ELASTOMER RATE-DEPENDENCE: A TESTING AND MATERIAL MODELING METHODOLOGY

Tod Dalrymple and Jaehwan Choi
DASSAULT SYSTÈMES SIMULIA CORP.
Great Lakes Region
Northville, Michigan
and
Kurt Miller
Axel Products Inc.
Ann Arbor, Michigan

Presented at the Fall 172nd Technical Meeting of the
Rubber Division of the American Chemical Society, Inc.

Overview

- **Motivation and Background**
- **Testing Comments**
- **Stress-relaxation Testing**
- **Prony Series Viscoelasticity**
- **Family of Constant Strain-Rate Testing**
- **Summary and Conclusions**

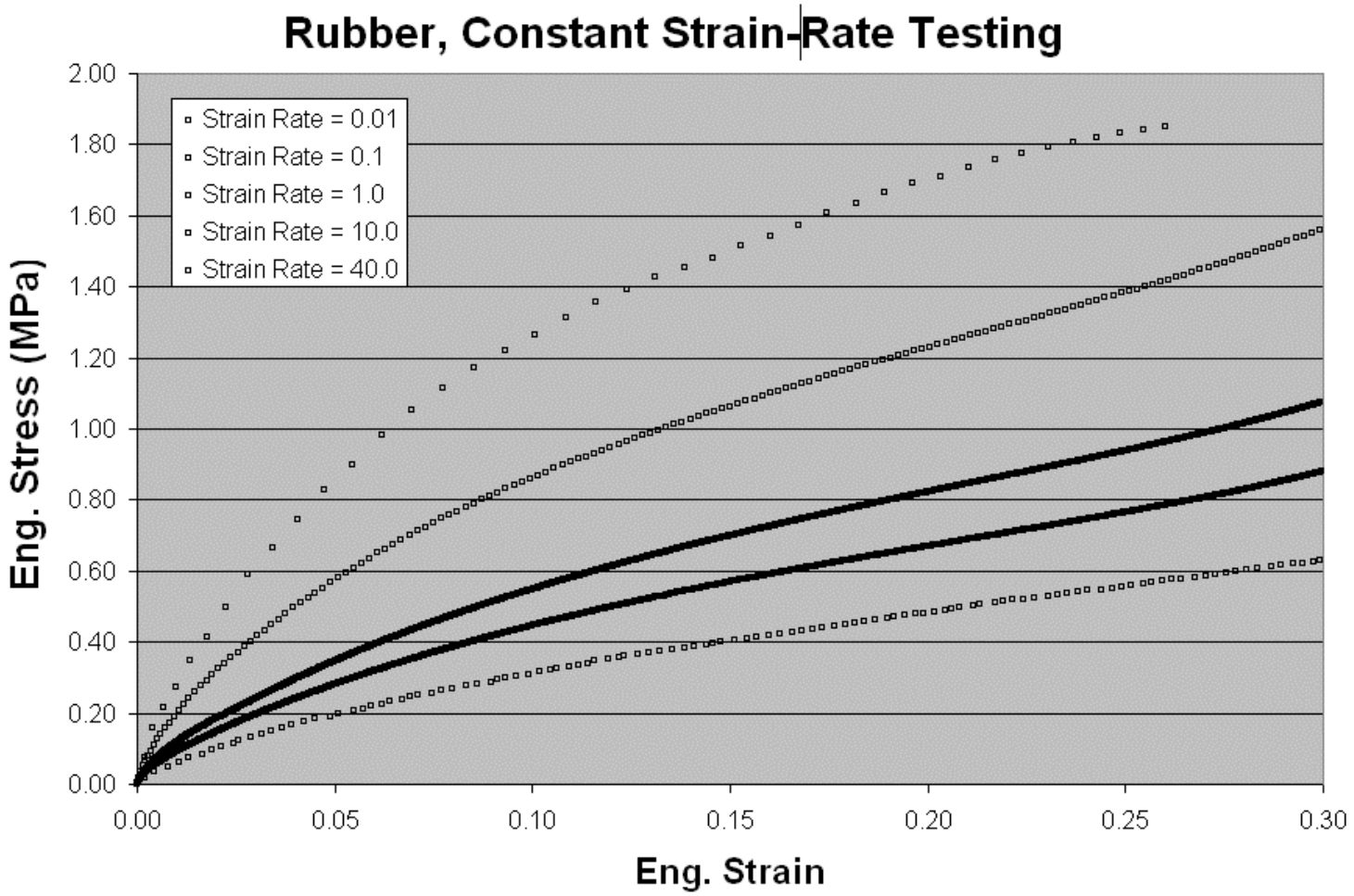
Motivation and Background

- **Time-dependence of Elastomers**
- **Stress Relaxation curve fitting exits in Abaqus/CAE for Prony series viscoelastic material definition**
- **Well defined recipe**
- **Relatively common for sealing applications (long time)**

- **New application for time domain dynamic impact events**
- **Desire to capture rate-dependence of stress-strain curves**
- **Typical test data is often a family of constant strain-rate stress-strain curves**

