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Pseudo-elastic description of polymeric foams at finite deformation with stress softening and residual strain effects

X.F. Zhang [a,b,*], F. Andrieux [a], D.Z. Sun [a]

[a] Fraunhofer Institute for Mechanics of Material, Wöhlerst. 11, 79108 Freiburg, Germany
[b] School of Mechanical Engineering, Nanjing University Science and Technology, Nanjing, Xiaolinwei 200, China

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ABSTRACT

Polymeric foams are typical materials for energy absorber in such areas as aircraft, car industry and in the field of electronic packaging. Besides the typical hyperelastic behaviour, non-linear stress–strain behaviour in large elastic deformation, polymeric foams may also exhibit some inelastic effects, like stress softening and residual strain. In this paper we first describe some experiment results that illustrate the stress softening in compressible expanded polypropylene (EPP) foams together with associated residual strain effects. Then, based on Ogden and Dorfmann's results, a pseudo-elastic model is introduced to capture the stress softening and residual strain effects by including of two variables in the energy function. Numerical simulations of uniaxial-compression tests of two types of EPP foam are used to determine the material parameters of Ogden's model, stress softening and residual strain effects. The numerical simulations indicate that the pseudo-elastic model provides reasonably accurate predictions of the inelastic behaviour of polymeric foam.

1. Introduction

Polymeric foam materials such as expanded polypropylene (EPP), polystyrene (PS) and polyurethane (PU) are often used in a variety of applications in ranging from the absorption of energy, the protection of components and in comfort situations, and with the mechanic properties of low Poisson's ratio, high compressibility and strain rate sensitive and slowly recovery rate. Unlike other polymer materials, the polymeric foam is neither crushable nor totally recoverable. Its particular stress–strain response shows very large strains with strongly non-linear behaviour which is described by several constitutive hyperelastic models based on the definition of different strain-energy functions. In the case of compressible polymer foam, a number of strain-energy functions are available in the literatures based on the work of Monney [1], Rivlin [2] and Ogden [3], and the most known of them are nowadays available in many commercial FEM software, such as ANSYS, LS_DYNA and ABAQUS. The usual way to considerate the hyperelastic behaviour for compressible polymer foam is decomposing the strain-energy function into the isochoric and the volumetric part using the modified stretches and the volume change (Jacobian). Hamid [4] and Doll [5] describe the choice of compressible strain energy density functions and the development of volumetric strain-energy functions. In existing models, the Ogden–Storakers [6,7], Schrodt [8] and Hill [9] hyperelastic foam model provides reasonably accurate predictions for describing the non-linear mechanical behaviour of highly compressible polymeric foam.

Besides hyperelasticity, the polymeric foam exhibits some inelastic phenomena, e.g., the stress softening and residual strain effects. Polymeric foams show a significant hysteretic response during unloading after prior loading in uniaxial tension, compression or shear, for example, the stress on unloading is significantly lower than that during loading at the same strain. This difference in the stress to the same strain level under loading and unloading depends on the polymer foam material properties. Despite of the hysteretic effect, the polymeric foam does not in general return to its initial state corresponding to natural stress-free configuration after loading and unloading, but exhibits a residual strain after all the loadings were released. This residual strain will slowly decrease in time and essentially disappears after a sufficiently large period of annealing. The magnitude of the residual strain depends on the polymer type and the maximum stretch of the foam specimen prior to unloading. For stress softening or hysteretic effect, Ogden [10,11] and Dorfmann [12] used a simple phenomenological model to account for the softening effect in filled rubber elastomers. Their model is based on the theory of incompressible isotropic elasticity amended by incorporation of a single continuous parameter, and can be used for modelling loading, partial or complete unloading and the subsequent reloading and unloading behaviour of rubber-like materials. For other material models

* Corresponding author at: School of Mechanical Engineering, Nanjing University Science and Technology, Nanjing, Xiaolinwei 200, China. Tel.: +86 2584317853.
E-mail address: lynx@mail.njust.edu.cn (X.F. Zhang).

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