The Effects of Moisture Ingress on PV Modules

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Thin Film Module Reliability Team Meeting

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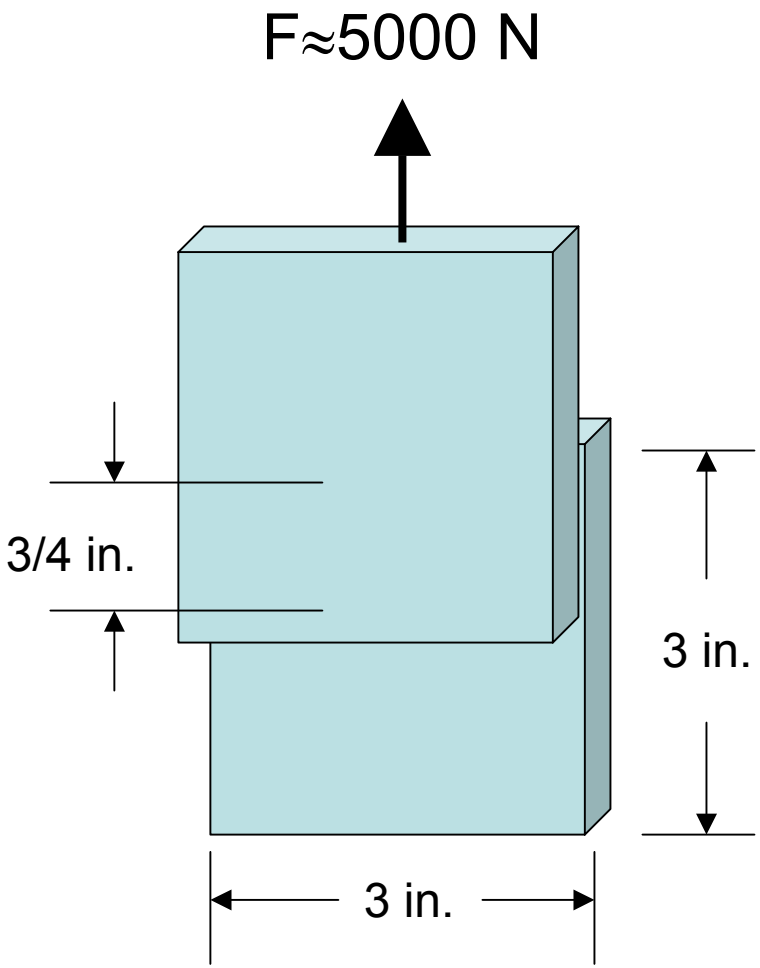
Motivation

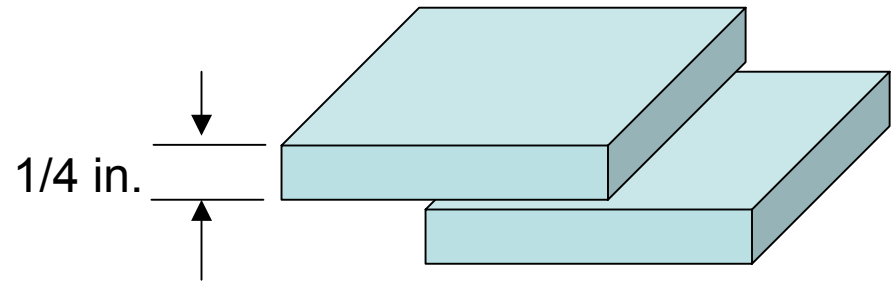
- Water is known to be correlated with an increase in the failure rate of PV modules.
- This is important for failure analysis of field exposure at hot humid sites.
- Therefore materials must be evaluated do determine if they can keep moisture out and if they can protect a device against the moisture that does enter.

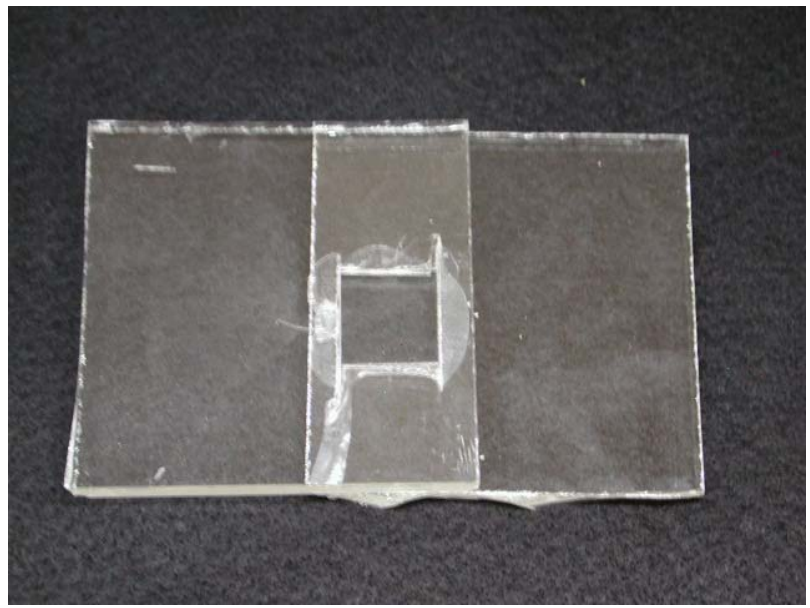
Outline

- Using a lap shear test to compare adhesion of different encapsulants.
- Diffusivity measurements used to determine time for moisture ingress.
  - Double glass laminates.
  - Breathable backsheets.

Lap Shear Test For Measurement of Adhesion

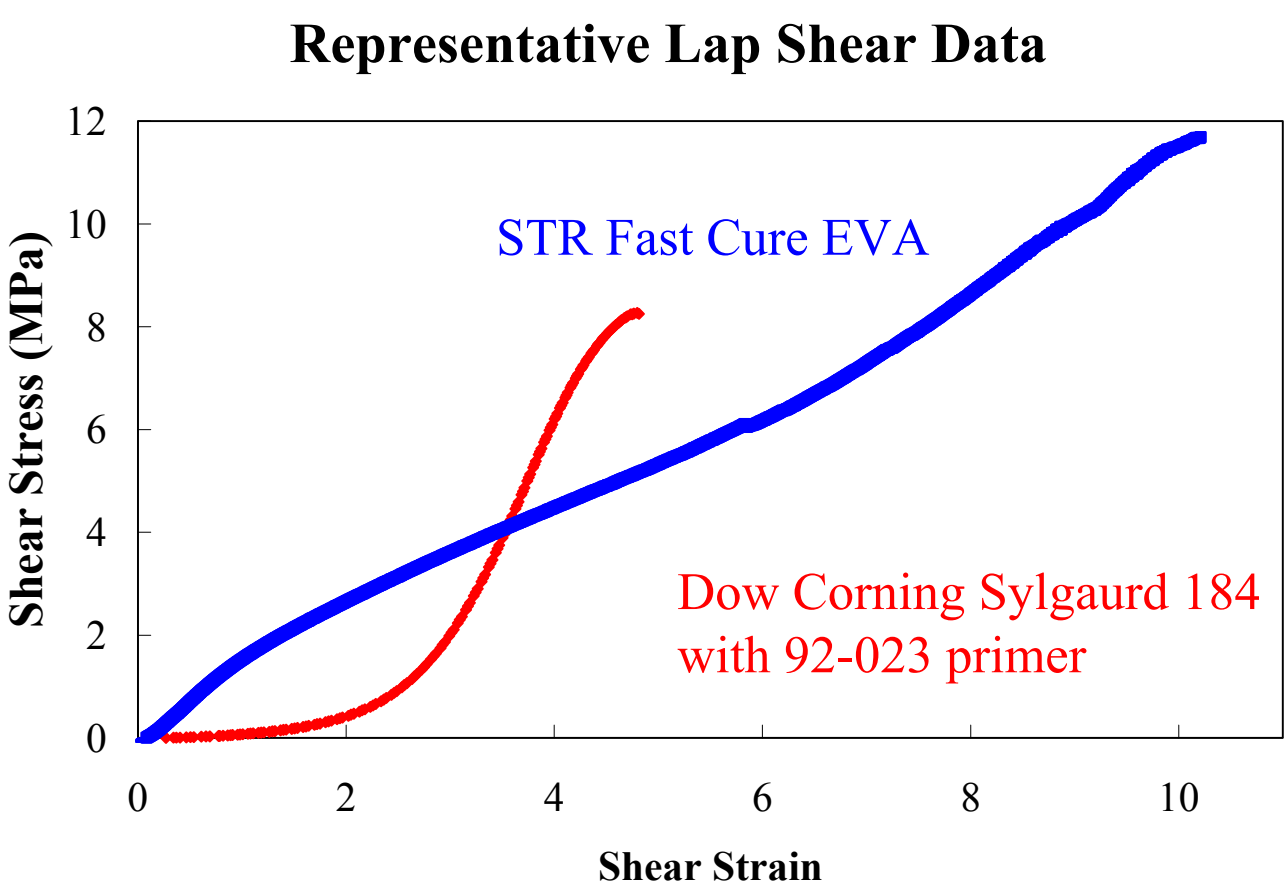




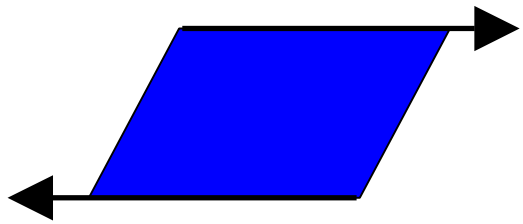


This geometry reduces edge effects and is strong enough to prevent glass breakage.

