A MICROSTRUCTURE-BASED MODEL OF THE STRESS-STRAIN BEHAVIOR OF FILLED ELASTOMERS

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To calculate the mechanical behavior of a loaded component and its dependence on temperature, frequency and the history of deformation, the engineer needs a model which describes the stress-strain-behavior of filled elastomers. A compound of rubber and a powderous filler shows a behavior which is not known from the constituting phases and is governed by the structure and interaction of these. This in particular leads to a wide variation of material properties. In order to relate material parameters of rubber and filler to those of the vulcanizate we use a microstructure-based approach where material parameters are physical quantities, instead of mere fit parameters.

Core of the model is the hydrodynamic reinforcement of rubber elasticity by fractal filler clusters.[1] Stiff clusters immobilize parts of the matrix, so that the deformation is concentrated at a smaller part of the total volume, characterized by the hydrodynamic amplification factor X.[2] Under stress, clusters can break and become soft, leading to deformation of larger parts of the volume. This causes stress softening by decreasing X, which can be expressed as an integral over the "surviving", hard, section of the cluster size distribution and is a function of the maximum deformation that has occured in the entire deformation history.[3] On the other hand, cyclic breakdown (stress release) an re-agglomeration of soft clusters causes hysteresis.

To describe the hyperelastic behavior of the rubber matrix, we use the non-affine tube model with non-Gaussian extension.[4],[5] Filled elastomers also show a certain inelastic behavior called setting. The corresponding stress contribution is modeled by a semi-empirical square root dependency with respect to maximum deformation, and the temperature dependence is taken into consideration.

Even if a rubber matrix shows little temperature dependence, reinforcement and hysteresis decrease with increasing temperature. We attribute this to an Arrhenius-activated behavior of the filler-filler bonds (glassy polymer bridges of some nanometers in thickness). Considering separate activation energies for virgin and damaged bonds, the bond strength can be computed for temperatures exceeding the glass transition.

Using dumbbell specimens, we have done uniaxial stress-strain measurements in tension an compression. Parameterfits show that the model satisfactorily describes tension as well as combined compression-tension tests. Generally, the parameters lie in a physically reasonable range.

For the first time hydrodynamic reinforcement (formulated by a reinforcement exponent) and stress softening have been implemented into FE-code. A simulation of a rolling "Grosch" rubber wheel under load is shown.

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