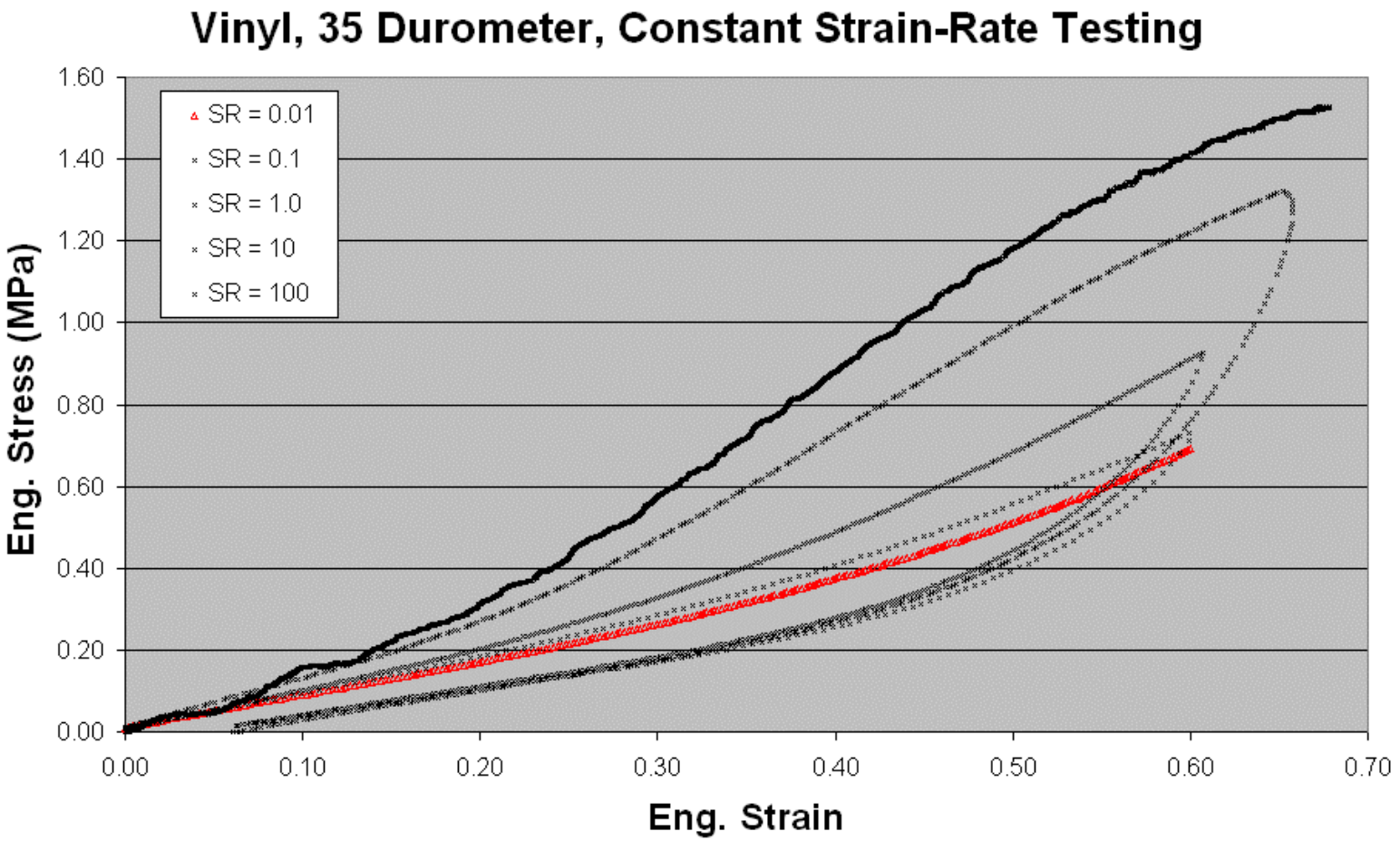
Motivation and Background

- **Typical test data for understanding rate-dependence**



Motivation and Background

- **Another example of typical test data**



Motivation and Background

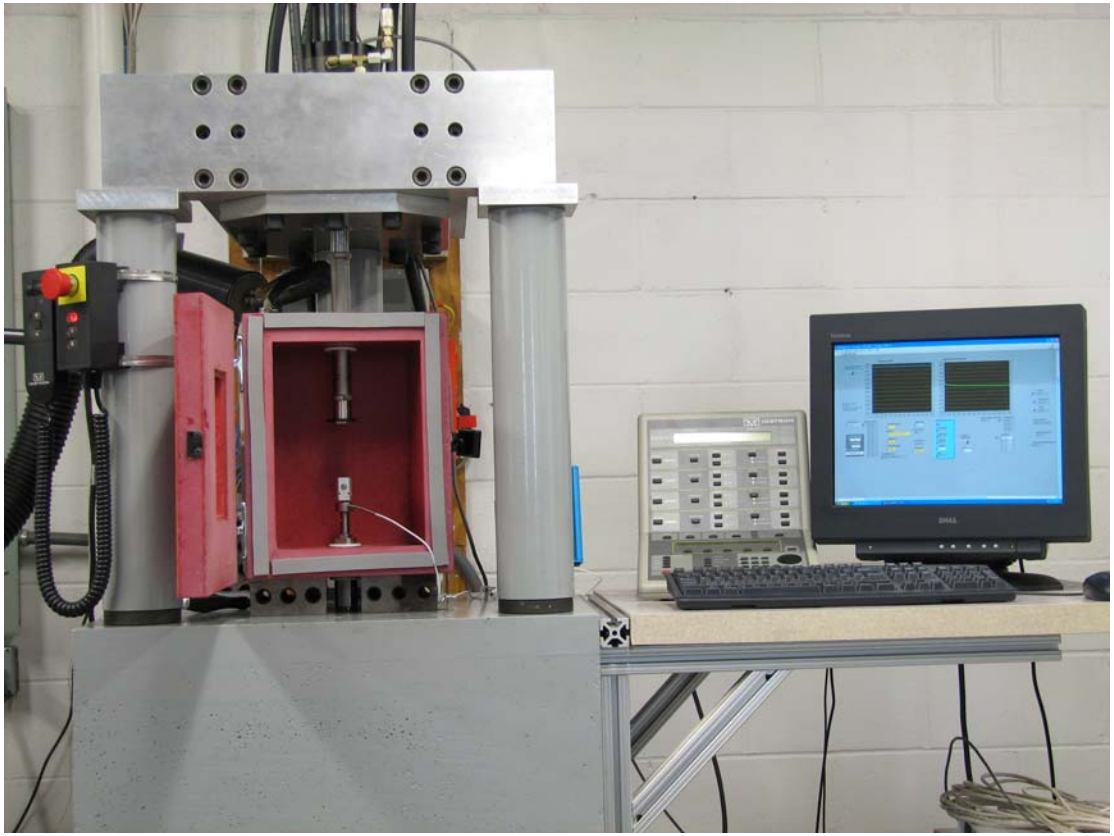
- **No curve fitting in Abaqus for this type of test data**
- **Testing itself can be more complicated than stress-relaxation testing**

- **Can we use stress-relaxation testing instead?**
- **Can we use existing curve fitting to Prony series material model?**
- **Will we capture the rate-dependence of the loading curves?**
- **Will we capture the hysteresis loops in the load / unload cycle?**

- **Focus on stress-relaxation testing at short times (milliseconds)**
- **All specimens pre-conditioned to remove Mullins effect**
- **All testing at room temperature**