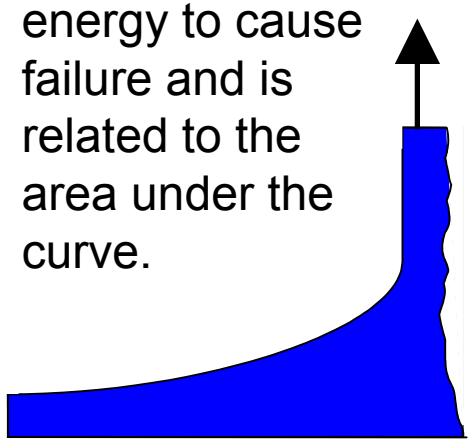
Stress vs. Strain Curves Can Be Very Different



Lap shear test measures the stress at failure.



Peel test measures the energy to cause failure and is related to the area under the curve.



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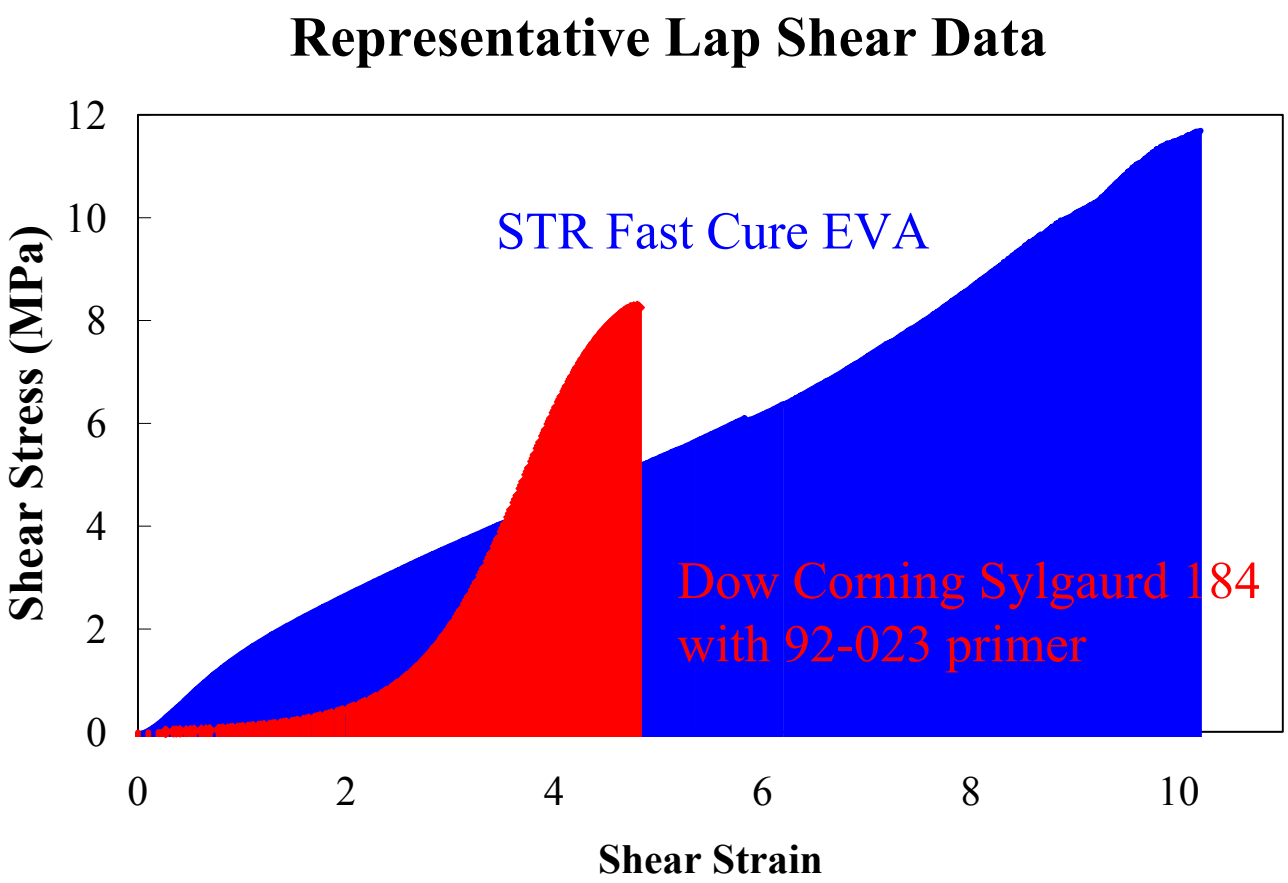

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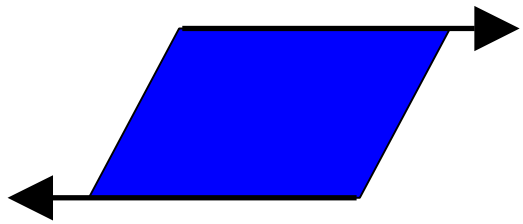

