# Experimental Data (continued)

*Unsteady shear flow*

•Small strain - SAOS, step strain

*linear polymers, material effects, temperature effects*

•Large strain - start-up, cessation, creep, large-amplitude step strain

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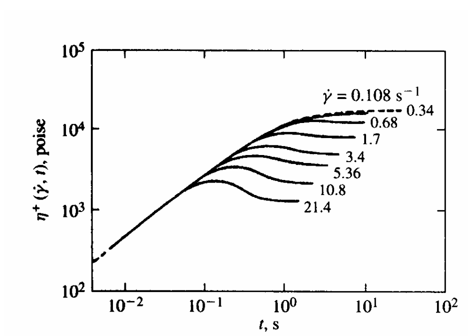
***lastly . ..***

*Steady elongation*
*Unsteady elongation*

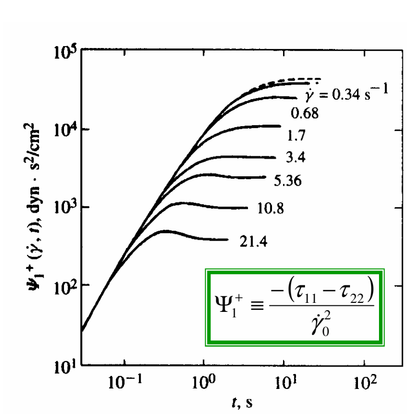


## Startup of Steady Shearing

$$\underline{v} \equiv \begin{pmatrix} \dot{\varsigma}(t)x_2 \\ 0 \\ 0 \end{pmatrix}_{123} \qquad \dot{\varsigma}(t) = \begin{cases} 0 & t < 0 \\ \dot{\gamma}_0 & t \geq 0 \end{cases}$$




$$\eta^+ \equiv \frac{-\tau_{21}(t)}{\dot{\gamma}_0}$$

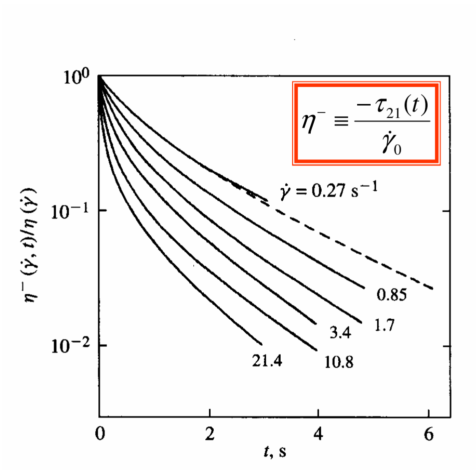



$$\Psi_1^+ \equiv \frac{-(\tau_{11} - \tau_{22})}{\dot{\gamma}_0^2}$$

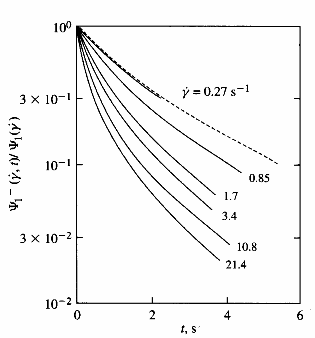
*Figures 6.49, 6.50, p. 208*
*Menezes and Graessley, PB soln*

## Cessation of Steady Shearing

$$\underline{v} \equiv \begin{pmatrix} \dot{\varsigma}(t) x_2 \\ 0 \\ 0 \end{pmatrix}_{123} \qquad \dot{\varsigma}(t) = \begin{cases} \dot{\gamma}_0 & t < 0 \\ 0 & t \geq 0 \end{cases}$$




$$\eta^- \equiv \frac{-\tau_{21}(t)}{\dot{\gamma}_0}$$




$$\Psi_1^- \equiv \frac{-(\tau_{11} - \tau_{22})}{\dot{\gamma}_0^2}$$

*Figures 6.51, 6.52, p. 209 Menezes and Graessley, PB soln*

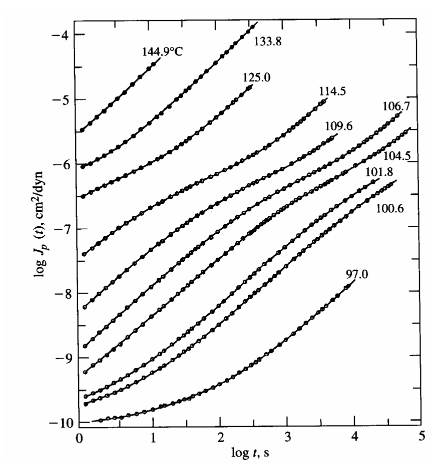


## Shear Creep

$$\underline{v} \equiv \begin{pmatrix} \dot{\gamma}_{21}(t) x_2 \\ 0 \\ 0 \end{pmatrix}_{123} \qquad \tau_{21}(t) = \begin{cases} 0 & t < 0 \\ \tau_0 & t \geq 0 \end{cases}$$

