PAMM · Proc. Appl. Math. Mech. **4**, 223–224 (2004) / **DOI** 10.1002/pamm.200410093

The influence of the filler volume fraction on the mechanical behaviour of thermoplastic materials

Thomas Kletschkowski*[1], Uwe Schomburg[1,2], and Albrecht Betram[2]

[1] Universität der Bundeswehr Hamburg, Technische Mechanik, Holstenhofweg 85, D-22043 Hamburg, GERMANY
[2] Otto-von-Guericke-Universität Magdeburg, Institut für Mechanik, Postfach 4120, D-39016 Magdeburg, GERMANY

Uniaxial experiments clarify that the mechanical behaviour of PTFE compounds depends strongly on the amount of filler particles. In order to describe these dependencies, a finite endochronic viscoplastic material model based on material isomorphisms has been applied to various glass fibre filled PTFE compounds. The model allows to characterize viscoplastic material behaviour with equilibrium hysteresis using a rate-independent endochronic elastoplastic model in parallel connection with a nonlinear Maxwell model.

1 Experimental investigations

Due to their tribological characteristics, chemical inertness and temperature stability, PTFE compounds are increasingly used in many engineering applications. It has been observed that the viscoplastic material behaviour of these materials depends strongly on the amount of filler particles (FVF). Therefore various PTFE compounds filled with short cylindrical glass fibres have been investigated. Figure 1 illustrates that the stress response in uniaxial tension decreases significantly if the FVF increases. The strain controlled tests, presented in Figure 1 A) and B), have been performed on an electromechanical tensile tester in combination with a temperature chamber at 23°C and constant strain rate ($\dot{\varepsilon}$ =10%/min). First the specimens have been strained up to 10% engineering strain. In order to measure the stress relaxation, the state of strain has been kept constant afterwards. Small test samples (58mm x 5mm x 2mm) have been used for the experiments.

2 Material model and numerical simulations

The finite viscoplastic material model applied to the PTFE compounds, compare [2], is motivated by a rheological model consisting of a Maxwell element and an endochronic elastoplastic element in parallel (Figure 1 B)). The associated approach to finite viscoplasticity has been derived from the theory of finite plasticity based on isomorphisms, see [1]. It starts with the definition of the independent and the dependent variables of a deformation process. If $\mathbf{F}$ is the deformation gradient and $\mathbf{T}$ Cauchy's stress tensor, then $\mathbf{C} = \mathbf{F}^T\mathbf{F}$ defines the right Cauchy-Green tensor and $\mathbf{S} = \mathbf{F}^{-1}\mathbf{T}\mathbf{F}^{-T}$ the material stress tensor. $\mathbf{S}_\infty$ is the material equilibrium stress of the endochronic branch and $\mathbf{S}_{ov}$ defines the overstress of the Maxwell model. The inelastic deformations are characterized by internal variables ($\mathbf{P_P}$ (called plastic transformation) and $\mathbf{P_V}$ (called viscous transformation)).

Elastic law for the volumetric stress contribution:

$$(1)\ S_{vol} = K\,(det\mathbf{C})^{-\frac{1}{2}} \ln\left\{\sqrt{\det \mathbf{C}}\right\}$$

Overstress of the Maxwell model:

$$(2)\ \mathbf{S}_{ov}^{DEV} = 2G_{ov}\,(det\mathbf{C})^{-\frac{5}{6}}\,\mathbf{N}\left[\mathbf{P}_V\left(\bar{\mathbf{C}}_{ev} - \mathbf{I}\right)\mathbf{P}_V^T\right] \ \mathit{with}\ \bar{\mathbf{C}}_{ev} = \mathbf{P}_V^T\bar{\mathbf{C}}\mathbf{P}_V \ \textbf{and}\ \bar{\mathbf{C}} = (det\mathbf{C})^{-\frac{1}{3}}\,\mathbf{C}$$

