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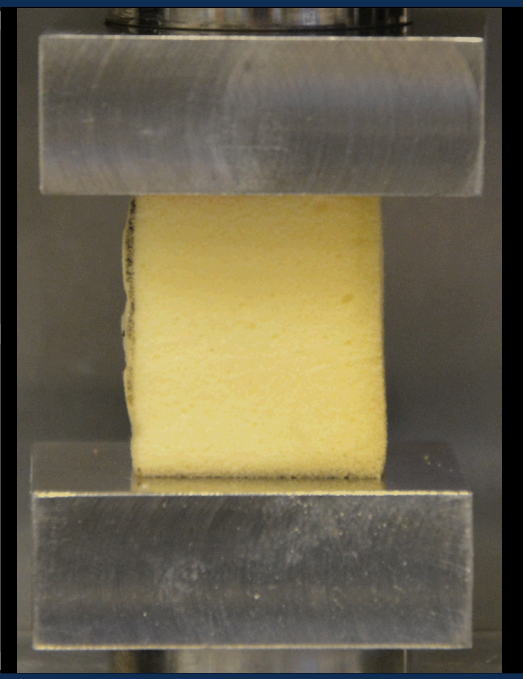

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# Quantifying the Effects of Aging on the Viscoelastic Behavior of Flexible Polyurethane Foams

Nicholas B. Wyatt[1], Nicholas H. Giron[1], Kevin N. Long[2], Mathias C. Celina[1], Matthew Neidigk[3]

[1]*Organic Materials Science Department*

[2]*Solid Mechanics Department*

[3]*Systems Engineering Division*

*Sandia National Laboratories, Albuquerque, NM 87185*

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# Overview

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Introduction

Aging Effects on Flexible Polyurethane Foam

Oxidation Rate Measurements

Looking Forward

A Word on Model Development

Summary

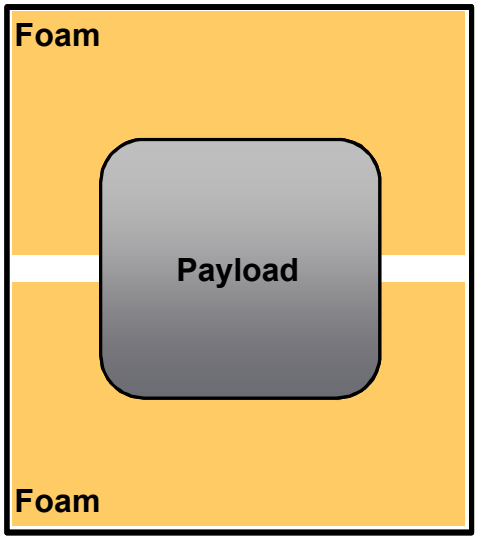
# Introduction

Flexible polyurethane foam is used in shipping containers throughout the DOE complex to isolate systems from external environments during handling and transportation

In an effort to expand Sandia's modeling and simulation capabilities of these materials, an extensive characterization effort was initiated

The historical approach to modeling these materials neglects the viscoelastic temperature and rate dependent response

In addition, foam stiffening has been identified in older parts, and may be the result of oxidative aging



