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

lastly ..

Steady elongation
Unsteady elongation

\[ \dot{\gamma} = \begin{cases} \dot{\gamma}(t) x_2 \\ 0 \\ 0 \end{cases}, x_{123} = \begin{cases} 0 & t < 0 \\ \dot{\gamma}_0 & t \geq 0 \end{cases} \]

Startup of Steady Shearing

\[ \eta^* \equiv -\frac{\tau_{ij}(t)}{\dot{\gamma}_0} \]

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

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Cessation of Steady Shearing

\[ \gamma = \begin{cases} \dot{\gamma}(t)x_2 & t < 0 \\ 0 & t \geq 0 \end{cases} \]

\[ \ddot{\gamma}(t) = \begin{cases} \ddot{\gamma}_0 & t < 0 \\ 0 & t \geq 0 \end{cases} \]

\[ \eta_+ = -\frac{\tau_{23}(t)}{\dot{\gamma}_0} \]

Shear Creep

\[ \gamma = \begin{cases} \dot{\gamma}_{21}(t)x_2 & t < 0 \\ 0 & t \geq 0 \end{cases} \]

\[ \tau_{21}(t) = \begin{cases} 0 & t < 0 \\ \tau_0 & t \geq 0 \end{cases} \]

\[ J_p = \frac{J(T)T_p}{T_{ref} P_{ref}} \]

Data have been corrected for vertical shift.
Shear Creep - Recoverable Compliance

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

recoverable strain

\[ \gamma(t) = \gamma_r(t) + t \gamma_r \]

total strain non-recoverable strain

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

Step shear strain - strain dependence

\[ G(t), \text{ Pa} \]

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.

\[ G(t, \gamma_0) = G(t)h(\gamma_0) \]

\[ \log G(t, \gamma_0) = \log G(t) + \log h(\gamma_0) \]

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.

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**Step shear strain - Damping Function**

![Graph](image.png)
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

lastly . ..

Steady elongation
Unsteady elongation
Steady State Elongation Viscosity

Both tension thinning and thickening are observed.

Figure 6.60, p. 215
Munstedt.; PS melt

Trouton ratio: \( Tr = \frac{\eta}{\eta_0} \)

Start-up of Steady Elongation

Strain-hardening

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

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

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

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Elongation
Step-Strain

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

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?