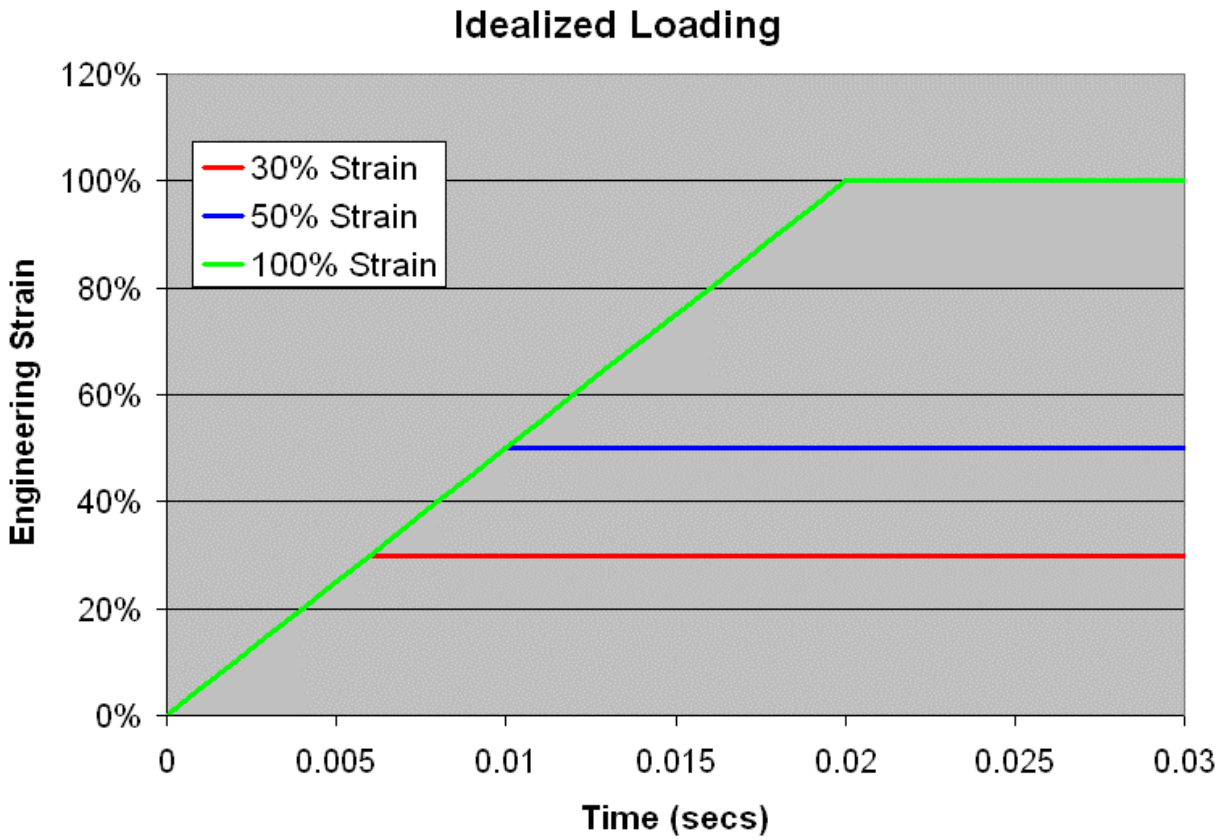
Testing Comments

- **All testing performed at Axel Products**
- **Instron Model 8800 Series servo-hydraulic test instrument**
- **Crosshead mounted 10 kN low mass high fidelity actuator**



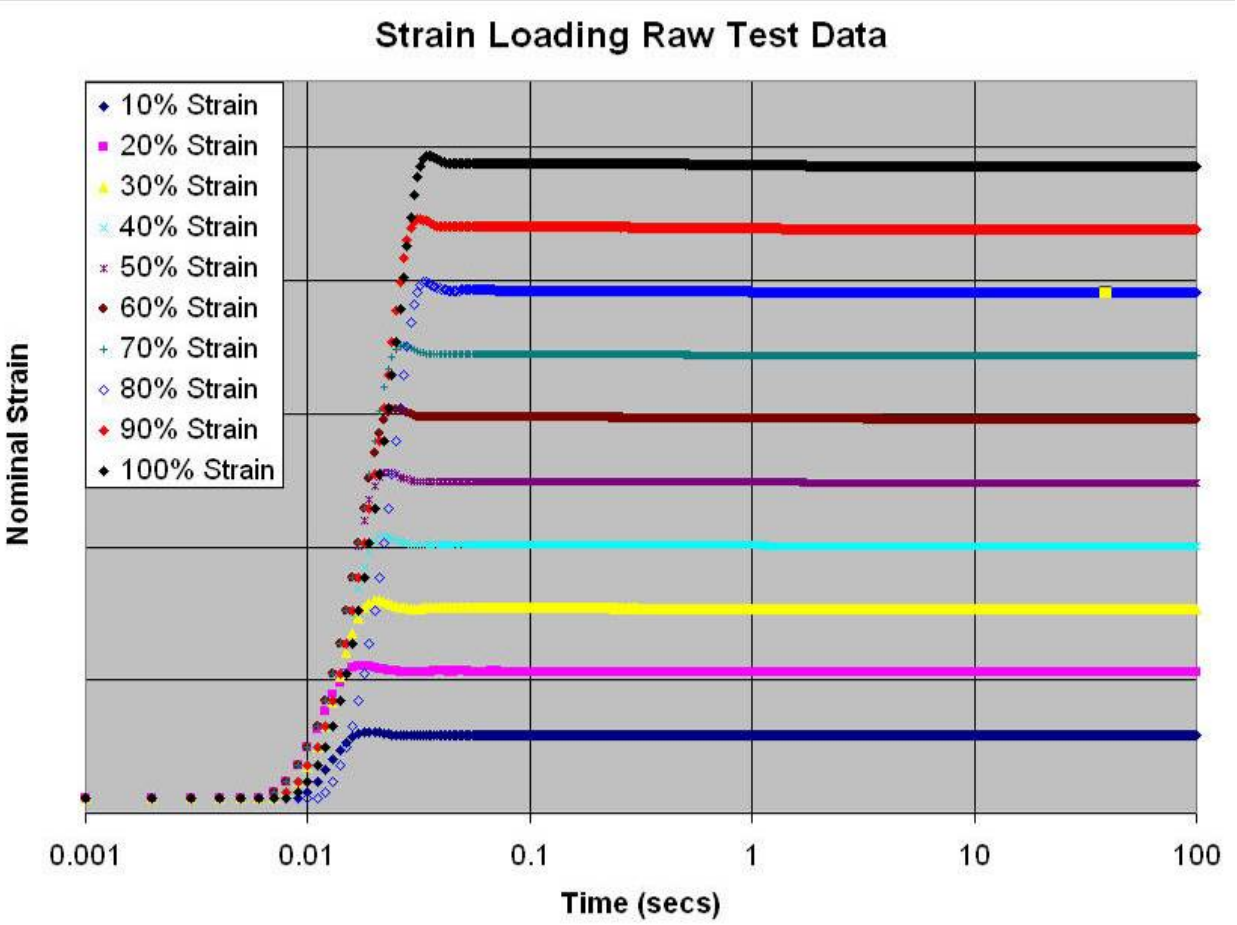
Stress Relaxation Testing

- **Be consistent about time-frame of interest**
- **Try to achieve loading of stress-relaxation test at 50 /sec**
- **Test data taken every 1 millisecond**