# Foam Materials

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**TF-6070**

Open-cell flexible polyurethane foam

High density polyether polyurethane foam

Available in 8.5–15 lb/ft$^3$ densities

Designed for shock isolation

Absorb large amounts of energy

Excellent shock isolation

Minimum creep

GP GENERALPLASTICS MANUFACTURING COMPANY

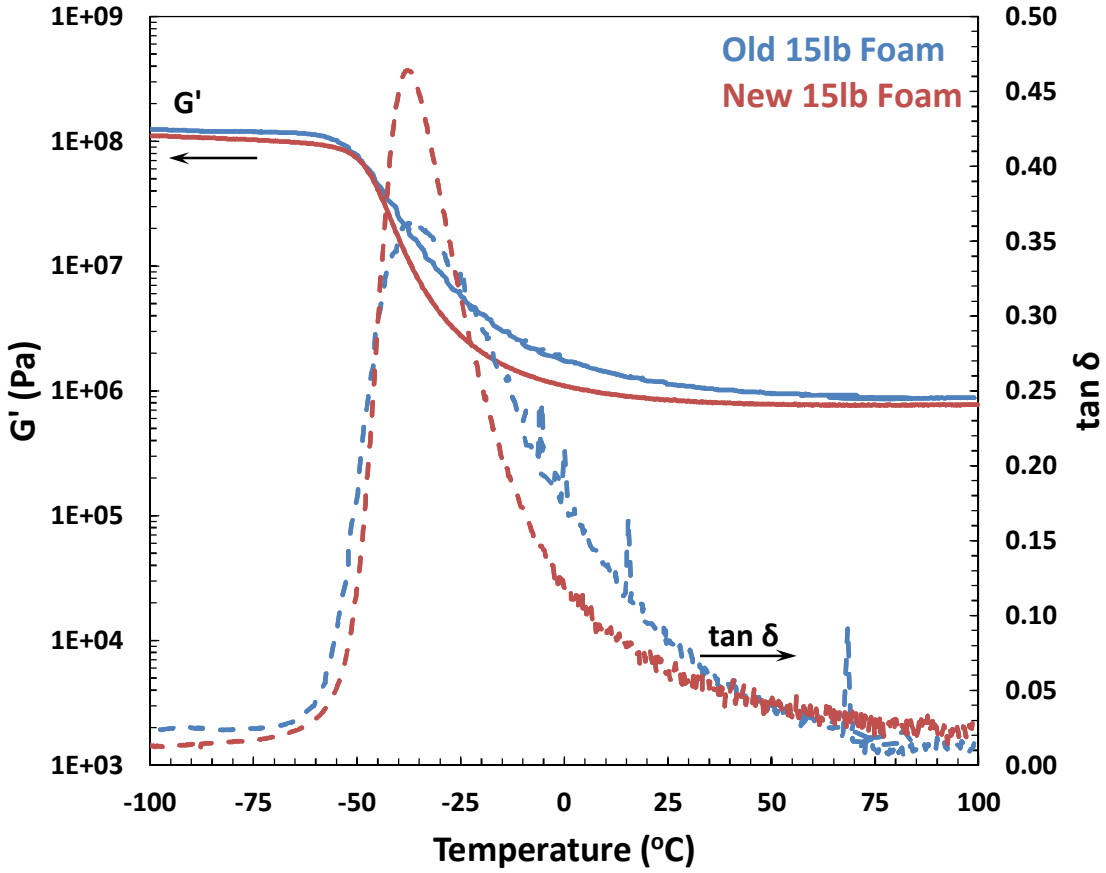
*www.generalplastics.com*

