Visco-pseudo-hyperelastic characterization of polymer foams

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Abstract

Polymer foams are widely applied cellular materials due to their excellent energy absorption properties, chemical resistance and thermal conductivity, whereas the production foams are low-cost and simple. Due to their cellular (open- or closed cell) structure, polymer foams are lightweight, and its elastic properties can be characterized with low moduli. The utilization of natural and synthetic foam covers a wide spectrum of both industrial and everyday applications including sport equipment, seat cushions, thermal insulations, electromagnetic shielding, filtrations, tissue scaffolds, flexible sensors, etc. Therefor there is a significant need to accurately characterize the mechanical behaviour of foams and to develop suitable constitutive models for numerical simulations.
From the mechanical point of view, the polymer foams show a complex behaviour including: i) highly nonlinear elastic behaviour in the finite strain regime with significant volumetric strains, ii) significant rate- or time-dependent, viscoelastic properties and iii) stress-softening properties (i.e. Mullins-effect) when it is subjected to loading-unloading cycles. Similarly, to filled elastomers, this latter behaviour is the most significant in the first few cycles, and after it disappears from the material response if the maximal stretches are kept constant. As the maximal stretches are increased, the material response returns to the original loading path and the Mullins-effect reappears.

In this contribution a visco-pseudo-hyperelastic constitutive model is introduced for polymer foams that is able characterize the above mentioned combined finite strain nonlinear elastic and viscoelastic properties with the stress-softening Mullins effect including also the residuals strains. The proposed constitutive models comprise of a Maxwell-type linear viscoelastic network in parallel with a time-independent pseudo-elastic branch that characterize the long-term hyperelastic behaviour with the Mullins effect. In the proposed constitutive model, the time-dependent material behaviour can be given in the form of Prony-series, while for the time-independent behaviour is given by the compressible Hyperfoam hyperelastic model which is combined with the Dorfmann-Ogden model that also characterise the residual strains as well.

For the stress-solution a linear numerical integration scheme has been adopted both for the volumetric and the deviatoric part of the hereditary integral of the constitutive model. The proposed numerical integration scheme can also be utilized in the parameter identification process.

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For this, uniaxial and biaxial compression tests, relaxation tests, cyclic loading tests were performed on open and closed cell polyurethane foam specimens, where all deformation components are well-observable. Based on the stress-integration scheme various parameter fitting strategies are proposed including a separated fitting approach where the parameters of the different sub-models are fitted separately and a one-step fitting procedure where all the parameters are fitted simultaneously to all available material test data. Finally, the efficiency and the sensitivity of the fitting procedures are evaluated using a complex non-homogeneous validation compression tests.

References

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