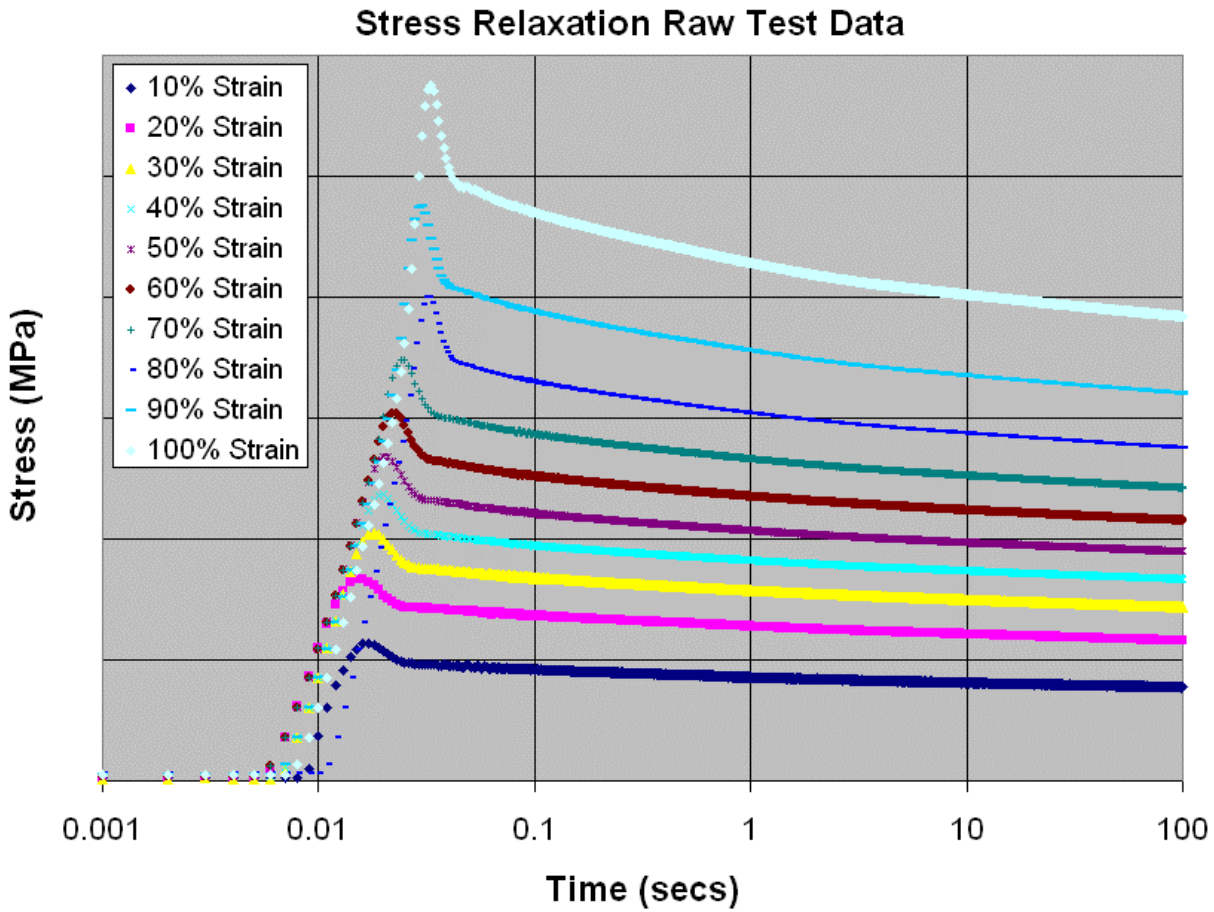
Stress Relaxation Testing

- **Some actual strain-time test data - inertia effects present**



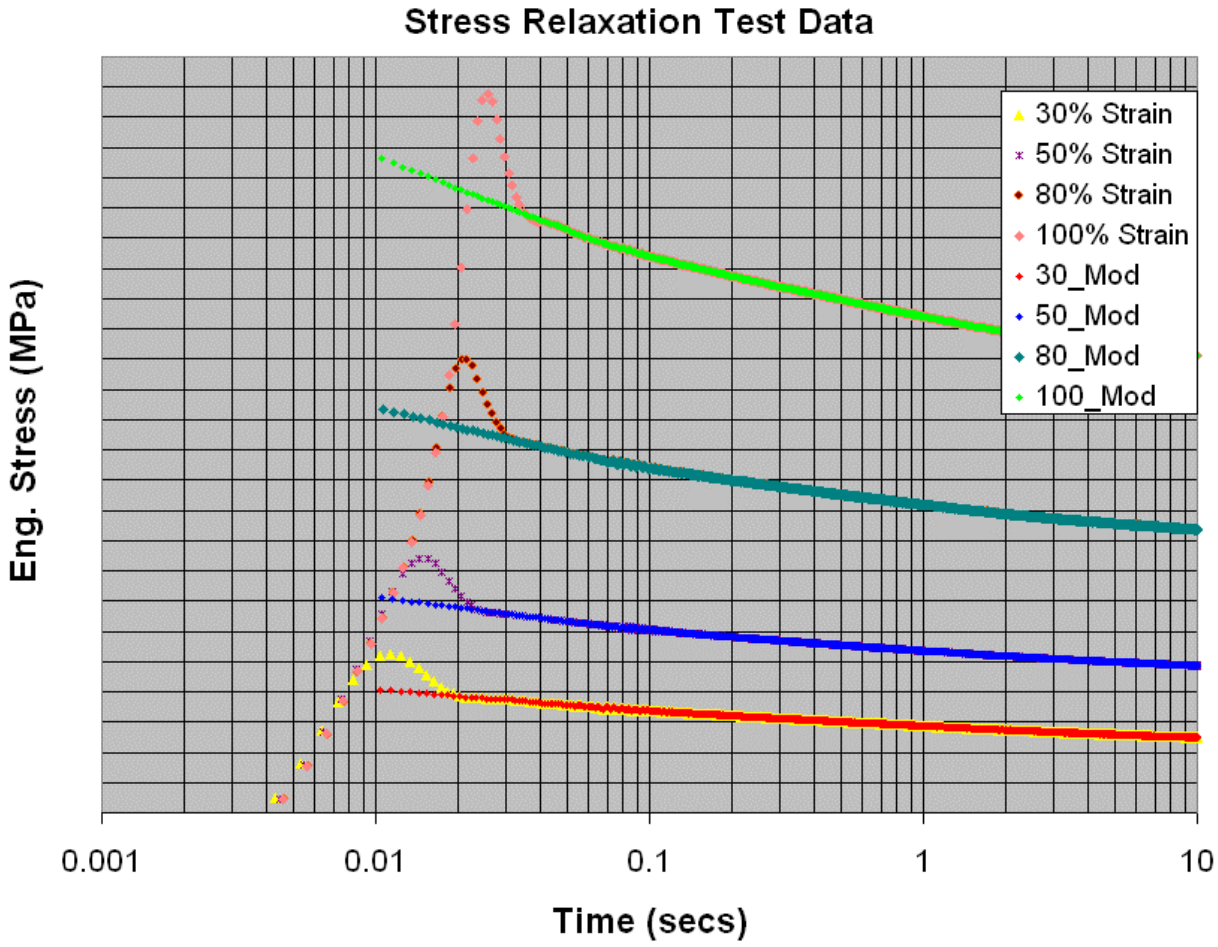
Stress Relaxation Testing

- **Corresponding Stress-time responses**



Stress Relaxation Testing

- **Data processed to align start and remove overshoot**



Prony Series Viscoelasticity

- **In ABAQUS the** time-dependent **behavior** $G(\tau)$ and $K(\tau)$ **can be represented in terms of a** Prony series**:**