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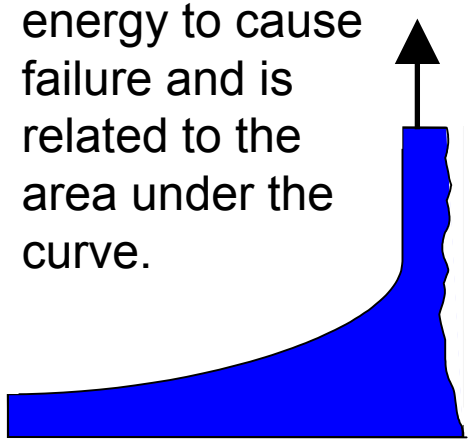
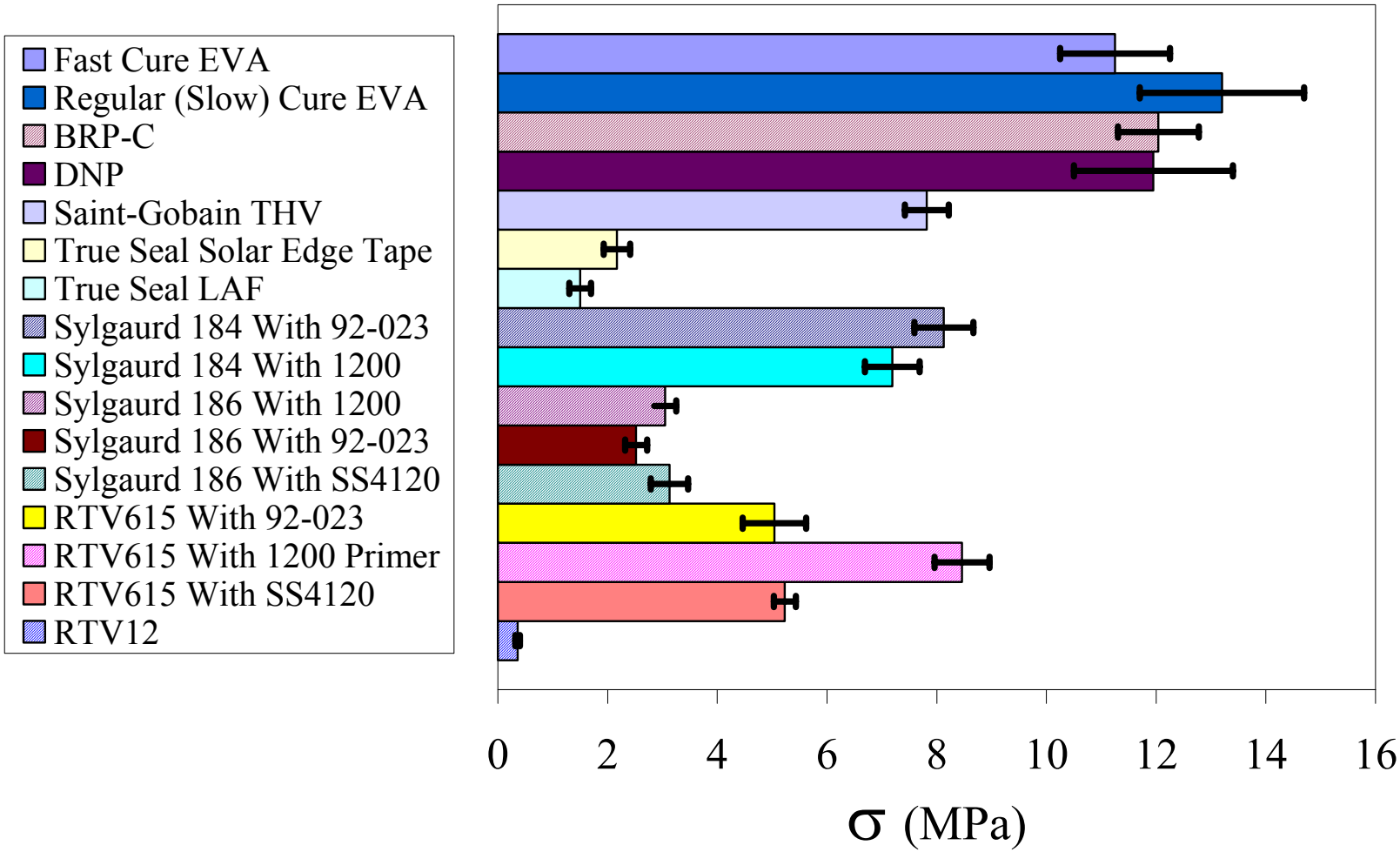
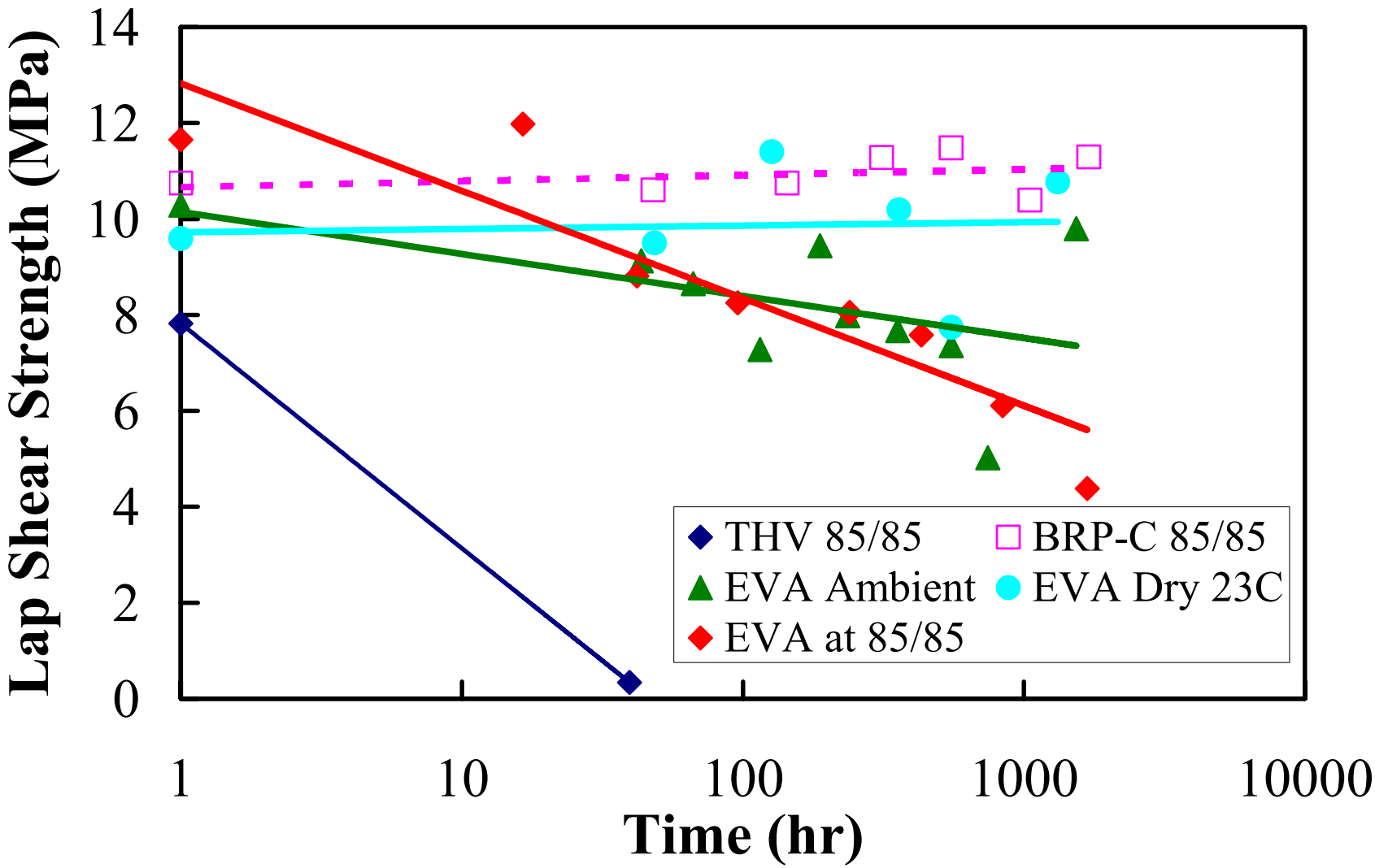


Unstressed Lap Shear Strength of Various Encapsulants



Stripped fill patterns failed cohesively. Solid fill patterns failed adhesively.

