Effect of Cell Morphology on the Macroscopic Mechanical Behavior of Three-Dimensional Open-Cell Foams

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Abstract

Solid foams are novel materials that have found numerous applications in the construction of light, stiff structures during the past few decades. At the micro-level, solid foams possess a cellular structure that comprises either closed or open cells. Open-cell foams, which are the concern of this study, are described as a network of inter-connected struts (or ligaments) with beam-like action. In order to assess their macroscopic mechanical behavior one needs to account for the micro-structural mechanisms inherent in such materials. Homogenization methods provide a natural solution by linking the response of each material point on the macro-scale to the response of a representative portion of the microstructure, namely RVE, on the micro-scale. Current study employs a version of these methods to study the effect of cell shape (cell morphology) variation on the macroscopic uniaxial compressive response of open-cell foams.

Keywords: Constitutive modeling, Homogenization, Open-cell foams, Morphology

1. INTRODUCTION

Solid foams are novel materials with outstanding characteristics that are finding more applications in the automotive and aerospace industry. Their high stiffness to weight ratio and exceptional energy absorption properties make them unique candidates for uses in lightweight structures, sandwich cores and mechanical energy dissipators [1].

At the micro-level, foam materials benefit from a cellular structure that comprises either closed or open-cells. Closed-cell foams, in their liquid state, can be imagined as an assembly of bubbles pressed against each other. The bubbles can be made in a variety of materials, from polymers to metals, depending on the particular application they are aimed at. Final product results from the solidification of bubbles. Each bubble (or cell), in this case, encloses a particular volume of void recognized by its faces. In short, closed-cell foams can be described as *light-weight* porous materials that are composed of voids with thin faces. In contrast, open-cell foams evolve when bubbles' faces burst in the liquid state and voids join. The resulting material can be pictured as a network of inter-connected struts with beam-like action.

The uniaxial compressive test on a foam specimen typically shows three distinct responses characterized by the so-called elastic, plateau, and densification regions in the stress-strain curve. Except for the last zone, which will not be examined in this study, the uniaxial curve can be ideally characterized by the four parameters of the Young's modulus (E), plateau stress (σ_P), the strain at which plateau initiates (λ_i), and the length over which plateau occurs ($\Delta\lambda$) (see Figure 1). For convenience, we will later refer to these parameters as *uniaxial properties*.

The mechanical design of foams requires their mechanical properties to meet certain criteria. These criteria can be satisfied by careful selection of the base material and the microstructural morphology. However, the selected material has to be manufactured, and manufacturing is by no means a perfect process. As a result, there is always a threat that the properties of the final material differ from the ones expected. The current study addresses this issue by exploring the effect of morphological imperfections on the uniaxial properties of *regular* open-cell foams. Such investigation requires an appropriate approach capable of relating the microstructural characteristics to the effective behavior of the material. Homogenization methods provide an approximate, yet promising, way to handle this problem.