SAND2017-1108PE

Adhesive Joint Failure and the Aging of Adhesive Joints

TCG-XIV – Munitions Reliability and Lifecycle Technology

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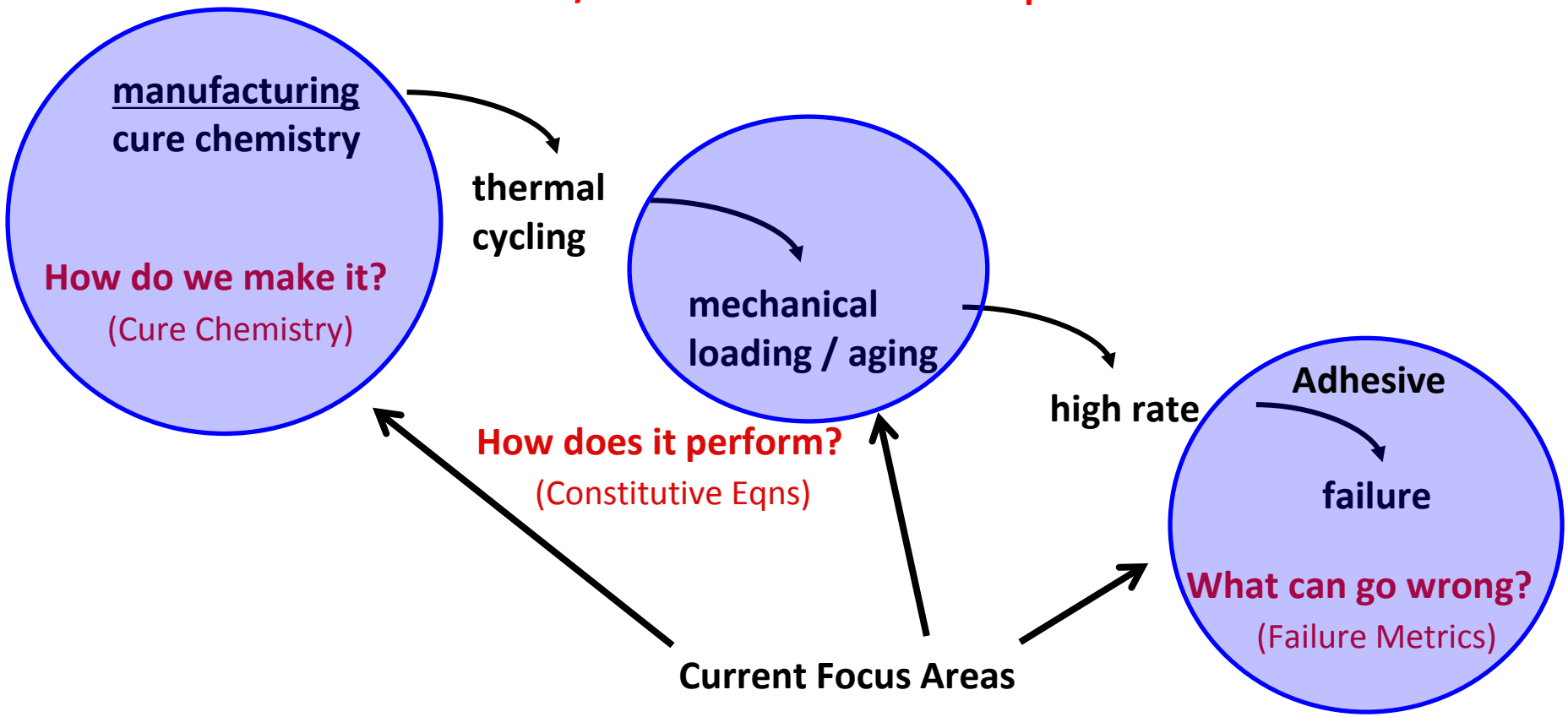
Our Vision: Validated Model-Based Lifecycle Engineering for Packaging Design

J.M. Caruthers, et al., *Polymer*, 2004, 45, 4577
D.B. Adolf, et al., *Polymer*, 2004, 45, 4599
D.B. Adolf, et al., *Polymer*, 2009, 50, 4257

