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Visco-hyperelastic constitutive law for modeling of foam's behavior

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ABSTRACT

This paper proposes a new visco-hyperelastic constitutive law for modeling the finite-deformation strain rate-dependent behavior of foams as compressible elastomers. The proposed model is based on a phenomenological Zener model, which consists of a hyperelastic equilibrium spring and a Maxwell element parallel to it. The hyperelastic equilibrium spring describes the steady state response. The Maxwell element, which captures the rate-dependency behavior, consists of a nonlinear viscous damper connected in series to a hyperelastic intermediate spring. The nonlinear damper controls the rate-dependency of the Maxwell element. Some strain energy potential functions are proposed for the two hyperelastic springs. compressibility effect in strain energy is described by entering the third invariant of deformation gradient tensor into strain energy functions. A history integral method has been used to develop a constitutive equation for modeling the behavior of the foams. The applied history integral method is based on the Kaye–BKZ theory. The material constant parameters, appeared in the formulation, have been determined with the aid of available uniaxial tensile experimental tests for a specific material.

1. Introduction

Elastomeric materials are often used to mitigate damages caused by impulsive or impact loads because of their low modulus, high damping and large extensibility. An Instant isolation bearings protect buildings and bridges from earthquakes by imposing a layer of low shear modulus between the structure and ground and allowing lateral, almost rigid body motion of the structure [1]. Shock absorber arrests impacting bodies with minimum force transmission by undergoing a sufficiently large deflection before bringing the body to rest. They also reduce large-amplitude vibrations and minimize rebound by dissipating energy via internal damping [2]. The common characteristic of the above applications is that the elastomer is loaded under a combination of large strain and wide range of strain rates [3,4].

The mechanical behavior of elastomeric materials under strain rate and large strain is more complicated [5]. The reason is that performing strain rate tensile tests on foams is very difficult.

Constitutive models have been developed addressing different aspects of the above observations. All these proposed models can be divided into two categories: equilibrium models and time-dependent models [6,7]. Most of the early works was devoted to predictions of the equilibrium response [8]. Fewer models attempt to predict the observed time-dependence for general strain histories. In more recent times, there have been renewed efforts to understand and model these effects [9–12]. However, most models capture only a subset of the experimentally observed phenomena and are mainly phenomenologically based. They are specific for particular materials being studied and can not easily be extended to other types of elastomers. Bergstrom and Boyce [13] developed a so-called BB model for rubbers which captures the nonlinear time-dependence deviation from the equilibrium state using a spring-dashpot network. Regarding foams, the paper is based on this network. It works very well for up-to-80% strain ranges and strain rates less than 1 s^{-1}. Recently, Ronan et al. [14] have modeled behavior of elastomers by using superposition method for considering effects of time and temperature. Another visco-hyperelastic model for rubbers and foams under strain rates proposed by Yang et al. [15,16] captures the three-dimensional large compression behavior of two rubbers with different hardness (SHA 30 and SHA 40) and two foams with different hardness (PORON-4701-59-25045-1648 and PORON-4701-59-20093-1648) at the strain rates ranging from static to 1000 s^{-1} using BKZ theory.

The objective of this paper is to develop a constitutive equation for elastomeric materials under large strain more than 100%, and considering strain rate-dependency of behavior of these materials. Such constitutive equations can then be used to predict the structural response of the elastomeric components under dynamic loadings. First, a static hyperelastic constitutive equation for these materials is considered; then, it is followed by examination of a viscoelastic constitutive model. The two are then combined to yield a visco-hyperelastic constitutive relationship for foams, loaded under different strain rates. Three different strain energy

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