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EXPERIMENTAL INVESTIGATION AND CONSTITUTIVE MODELLING OF HIGH DAMPING RUBBER

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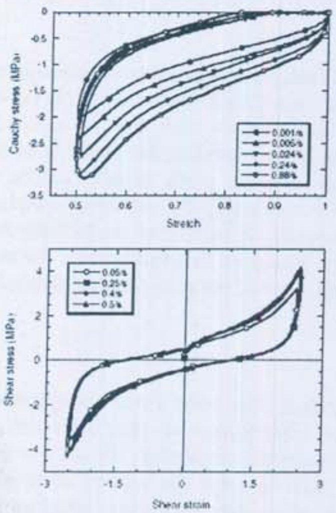
The rate-dependent material behaviour of filler-reinforced natural rubber and high damping rubber is investigated and a constitutive model of nonlinear finite viscoelasticity is proposed. To this end, quasistatic isothermal tests under finite compression and shear deformations are carried out. Monotonic and cyclic processes with and without relaxation periods were driven on a servohydraulic testing machine under strain control. The constitutive model is based on a multiplicative decomposition of the deformation gradient into elastic and inelastic parts in combination with a decomposition of the stress into equilibrium and non-equilibrium parts. In order to identify the constitutive equation for the nonlinear viscosity function, an experimentally-based procedure is proposed. It motivates to consider both the current overstress and the current deformation as arguments for the viscosity. Based on this motivation, the evolution equation for the inelastic deformation is formulated. The model fits the general trend of the experimental data quite well and is compatible with the second law of thermodynamics.

Introduction

Vulcanized elastomers are one of the most remarkable materials having a wide range of applications including tires, mounts, seals, etc. Fillers, for example, carbon black or silica are added for improving the strength and toughness properties. The recent development of high damping rubber (HDR) in base isolation devices for protecting buildings and bridges is another emerging dimension of applications of rubber (see e.g. Dorfmann and Burtscher, 2000). These bearings are usually made of thin horizontal rubber layers bonded with alternately placed horizontal steel plates. These plates imply large stiffness under vertical loadings and the rubber layers incorporate low horizontal stiffness when the structure is subjected to lateral loads. In order to estimate the performance of the bearings and thereby finding their optimum design, engineers usually deal with test data obtained from expensive tests conducted on prototypes or full scale specimens. On the other hand, there exists another possibility to develop a reliable numerical procedure like the finite element method for predicting the performance (see e.g. Besdo and Ihlemann 2003). Nevertheless, the core of such a numerical procedure depends on the constitutive model that is adequate enough for describing the major phenomena of HDR in the relevant deformation range. Under compression and shear deformations, HDR is expected to exhibit a high stiffness under low strains so that motions of the structure due to service loads, traffic and wind become as low as possible. However, when the structure is subjected to large cyclic or stochastic loads arising from earthquakes, the base isolation system should facilitate the absorption of the delivered energy through its hysteresis properties. To achieve all these features in HDR, a large amount of filler including carbon black, silica, oils and some other particles is added during the vulcanization process (e.g. Yoshida et al. 2004). Thus, HDR is developed to exhibit a strong rate-dependent response under monotonic loadings and significant hysteresis during cyclic loads. A study on modeling the quasi-static cyclic behavior of HDR under shear is reported in Yoshida et al. (2004). All these studies, however, revealed the existence of significant rate-dependence phenomena in HDR. This emphasizes the need for a thorough experimental characterization and the development of modeling techniques for rate-dependent behavior. The current work addresses these aspects.

