

Multi-relaxation time viscoplastic modeling of thermorheological simple materials

Citation for published version (APA):

Breemen, van, L. C. A., Govaert, L. E., & Meijer, H. E. H. (2007). *Multi-relaxation time viscoplastic modeling of thermorheological simple materials*. Poster session presented at Mate Poster Award 2007 : 12th Annual Poster Contest.

Document status and date:

Published: 01/01/2007

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

Take down policy

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

openaccess@tue.nl

providing details and we will investigate your claim.

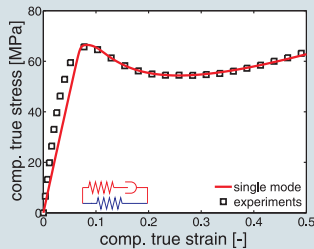
Multi-relaxation time viscoplastic modeling of thermorheological simple materials

L.C.A. van Breemen, L.E. Govaert and H.E.H. Meijer
Eindhoven University of Technology, Department of Mechanical Engineering

introduction

Over several decades, an in-house constitutive model for glassy polymers was developed [1, 2], that accurately captures the yield and post-yield response of glassy polymers. Despite these capabilities, several problems exist due to the nature of the single-mode modeling:

- inaccurate description of the pre-yield regime.
- incapability to qualitatively predict elastic recovery.



$$\sigma = \kappa(J-1)\mathbf{I} + \dots$$

$$G\tilde{\mathbf{B}}_e^d + G_r\tilde{\mathbf{B}}^d$$

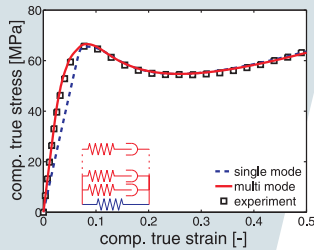
$$D_p = \frac{\sigma_s^d}{2\eta(\bar{\tau}, p, T, S)}$$

$$\eta = \eta_0 \cdot a_\sigma \cdot a_p \cdot a_{Sa}$$

Figure 1 Experiment and simulation using the single-mode model for uni-axial compression (left); governing constitutive relations (right).

solution

An elegant solution to this problem was proposed by [1], hence a multi-mode approach is employed.



$$\sigma = \kappa(J-1)\mathbf{I} + \dots$$

$$\sum_{i=1}^n (G_i\tilde{\mathbf{B}}_{e_i}^d) + G_r\tilde{\mathbf{B}}^d$$

$$D_{p_i} = \frac{\sigma_{s_i}^d}{2\eta_i(\bar{\tau}, p, T, S)}$$

Figure 2 Experiment and simulation using the multi-mode model for uni-axial compression (left); modified constitutive relations (right).

This is a straightforward extension to multi-relaxation times, with the special feature that the non-linearity is coupled to the total stress.

material characterization

As model material, polycarbonate was selected, and values for material parameters were taken from literature [2]. The moduli and initial viscosities of the modes were obtained from an intrinsic deformation curve as depicted in figures 1 and 2. The stress up to yield can be described with the well known Boltzmann integral.

/department of mechanical engineering

By taking into account the non-linearity of the stress in the viscosities, the moduli and corresponding viscosities can be calculated.

$$\sigma(t) = \sum_{i=1}^n \left[E_i \dot{\epsilon} \int_{-\infty}^t \exp\left(-\frac{\psi - \psi'}{\lambda_i}\right) dt' \right] ; \quad \eta_i = \lambda_i \cdot E_i$$

where

$$\psi = \int_{-\infty}^t \frac{dt''}{a_\sigma[\sigma(t'')]} \quad \psi' = \int_{-\infty}^{t'} \frac{dt''}{a_\sigma[\sigma(t'')]} \quad a_\sigma = \frac{\bar{\tau}/\tau_0}{\sinh(\bar{\tau}/\tau_0)}$$

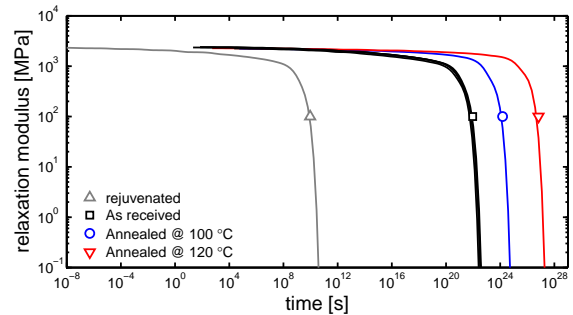


Figure 3 Relaxation moduli versus time.

Similar to the single-mode approximation [2], a unique rejuvenated relaxation time spectrum can be defined that accurately describes the pre-yield range in different strain rates and thermal history.

results

The multi-mode model accurately describes the pre-yield regime and is therefore capable of calculating loading and unloading curves for flat-tip indentation (Figure 4).

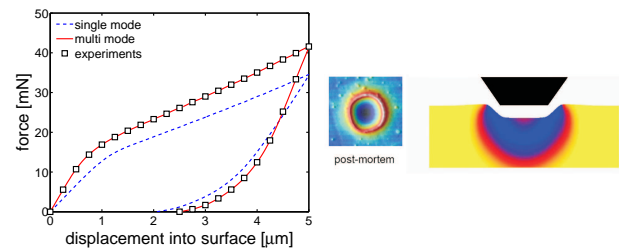


Figure 4 Flat-tip indentation using the single and multi-mode model.

conclusion

The new multi-mode implementation is capable of describing the non-linear viscoelastic pre-yield regime accurately, while the post-yield behavior of the single-mode model remains unaffected.

References:

- [1] TERVOORT, T.A.: *Constitutive modelling of polymer glasses. Finite, non-linear viscoelastic behaviour of polycarbonate* (Eindhoven University of Technology 1996)
- [2] KLOMPEN, E.T.J.: *Mechanical properties of solid polymers: Constitutive modelling of long and short term behaviour* (Eindhoven University of Technology 2005)