$$G(\tau) = G_0\left(1 - \sum_{i=1}^{N} \bar{g}_i^p \left(1 - e^{-\tau/\tau_i^G}\right)\right)$$

material coefficients are

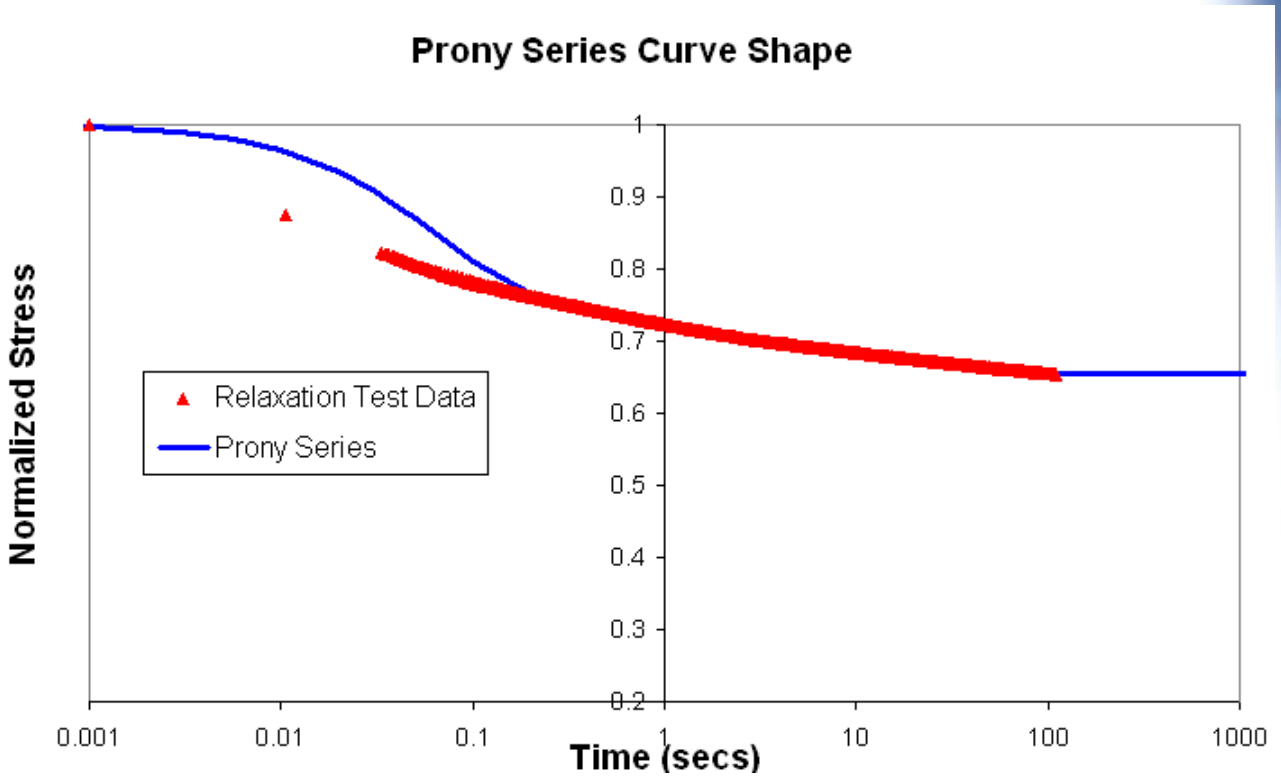
up to N *pairs of* $\bar{g}_i^p$ *and* τ_i^G

- G_0 **and** K_0 **are determined from the elasticity definition.**
- **These are simply a sum of a series of exponential decays.**
- **For many solid elastomers, the relaxation behavior is dominated by shear relaxation. In these cases it is not necessary to specify** $K(\tau)$.
- **Rule of thumb is to have as many Prony terms as decades of time data.**

Prony Series Viscoelasticity

- **It is useful to understand the Prony Series curve shape**
- **For this we use a Excel-based ”what-if” tool**

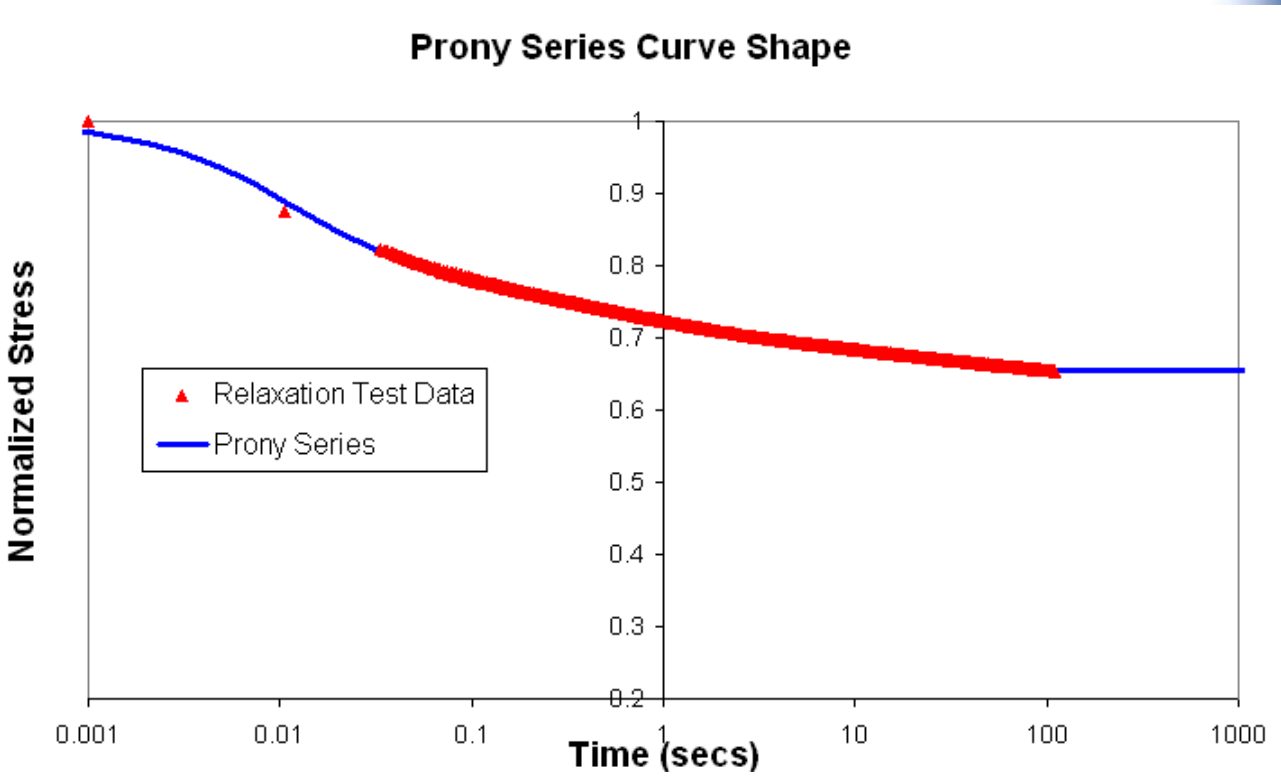
G_1	1.52E-01	Tau_1	0.06
G_2	7.26E-02	Tau_2	0.06
G_3	5.19E-02	Tau_3	0.54
G_4	3.70E-02	Tau_4	3.34
G_5	3.31E-02	Tau_5	37.80