Degradation of Lap Shear Under Accelerated Environmental Stress

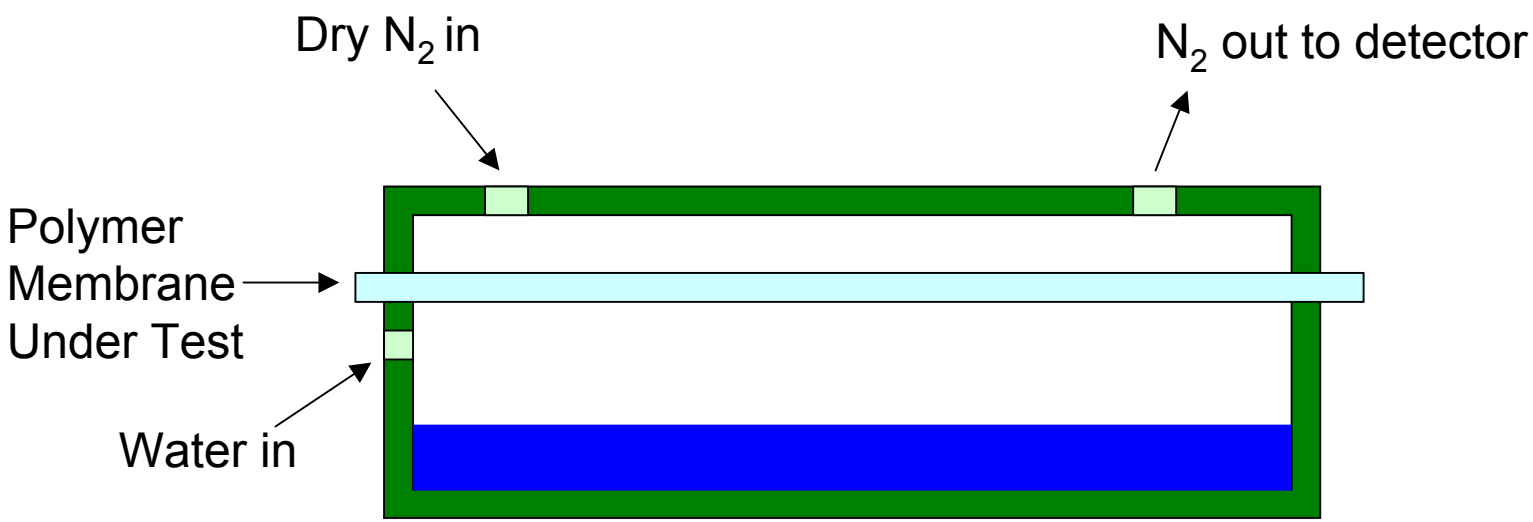


EVA Decomposes to Produce Acetic Acid

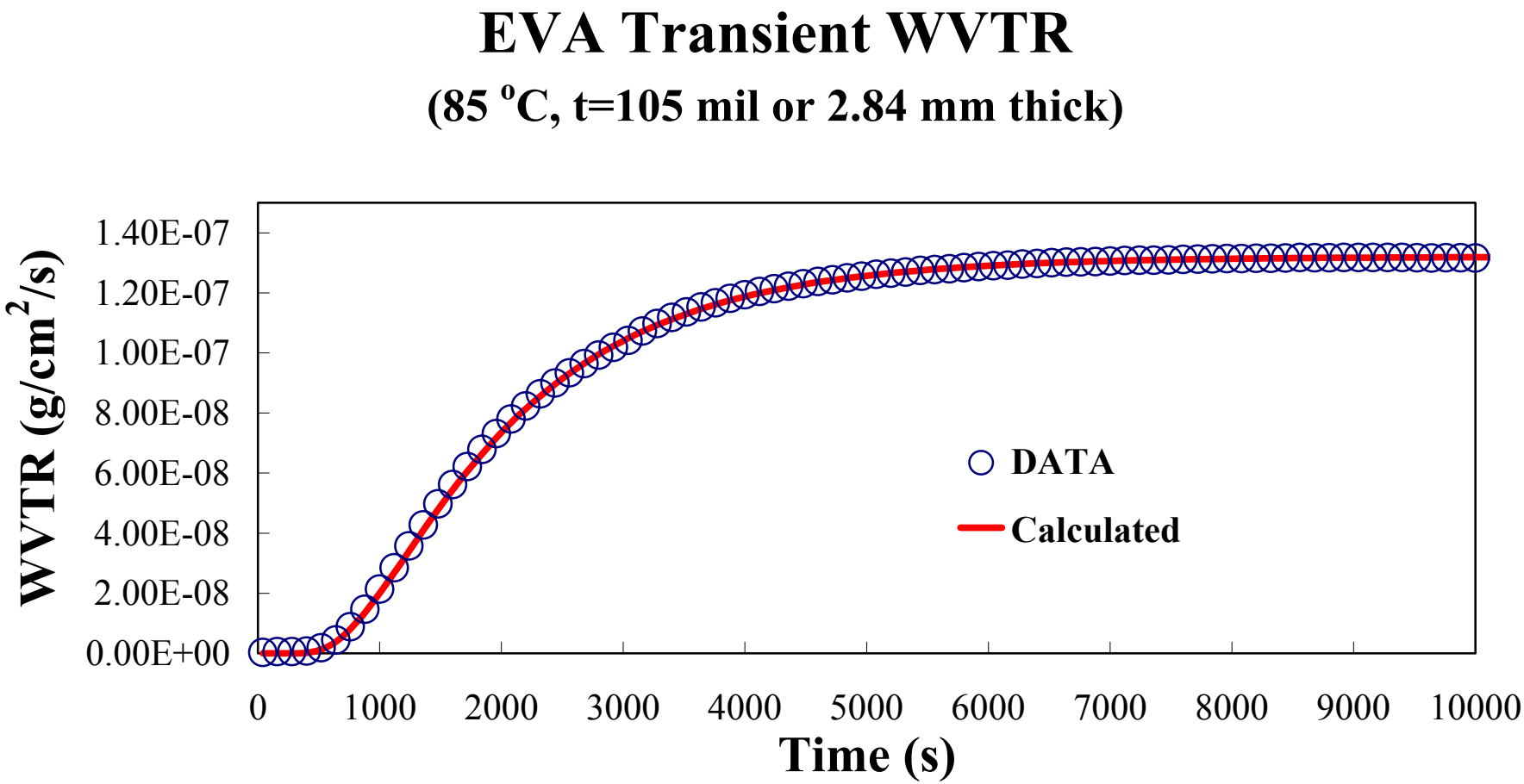
- EVA was exposed to elevated temperatures in humidified air and off-gases were collected in a basic aqueous solution.
- At 125 ^{o}C 21.0$\pm$4.3 nanograms of acetate per min per gram EVA
- At 105 and 85 ^{o}C acetate has been detected but not accurately quantified yet.

Experiments performed by Theodore Borek at Sandia National Laboratory.

Instrumental Set-Up for Diffusivity Measurements

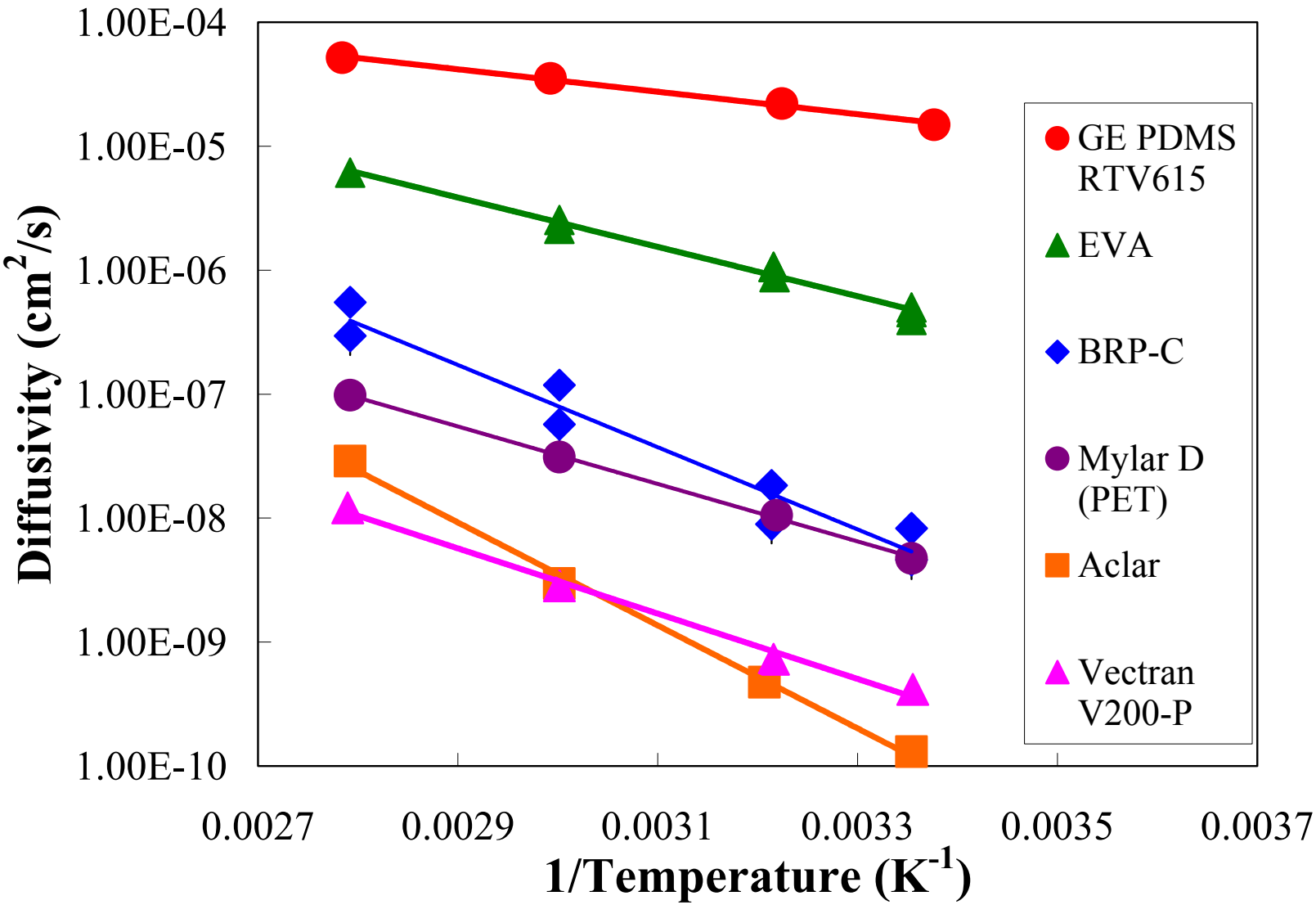


Transient WVTR for Diffusivity Measurement



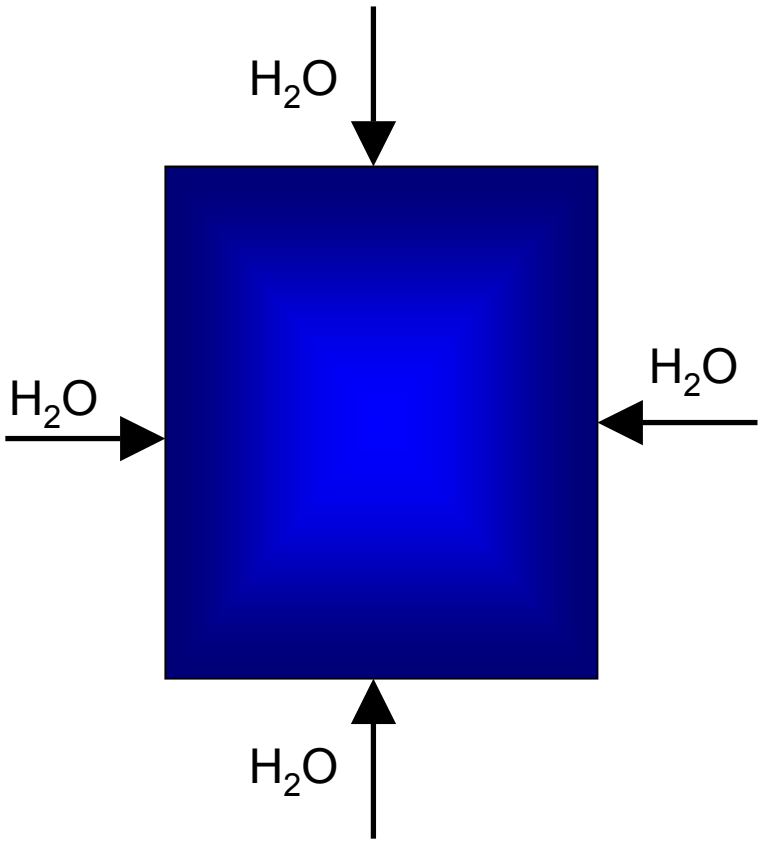
$$WVTR(t) = \frac{DC_S}{l}\left[1 + 2\sum_{n=1}^{\infty}(-1)^n e^{\left(\frac{-Dn^2\pi^2 t}{l^2}\right)}\right]$$