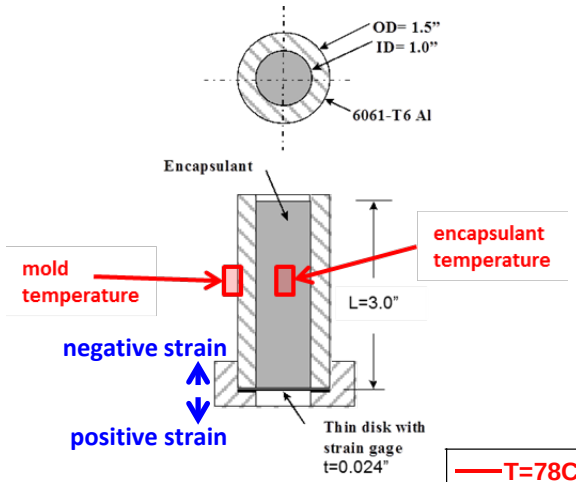
Polymer Nonlinear Viscoelastic (NLVE) Model

Current talk **Predict Stress/Strain and Understand Impact on Performance**

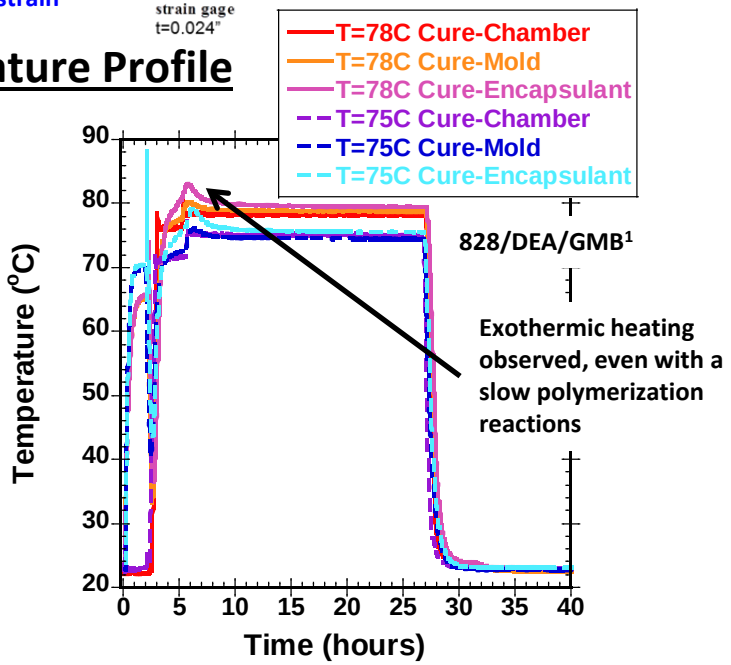


Why is Cure Stress Important?