Prony Series Viscoelasticity

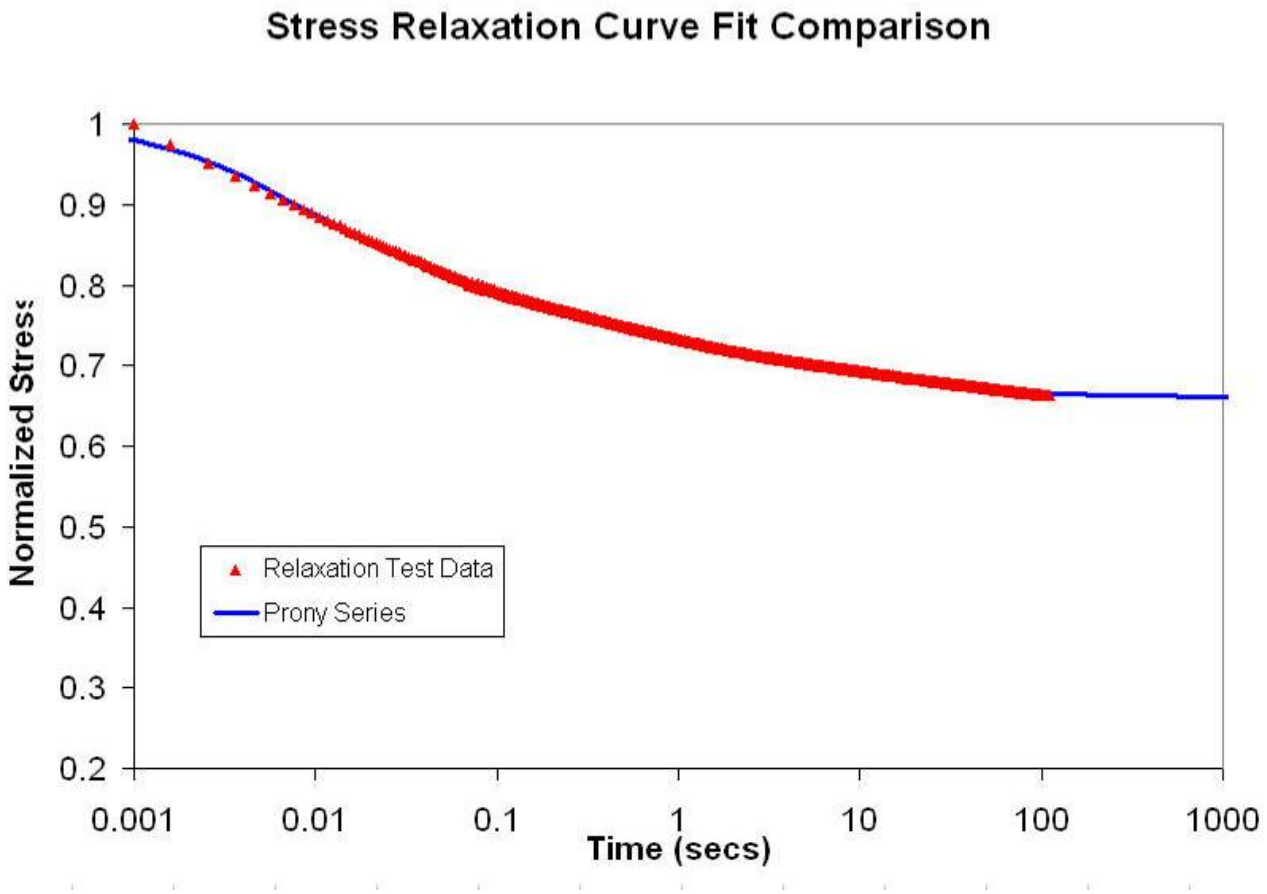
- **Shape of the curve is improved with some very early time tau**
- **Prony series improved with early time test data**

G_1	1.52E-01	Tau_1	0.01
G_2	7.26E-02	Tau_2	0.06
G_3	5.19E-02	Tau_3	0.54
G_4	3.70E-02	Tau_4	3.34
G_5	3.31E-02	Tau_5	37.80