Diffusivity Varies Greatly Among Different Polymers



Half Time for 2-D Moisture Ingress

$$\frac{C_s - C(X,Y,t)}{C_s} = \frac{16}{\pi^2}\sum_{m=0}^{\infty}\frac{1}{2m+1}\sin\left[\frac{(2m+1)\pi X}{l_X}\right]e^{\left(-\frac{D(2m+1)^2\pi^2 t}{l_X{}^2}\right)}\sum_{n=0}^{\infty}\frac{1}{2n+1}\sin\left[\frac{(2n+1)\pi Y}{l_Y}\right]e^{\left(-\frac{D(2n+1)^2\pi^2 t}{l_Y{}^2}\right)}$$

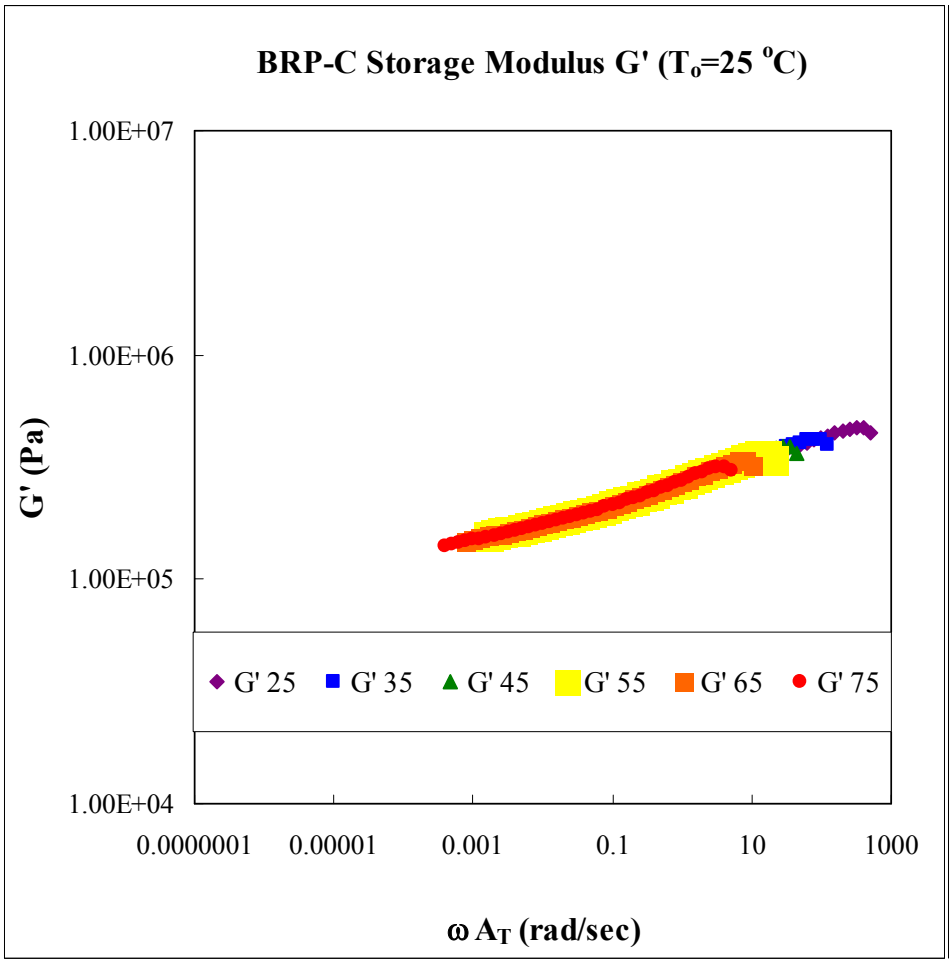


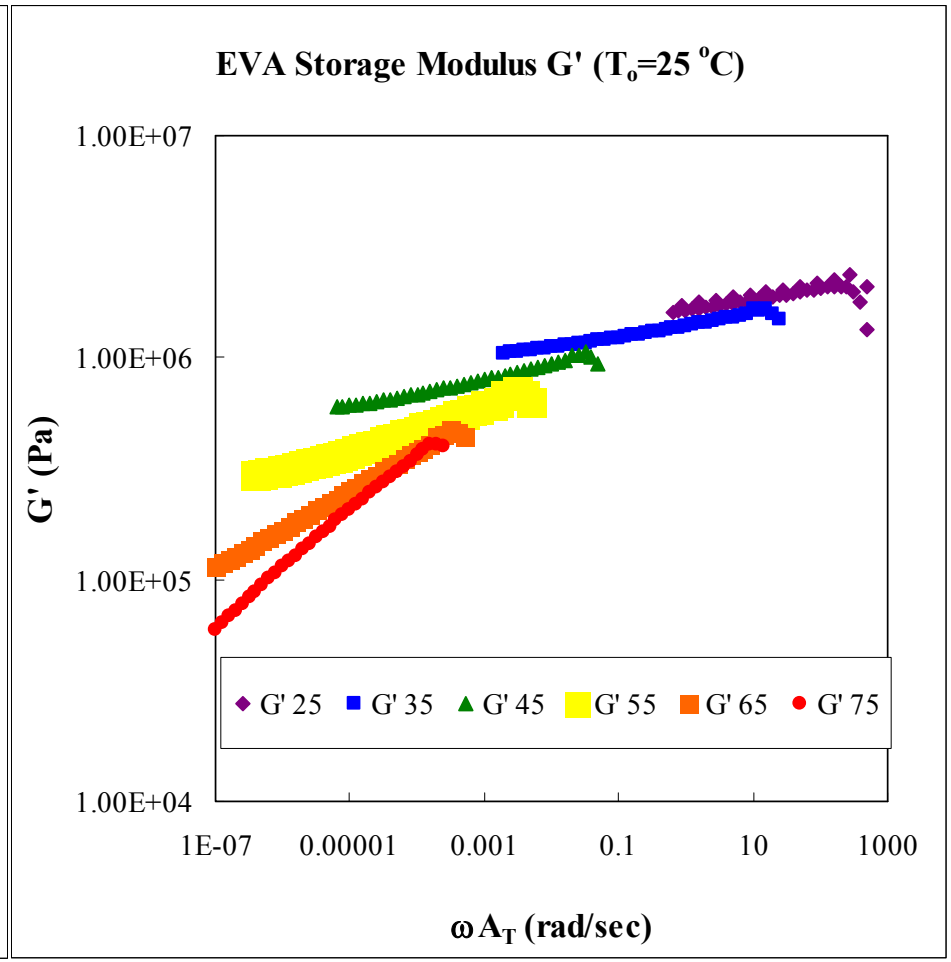
$$\tau_{1/2,square} = 0.0593\frac{l^2}{D}$$

l is the length of the sides.

