EXPERIMENTAL IDENTIFICATION OF VISCOELASTIC PROPERTIES OF RUBBER BLENDS BY MEANS OF A TORSIONAL RHEOMETER

Herbert W. Müllner [1], Andreas Jäger [1], Josef Eberhardsteiner [1]

[1] Institute for Mechanics of Materials and Structures, Vienna University of Technology, Vienna, Austria

1. Introduction

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. The research work is performed in a co-operation with Semperit Technische Produkte Ges.m.b.H & Co KG which provides the rubber blends as well as the experimental devices. So far, several non-vulcanised rubber blends, containing mainly Ethylene propylene diene monomer (EPDM) and carbon black in different compositions, have been investigated. These are used for window sealings, pipeline constructions and various parts of cars. The materials are described as non-NEWTONian fluids with pseudo-plastic melt behaviour, i.e. the viscosity decreases with increasing shear strain rate.

Fig. 1: Rubber process analyzer (torsion-rheometer).

2. Experimental Investigations

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, which belongs to the group of cone-cone-rheometers, were carried out (see Fig. 1). This type of torsion-viscometer strains a sample in shear by oscillating the lower die sinusoidally. Oscillation frequency has been set from 0.1 to 30 Hz. The machine is designed to measure both elastic and viscous properties of elastomers and compounds. A complete description of this testing device has been summarised by DICK et al [1]. After a certain procedure the storage modulus G' and the loss modulus G'' for all investigated angular frequencies ω are provided. So far, three different temperatures were investigated, which are typical for the extrusion process of rubber profiles.

Generally, the constitutive modelling of the viscoelastic behaviour consists of two parts. After the type of viscoelastic model has been chosen, the corresponding material parameters have to be fitted to the measured data. For this purpose the experimental data is plotted in terms of two temperature independent diagrams, the COLE-COLE diagram and the so-called BLACK diagram. In Fig. 2 a typical COLE-COLE diagram for a rubber blend is depictured, i.e. the loss modulus G'' is plotted over the storage modulus G'. Both representations are common for the determination of viscoelastic properties of asphalt and bitumen, as described in JÄGER & LACKNER [4].

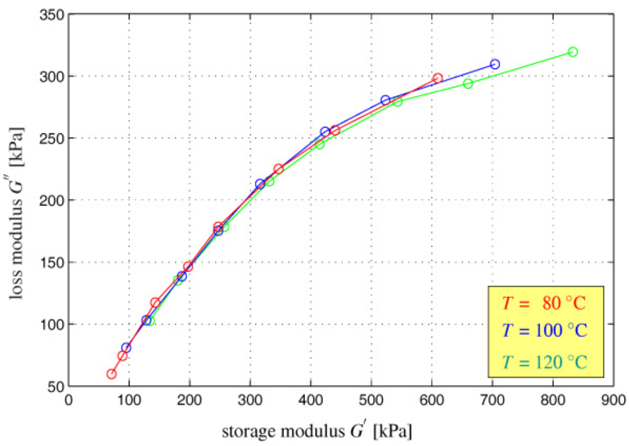

Fig. 2: Typical COLE-COLE diagram for rubber blends.

3. Models for the description of the viscoelastic behaviour of rubber blends

Viscoelasticity is concerned with materials which show strain rate effects in response to applied stress. These effects are described by means of creep under constant stress and stress relaxation under constant strain, respectively. In order to be able to predict the change of stress and strain distributions with time, a viscoelastic stress analysis is required. For the constitutive modeling of the viscoelastic behaviour of the investigated rubber blends three different models are used:

a) Maxwell model: This well-known model will be used to show that without introducing nonlinearity no realistic characterisation of rubber blends is possible. However, this model would be applicable for small angular frequencies which do not occur during the extrusion process.

b) Wiechert model: This parallel connection of an arbitrary number of MAXWELL models increases the agreement between experimental data and viscoelastic model. However, the expected nonlinear behaviour of rubber blends can only be modeled under application of a minimum of ten MAXWELL models. Therefore, the large number of material parameters is disadvantageous.

c) *Huet model:* This model consists of a series connection of one linear spring and two nonlinear dashpots. In order to keep the model as simple as possible two assumptions for the HUET model [3] can be used for rubber blends. With only one nonlinear dashpot and an equal creep compliance of the linear spring and the remaining dashpot good agreement between the experimental data and the viscoelastic model is achieved. Therefore two material parameters have to be determined.