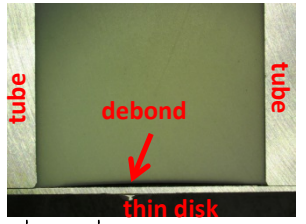
Geometry: Thin Disk on Cylinder

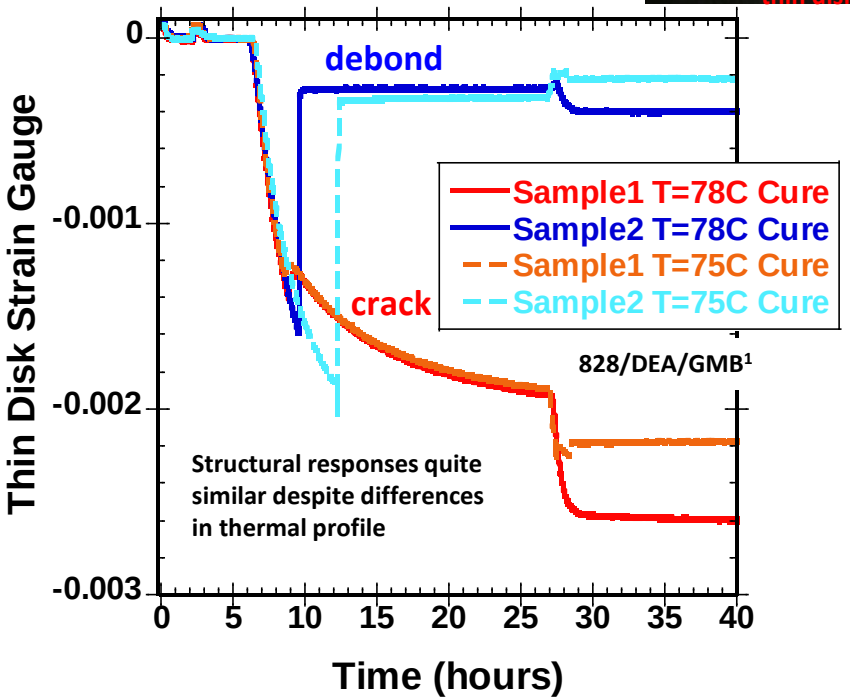


Temperature Profile

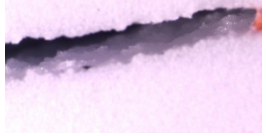


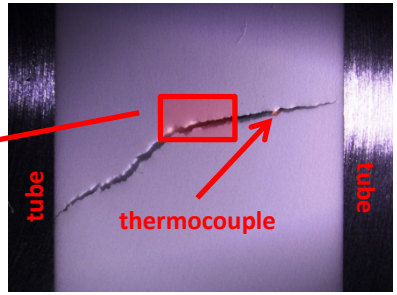
Structural Response





Rough crack surface consistent with "tearing" in rubbery state?





Failure can occur during cure!

[1]http://www.sandia.gov/polymer-properties/828_DEA_GMB.html

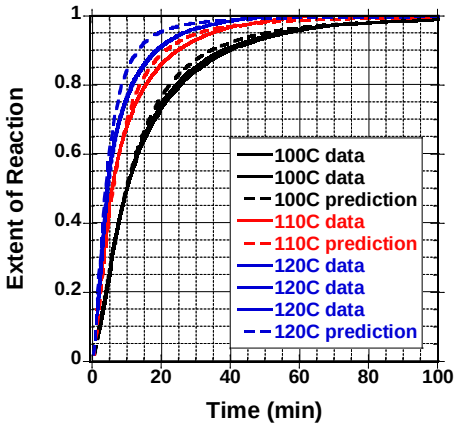
Kropka et al., SAND2016-5543

Predicting Cure Stress: Parameterizing the SPEC Cure Model

Reaction Kinetics

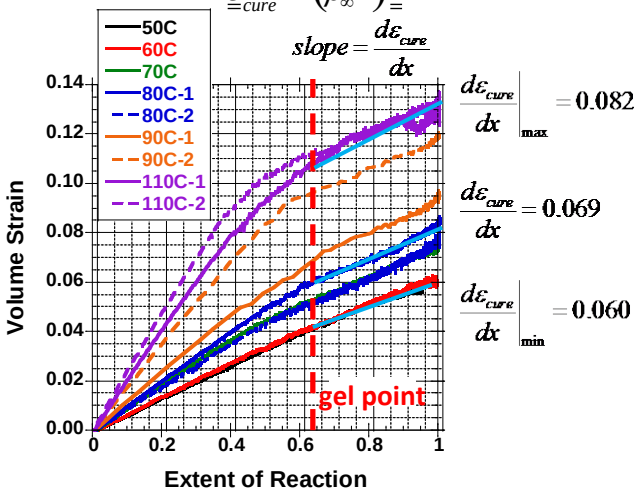
$$\frac{dx}{dt} = \hat{k}\left(b + x^m\right)(1-x)^n \qquad \hat{k} \equiv \frac{k}{(1+w\,a)^\beta} \qquad k = k_o\, e^{-\frac{E_a}{RT}}$$

828/T403 Chemistry Limited Reaction Parameters	
Parameter	Value
E_a	13.8 kcal/mole
k_o	2.17x10^5 s^{-1}
b	0.17
m	0.33
n	1.37



Volumetric Cure Shrinkage

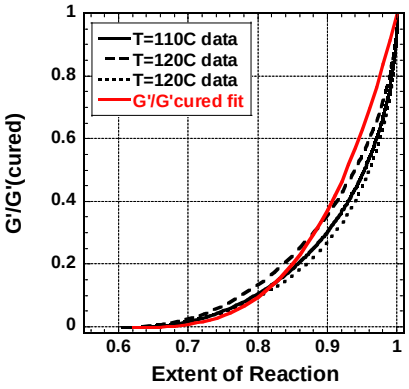
$$\underline{\underline{\varepsilon}}_{cure} = \left(\beta_\infty x\right)\underline{\underline{I}}$$