T=85 °C	l=3/4 in.	l=4 in
EVA	0.39 days	11.1 days
BRP-C	6.35 days	181 days

BRP-C Has a Lower Modulus

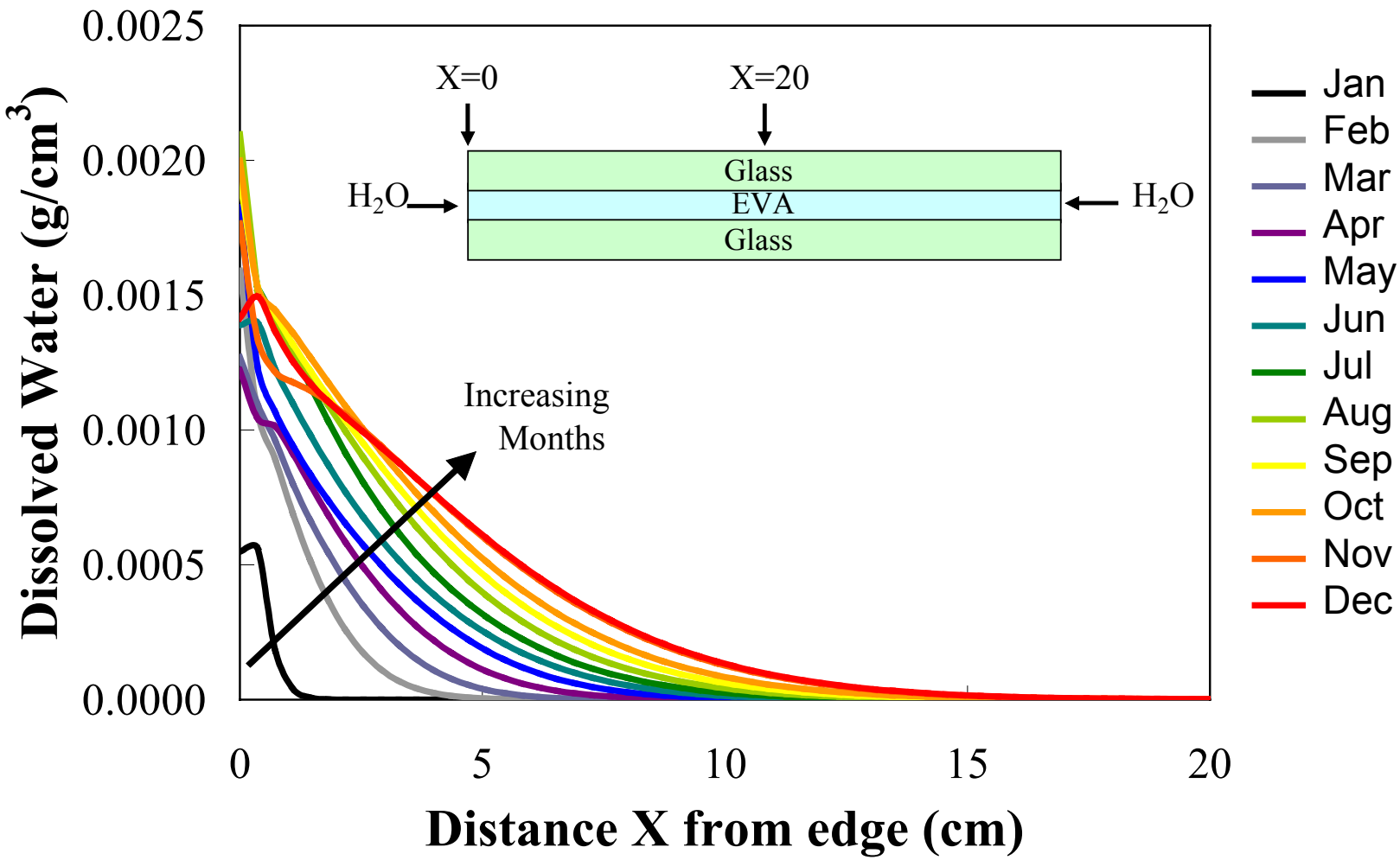




Rheological measurements performed at Sandia National Lab with Jeffrey Galloway

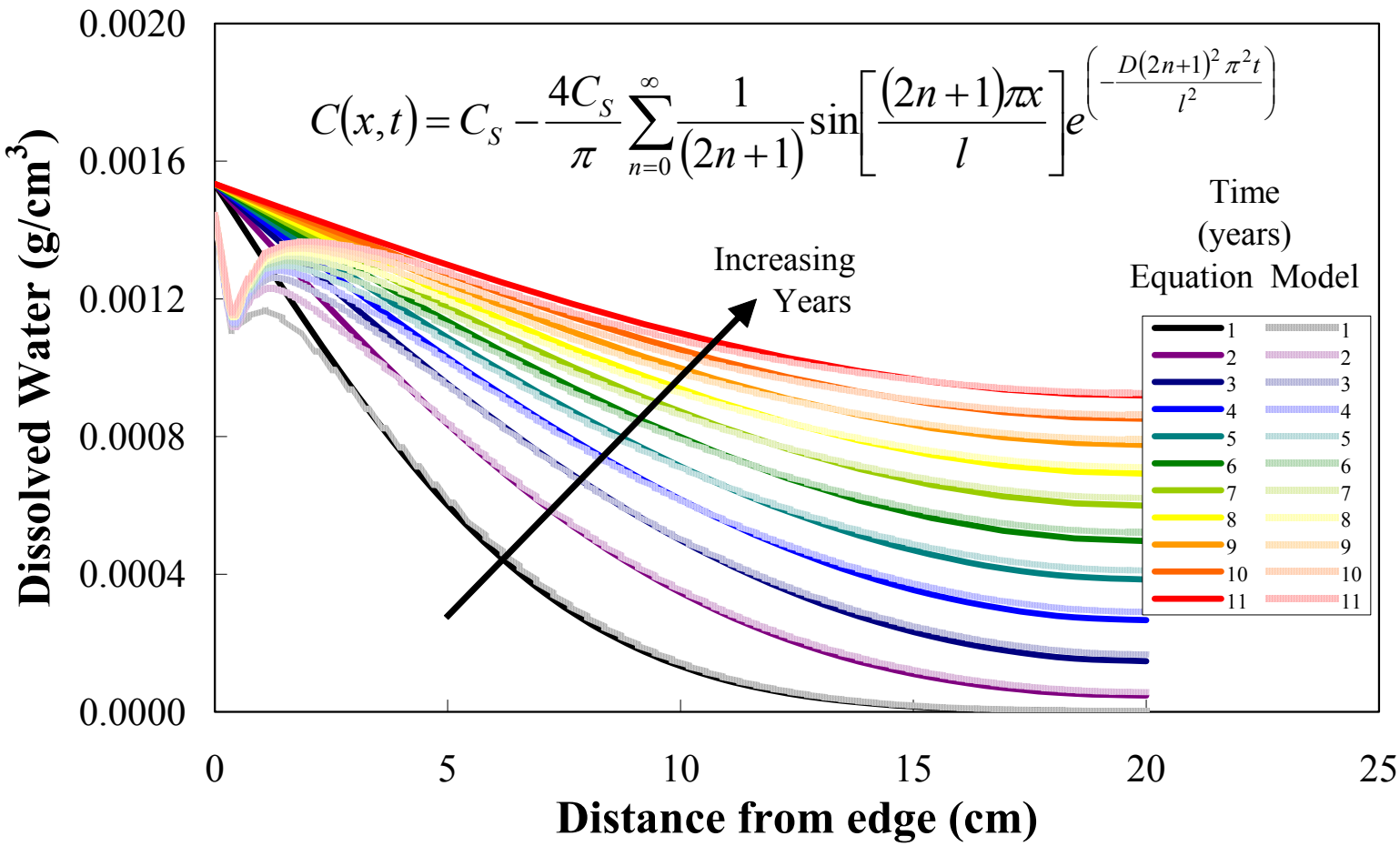
Diffusivity and Solubility Allow Modeling of Water Concentration

Explicit finite element analysis using meteorological data from Miami Florida 2001