# Foam Modulus and $T_g$

Initial thermal-mechanical measurements showed differences in the response of new and aged foams

Glassy and rubbery shear modulus is 10-15% higher in the aged foam

Peak in tan δ (associated with glass transition) broader in aged foam



# Temperature Affects Modulus

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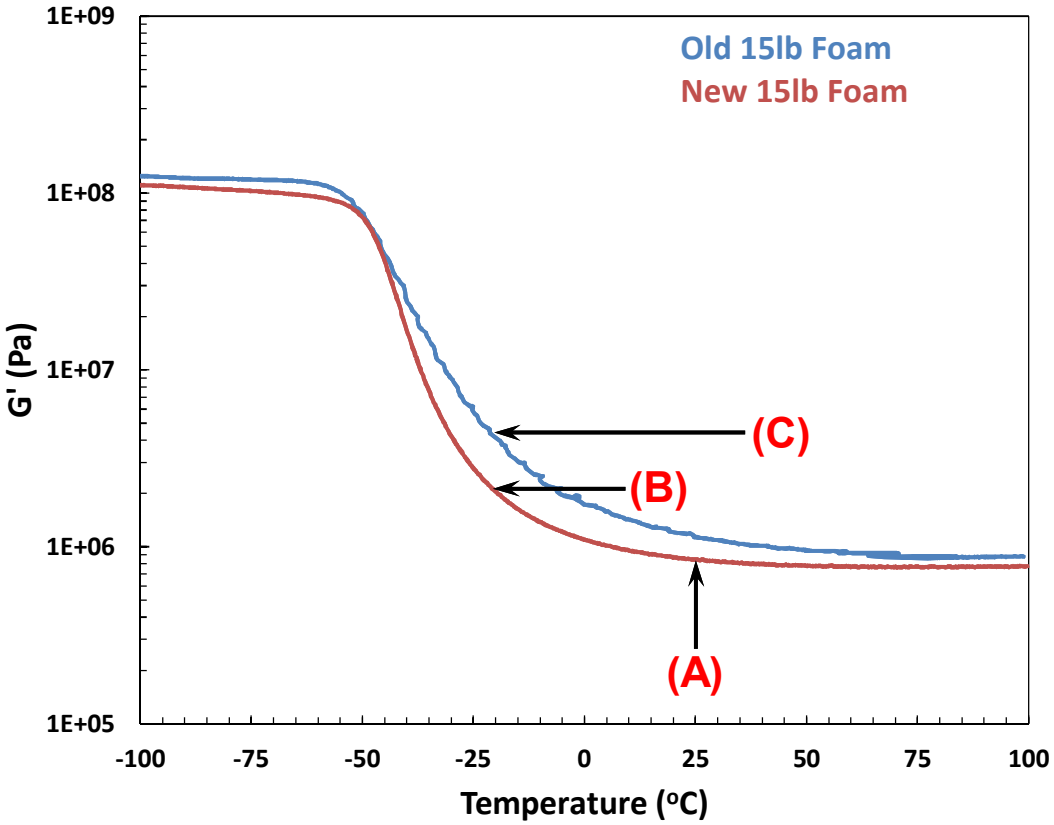
Significant changes to modulus (stiffness) appear to occur as the foam ages