Evolution of Equilibrium Shear Modulus During Cure

$$\frac{G_\infty(x)}{G_\infty(1)} = \left[\frac{x^2 - x_{gel}^2}{1 - x_{gel}^2}\right]^{8/3}$$

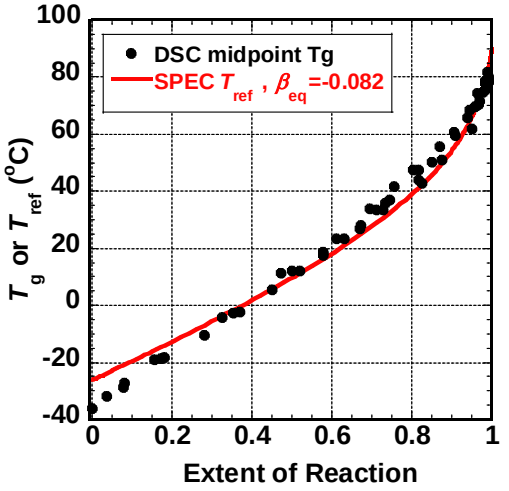
828/T403 $G_\infty(x)$ Parameterization	
Parameter	Value
x_{gel}	0.62



Evolution of Glass Transition Temperature During Cure

$$T_{ref}(x) = T_{ref} - \frac{\left[C_3\beta_\infty + C_5(x(t))\right]\left(x(t) - x_{ref}\right)}{\left(1 - C_3 \propto_\infty\right)} \qquad C_5(x(t)) = C_{5a} + \frac{C_{5c}}{\left(C_{5d} - C_{5b}x\right)^{C_{5e}}}$$

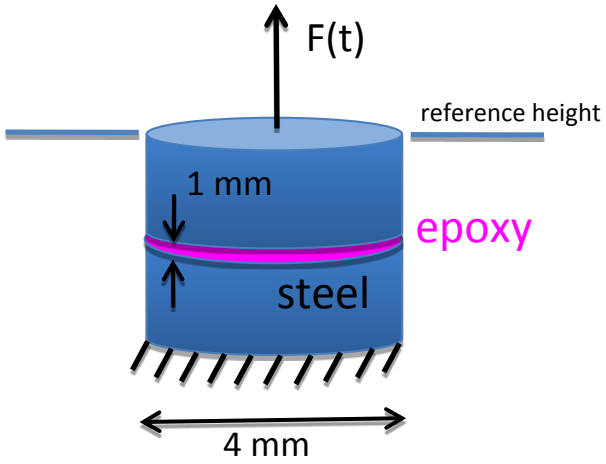
828/T403 T_{ref} Parameterization	
Parameter	Value
C_3	900 C
α_∞	500 ppm/C
C_{5a}	10 C
C_{5b}	0.97
C_{5c}	-105 C
C_{5d}	1.0088
C_{5e}	0.73