Figure 3 shows the symbols for these three rheological models under indication of the corresponding material parameters.

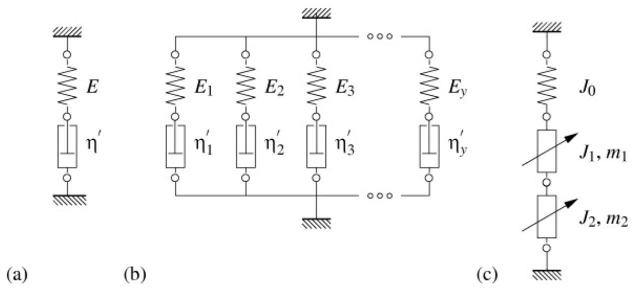

Fig. 3: Used viscoelastic models for rubber blends (a) Maxwell, (b) Wiechert, and (c) Huet model.

For the comparison of the experimental data $G'(\omega)$, $G''(\omega)$ 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]. Then, the material parameters are determined by means of a GAUSSian quadrature. The corresponding results can be compared with the experimental data as shown in the next chapter.

4. Experimental validation of used rheological models for rubber blends

Figure 4 shows the resultant curves for one amorphous structured rubber blend for all three rheological models. The depictured experimental data corresponds with the used temperatures in Fig. 2. The black curve shows the results for the used rheological model. Although the HUET model requires only two material parameters it leads to the best agreement between experimental and numerical results for all investigated rubber blends.

5. References

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.
3. C. Huet: *Etude par une méthode d'impédance du comportement viscoélastique des matériaux hydrocarbonés*, PhD-Thesis, Université de Paris I Panthéon Sorbonne, 1963.
4. A. Jäger, R. Lackner: nanoScale Characterization of Bitumen – Back Analysis of Viscoelastic Properties, *Proceedings of the 6th European Symposium on nanomechanical Testing*, 2005, 22 - 23.
5. H.W. Müllner, J. Eberhardsteiner & A. Wieczorek: Experimental Investigation and Identification of Material Parameters for Rubber Blends, *Proceedings of the 22nd Danubia-Adria Symposium on Experimental Methods in Solid Mechanics*, 2005, 188 - 189.

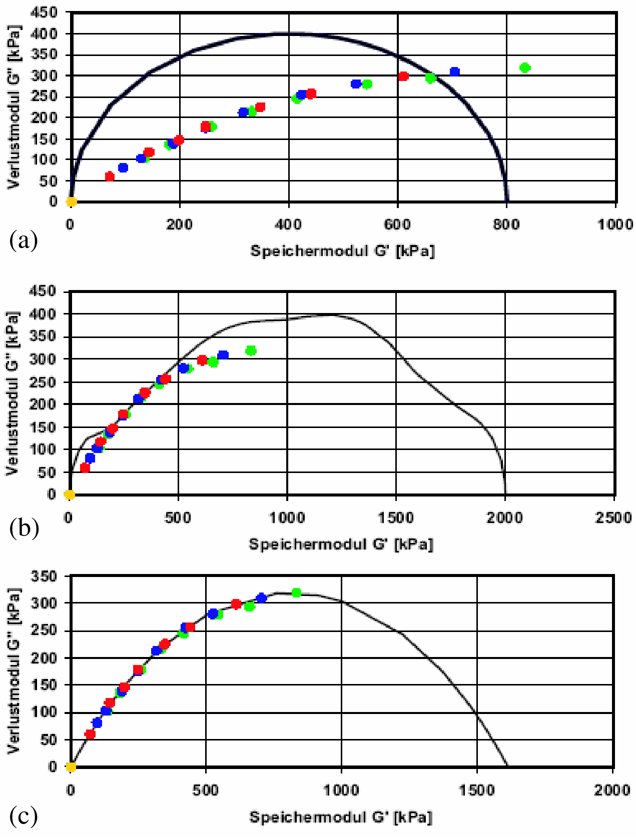

Fig. 4: Experimental validation of viscoelastic models (a) Maxwell, (b) Wiechert, and (c) Huet model.