Note how the shear modulus at -20°C (B) of the new foam is about 100% higher than at room temp (A)

For the aged foam at -20°C (C), shear modulus is about 400% higher than new foam at room temp (A)

Also, room temperature viscoelasticity appears to become more important as the foam ages

Changes in foam properties due to temperature and/or age must be accounted for in development of component specs

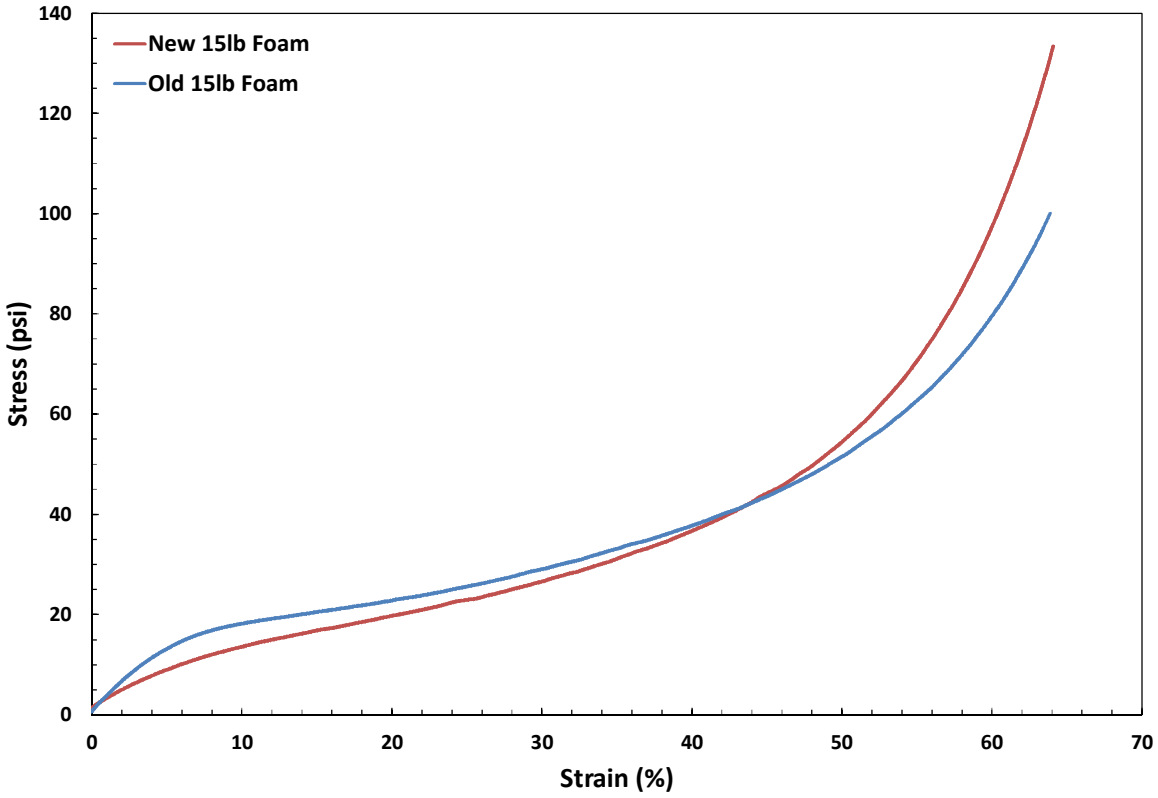


# Compression

Aged foam also shows an increased compressive modulus at low strains

At high strains (above 45%), new foam has a higher modulus at a given strain

Generally interested in the low strain regime



# Rate Dependence

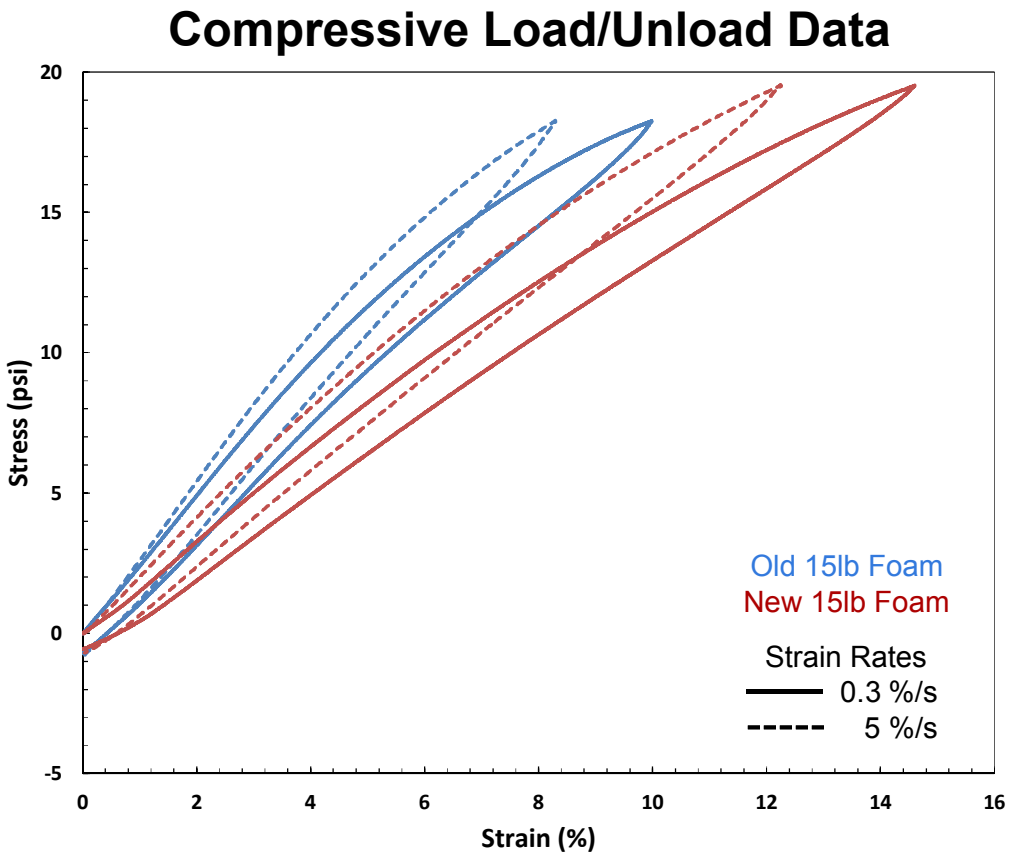
Since the foam is viscoelastic, there is a strong dependence of the response on the strain rate

Hysteresis observed in load/unload curves due to relaxation

Higher strain rates produce higher modulus (higher stress at a given strain value)

