5t-\delta)}$$

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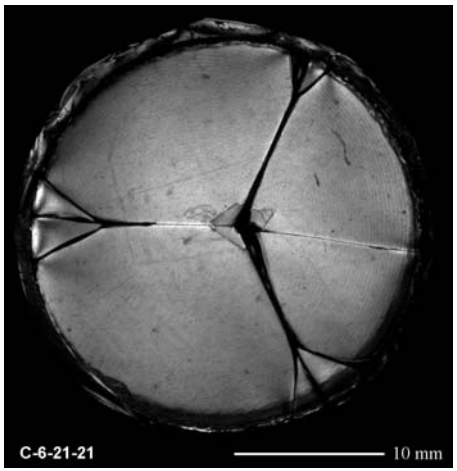
Fragment Size Comparisons for Two Glasses with Equivalent t's and σ_t's

Corning 0317



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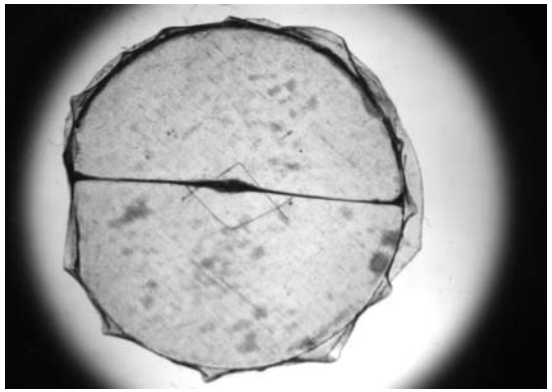

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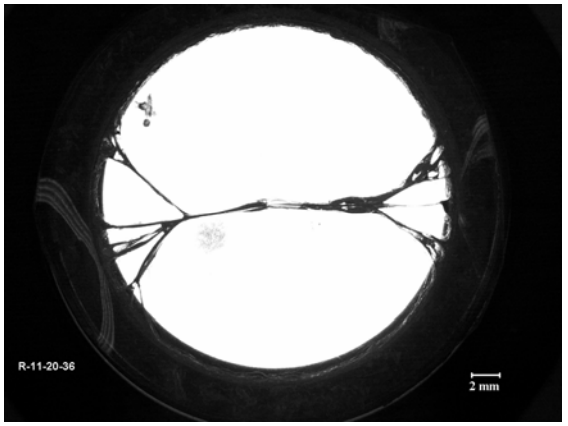

R-11-20-36
t=0.085"=2.2 mm
500C/192 hr
σ_t=47 MPa

$$x = \frac{K_{1c}^2}{\sigma_t^2}(1+\nu)\frac{t}{(0.5t-\delta)}$$

Critical σ_t is ~ 34 MPa for Corning and 47 MPa for Robax (ratio=0.72)

Toughness ratio=0.75 (0.82 vs. 1.09 MPa·m$^{0.5}$)

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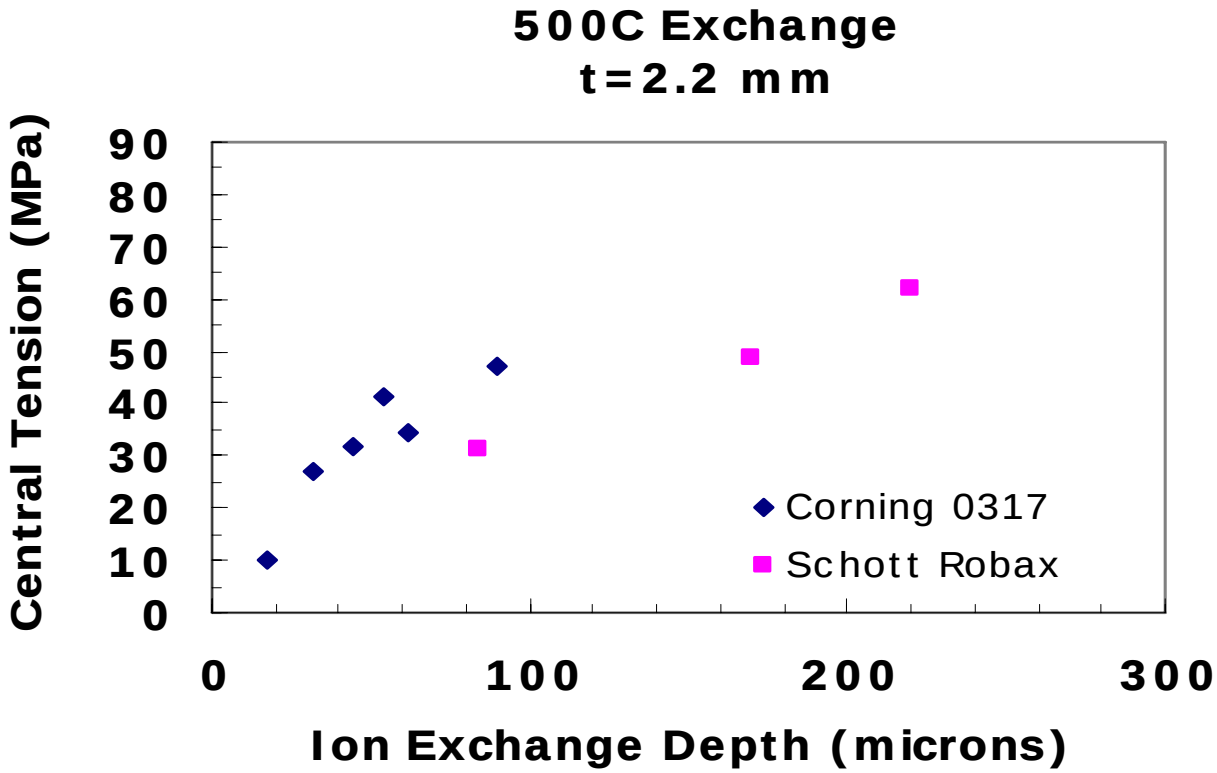
For a Given Ion Exchange Depth There is More Central Tension in the Corning Glass



