Modeling the flow of nonlinear viscoelastic polymers in a filament stretching rheometer

polymer technology

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Modeling the flow of nonlinear viscoelastic polymers in a filament stretching rheometer

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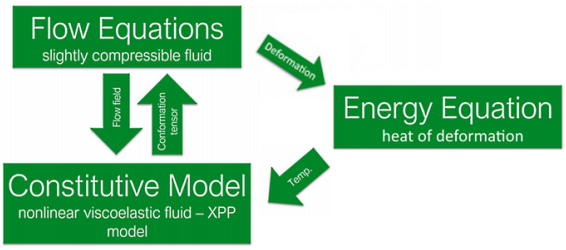
Motivation

A wide range of techniques can be used to obtain information about the rheological properties of polymers. Here, the filament stretching rheometer is studied, which is used to characterize molten polymers in a pure uniaxial extensional flow. Although the flow at the mid-filament region is controlled to be pure uniaxial extension, shear contributions near the plates can affect the measured force signal. So, it is essential to correct for these shear contributions in order to measure the pure uniaxial viscosity. Such correction factors are presented in literature by Nielsen et al. [1] and Huang et al. [2], but these are only valid in the linear viscoelastic regime. This project aims at developing a 'nonlinear shear correction factor' by means of finite element simulations.

Methods

A finite element model is presented to describe the flow and resulting stresses in a filament stretching rheometer. The presented model consists of a non-isothermal, nonlinear viscoelastic flow solver, implemented in an in-house finite element package.



In Figure 1, the geometry of a polymer sample confined between two plates is shown. Both plates move in opposite directions with the same velocity.

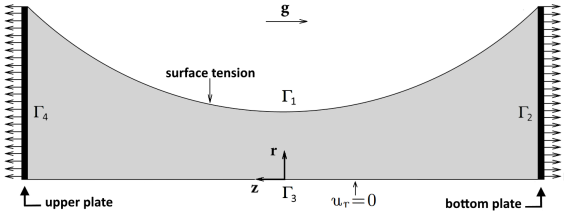


Figure 1: Initial geometry after pre-stretch

In this paper, the nonlinear shear correction factor is defined as:

$$f_{\text{shear}} = \frac{\bar{\eta}^+_{\text{XPP}}}{\bar{\eta}^+_R}. \qquad (1)$$

Here, $\bar{\eta}^+_R$ is the real extensional viscosity determined from the simulated force on the bottom plate and $\bar{\eta}^+_{\text{XPP}}$ is the extensional viscosity in a pure uniaxial flow (determined by solving the nonlinear XPP model).

Results

Numerical simulations have been run for different strain rates, aspect ratios and materials. For this, the shear correction factors are determined (see Figure 2).

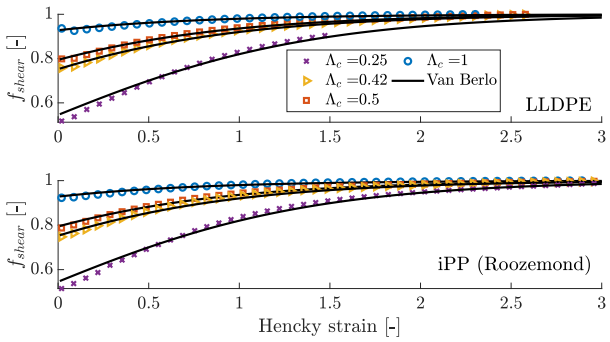


Figure 2: Simulated shear correction factors versus the Hencky strain $\varepsilon(t)$ (markers). Multiple initial geometries are simulated with different (compressed) aspect ratios Λ_c (pre-strains is $\varepsilon_{\text{pre}} = 0.81$). This is done for an iPP and LLDPE which have distinctive nonlinear viscoelastic properties. The solid lines represent the proposed nonlinear shear correction factor in Eq. (2).

An empirical function for the nonlinear shear correction factor is proposed for polymer melts:

$$f_{\text{shear}} = \left[1 + \frac{\exp[-4(\varepsilon(t)+\varepsilon_{\text{pre}})/3 - \exp(-\Lambda_c)]}{3\Lambda_c^2}\right]^{-1}. \qquad (2)$$

Conclusions

The proposed empirical function for the shear correction factors shows excellent agreement with the simulated shear correction factors. This function is strain rate independent and can be used to correct for shear contributions for a wide range of (nonlinear) polymer melts.

[1] J.K. Nielsen et al. (2008). "Stress relaxation of narrow molar mass distribution polystyrene following uniaxial extension". *Journal of Rheology* **52.4**, 885–899.

[2] Q. Huang et al. (2012). "Stress relaxation and reversed flow of low-density polyethylene melts following uniaxial extension". *Journal of Rheology* **56.6**, 1535–1554.