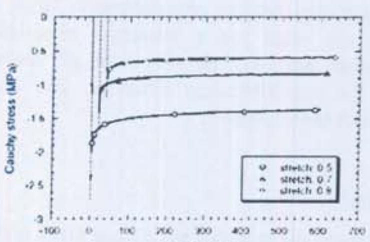
Experimental

In order to study the material behaviour HDR and NR specimens were tested under compression and simple shear. The specimens were manufactured by the Yokohama Rubber Company in Japan. The tests were carried out using a computer-controlled servo hydraulic testing machine. The displacement was applied in the vertical direction of the specimen and the force was measured by a load cell. The specimens used for the compression tests were cylindrical in shape, i.e. 41mm in height and 49mm in diameter. Since a lubricant and a polypropylene sheet were used to reduce the platen-specimen friction, it was possible to obtain a nearly homogeneous state of uniaxial compression. The simple shear specimens had a net shear area of 25mm x 25mm. All tests were carried out at room temperature. Further details of the test setups and the procedures are described in Amin et al. (2006). The Mullins effect was removed by a cyclic preloading which is common practice in experimental testing of rubber (see e.g. Lion 1996). In the preloading for compression tests, a strain rate of 0.01/s was applied for each cycle with a stretch of 0.5. In the shear specimens, the strain rate applied during the preloading up to 2.5 shear strain was 0.05/s. The real tests of interest were driven 20 minutes after completing the preloading to regularize healing effects that can occur in the specimens.



Each test was conducted with a new specimen that only contained the history of the preloading process.

Typical data of HDR under compression and shear is shown in the above figure. Besides the pronounced hysteresis we observe strong rate sensitivity during the loading phase and much weaker rate sensitivity during unloading.



In the presentation similar experiments on specimens made of NR are shown as well as single and multi step relaxation tests. Relaxation tests at different stretches on HDR are plotted in the above figure.

Results and Discussion

Under cyclic compression and shear both HDR and NR exhibit pronounced rate-dependent phenomena in the loading phases whereas during the unloading phases the rate-dependence is much weaker. Furthermore, the characterization of rate-dependent phenomena through simple relaxation experiments shows very fast stress decay at the very beginning of the relaxation process followed by a very slow decay in the long-term range. These observations provide a motivation to consider the nonlinear dependence of the viscosity in modeling the rate-dependent behavior of HDR and NR. To this end, a finite strain viscoelasticity theory based on a multiplicative splitting of the deformation gradient into elastic and inelastic parts is developed (e.g. Haupt 2000). The relation between the inelastic strain rate and the overstress describes the viscosity phenomena. Since the second law of thermodynamics only requires the viscosity to be positive, there is the possibility to formulate the flow rule by considering a nonlinear dependence on other process quantities or even internal variables. To maintain the physical meaning of the flow rule it is preferable to make such a generalization based on clear experimental evidences. In this context, we employ an analytical scheme founded on the basis of the multiplicative split of deformation gradient to analyze the data obtained from stress relaxation tests. In order to reduce the scattering of the numerically differentiated experimental data in this process, the moving averaging technique was applied. Since this technique does not eliminate all oscillations it should be better to smooth the overall signals by fitting an appropriate function on it, for example, an exponential function or a power law. We identify a nonlinear relation for the viscosity which is based on two power laws for the investigated materials. The finite strain viscoelasticity model with a nonlinear equation for the viscosity maintains a compact and simple form. The numerical simulation of the monotonic processes with different strain rates, simple and multi-step relaxation tests illustrate the adequacy of the developed model and the identified parameters. Although the analytic approach to evaluate the stress relaxation data to identify the evolution law for the viscosity has been utilized only for HDR and NR, we believe that this technique is conceptually applicable for other solid materials as well.

In order to represent the pronounced difference in the rate sensitivity under loading and unloading processes we introduced an additional scalar material function in the nonlinear viscosity which depends on the stress power.

References

1. A. Dorfmann; S. Burtscher *J. Struct. Engrg.*, 2000, *126*, 573.
2. J. Yoshida; M. Abe; Y. Fujin *J. of Engrg. Mech.*, 2004, *130*, 129.
3. A.F.M.S. Amin; A. Lion; S. Sekita, Y. Okui *Int. J. Plasticity*, 2006, *19*, 1610.
4. D. Besdo, J. Ihlemann *Int. J. Plasticity*, 2003, *19*, 1019.
5. P. Haupt, *Continuum Mechanics and Theory of Materials*, Springer, Berlin, 2000.
6. A. Lion *Continuum. Mech. Thermodyn.*, 1996, *8*, 153.