Equilibrium stress of the endochronic model:

$$(3)\ \mathbf{S}_\infty^{DEV} = 2G_\infty\,(det\mathbf{C})^{-\frac{5}{6}}\,\mathbf{N}\left[\mathbf{P}_P\left(\sum_{i=1}^{3} s_i\mathbf{n}_i\otimes\mathbf{n}_i\right)\mathbf{P}_P^T\right] \ \mathit{with}\ \bar{\mathbf{C}}_{ep} = \mathbf{P}_P^T\bar{\mathbf{C}}\mathbf{P}_P,$$

$$(4)\ s_i = \ell n\left(1 + B\left\langle\lambda_i\right\rangle\right) - \ell n\left(1 - B\left\langle-\lambda_i\right\rangle\right),\ (\lambda_i, \mathbf{n}_i) = Eigensystem\left[\bar{\mathbf{C}}_{ep} - \mathbf{I}\right]$$

Evolution equations for the viscous and plastic transformation:

$$(5)\ \dot{\mathbf{P}}_\mathbf{V}\mathbf{P}_\mathbf{V}^{-1} = -\frac{3}{2\eta}\left[\sinh\left(\frac{\sigma_{VV}}{\sigma_0}\right)\right]^\kappa \frac{\left(\mathbf{S}_{ov}^{DEV}\mathbf{C}\right)}{\sigma_{VV}} \ \textbf{and}\ \dot{\mathbf{P}}_P\mathbf{P}_P^{-1} = -\frac{3}{2Y}\sigma_{VP}\dot{\varepsilon}_V\frac{\left(\mathbf{S}_\infty^{DEV}\mathbf{C}\right)}{\sigma_{VP}}$$

Equivalent material stresses and equivalent strain rate:

$$(6)\ \sigma_{VV} := \sqrt{\tfrac{3}{2}tr\left\{\left(\mathbf{S}_{ov}^{DEV}\mathbf{C}\right)\left(\mathbf{S}_{ov}^{DEV}\mathbf{C}\right)\right\}},\ \sigma_{VP} := \sqrt{\tfrac{3}{2}tr\left\{\left(\mathbf{S}_\infty^{DEV}\mathbf{C}\right)\left(\mathbf{S}_\infty^{DEV}\mathbf{C}\right)\right\}} \ \textbf{and}\ \dot{\varepsilon}_V := \sqrt{\tfrac{2}{3}tr\left\{\mathbf{D}^{dev}\mathbf{D}^{dev}\right\}}$$

Table 1: Constitutive equations

* Corresponding author: e-mail: Kletsch@unibw-hamburg.de, Phone: +49 04(0) 6541 2282, Fax: +49 04(0) 6541 2822

Motivated by the rheological model the stress response is decomposed additively $\mathbf{S} = S_{vol}\mathbf{C}^{-1} + \mathbf{S}_{\infty}^{DEV} + \mathbf{S}_{ov}^{DEV} \Leftrightarrow \mathbf{T} = T_{vol}\mathbf{I} + \mathbf{T}_{\infty}^{dev} + \mathbf{T}_{ov}^{dev}$. $(\bullet)^{\mathbf{dev}} := (\mathbf{I} - \frac{1}{3}\mathbf{I} \otimes \mathbf{I})[\bullet]$ defines the classical deviator operation. The physical deviator in the reference configuration is given by $(\bullet)^{\mathbf{DEV}} := (\mathbf{I} - \frac{1}{3}\mathbf{C}^{-1} \otimes \mathbf{C})[\bullet]$. The complete set of constitutive equations (elastic laws and associated flow rules) is summerized in Table 1. The model has been identified numerically for various PTFE compounds. As illustrated by Figure 1 A)and B), all numerical results are in good agreement with the experimental data for both loading and stress relaxation.