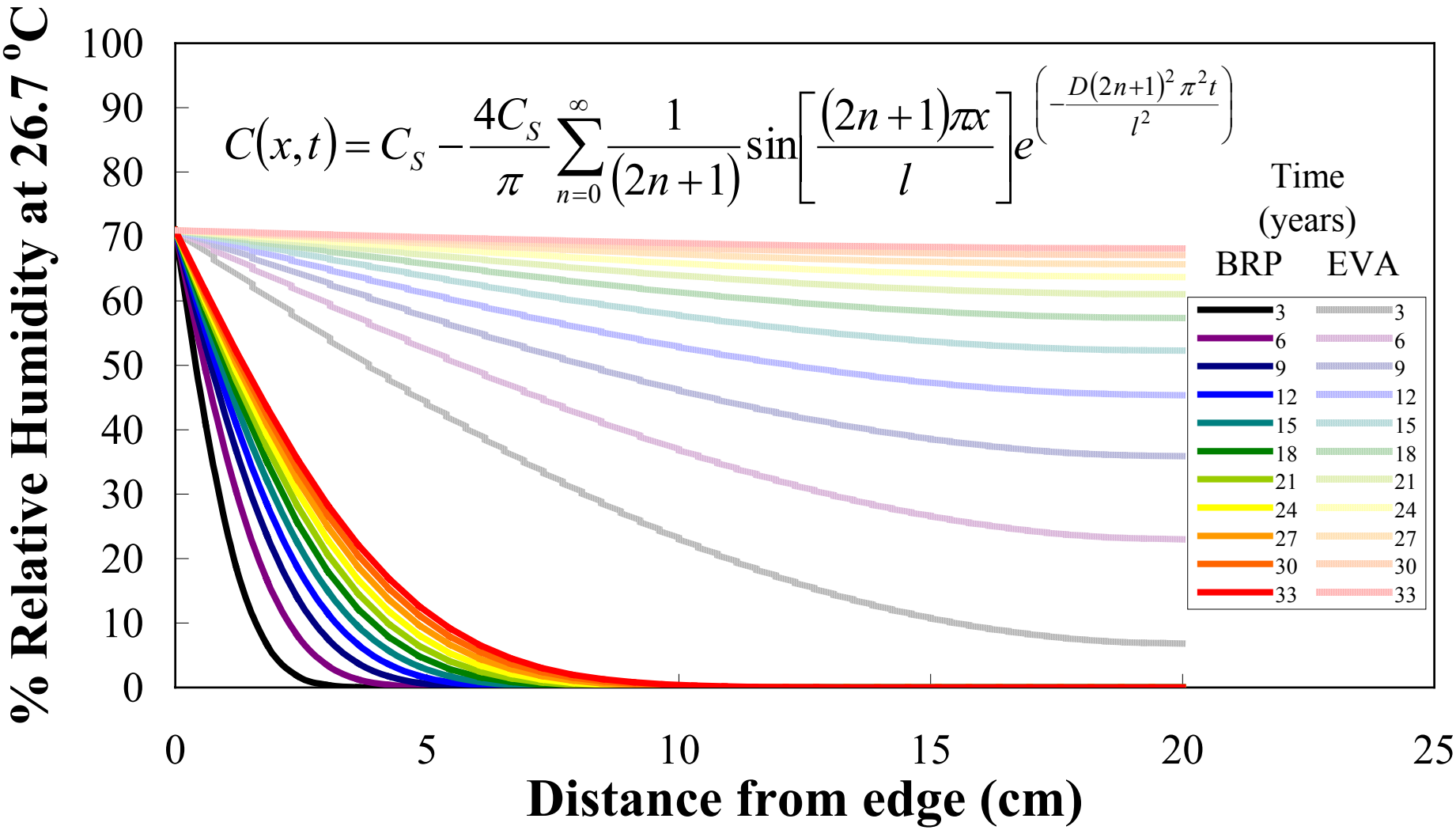
Similarity of Finite Element Analysis and Transient Equation

The model assumes T=26.7 °C and 71% Relative Humidity

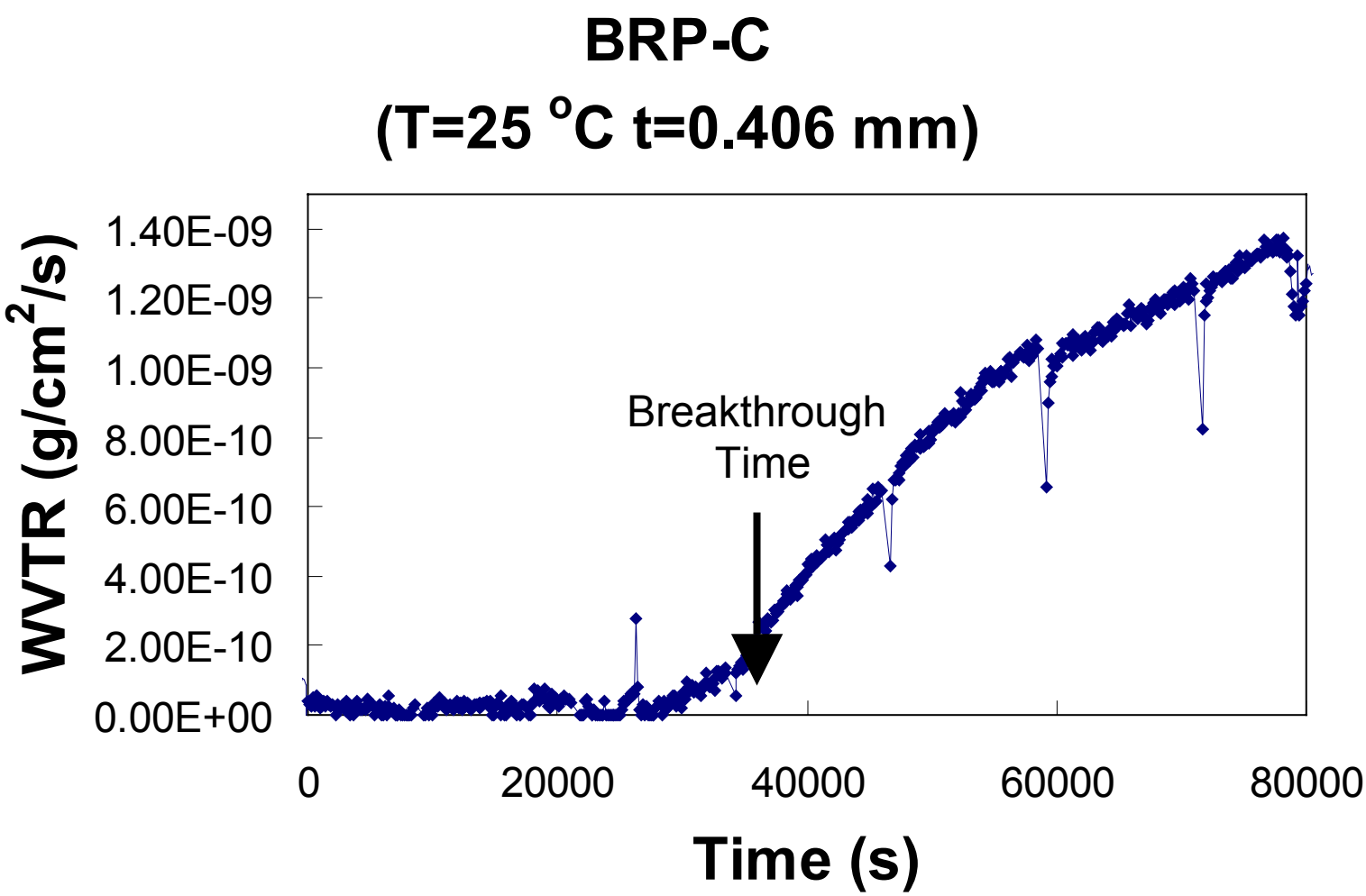


Crank, “The Mathematics of Diffusion”, pg. 50, Clarendon Press, Oxford (1975)

Comparison of EVA to BRP-C

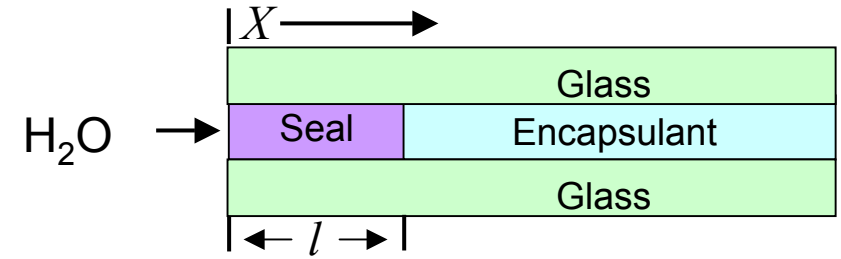


Long Breakthrough Times Delay Moisture Ingress



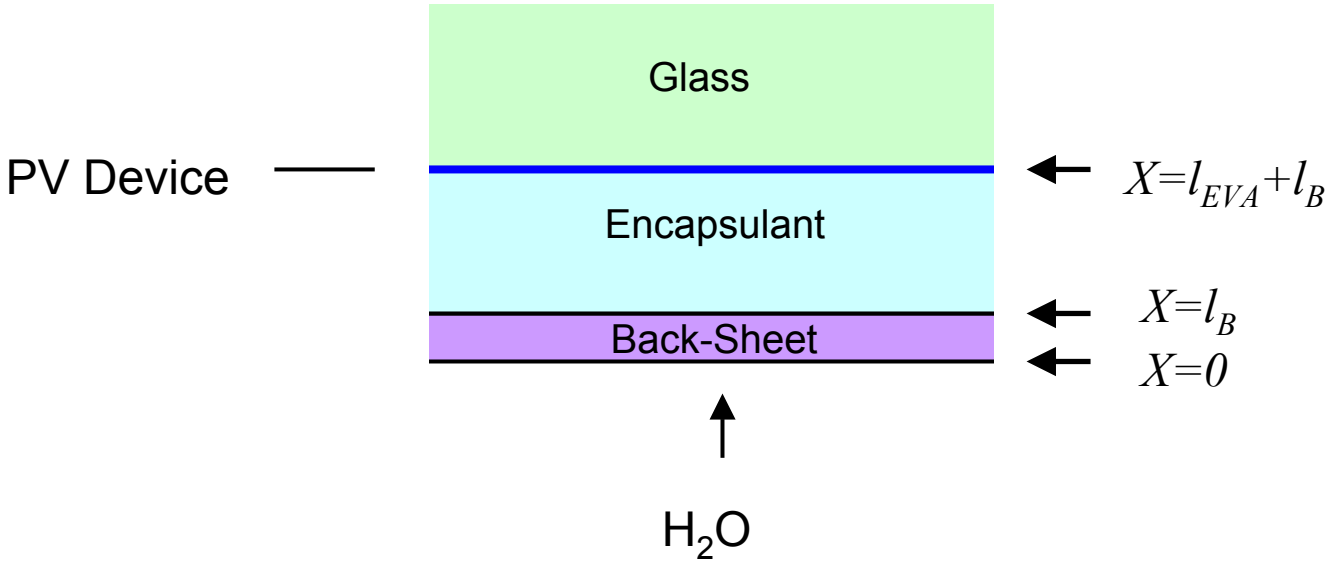
Long Breakthrough Times Make Good Edge Seals