$$J_p = \frac{J(T) T \rho}{T_{ref} \rho_{ref}}$$

*Data have been corrected for vertical shift.*




$$J(t, \tau_0) \equiv \frac{\gamma_{21}(0,t)}{-\tau_0}$$

*Figure 6.53, p. 210 Plazek; PS melt*

## Shear Creep - Recoverable Compliance

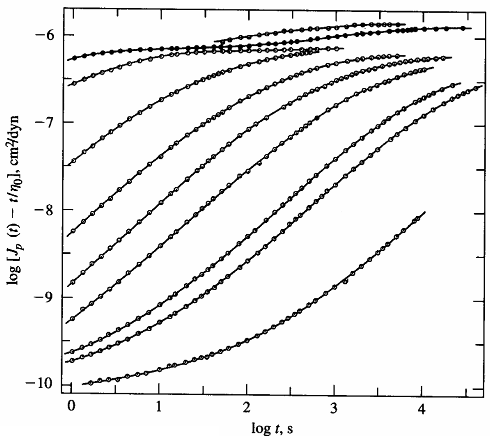
$$J(t) = R(t) + \frac{t}{\eta_0}$$

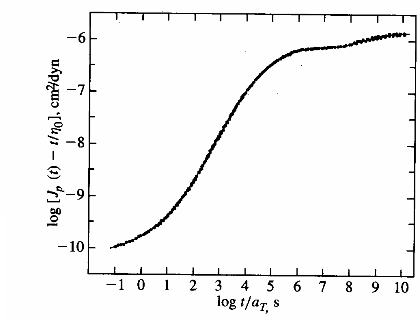
recoverable strain

$$\gamma(t) = \gamma_r(t) + t\dot{\gamma}_\infty$$

total strain

non-recoverable strain




*Figures 6.54, 6.55, p. 211*
*Plazek; PS melt*



## Step shear strain - *strain dependence*

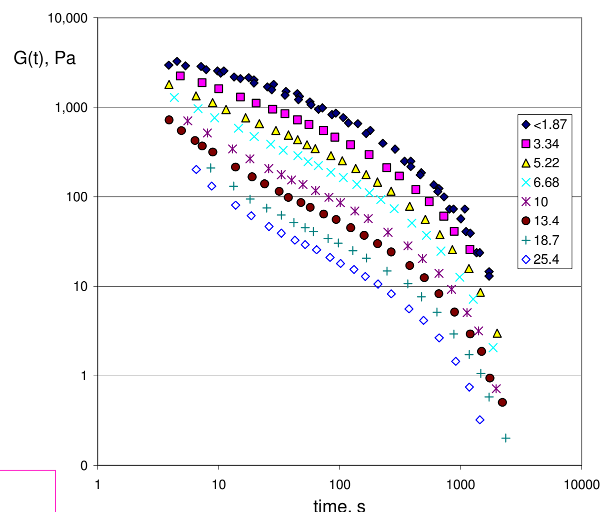



*Figure 6.57, p. 212*
*Einaga et al.; PS soln*

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## Shear Damping Function

*Observation*: step-strain moduli curves have similar shapes and appear to be shifted down with strain.

Damping function

$$G(t,\gamma_0) = G(t)h(\gamma_0)$$

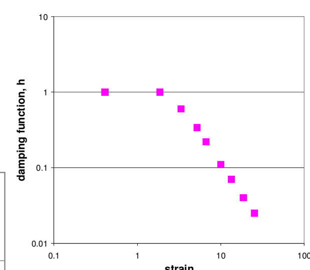
$$\log G(t,\gamma_0) = \log G(t) + \log h(\gamma_0)$$

The damping function gives the strain-dependence of the step-strain relaxation modulus.

When $G(t,\gamma_0) = G(t)h(\gamma_0)$ the behavior is called time-strain separable.

This behavior is predicted by some advanced constitutive equations.

## Step shear strain - **Damping Function**



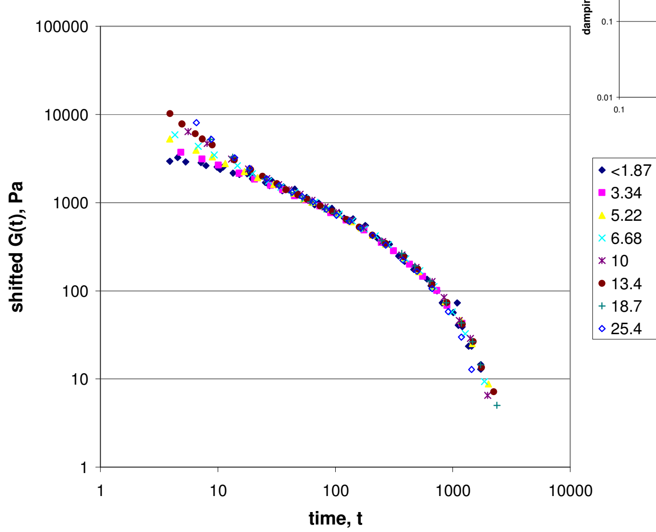




*Figure 6.58, p. 213*
*Einaga et al.; PS soln*

*Unsteady shear flow* **Summary**

Small strain - SAOS, step strain

- *linear polymers show classic shape that can be used to identify materials*
- *very easy to perform; reproducible*
- *easy to intercalculate material functions (with LVE model)*
- *SAOS has better signal/noise than step strain*