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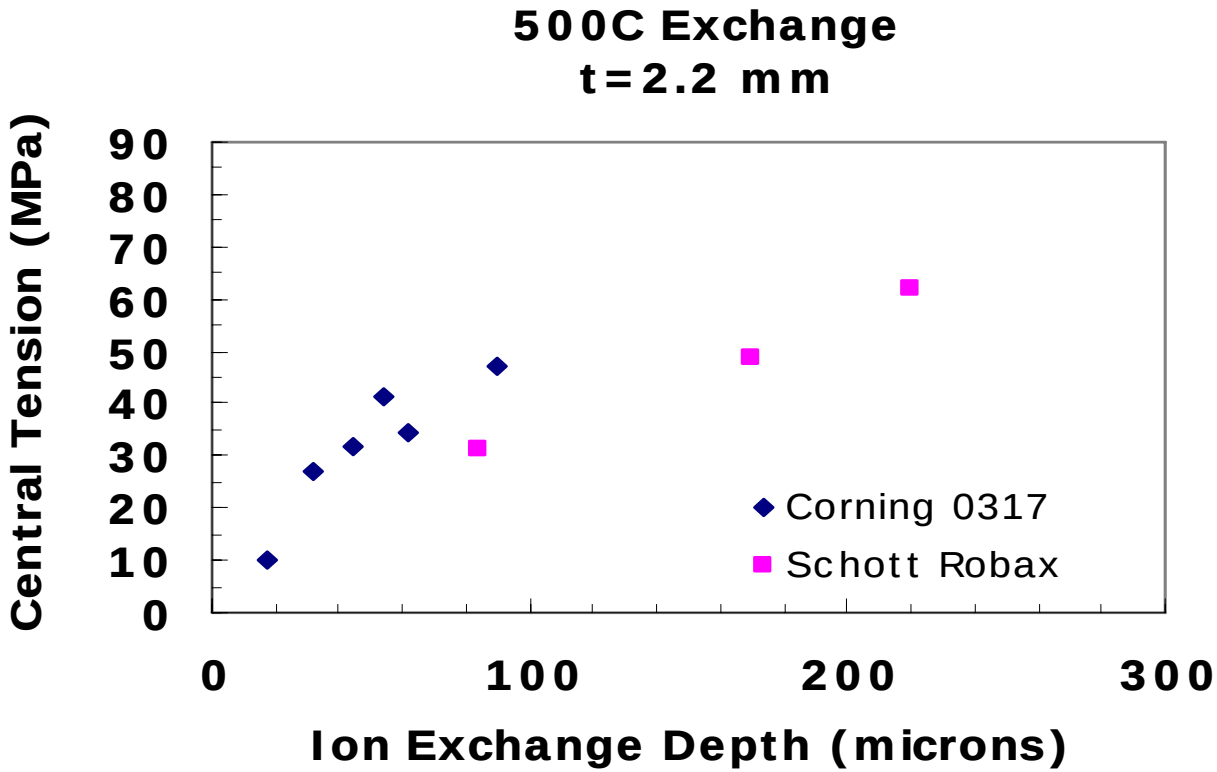

Corning: 12.14 mol% Na_2O (+3.71 mol% Li_2O) being replaced by K_2O
Robax: 6.87 mol% Li_2O + 0.37 mol% Na_2O being replaced by K_2O

