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Automation in forming constitutive relation of linear elastic foams

Tinggang Zhang
Mechanical Engineering Department, University of Alaska Fairbanks, Fairbanks, AK99775,
E-mail: tgzhang@acsalaska.net.

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Abstract

An automation procedure in forming the constitutive relation of foams or cellular materials is proposed in this paper, which could be employed in multi-scale finite element analysis. Considering the effort spent in developing the constitutive relation of foams in both analytical and experimental methods, the proposed procedure provides an economic, robust, scalable, and accurate methodology and has practical implications in the study of the mechanical behavior of foams or cellular and composite materials. This methodology is a combination of the finite element method, symbolic calculation, and the micromechanics homogenization scheme. For a representative unit cell of foam microstructure, the symbolic analysis at microscopic level is first conducted to find the primary variable at each node of its finite element model. The macroscopic strain defined at the external surface of the unit cell is then determined using volume average homogenization scheme. Based on the assumption that there exists the strain energy potential, the constitutive relation is finally obtained. The proposed procedure is used to derive the constitutive relations of a cubic unit cell with open cell structure. From the constitutive relation, the uniaxial elastic moduli, the bulk modulus, and Poisson's ratio are deduced. The comparison between the automatically derived elastic moduli and those obtained from the available semi-empirical and analytical models agree well at low and medium relative densities. Parametric study shows that both isotropic and anisotropic constitutive relations could be used to characterize the mechanical behavior of foams depending on their strut geometries.

Key words: *Automation, Constitutive relation, Elastic foam, Cellular materials*

1. Introduction

Foams or cellular materials have found broad applications in a variety of engineering disciplines and in our everyday life. Most of the materials are traditionally synthesized or manufactured foams or honeycombs from polymers, metals, and ceramics and naturally existing materials like human tissue, bones, wood, and sponge. These materials' unique cellular structure and corresponding physical and mechanical properties at macroscopic level brought not only their applications in automobile and aircraft structures, but also their particular usefulness in shock mitigation and energy absorption, in thermal and sound insulation, in water- and air-filtration systems, and in biological engineering. The difficulty in accurately characterizing the mechanical properties of

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