$$\tau_b = K\frac{l^2}{D}$$



	Membrane Breakthrough Time at 25 °C τ_b (min)	Membrane Thickness l (mm)	$\frac{\tau_b}{l^2}$ (min/mm^2)	Edge Seal Breakthrough time for l=12.5 mm
RTV615 PDMS	4.67	3.25	0.442	1.15 hrs
EVA	3.6	0.457	17.2	2 days
BRP-C	550	0.406	3,336	362 days
Aclar	35	0.0229	66,740	20.3 yrs

Moisture in Breathable Back-Sheets



Model Assumptions:

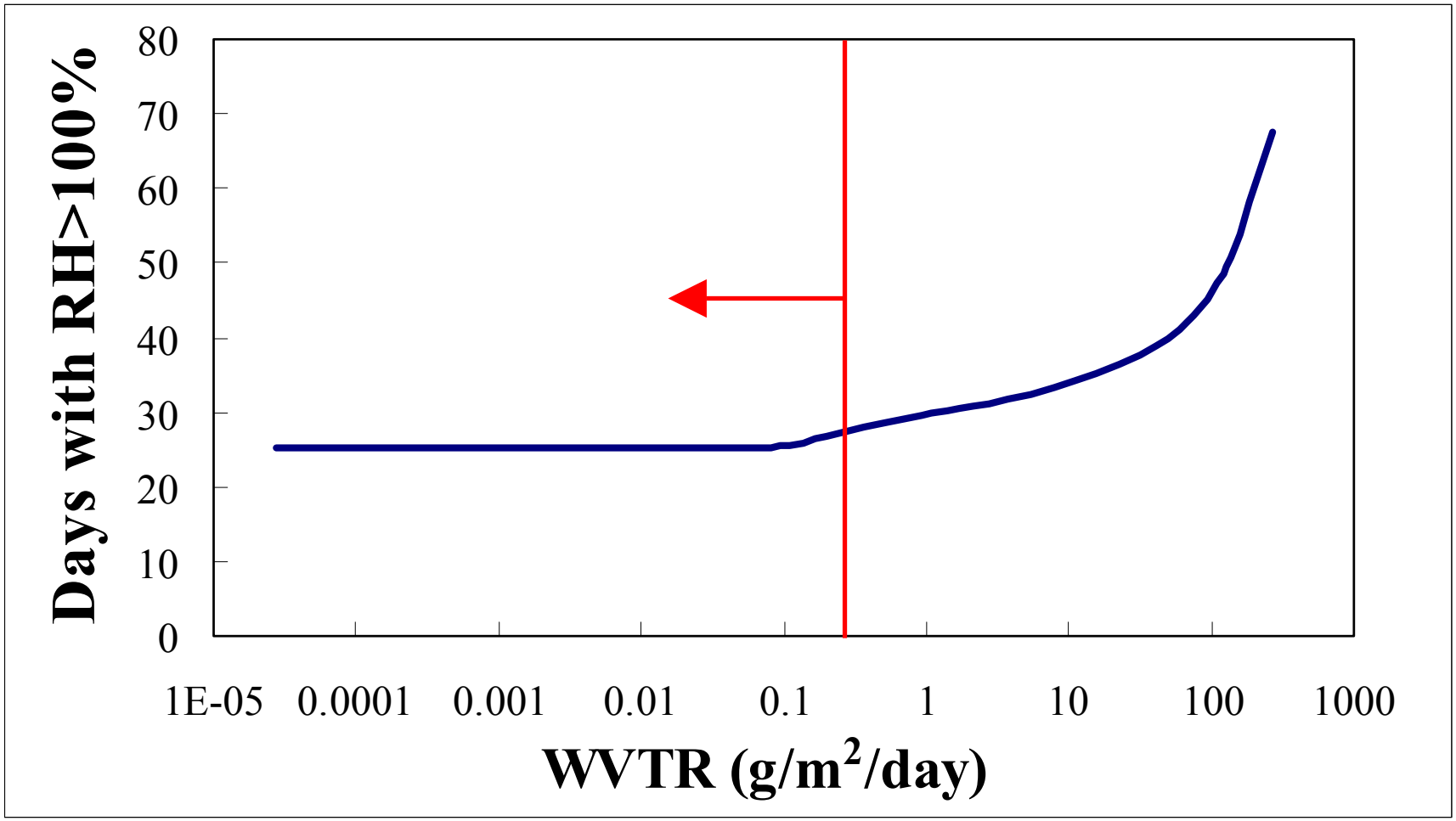
C_{EVA} not a function of position X

(i.e. $D_{EVA}>>D_B$)

WVTR is proportional to ΔC_B

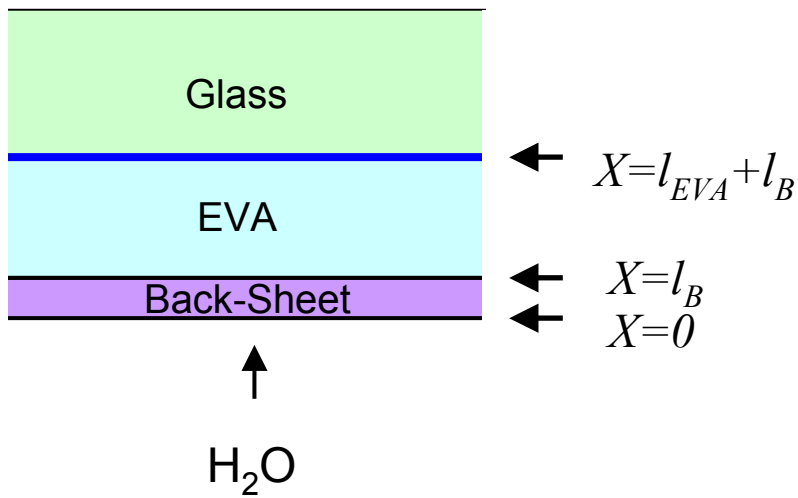
$$\frac{dC_{EVA}}{dt}=\frac{WVTR_{B,Sat}}{C_{E,Sat}.l_{EVA}}\left[C_B(0)-C_B(l_B)\right]$$

In Breathable Backsheets the Module RH Can Exceed 100%



Model based on atmospheric data for Miami Florida in 2001 using an activation energy of 0.74 eV for water vapor trasmission and for an EVA thickness of 18 mil.

Time Constant for Water Ingress



$$\frac{dC_{EVA}}{dt} = \frac{WVTR_{B,Sat}}{C_{E,Sat}.l_{EVA}}\left[C_B(0) - C_B(l_B)\right]$$

$$\frac{C(t)}{C(0)} = 1 - e^{-\frac{C_{Sat,EVA}l_{EVA}t}{WVTR_{B,Sat}}}$$

$$\tau_{1/2} = 0.693\,\frac{C_{Sat,EVA}l_{EVA}}{WVTR_{B,Sat}}$$

l_{EVA}=18 mil, T=27 ^{o}C, $C_{Sat,EVA}$=0.0022 g/cm^3

For WVTR<0.3 g/m^2/day

$\tau_{1/2}$>3 days

M. Tencer, “Moisture Ingress into Nonhermetic Enclosures and Packages.”, IEEE 1994

Conclusions

- EVA quickly loses adhesion in 85/85.
- EVA produces acetic acid as a by-product.
- A low diffusivity material is able to significantly reduce moisture ingress in a double glass PV module.
- For breathable backsheets WVTR<0.3 $g/m^2/day$ and $\tau_{1/2}$>3 days will reduce the time when RH>100%.
- Better materials than EVA can be found.