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Finite element implementation of a microstructure-based model for filled elastomers

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ABSTRACT

To describe the inelastic mechanical behavior of filled elastomers a microstructure-based material model for uniaxial loadings has been developed. The generalization of this one-dimensional material description to a fully three-dimensional constitutive model has been accomplished by using the concept of representative directions. The generalized model shows a very good agreement with cyclic uniaxial tension and compression tests as well as simple shear measurements for several rubber compounds. The FE-implementation enables finite element simulations of technical components though the original input model predicts the material behavior for uniaxial loadings only.

1. Introduction

Numerous technical applications require the employment of filler-reinforced elastomers which are characterized by a complex mechanical behavior. Beside strong nonlinearities due to large deformations the inelastic effects like hysteresis, stress softening and residual stresses are often of great significance to the function of a structure containing rubber parts. Thus, the application of the finite element method in engineering leads to the demand of appropriate material models that are able to describe the complex behavior of filled elastomers adequately.

To establish a physical relation to the real structure of the material the development of constitutive models considering the microstructure of polymer chains and filler networks are desired. This usually means a huge amount of work, so that physically-based models are often restricted to a one-dimensional formulation describing uniaxial tension only. But the finite element method usually requires completely three-dimensional constitutive models. Thus, most of the existing material models for filled elastomers are derived phenomenologically (e.g. Rendek and Lion, 2009; Dorfmann and Ogden, 2004; Besdo and Ihlemann, 2003). But this does not only apply for models of particle-reinforced rubber but also for those of other polymeric materials. As an example it should be mentioned the phenomenological model of Zairi et al. (2005) which describes the stress–strain behavior and the strain rate dependency of glassy polymers (also see Zairi et al., 2008).

In this paper we present a microstructure-based model for filled elastomers whose material parameters are physical quantities. This so-called dynamic flocculation model has already been discussed in previous publications (Lorenz et al., 2010; Lorenz and Klüppel, 2009). But so far, the model could not been implemented into the finite element method because in its original form it describes the material behavior for uniaxial tension and compression only. In fact, the previous development of such a one-dimensional material model as an intermediate stage is a common approach in the field of constitutive

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