Trend is similar between new and aged foams

Modulus of aged foams is higher at all strain rates tested



# Oxidation Behavior

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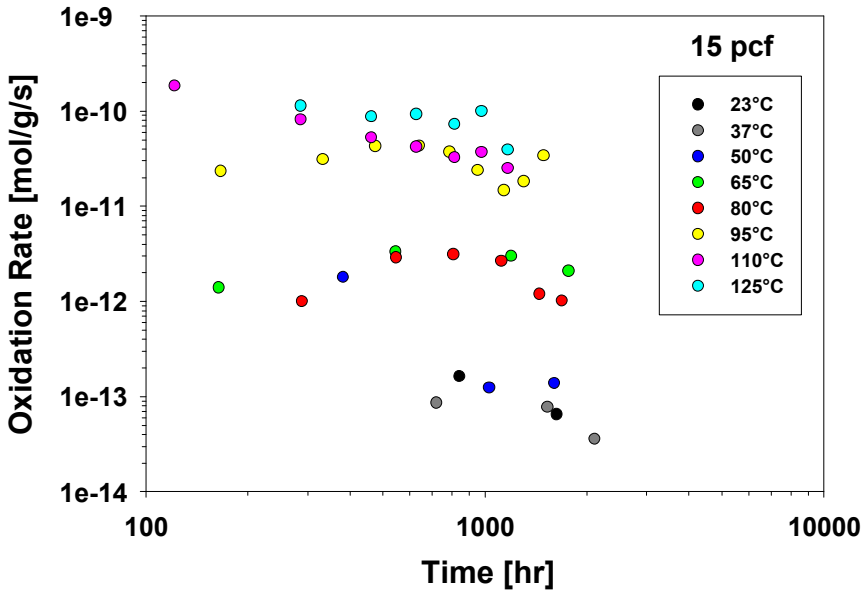
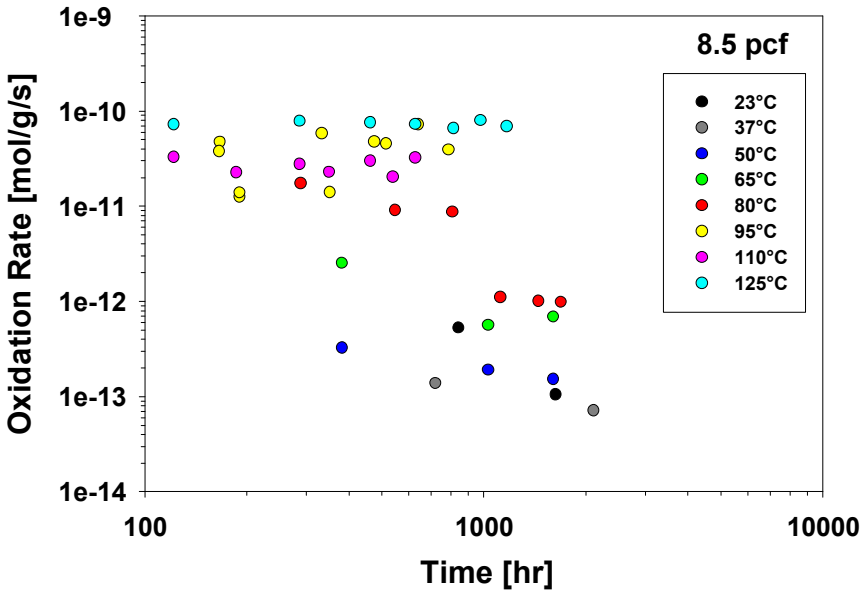
Preliminary oxidation rate data (oxygen consumption measurements) are shown for two polyurethane foam densities (8.5 and 15 lb/ft$^3$) between room temperature and 125$^o$C

While the data show a relatively high level of scatter, average oxidation rates are within range of rates measured previously for a similar foam