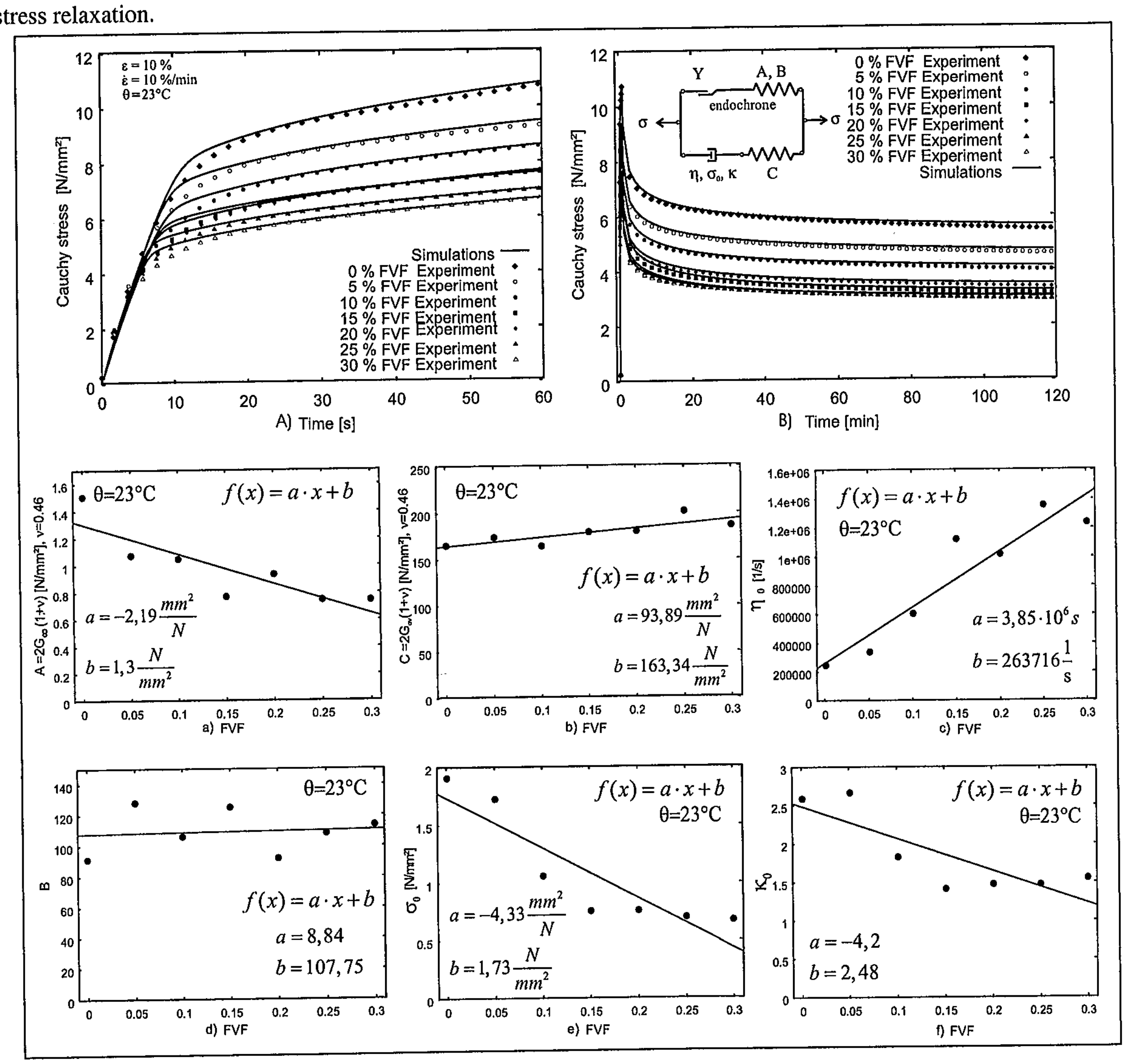

Figure 1: Rheological model, simulations (solid lines) and experimental data (dotted lines)

The dependence of the model parameters on the FVF is illustrated by Figure 1 a)-f). In order to get a first insight the parameters have been fitted to straight lines. It has been found that the elastic constants G_∞ and G_{ov} as well as the viscosity parameter η depend nearly linear on the FVF. But the dependence of the inelastic model parameters κ and σ_0 on the FVF can not be modeled by a linear function. B can be assumed to be independent of the FVF.

References

[1] A. Bertram, Finite thermoplasticity based on isomorphisms, Int. J.of Plasticity **19**, 2027–2050 (2003).

[2] T. Kletschkowski, U. Schomburg and A. Bertram, Endochronic viscoplastic material models for filled PTFE, Mechanics of Materials **34**, 795–808 (2002).

[3] K. Valanis, A theory of viscoplasticity without an yield surface, Part I: general theory, Archive of Mechanics **23**, 517–533 (1971).