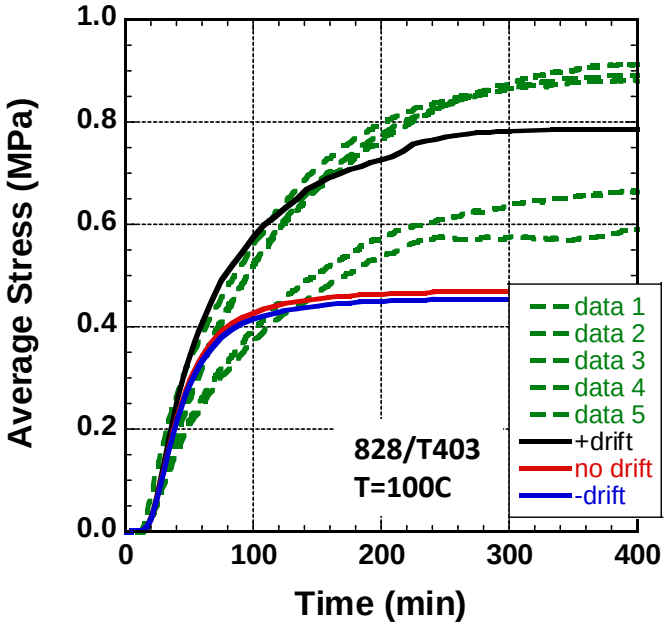
Kropka et al., SAND2013-8681

Predicting Cure Stress: Validation Tests

The Simple Test



Rubbery Cure Results

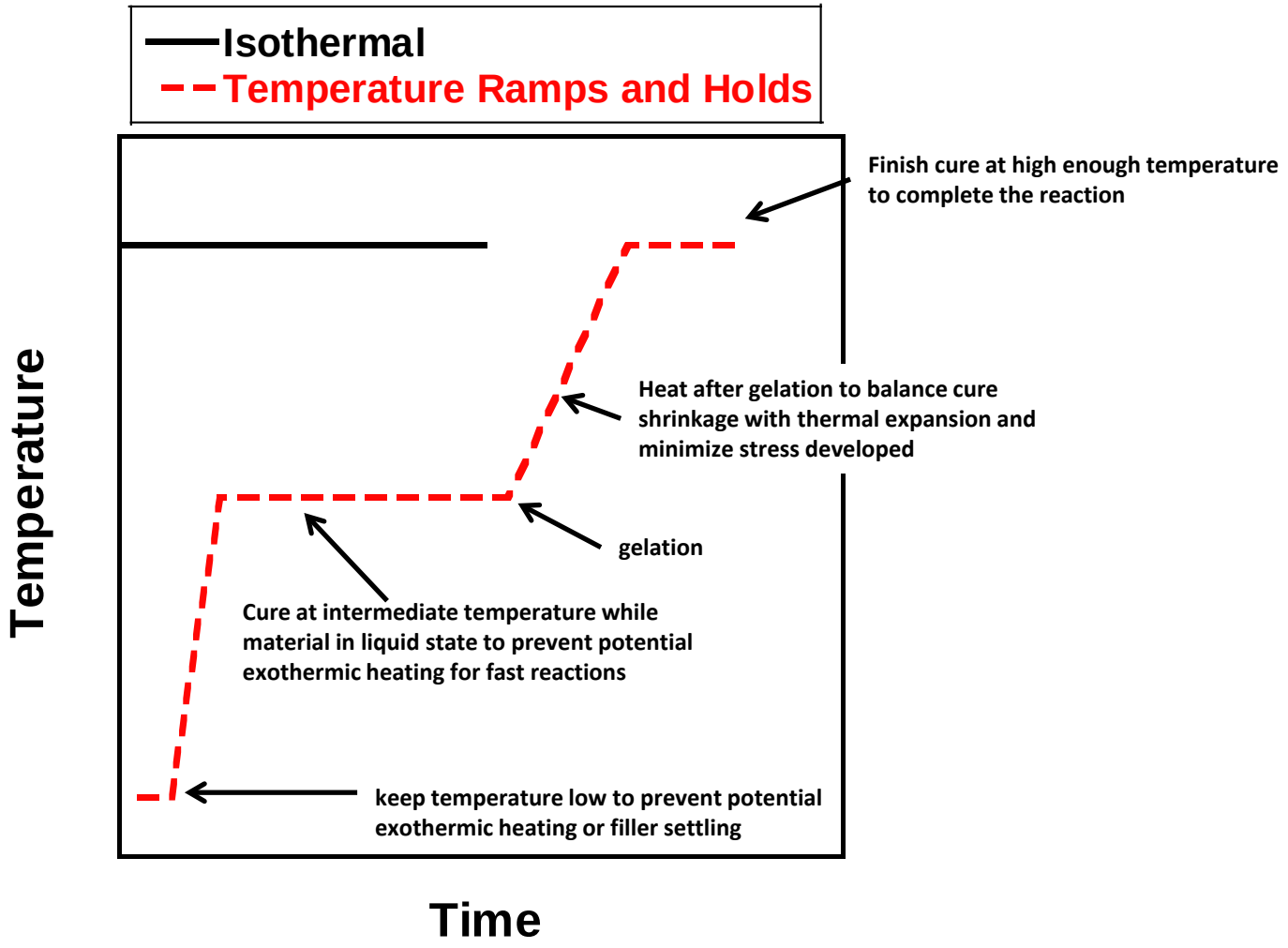


Good agreement between predictions and data, with known variations in boundary conditions during the test accounting for the spread in the data

