Experimental Indentification of Viscoelastic Properties of Rubber Blends by means of a Torsional Rheometer

Herbert W. MÜLLNER*, Andreas JÄGER*, Josef EBERHARDSTEINER*

* Institute for Mechanics of Materials and Structures, Vienna University of Technology, Austria
in co-operation with Semperit Technische Produkte Ges.m.b.H. & Co KG, Wimpassing, Austria

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Overview

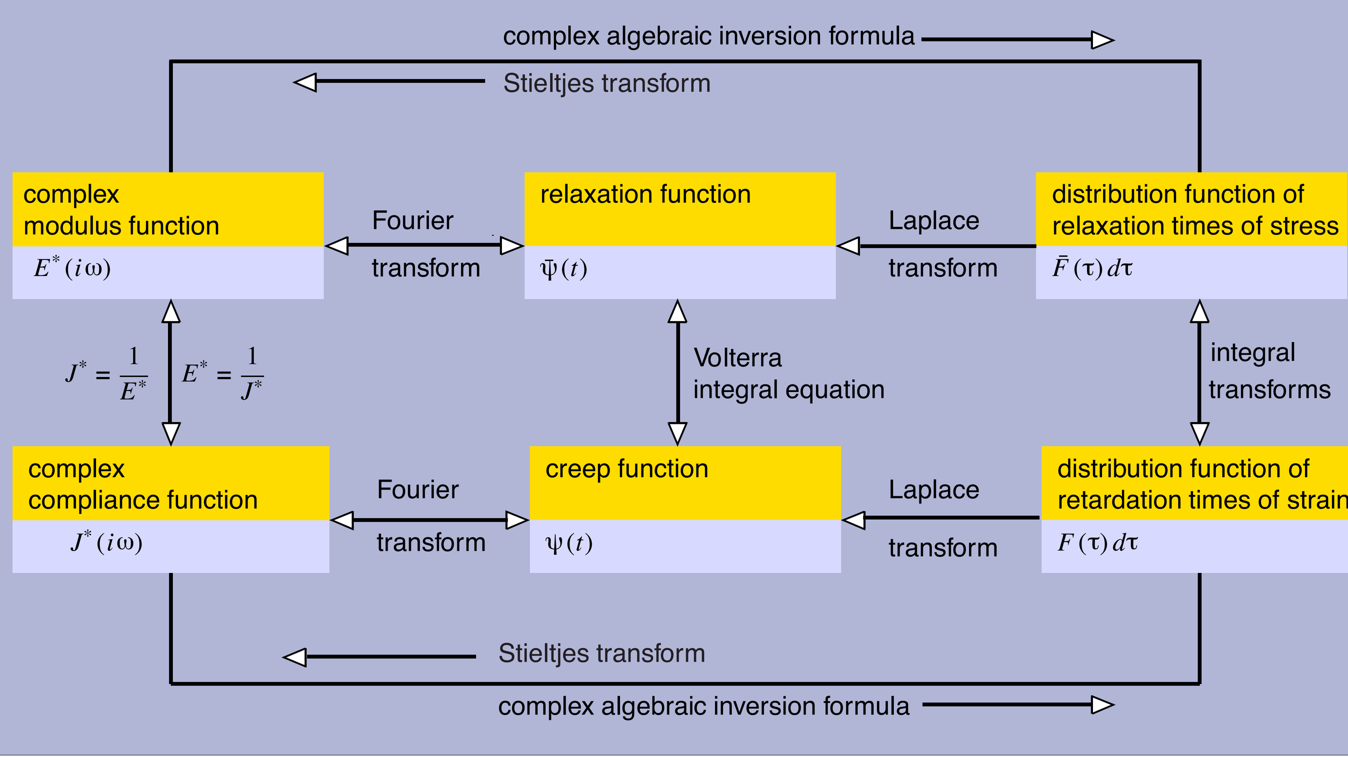
The dimensioning of injection heads for the extrusion of rubber profiles is exclusively based on empiric knowledge of the non-linear flow behaviour of elastomers. The swelling of the extrudate when emerging from a capillary is typical for viscoelastic fluids, such as polymers and rubber blends, respectively. Therefore, the experimental investigation and numerical treatment of this swelling behaviour is of high interest. This was one of the motivations for starting a research project in the field of rubber blend technologies. The knowledge of die swell phenomenon is important for manufacturing rubber profiles. Thus, the final goal of this project is the numerical prognosis concerning injection heads and tools for the extrusion of rubber. So far, several rubber blends, containing mainly EPDM and carbon black in different compositions, have been investigated. These are used for window sealings, pipeline constructions and various parts of cars.