Large strain - start-up, cessation, creep, large-amplitude step strain

- *easy to perform; reproducible*
- *give large-strain behavior*
- *needed to differentiate constitutive equations*

*Time-temperature superposition is a key technique to extend the apparent frequency range (or shear-rate range) of data.*



# Experimental Data (continued)

*Unsteady shear flow*

✓ •Small strain - SAOS, step strain

*linear polymers, material effects, temperature effects*

✓ •Large strain - start-up, cessation, creep, large-amplitude step strain

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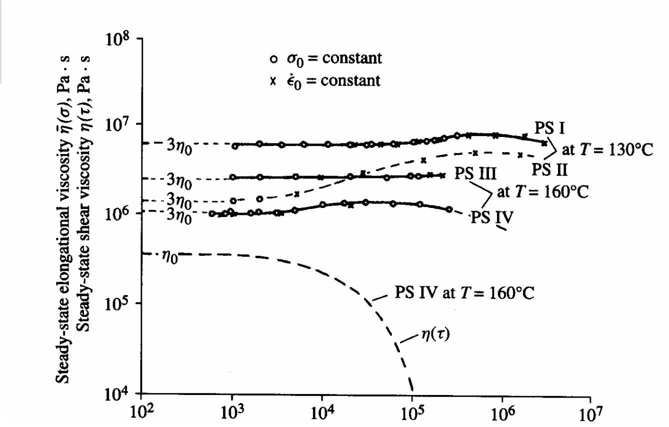
➡ ***lastly . ..***

*Steady elongation*

*Unsteady elongation*

## Steady State Elongation Viscosity




Both tension thinning and thickening are observed.

*Figure 6.60, p. 215*
*Munstedt.; PS melt*

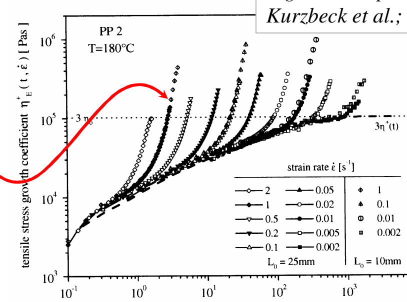
$$\text{Trouton ratio:}\ \ Tr \equiv \frac{\bar{\eta}}{\eta_0}$$

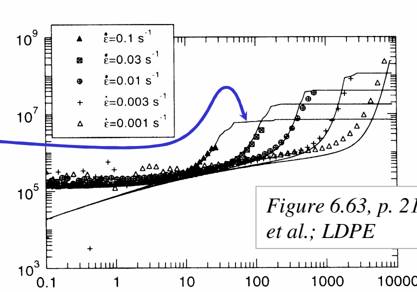


## Start-up of Steady Elongation

*Figure 6.64, p. 218*
*Kurzbeck et al.; PP*

Strain-hardening

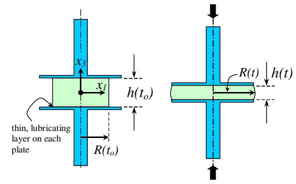


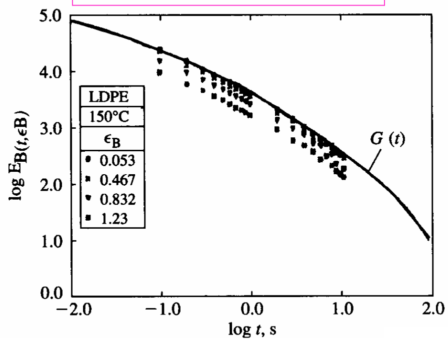

Fit to an advanced constitutive equation (12 mode pom-pom model)

*Figure 6.63, p. 217 Inkson et al.; LDPE*

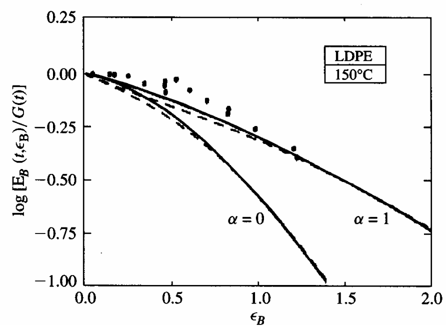
## Elongation Step-Strain




*Figures 6.68, 6.69, pp. 220-1*
*Soskey and Winter; LDPE*




Relaxation function for step biaxial elongation




Damping function for step biaxial elongation



## Experimental Data *(Summary)*

*Steady elongation -*

- *difficult to perform reproducible experiments*
- *difficult to obtain steady state*
- *important data for many processing flows and for distinguishing constitutive equations*

*Unsteady elongation -*

- *difficult to perform reproducible experiments*
- *open question: how real is strain hardening?*