This capability will enable the design of cure schedules to minimize stress

Kropka et al., SAND2013-8681

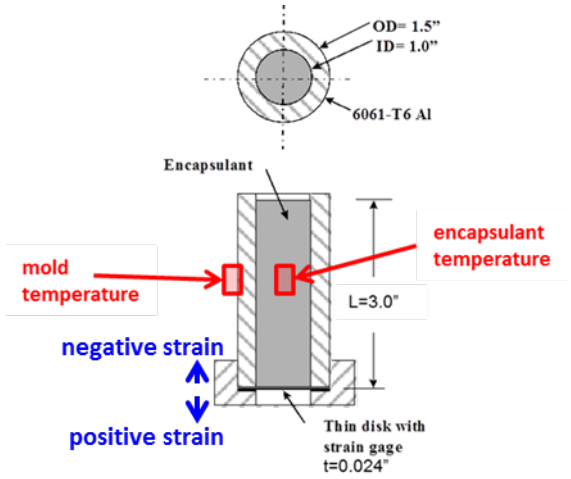
Designing an Optimum Cure Schedule

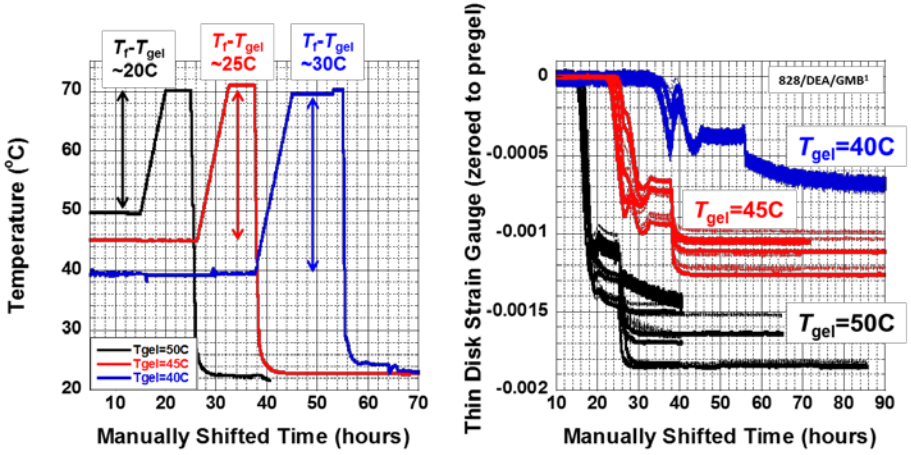


Isothermal reaction at a high temperature may be the fastest method to achieve complete cure, but other factors may drive the time-temperature profile in a different direction