Literature:

[1] J.S. Dick, C. Harmon, A. Vare: Quality assurance of natural rubber using the rubber process analyzer, Polymer Testing, 18 (1999): 327-362.
[2] W.N. Findley, J.S. Lai, K. Onaran: Creep and relaxation of nonlinear viscoelastic materials, Dover Publications, New York, 1976.

Mathematical Structure of Viscoelasticity

For numerical simulations of injection heads the determination of the viscoelastic properties of the rubber blends is required. Therefore experiments with a rubber process analyzer were carried out. For the comparison of the experimental data and the rheological model governing equations for both, storage modulus and loss modulus, subjected to the corresponding material parameters are required. These equations are based on a relation between creep and stress relaxation which can be found by means of Laplace and Fourier transformation according to Findley et al. [2].



stress at time instant t

$$\sigma(t) = \int_{\tau=0}^{t} E(t-\tau)\frac{\partial\varepsilon(\tau)}{\partial\tau}d\tau$$

relaxation modulus E(t)

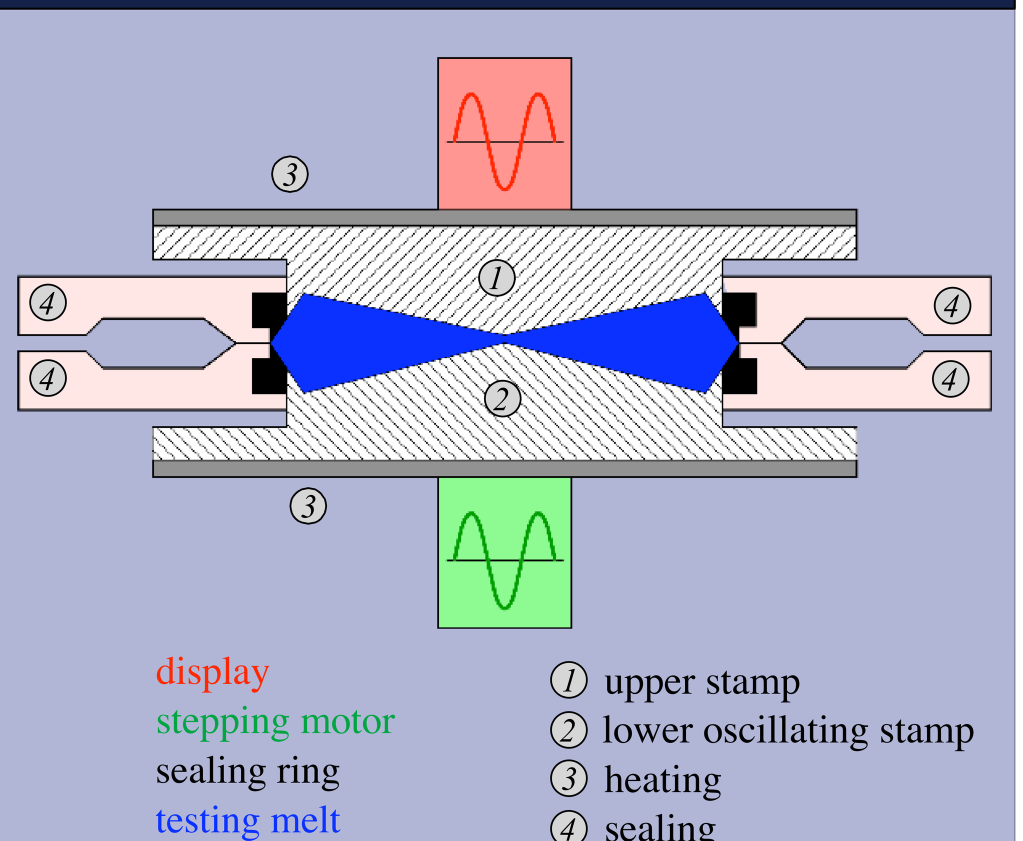
same material

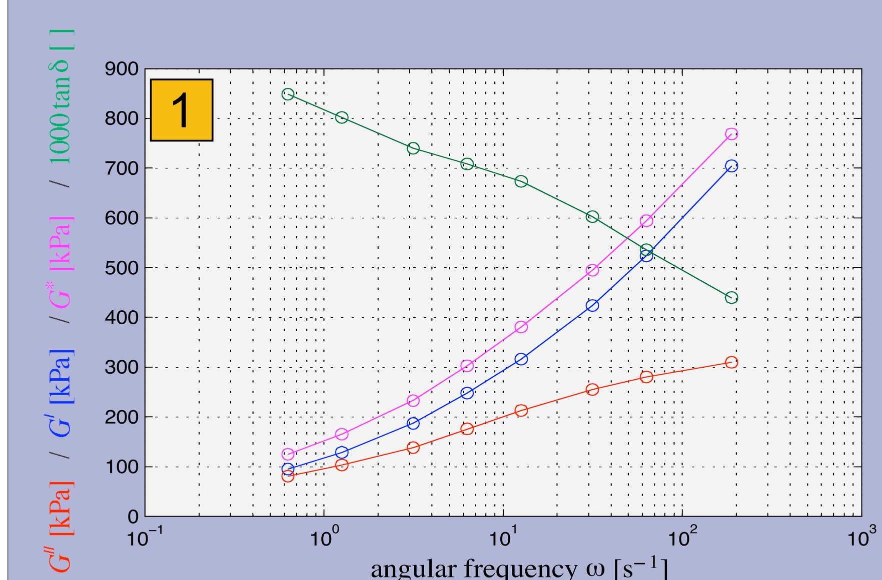
creep compliance J(t)

$$\varepsilon(t) = \int_{\tau=0}^{t} J(t-\tau)\frac{\partial\sigma(\tau)}{\partial\tau}d\tau$$