Foam density does not appear to significantly affect oxidation sensitivity

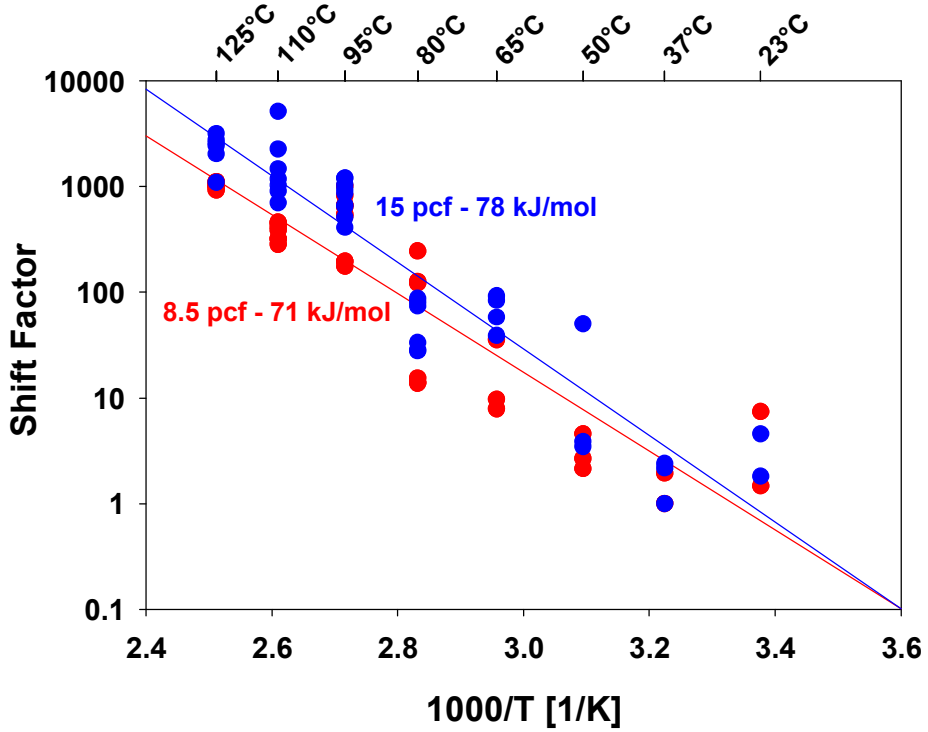


# Oxidation Behavior

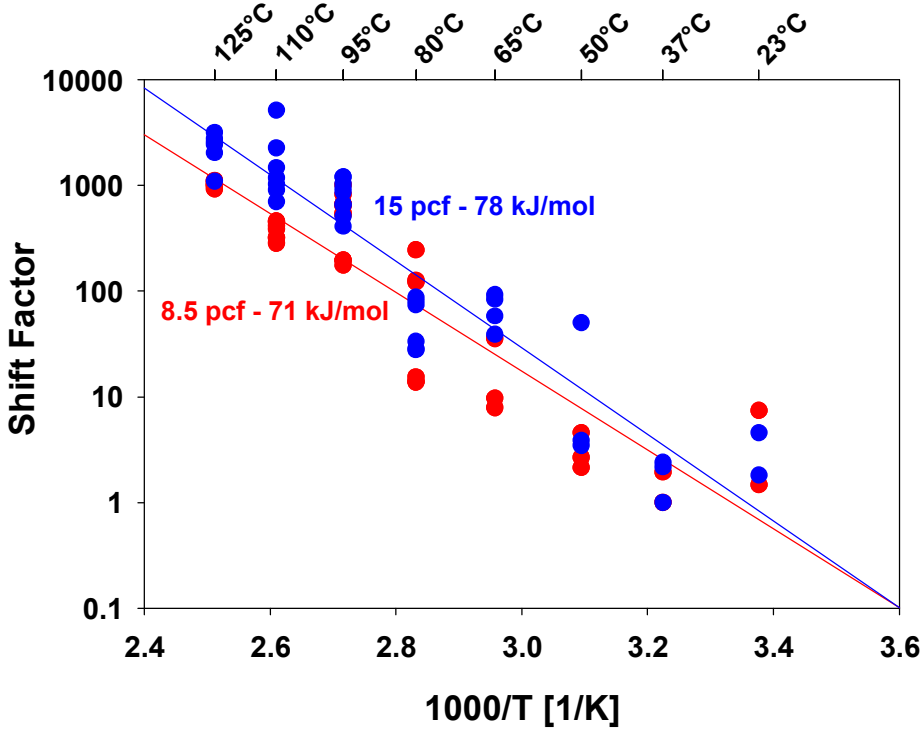
Preliminary activation energies were computed from oxidation rates measured between room temperature and 125°C

Despite scatter, relative oxidation rate behavior appears to be generally linear with some possible deviation from Arrhenius behavior at low temperature




Oxidation rates can be used to predict oxidation levels with time at lower temperatures

# Moving Forward




- Ultimate goal is to correlate changes in mechanical properties with degree of oxidation (age)
- Further refine the oxidation rate measurements and predictions
- Use those rates and predictions to age samples to a known oxidation state
- Perform mechanical measurements to obtain the correlation between age and mechanical property changes

# A Word on Modeling

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Desire to have a model that can more accurately account for viscoelasticity in material behavior

