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The influence of mesoscopic irregularities on the macroscopic behavior of metal foam

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ABSTRACT

Introduction

Due to their useful properties in lightweight construction and due to their excellent behavior in energy absorption for example in crash mechanics, metal foams became an interesting, often utilized and investigated material. For the determination of the mechanical properties of metal foams without the help of expensive experiments, a way for computing these properties is searched. The problem in doing so is that metal foams can be composed out of randomly distributed edges and faces with varying thickness and of other inhomogeneities on the mesoscale like imperfections.

In order to calculate the mechanical properties, a finite element method model of a sample of metal foam is observed. Since the structure of metal foam is very irregular, the sample size must be big enough so that it can be considered as a representative volume element. The results of a simulation are then the effective properties of the observed metal foam.

In order to minimize the computational effort, periodic volume elements of metal foam are observed being smaller than the mentioned representative volume element. The obtained apparent mechanical properties, which are averaged over the volume of the sample, vary with each representation. In order to find bounds for the effective mechanical properties, load cases representing the classical bounds of Voigt and Reuss are used. These load cases are expressed by kinematic uniform boundary conditions (KUBC) for the Voigt- and static uniform boundary conditions (SUBC) for the Reuss-bound ([2],[4]). For the stiffness tensor $\boldsymbol{C}$ and the compliance tensor $\boldsymbol{S}$, combining the macroscopic stresses and strains, these relations can be summarized as follows:

$$\boldsymbol{C}^{\text{Reuss}} \leq \boldsymbol{C}^{\text{app}}_{\text{SUBC}} \leq \boldsymbol{C}^{\text{eff}} = (\boldsymbol{S}^{\text{eff}})^{-1} \leq \boldsymbol{C}^{\text{app}}_{\text{KUBC}} \leq \boldsymbol{C}^{\text{Voigt}}$$

or respectively

$$\boldsymbol{S}^{\text{Voigt}} \leq \boldsymbol{S}^{\text{app}}_{\text{KUBC}} \leq \boldsymbol{S}^{\text{eff}} = (\boldsymbol{C}^{\text{eff}})^{-1} \leq \boldsymbol{S}^{\text{app}}_{\text{SUBC}} \leq \boldsymbol{S}^{\text{Reuss}}$$

Modeling the volume element on the mesoscale

Starting with honeycombs as written in [1], mesoscopic models for an open-celled metal foam are derived. Since the main deformation mechanism of metal foams under compression is bending, the cell edges are represented by beams of Euler-Bernoulli type. With the help of so called Voronoï-maps, which are based on the grain growing from randomly distributed points, periodic volume elements with random structure are computed and analysed by a commercial finite element software.

To get more information of the macroscopic behavior in dependence on the structure of the mesoscale, imperfections are introduced by randomly erase cell edges or cell vertices. Furthermore the thickness t of the cell edges at the position x on their mid line can be varied with the help of the quadratic approach

$$t(x) = t_0 \left[3(1 - t_{\text{rel}}) \left(\frac{2x}{\ell} - 1 \right)^2 + t_{\text{rel}} \right] \quad [3],$$

keeping the relative density $\rho_{\text{rel}} = \frac{\rho_{\text{foam}}}{\rho_{\text{solid}}}$ of the metal foam constant (parameter t_0). The curvature of the thickness can be set by the other parameter t_{rel}.

With the help of some representations of these volume elements, the distributions of the mechanic properties can be derived and measured, for example, by the mean value and the standard deviation [5].

Step to the macroscale

One possibility to get information of the macroscopic behavior of a body consisting out of metal foam, is to analyze the body consisting of a homogeneous material corresponding to the mean values of the mechanical properties computed on the mesoscale. In this contribution the mechanical properties are varied locally by analyzing a mesoscopic volume element in each integration point on the macroscale and several representations are computed for the observed body. The results are statistically evaluated. With this hierarchical method the propagation of uncertainties from the mesoscale to the macroscale can be assessed.

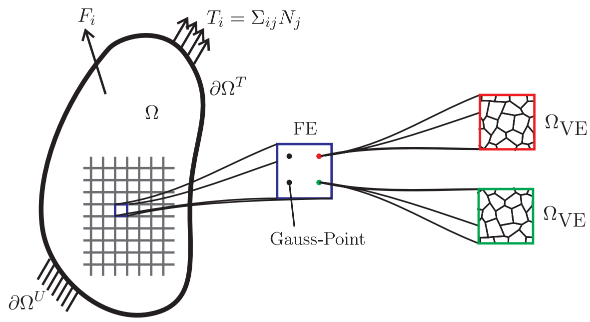

Figure 1: Schematic step: from the mesoscale to the macroscale

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