Pauling's ionic radii: Li^+=1.2Å, Na^+=1.90Å, K^+=2.66Å

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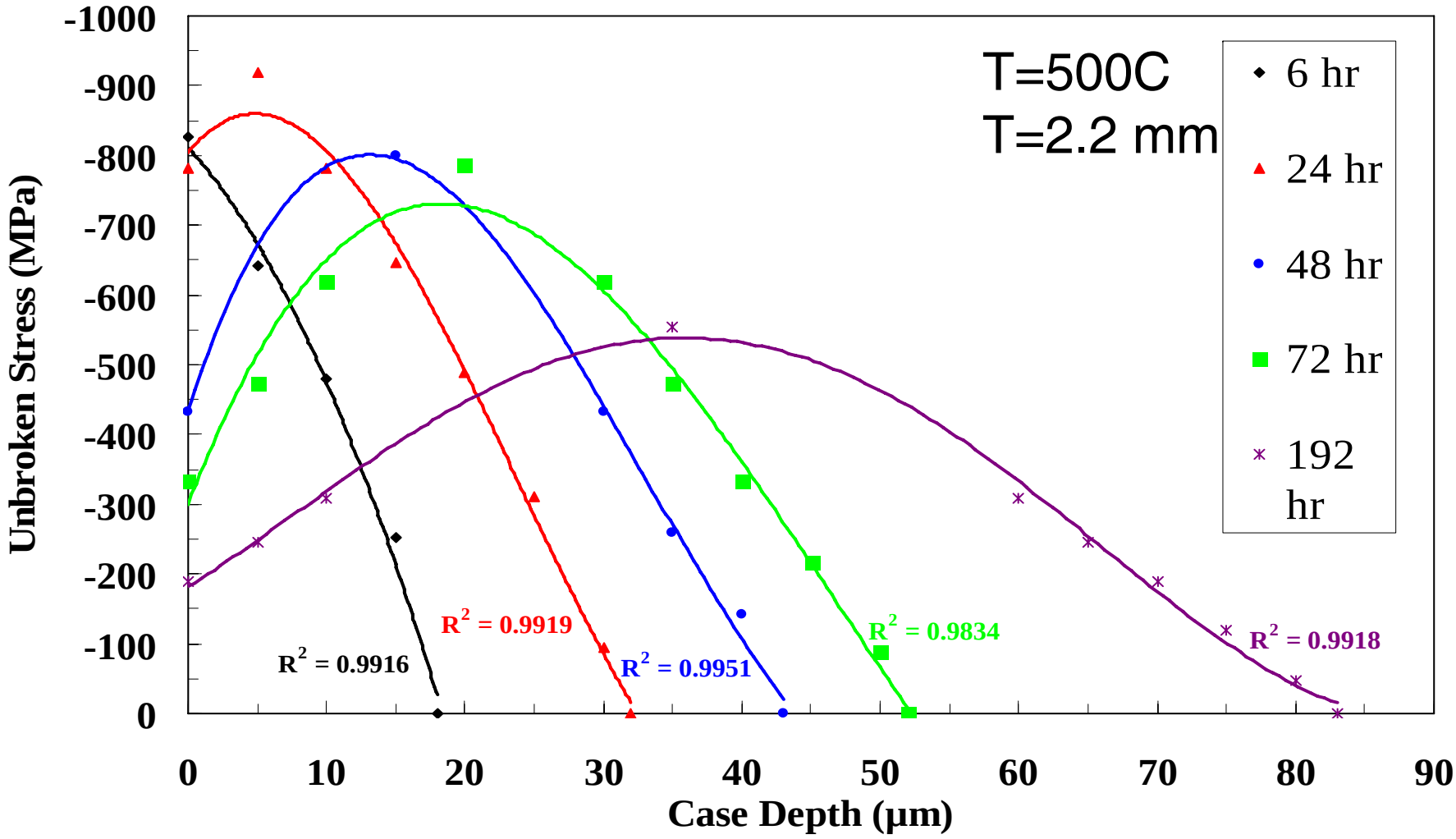
Surface Residual Stress Profile and Case Depth Measurements for Schott Robax



Measurements by I. Spinelli, Saxon Glass Technology, Inc.

