The Bauschinger effect in polymers

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The Bauschinger Effect in Polymers

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Introduction

During the processing of a polymer, the long molecular chains in the material orient themselves, resulting in a product with strongly anisotropic mechanical properties. To predict the performance of such products, it is essential that constitutive models capture the effect of orientation. Here, one of the simplest cases is considered: the effect of orientation in one direction on the uniaxial deformation behavior in that direction. While the difference between the mechanical behavior in tension and compression is small for isotropic polymers, it is enormous for oriented polymers, as shown in Fig. 1. This phenomenon is named after Johann Bauschinger, who described a similar effect in metals already in 1881.

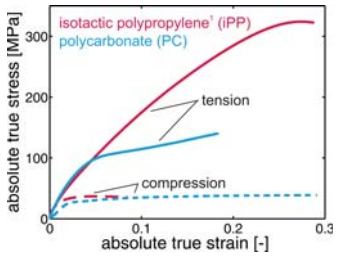

Figure 1: Oriented polymers exhibit a dramatic Bauschinger effect.

Modeling the Bauschinger effect

Traditional models (Fig. 2a) describe a polymer's mechanical response with a viscous flow stress, added to an elastic stress that represents the response of the entanglement network. Simulation results (Fig. 2b) show that, after the material has been oriented in tension, these models predict the yield point in compression to occur at positive stress levels. This is physically incorrect.

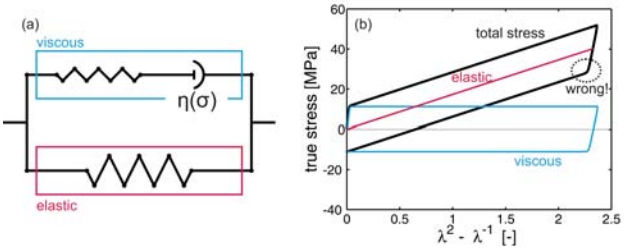

Figure 2: Traditional modeling approach: (a) analogue (b) results.

To resolve this issue, a deformation (λ) dependence of the viscous contribution is proposed. In order not to change the model predictions in the isotropic case, the elastic contribution is reduced accordingly, see Fig. 3a. Now, the experimentally observed Bauschinger effect is qualitatively described by the model. This is illustrated in Fig. 3b, where, after orienting the material in tension, the compressive yield stress is predicted to be of similar magnitude as that of isotropic material.

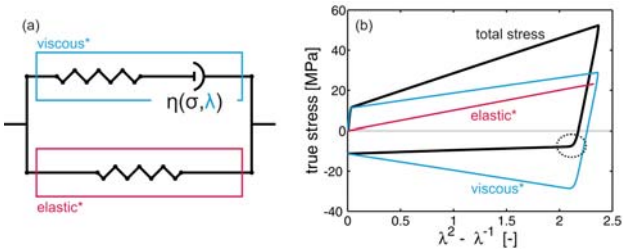

Figure 3: Proposed modeling approach: (a) analogue (b) results.

Introducing a deformation dependence in the viscous contribution causes the strain rate dependence of the yield stress (the yield kinetics) of the model to change with orientation. Is this also observed in experiments?

Orientation dependence of yield kinetics

Yield kinetics of polymers are indeed strongly influenced by orientation, as shown by the experimental data in Fig. 4. The nature of the effect differs between polymers: a shift for PC, but (mostly) a slope change for iPP. The physical cause for this difference is still unclear.

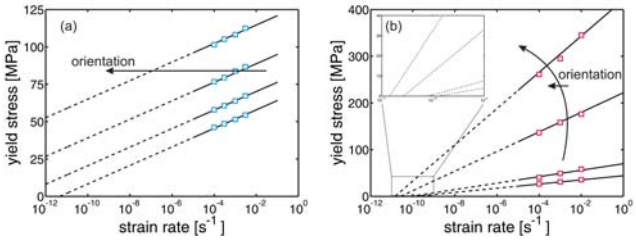

Figure 4: Influence of orientation on yield kinetics: (a) PC (b) iPP[2].

References

[1] R.A. Duckett *et al.*, *J. Mater. Sci.* 7, (1972), 480-482
[2] T.B. Van Erp *et al.*, *J. Polym. Sci: Part B: Polym. Phys.* 47, (2009), 2026-2035