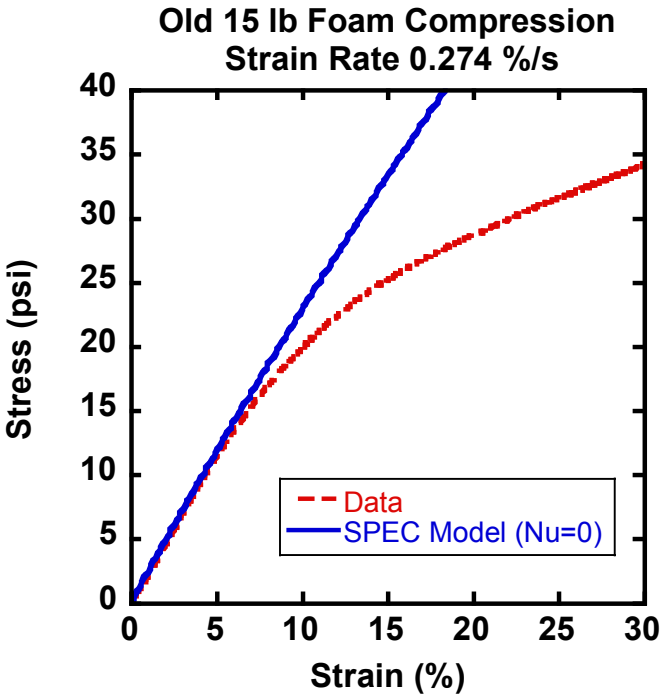
Simplified Potential Energy Clock (SPEC) model was originally developed for glassy thermoset materials and has not been previously applied to a flexible foam material

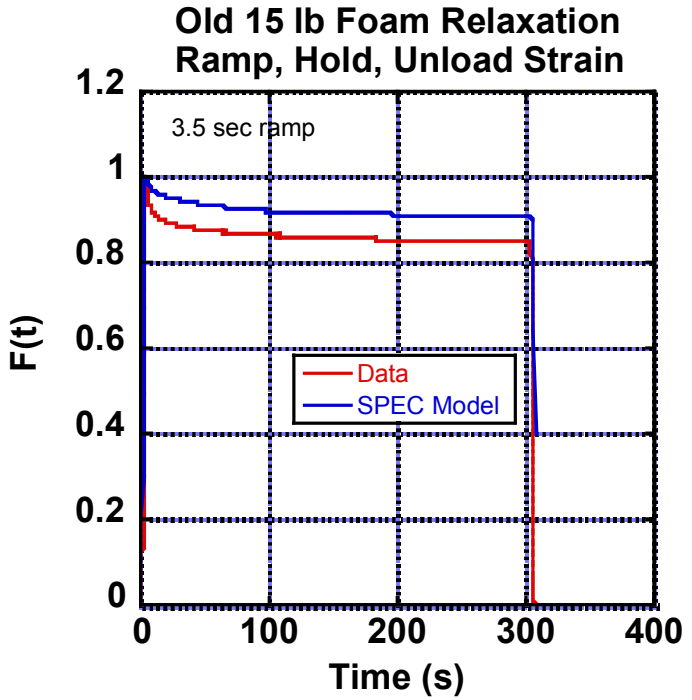
Model is parameterized from a series of thermal-mechanical measurements on the material

Once parameterized, the model can be used to calculate/predict stresses and other polymer behaviors

Preliminary work done by Bob Chambers (SNL – retired), continues under Kevin Long (SNL)

# SPEC Model Performance




Initial slope prediction is very good (strain < 9%)

Model does not accurately predict the correct “softening” of the foam (viscoelasticity? Structural effects?)