Designing Cure Schedules to Minimize Stress

Confined Cure

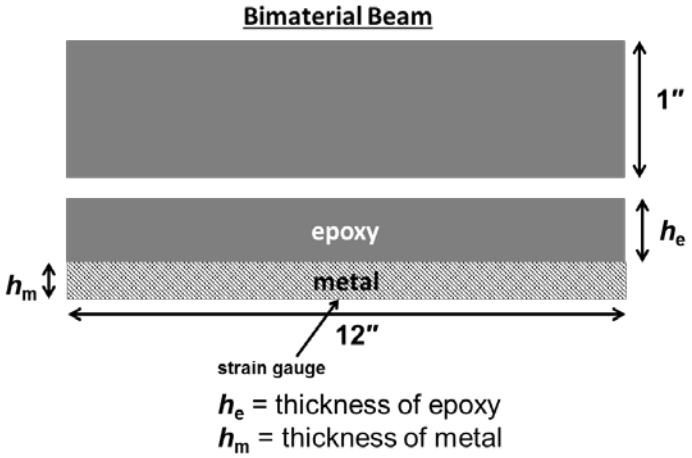


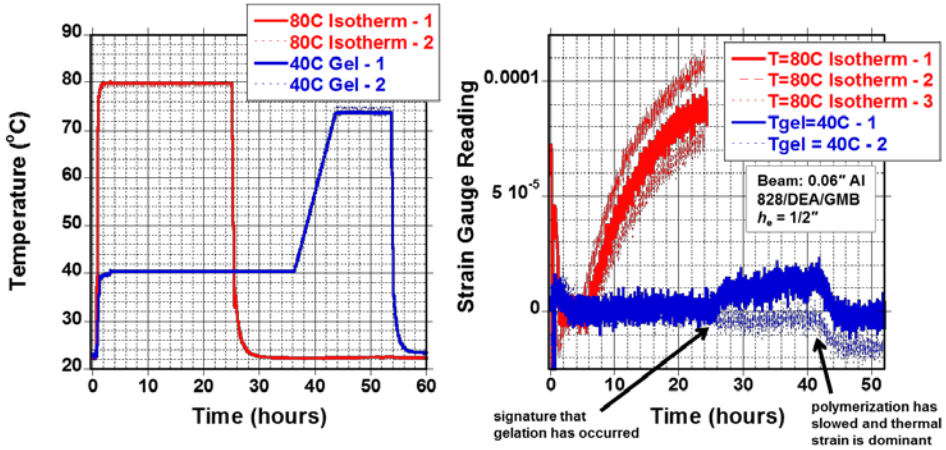


The difference between gel temperature (T_g) and final cure temperature (T_f) appears to be a primary factor in determining residual stress developed

Kropka et al., SAND2016-5543

Free-Surface Cure

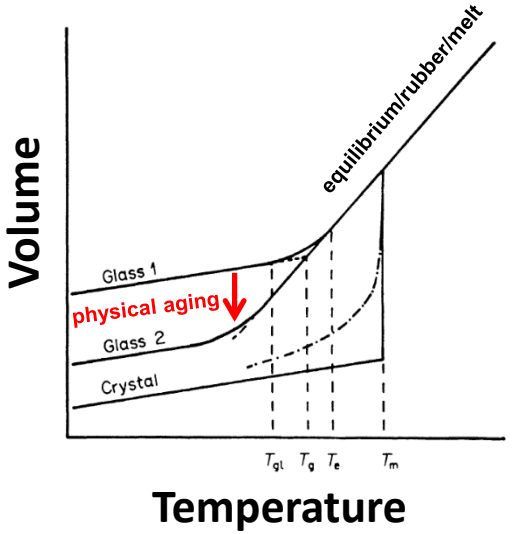




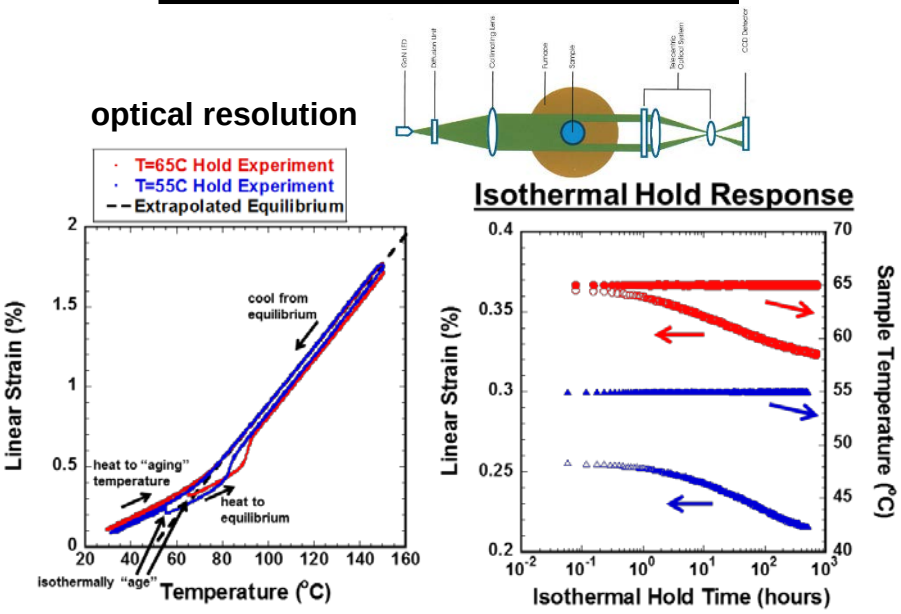
Stress developed during free-surface cure can be reduced by implementing a post-gelation temperature ramp, as observed in confined cure