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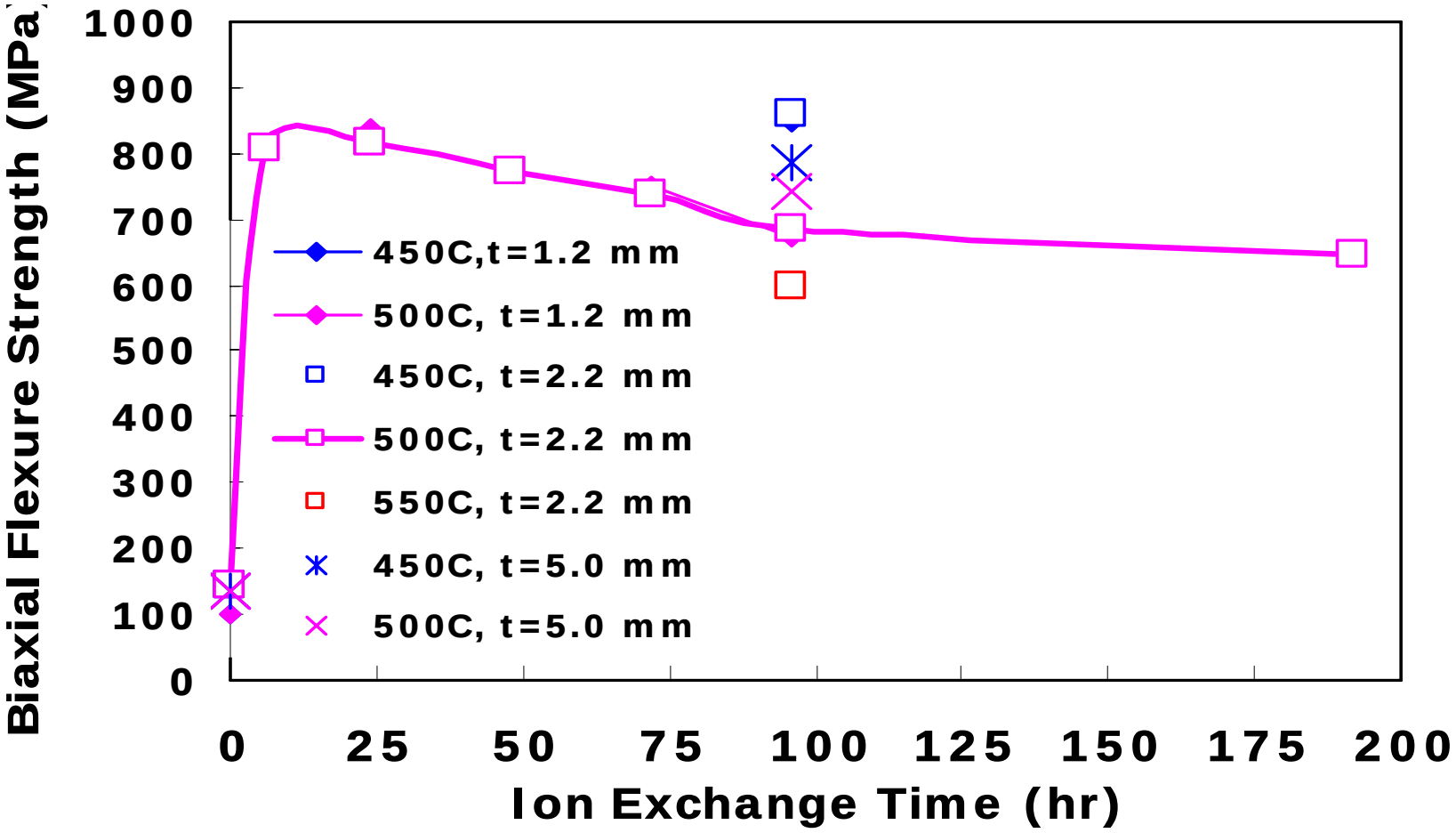
Schott Robax Biaxial Flexure Strength vs. Ion Exchange Time



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Summary and Conclusions

- Ion exchange provides remarkable damage tolerance and strengthening of glass
- Indentation induced fragment size determined by branching distance (central tension, t, δ) and number of branches
- Corning 0317 has greater ion exchange depth and central tension than Schott Robax for a given exchange time and T
- For similar values of central tension Corning has greater degree of fragmentation than Robax because of lower toughness (0.82 vs. 1.09 MPa·$m^{0.5}$, ratio=0.75)
- Critical σ_t for fragmentation is ~ 34 MPa for 2.2 mm Corning and just below 47 MPa for Robax (ratio=0.72)
- Glasses with higher K_{IC} require higher central tensions to achieve fragmentation and have larger fragments for a given σ_t
- High values of surface compression and strengths can be achieved for Schott Robax - K^+ for Li^+ exchange
- High strengths, even for long exchanges, suggest that fracture controlled by compressive maximum

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- Clay Newton and Ed Beauchamp, Sandia National Labs

- Students: Jason Kooi, Erica Hoover, Jen Rygel, Roman Wolf-Cecil, Karl Nieman, Luke Degruyter
- D. Gerling, Sierracin/Sylmar Corp., Sylmar, CA

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End

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