strain at time instant t

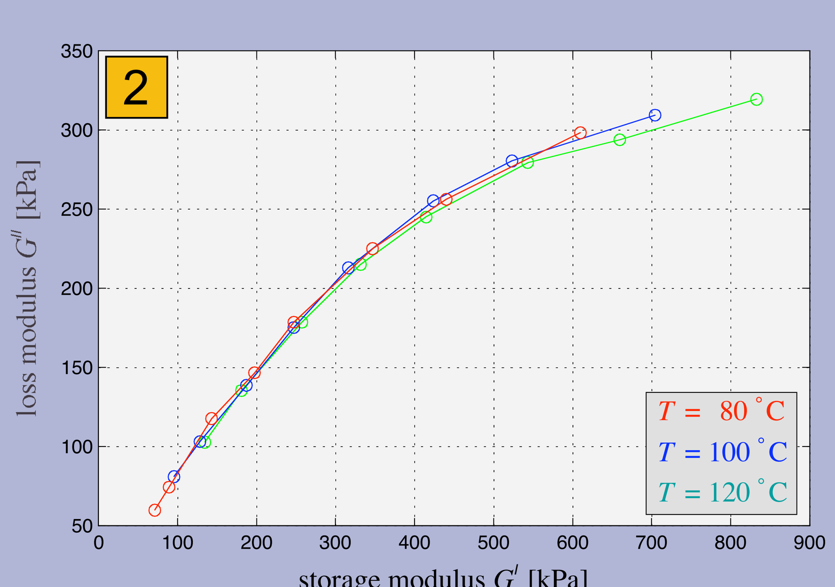
Experimental Investigations





A torsion rheometer or Rubber Process Analyzer (RPA) is used for the determination of the dynamic properties of unvulcanised rubber blends. A certain shear strain is applied by oscillating the lower stamp. The upper stamp is conntected with a measuring tool which records the applied torsional moment.

Due to the viscoelastic properties this complex turning moment S^* has not the same phase as the applied strain. By means of a Fourier transformation S^* is split into an elastic component S' and a viscsous one S''. With a form factor the so-called storage modulus G' and the loss modulus G'' are determined. More details are collected in Dick et al. [1].



The result of one RPA experiment is therefore the storage modulus G' and the loss modulus G'' for a certain angular frequency ω. With one experiment normally more than one angular frequency is investigated. In this context r denotes the number of investigated duty point and s the number of investigated duty points. With G' and G'' the complex modulus G^* and the phase angle δ are determined:

$$|G^*| = +\sqrt{G'^2 + G''^2} \quad \text{and} \quad \tan\delta = \frac{G''}{G'}$$