Kropka et al., SANDTBD

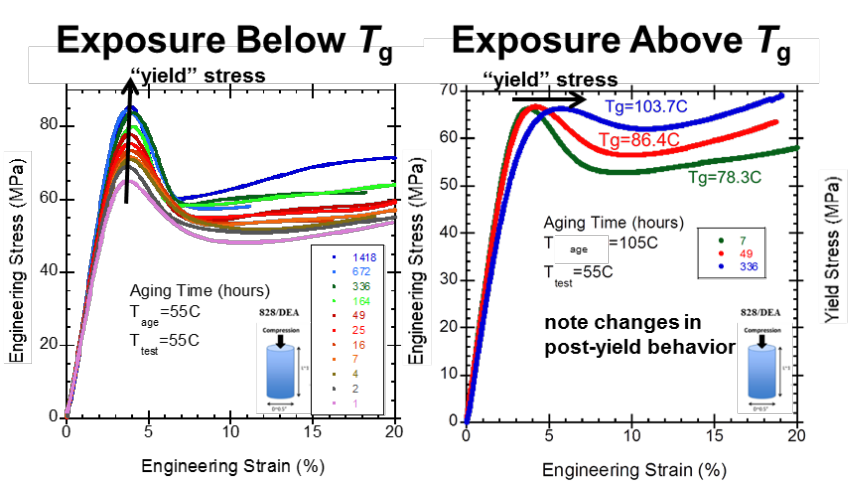
Polymer Glass Aging

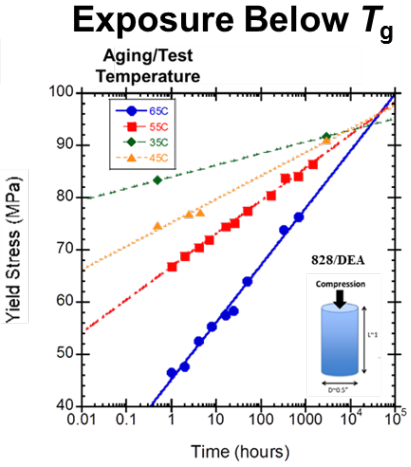


Material Volume Changes



Material Mechanical Response Changes





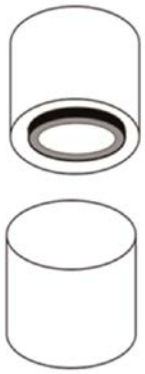
SNL NLVE polymer models (e.g., SPEC) have the framework to predict the aging behavior and are currently being tested against measurements

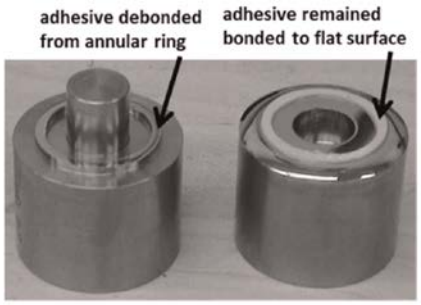
Clarkson, McCoy and Kropka, *Polymer*, 94 (2016) 19-30

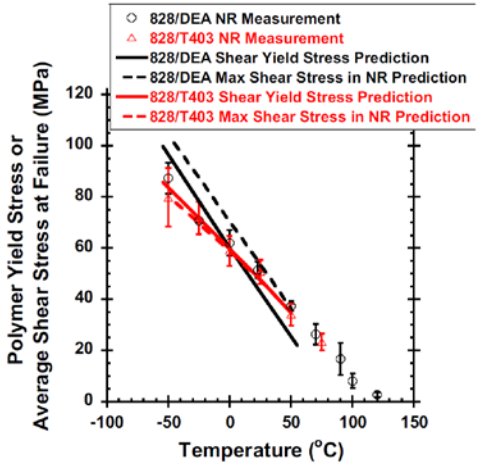
Arechederra et al., APS 2016

Polymer Failure: Adhesive Joints

Shear Loading: Napkin Ring

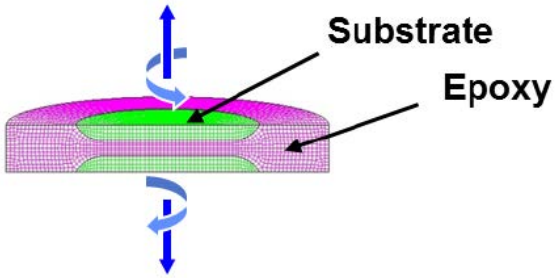






Kropka et al., *Int. J. Adhn. & Adhs*, 63 (2015) 14-25

Combined Shear and Tension/Compression Loading: Saucer



Test geometries to measure the initiation of adhesive failure at an "embedded interface"