How strong is your product?

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Introduction

An attempt has been made to predict the development of mechanical properties during processing. As a starting point the temperature dependence of the evolution of the yield stress during annealing treatments on polycarbonate below T_g, as derived by Klompen et al. [1], is used. In combination with the process-related thermal history, which can be derived from numerical simulations of the injection molding process, an estimate of the yield strength distribution throughout the product can be obtained.

Model

From yield data obtained by annealing at different temperatures a master curve can be constructed using (annealing) time-temperature superposition, see figure 1.

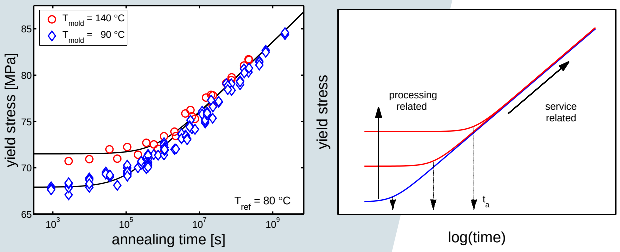

Figure 1 *Annealing kinetics*

The kinetics of the yield stress are captured by the following set of equations:

$$a_T(T) = exp\left(\frac{\Delta U_a}{R} \cdot \left(\frac{1}{T} - \frac{1}{T_{ref}}\right)\right) \quad (1)$$

$$\sigma_y(t) = c_0 + c_1 \cdot log(t_{eff} + t_a) \quad (2)$$

$$t_{eff} = \int_0^t a_T^{-1}(T(\xi))d\xi \quad (3)$$

The evolution of the yield stress is assumed to begin when the glass transition temperature, T_g, is passed.

Experimental

From a commercial grade of polycarbonate, Lexan 141R, injection molded samples were made. Mold temperatures were varied from $30°$C to $130°$C. Subsequently tensile bars were machined from the injection molded samples to determine the resulting yield stress, see figure 2 below.

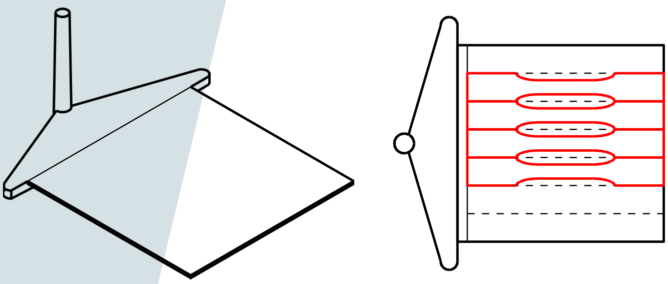

Figure 2 *Injection molded part and tensile bars*

Results

Evaluation of the thermal history of the injection molded samples as obtained by Moldflow; see figure 3 (left), leads to the predicted yield stresses as shown in figure 3 (right).

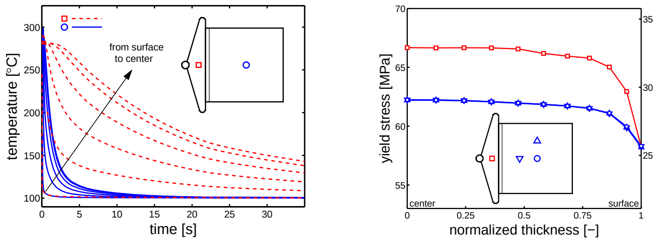

Figure 3 *Temperature (left) and yield stress distributions (right)*

For different mold temperatures the resulting experimental verus numerical yield stresses are presented below.

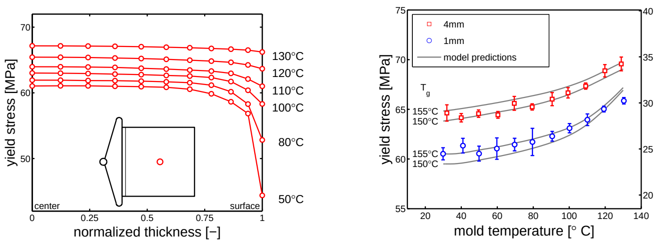

Figure 4 *Numerical versus experimental results*

Conclusions

A new simulation tool has been developed which enables the analysis of the development of yield stress during processing of glassy polymers. With the current state of the art in constitutive modeling, the knowledge of the yield stress distribution is sufficient to perform life-time predictions in static and dynamic loadings [2]. In combination this opens a route to true product optimization without ever performing a single mechanical test.

Future work

- ☐ Incorporate equilibrium kinetics; in this approach the glass transition temperature is treated as a parameter rather then a result of kinetic vitrification.
- ☐ Investigate the influence of pressure on the evolution kinetics.

References:

[1] Klompen, E.T.J., Engels, T.A.P., Govaert, L.E., Meijer, H.E.H.: *Elastoviscoplastic modeling of the large strain deformation of glassy polymers: influence of thermo-mechanical history.* (J.Rheol., submitted.)

[2] Klompen, E.T.J., Engels, T.A.P., van Breemen, L.C.A., Schreurs, P.J.G., Govaert, L.E., Meijer, H.E.H.: *A 3-D plasticity approach to time-dependent failure of polycarbonate.* (J.Rheol., submitted.)

[3] Govaert, L.E., Engels, T.A.P., Klompen, E.T.J., Peters, G.W.M., Meijer, H.E.H.: *Processing induced properties of glassy polymers: Devolopment of the yield stress in polycarbonate.* (IPP, submitted.)

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