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Energy-Based Approach to Limit State Criteria of Cellular Materials

Abstract

Cellular materials are made of interconnected network of cells with solid edges. The 2D or 3D regular geometric arrangements of solid skeleton are called honeycombs, while the other cellular materials are called foams. The term solid foams is commonly used for describing three-dimensional cellular materials with highly dispersive solid phase arranged into cells-polyhedra, which fill the three dimensional space. The cells can be either open or closed. Such a kind of structure can be found in many natural materials, for example cork, wood and cancellous bone. High technology foams are manufactured from polymers, ceramics and metals and can be used in reinforced lightweight structures, packaging and crash protection systems. Because of their structure natural and synthetic cellular solids show unique physical properties, which provide their optimal functionality. The development of mechanics of cellular solids is documented in L.J.Gibson,M.F.Ashby [1].

We assume that essential macroscopic features of mechanical behaviour of cellular materials can be inferred from the deformation response of a representative microstructural element. The analysis is based on material properties of a solid phase and topological arrangement of cell structure for a wide range of cellular materials characterized by different types of symmetries, morphologies and type of solid materials from which microstructure is built. The aim of the paper is to develop a constitutive description of the linear elastic behaviour of honeycombs and open cell foams on the basis of microstructural modellingof their skeleton. An analytical formulation of force-displacement relations for the skeleton struts can be found by considering the affinity of node displacementsin tensile, bending, and shear deformation.The elementsof the stiffness matrix for a single cell are expressed as functionsof the compliance coefficients for stretching and bending of struts. The energy-based Rychlewski criterion of the limit state in anisotropic solids, which in our case correspondsto the limit of linear elasticity, is considered [2]. We propose the identification of this criterion for cellular materials and show how to calculate the critical energy density pertinent to a particular orthogonal energy state accounting for elementary interactions in a microstructure. The study based on the assumption of linear elasticity leads to simple analytical formulae. The modelling possibility of the influence of the strength of struts forming the cellular structures of diverse symmetries on the distribution of energy limits was studied. Basing on the available data, the analysis was conducted with the lesser or greater approximation for the cases of cancellous bone and diverse cellular materials made of ceramics, polymers or intermetalics.

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