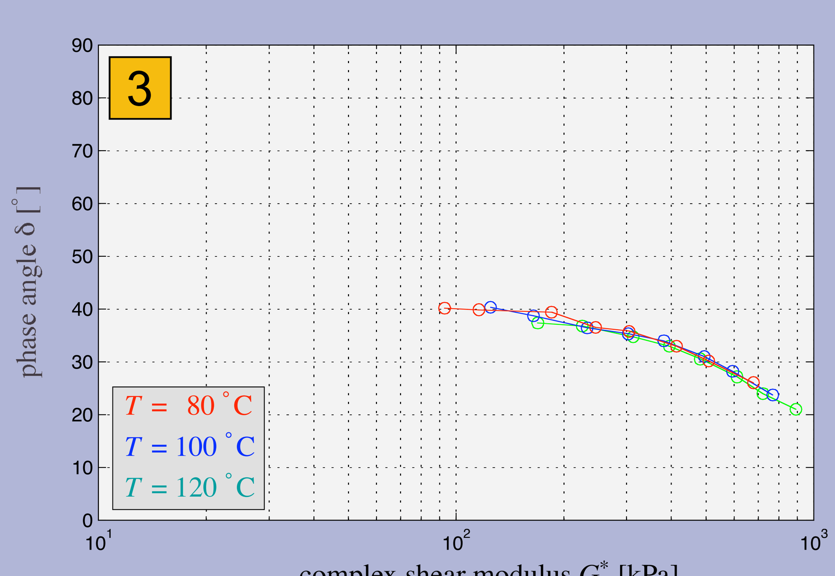


Figure 1 shows the results of one RPA experiment at a temperature of 100 °C. Both the storage and loss modulus increase montone with increasing angular frequency.

For the determination of viscoelastic material parameters two diagrams are well suited : In Figure 2 the so-called Cole-Cole diagram is shown. It plots the loss modulus G'' versus the storage modulus G'. In Figure 3 the so-called Black diagram is shown. It plots the phase angle δ versus the complex shear modulus G^*. Both diagrams show a temperature independence of the elastic properties. The obtained characteristics are similar for other rubber blends.

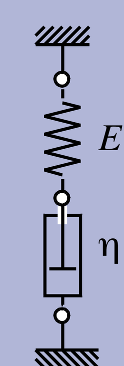
Application to Viscoelastic Material Models

1.) Maxwell model

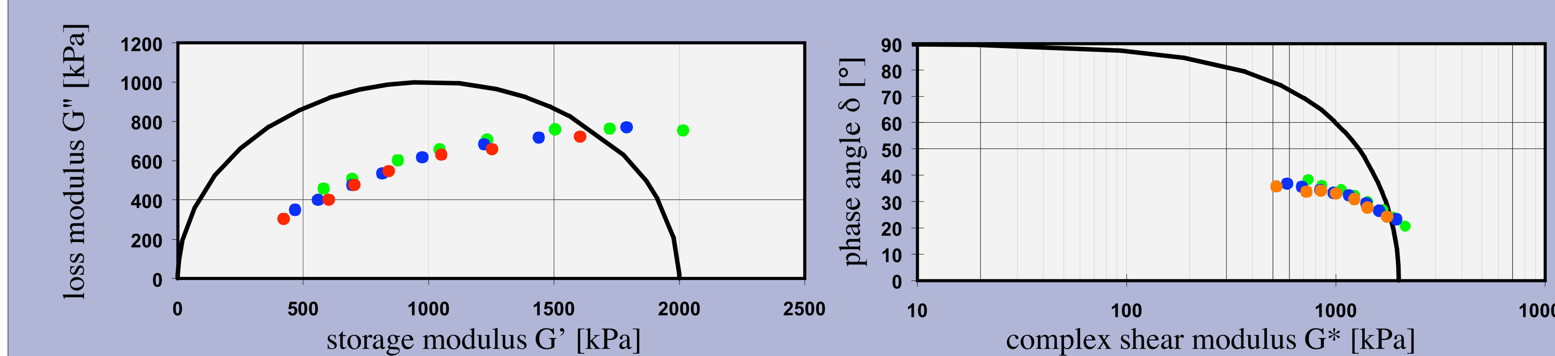
$$G'(E,\eta) = E\frac{\omega^2\lambda^2}{1+\lambda^2\omega^2}$$

$$G''(E,\eta) = E\frac{\omega\lambda}{1+\lambda^2\omega^2}$$

$$\text{with } \lambda = \frac{\eta}{E_x}$$



The Maxwell model is not applicable for the investigated rubber blends. This model leads to a semi circle in the Cole-Cole diagram, in the Black diagram a phase angle of 90 ° is obtained.