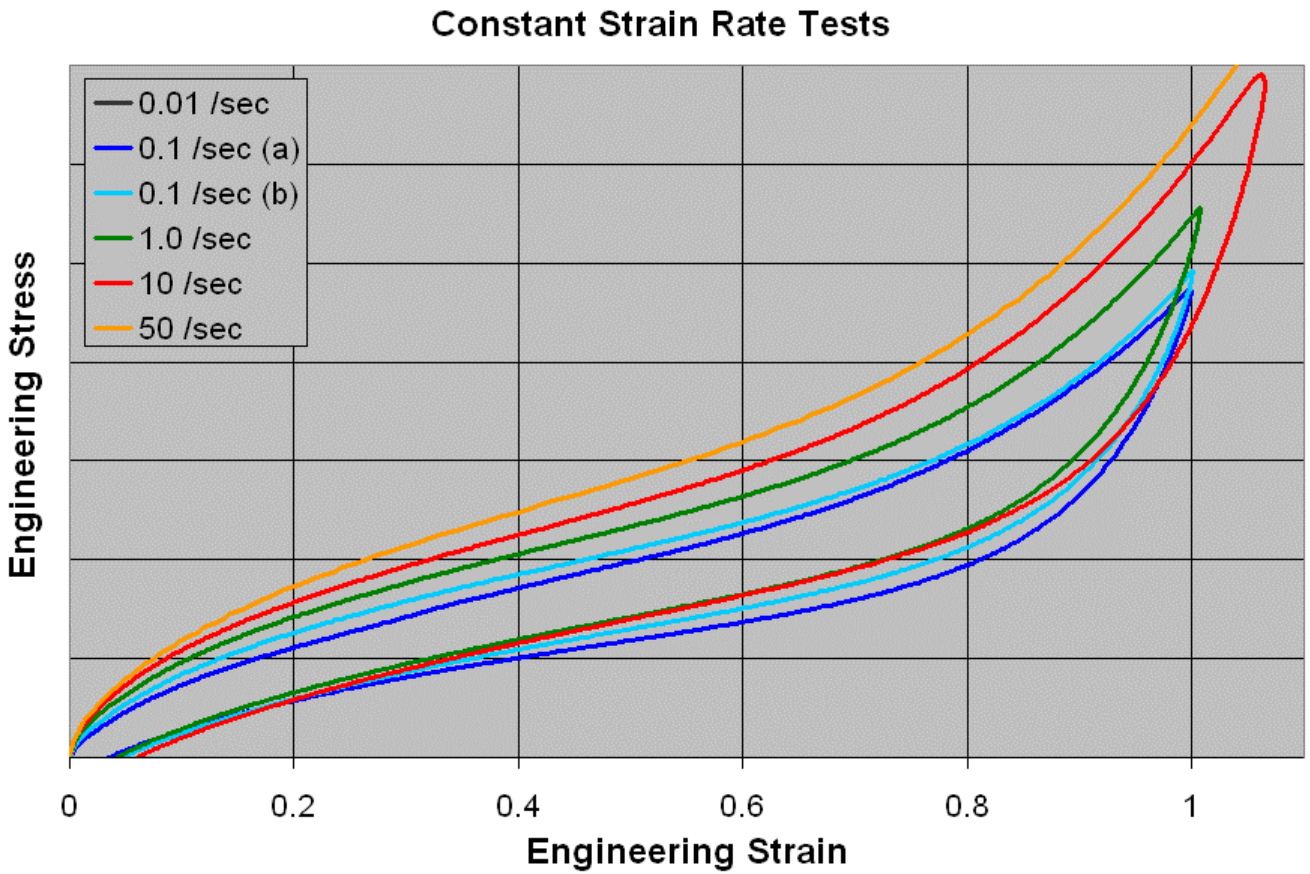
Prony Series Viscoelasticity

- **Resulting Prony Series curve fit to the stress-relxaation test data**



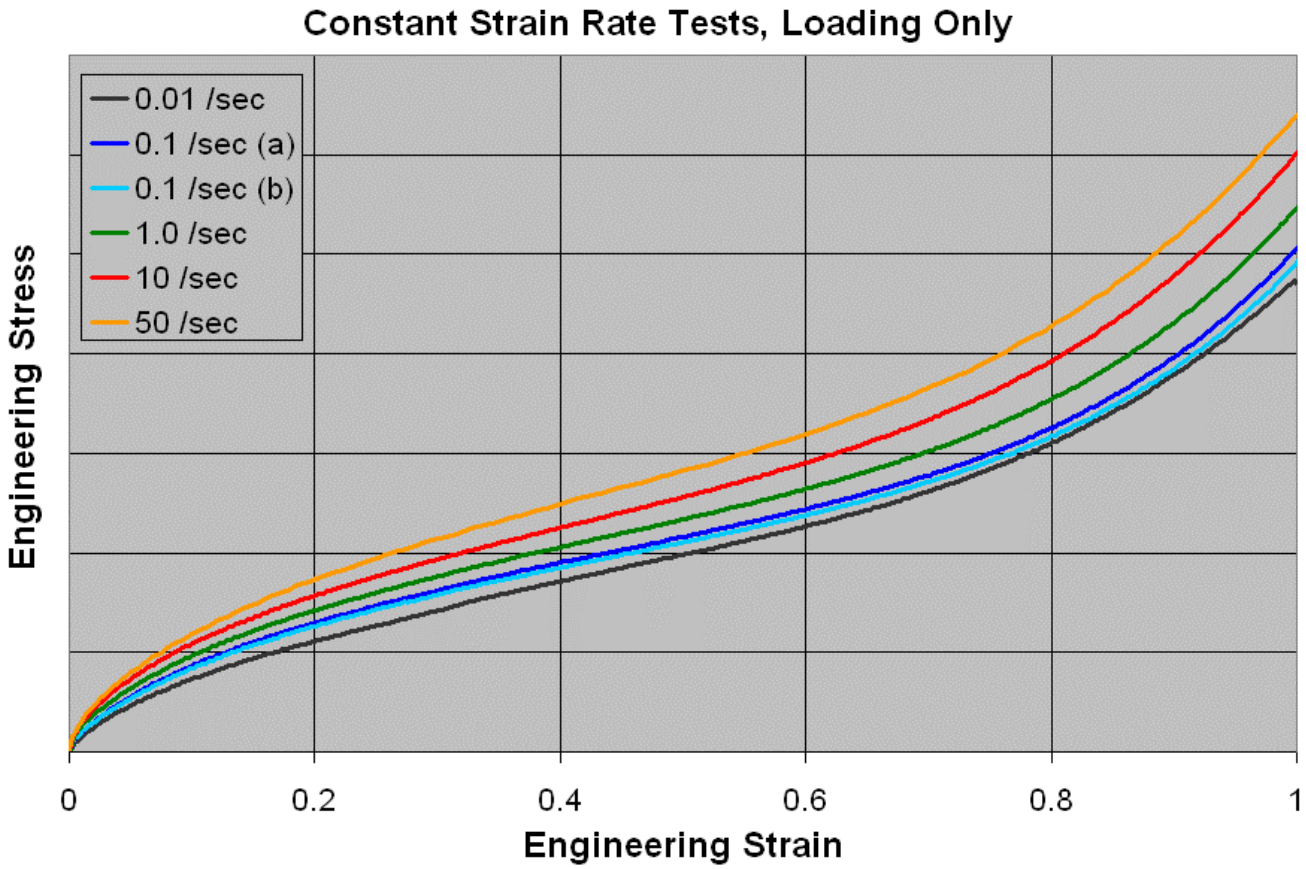
Family of Constant Strain-Rate Data

- **Test Result from load / unload cycle**



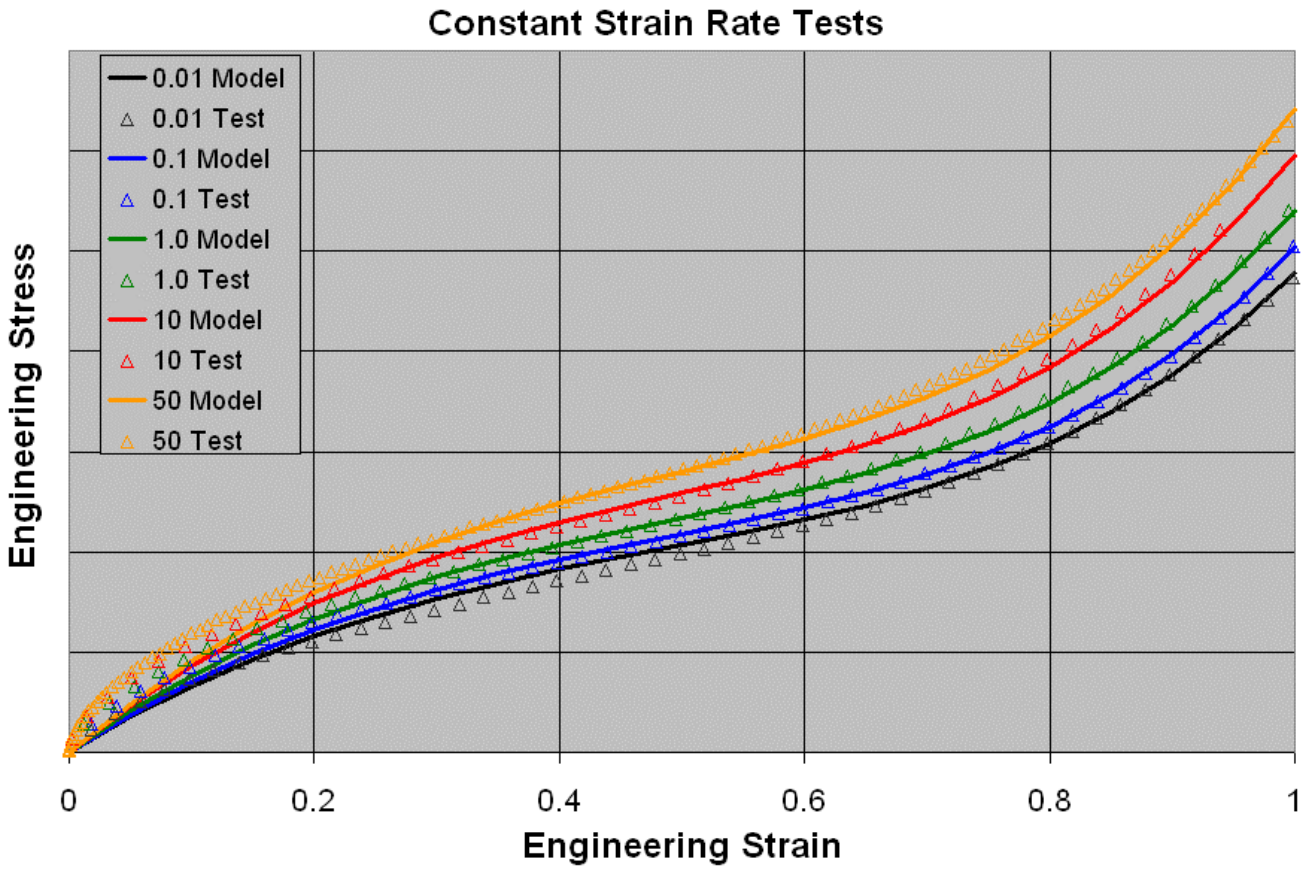
Family of Constant Strain-Rate Data

- **Focus on just the load curves**



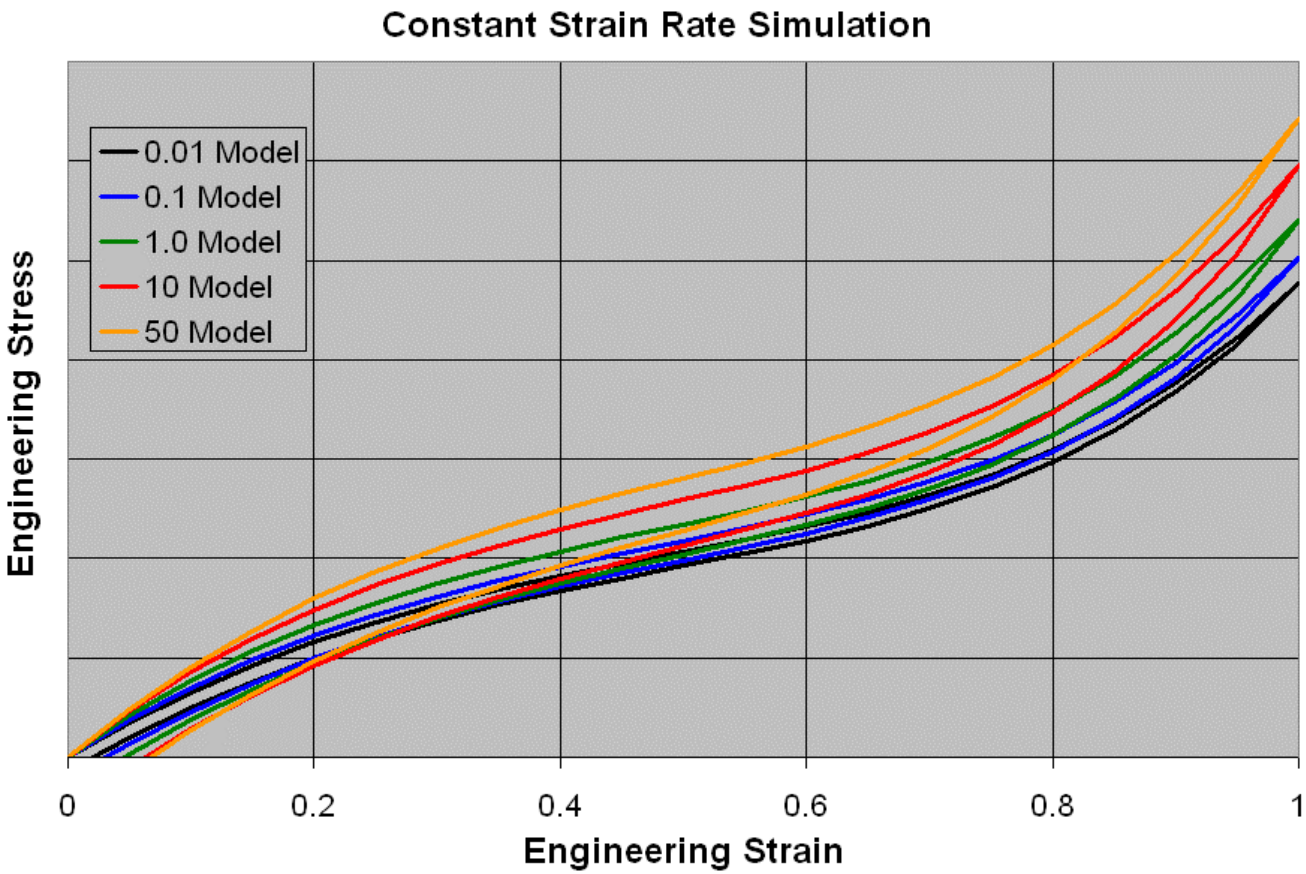
Family of Constant Strain-Rate Data

- **Comparison of Prony series material model to test data**



Family of Constant Strain-Rate Data

- **How about the load / unload hysteresis loop?**



Summary / Conclusions

- **Stress-relaxation tests were performed at short times**
- **Curve fitting in Abaqus/CAE used to calibrate Prony series viscoelasticity**
- **The material model correlated very well with the test data**

- **Family of constant strain-rate test data also performed**
- **Test data not used for calibration**
- **Prony series material mode represents load curves very well**
- **Prony series does a poor job representing the hysteresis loop**

ELASTOMER RATE-DEPENDENCE: A TESTING AND MATERIAL MODELING METHODOLOGY

Tod Dalrymple and Jaehwan Choi
DASSAULT SYSTÈMES SIMULIA CORP.
Great Lakes Region
Northville, Michigan
and
Kurt Miller
Axel Products Inc.
Ann Arbor, Michigan

Presented at the Fall 172nd Technical Meeting of the
Rubber Division of the American Chemical Society, Inc.