

# Modeling of thermorheologically complex deformation of glassy polymers

**Citation for published version (APA):**

Breemen, van, L. C. A., Govaert, L. E., & Meijer, H. E. H. (2005). *Modeling of thermorheologically complex deformation of glassy polymers*. Poster session presented at Mate Poster Award 2005 : 10th Annual Poster Contest.

**Document status and date:**

Published: 01/01/2005

**Document Version:**

Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

**Please check the document version of this publication:**

- A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
- The final author version and the galley proof are versions of the publication after peer review.
- The final published version features the final layout of the paper including the volume, issue and page numbers.

[Link to publication](#)

**General rights**

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license above, please follow below link for the End User Agreement:

[www.tue.nl/taverne](http://www.tue.nl/taverne)

**Take down policy**

If you believe that this document breaches copyright please contact us at:

[openaccess@tue.nl](mailto:openaccess@tue.nl)

providing details and we will investigate your claim.

# Modeling of thermorheologically complex deformation of glassy polymers

L.C.A. van Breemen, L.E. Govaert and H.E.H. Meijer

## Introduction

For the past years a constitutive model to describe glassy polymer deformation has been developed [1,2]. In this model the viscosity approach is thermorheologically simple, unfortunately few polymers show this type of deformation. The approach presented here extends the model to be used for thermorheologically complex deformation. For thermorheological simple deformation, like Polycarbonate (PC), the rate dependence of the yield drop remains constant, however for thermorheological complex materials, such as polymethylmethacrylate (PMMA), there is a pronounced difference in yield drop depending on strain rate [3]. An extensive validation of this new approach can be found in [4].

## Model

The model is employed as two parallel parts, i.e. the part describing the yield and strain softening  $\sigma_s$  and the other describing the strain hardening  $\sigma_r$ .

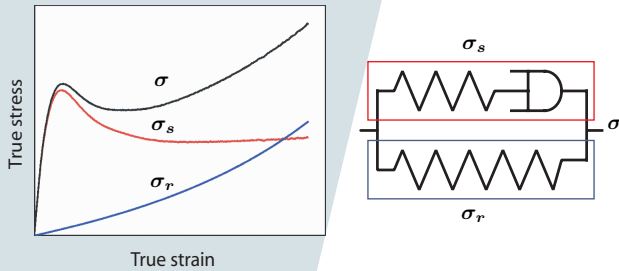


Figure 1 **Left:** True stress-strain curve **Right:** Mechanical analog.

$$\sigma = \kappa(J - 1)\mathbf{I} + G\tilde{\mathbf{B}}_e^d + G_r\tilde{\mathbf{B}}^d$$

The plastic deformation rate tensor  $D_p$  is related to the effective deviatoric stress tensor  $\sigma_s^d$  by a non-Newtonian flow rule with an Eyring viscosity  $\eta$ :

$$D_p = \frac{\sigma_s^d}{2\eta(\bar{\sigma}, p, T, S)} = \frac{G}{2\eta}\tilde{\mathbf{B}}_e^d$$

## Rheological complex viscosity

Where the old approach incorporates only the  $\alpha$  process this approach uses both the  $\alpha$  and  $\beta$  processes, see left hand side of figure 2.

$$\eta = \eta_{0\alpha} \left[ a_{\sigma\alpha} + \frac{\eta_{0\alpha+\beta}(S_a)}{\eta_{0\alpha} \exp[S_a]} a_{\sigma\alpha+\beta} \right] \exp \left[ \frac{\mu p}{\tau_{0\alpha}} \right] \exp [S_a R(\bar{\gamma}_p)]$$

where

$$\alpha_{\sigma\alpha} = \frac{\frac{\bar{\tau}}{\tau_{0\alpha}}}{\sinh \left[ \frac{\bar{\tau}}{\tau_{0\alpha}} \right]} \quad \text{and} \quad \alpha_{\sigma\alpha+\beta} = \frac{\frac{\bar{\tau}}{\tau_{0\alpha+\beta}}}{\sinh \left[ \frac{\bar{\tau}}{\tau_{0\alpha+\beta}} \right]}$$

The summation of the two viscosity functions, as shown here, is only allowed if the zero-viscosity  $\eta_{0\alpha}$  of the  $\alpha$  process is much larger than the zero-viscosity  $\eta_{0\alpha+\beta}$  of the  $\alpha + \beta$ . This

summation of the two viscosity functions for PMMA is shown in the right hand side of figure 2.

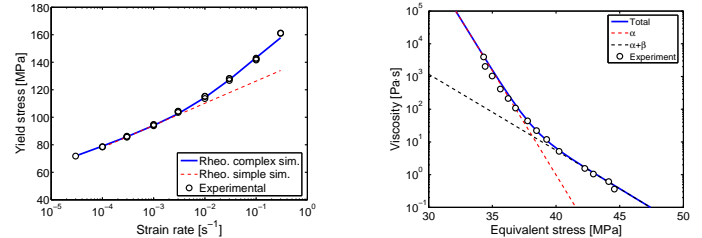


Figure 2 **Left:** Yield stress versus strain rate **Right:** Viscosity versus equivalent yield stress.

## Characterization

The input parameters for the model are derived from uniaxial compression tests. However for uniaxial compression simulations with different pressure dependence parameter ( $\mu$ ) values, identical simulation results will be obtained. To determine the pressure dependence parameter ( $\mu$ ) micro indentation experiments were performed. A best fit is obtained for 0.13. The current thermal state ( $S_a$ ) is obtained by fitting the true yield stress of the simulation to the experiment.

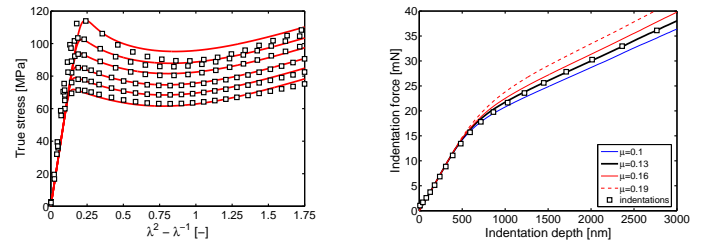


Figure 3 **Left:** Uniaxial compression simulations show identical results for different  $\mu$  values **Right:** Pressure dependence parameter  $\mu$  determined via micro indentation.

## Conclusions

- With this new approach yield stresses for all strain rates can be predicted.
- The pressure dependence can be determined using micro indentation.

## Future work

- Extend the model for friction and wear simulations.

## References:

- [1] KLOMPEN, E.T.J., ENGELS, T.A.P., GOVAERT, L.E. AND MEIJER, H.E.H.: *Elastoviscoplastic modeling of the large strain deformation of glassy polymers: influence of thermo-mechanical history.* (Macromolecules.)
- [2] KLOMPEN, E.T.J., ENGELS, T.A.P., VAN BREEMEN, L.C.A., SCHREURS, P.J.G., GOVAERT, L.E. AND MEIJER, H.E.H.: *A 3-D plasticity approach to time-dependent failure of polycarbonate.* (Macromolecules.)
- [3] KLOMPEN, E.T.J.: *Mechanical properties of solid polymers.* (PhD Thesis.)
- [4] JANSSEN, R.P.M. ET AL. : *Mate poster contest 2005*