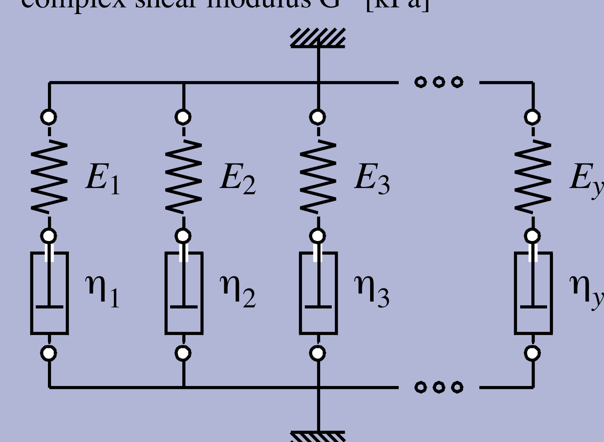


2.) Wiechert model

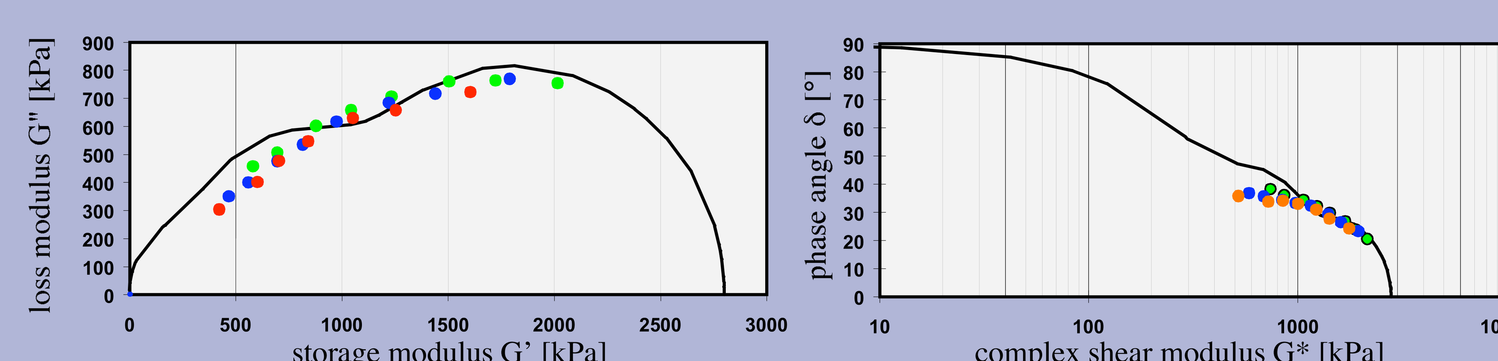
$$G'(E,\eta_x) = E_x\sum_{x=1}^{y}\frac{\omega^2\lambda_x{}^2}{1+\lambda_x{}^2\omega^2}$$

$$G''(E,\eta_x) = E_x\sum_{x=1}^{y}\frac{\omega\lambda_x}{1+\lambda_x{}^2\omega^2}$$

$$\text{with } \lambda_x = \frac{\eta_x}{E_x}$$



The Wiechert model can be described as a generalised Maxwell model. It achieves a better agreement as the Maxwell model. Disadvantage of this model is the large number of parameters.

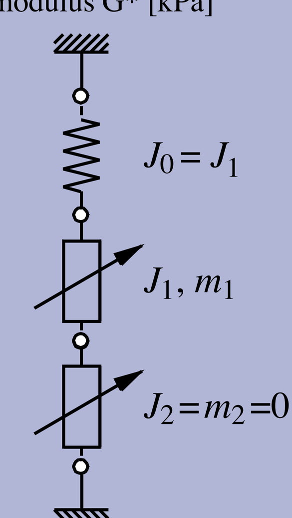


3.) Huet model

$$G'(J_0,J_1,m_1) = \frac{J_0}{\Delta} + \frac{J_1}{\Delta}\Gamma(1+m_1)\omega^{-m_1}\cos\frac{m_1\pi}{2}$$

$$G''(J_0,J_1,m_1) = \frac{J_1}{\Delta}\Gamma(1+m_1)\omega^{-m_1}\sin\frac{m_1\pi}{2}$$

$$\text{with } \Delta = J_0{}^2 + 2J_0J_1\Gamma(1+m_1)\omega^{-m_1}\cos\frac{m_1\pi}{2} + \left(J_1\Gamma(1+m_1)\omega^{-m_1}\right)^2$$



The Huet model yields the best agreement for all investigated rubber blends. For a small complex modulus values of phase angles < 90 ° are obtained, in spite of using two parameters.