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Polymer Technology

Prediction of yield and long-term failure of oriented polypropylene: kinetics and anisotropy

T.B. van Erp, C.T. Reynolds, J.A.W. van Dommelen, L.E. Govaert

Introduction

Polymer products are often manufactured by injection molding in which the molten material is subjected to shear and elongational flow, inducing a degree of orientation[1]. As a result, especially for semi-crystalline polymers, the mechanical behavior becomes anisotropic. The present study is focussed on the deformation kinetics of oriented polypropylene tapes and a viscoplastic model is proposed to predict the off-axis yield and failure behavior.

Materials and methods

An isotactic polypropylene tape is extruded and subsequent solid state drawing is performed at a drawing temperature of 120°C producing different tapes with draw ratios of $\lambda = 1$, 4 and 6.

Dogbone-shaped samples are cut directly from the tapes at different angles θ between 0° and 90°, with respect to the drawing direction (DD), see figure 1, to perform uniaxial tensile tests and long-term failure experiments.

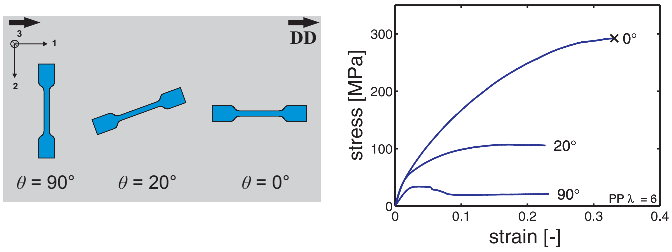

Figure 1 : *Orientation of samples with respect to the DD and the resulting stress-strain curves showing evident anisotropic behavior.*

Modeling

A phenomenological anisotropic viscoplastic model for the rate-dependency of the yield stress is presented. In this model, the anisotropic yield criterion of Hill[2] is used as a criterion for flow based on a given stress situation and combined with the Eyring-flow theory. The deformation rate tensor $\mathbf{D}_p$ is given by:

$$\mathbf{D}_p = \dot{\lambda}\mathbf{N}$$

where $\dot{\lambda}$ is the magnitude of plastic flow and $\mathbf{N}$ the direction of the deformation rate given by an associated flow rule.

A failure criterion is adopted which states that the product of the time and strain rate at failure is constant for any stress[3]. Here, the equivalent plastic strain rate is used and consequently, failure will occur when an equivalent critical strain is exceeded. Time-to-failure is given by:

$$t_f = \frac{\bar{\epsilon}_{cr}}{\dot{\bar{\epsilon}}_p}$$

Results

The model is developed such that the anisotropy is decoupled from the deformation kinetics. First, for different tapes the anisotropy is determined using Hill's criterion[2], see figure 2.Second, the deformation kinetics are determined. Remarkably, parallel slopes are found using a double logarithmic scale. Therefore, Hill's criterion is a powerful tool since this provides the possibility to factorize the deformation kinetics for different orientations. The results of the predicted yield stress and time-to-failure, for iPP tape with draw ratio of six, are presented in figure 3.

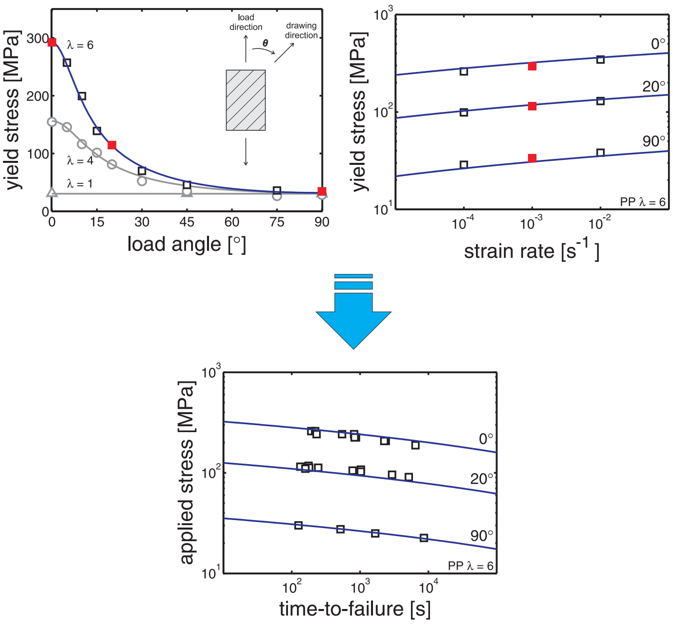

Figure 2 : *Orientation and draw ratio dependence (top left) combined with rate dependence (top right) resulting in prediction of time-to-failure for oriented PP tape.*

Conclusions

The objective of capturing orientation effects in oriented tapes is fulfilled. The presented anisotropic viscoplastic model is based on factorization of the strain rate and draw ratio dependence and is capable of quantitatively predicting the strain rate, angle and draw ratio dependence of the yield stress as well as time-to-failure in various off-axis static loading conditions characterized solely of the transverse direction.

References

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