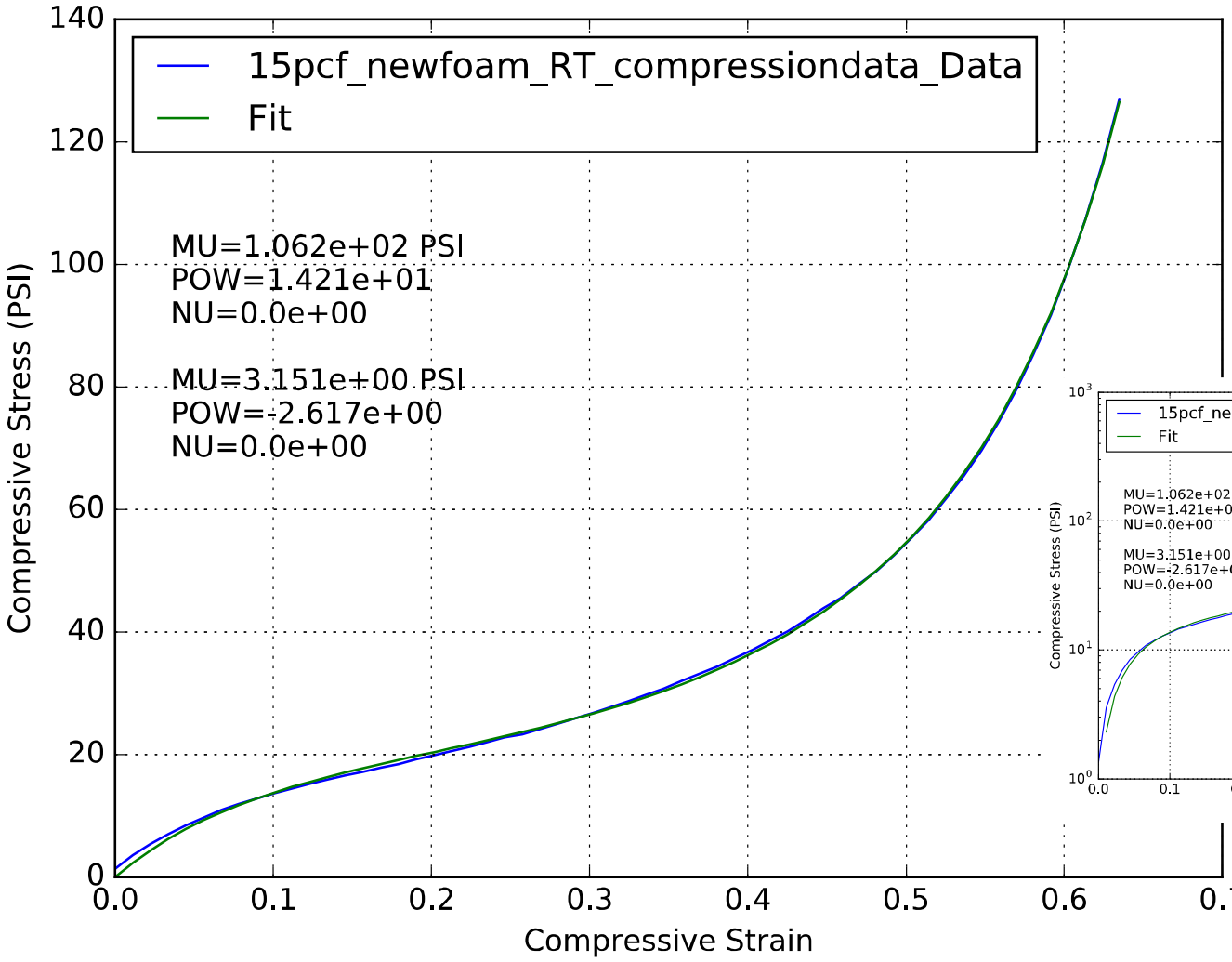
Model does not capture enough relaxation

Hysteretic load/unload curves also show model underpredicts the dissipation (time dependence) observed

# HYPERFOAM Model

Non-linear elastic model for T>Tg and targeted temperatures and strain rates

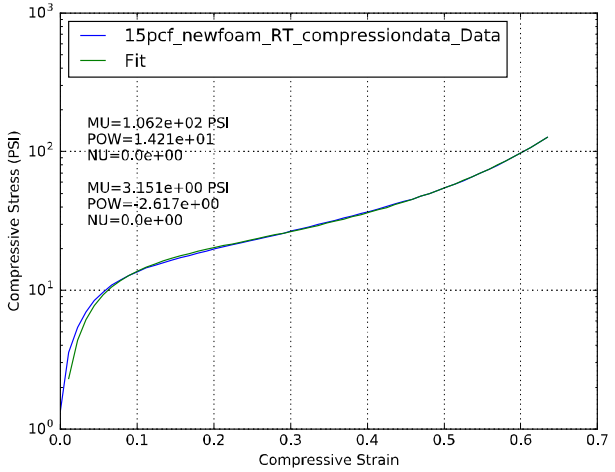
More limited utility than SPEC model (potentially)




Room temperature

Poisson Ratio = 0.0

(Uniaxial Strain)



# Summary

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Flexible polyurethane foams are highly viscoelastic

Age tends to increase the modulus (stiffness) of the foam

Age and temperature induced stiffening should not be neglected in analyzing use conditions

Preliminary and ongoing oxidation rate measurements should allow future correlation of mechanical property changes to known age state

Initial work at parameterizing SPEC model to accurately model polyurethane foams is promising

- Good predictions for strain < 9%
- Does not yet capture the correct softening of the foam at higher strains
- Under predicts relaxation effects

Parameterized HYPERFOAM is promising, but limited in utility to specific conditions and situations