Numerical simulations of auxetic metallic foam fabrication process

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Abstract

The subject of the study are metallic open-cell foams. In particular, the foam of Cu skeleton is considered. To simulate the deformation processes of such a material the finite element program ABAQUS is used. The *tomogram* reconstructing the 3D virtual volume of a real foam structure with the use of computed tomography is applied to formulate the finite element model of the convex open-cell foam cube of the edge of 800 voxels, 1 voxel = 2.52 10^{-6} m, created with application of ABAQUS/CAE. The initial cube of convex open-cell skeleton is subjected to three-axial compression applied as uniform displacements normal to the surface of cube faces in order to simulate numerically auxetic foam fabrication process. Repeating the process of three-axial compression for different displacement boundary conditions the optimal values of the face displacements can be obtained with respect to the required structure of the auxetic foam skeleton.

Keywords: auxetic foam, micro-tomography, tomograms, negative Poisson's ratio, numerical simulation, metallic foam, open-cell foam, foam fabrication

1. Introduction

Depending on manufacturing method of metallic foams the resulting skeleton consists of convex or concave shape cells. The materials with convex cell structure reveal positive value of Poisson's ratio, that is if a sample is stretching, then its cross-section is getting thinner. The complex structure of the foam related with reentrant cells produce the opposite effect during stretching of a sample, i.e. its cross-section is increasing. Then the negative Poisson's ratio is observed and such foams become auxetic.

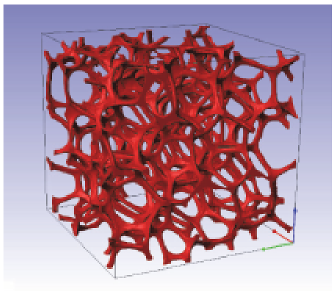
The aim of the present study is to tackle the following problems:

- how to produce *tomograms*, i.e. 3D virtual volume reconstructions of real foam structure with use of computed tomography [1],
- elaboration of the numerical simulations methodology of auxetic foam fabrication process with use of the *tomograms*.

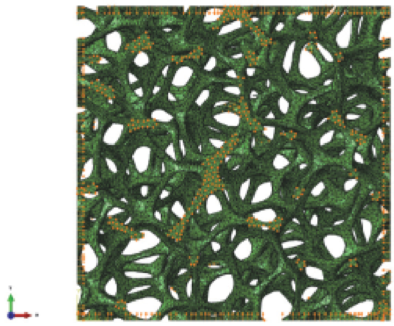
The motivation for such an approach can be found in [2], where the following statement was formulated: *„Ideally, in an attempt to reduce laboratory expense, one would like to make predictions of a new material's behaviour by numerical simulations, with the primary goal being to accelerate the trial and error laboratory development of new high performance materials."* – from Preface, p. v. Accordingly, numerical simulation of fabrication process of auxetic foam is developed.

2. Description of the procedure

The subject of the study are metallic open-cell foams. In particular, the foam of Cu skeleton is considered. To simulate the deformation processes of such a material the finite element program ABAQUS is used. Finite element discretization is derived from real foam specimen with the use of computed tomography images implementing the procedures described in [3], [4], [5]. The initial cube of convex open-cell skeleton is subjected to three-axial compression applied as uniform displacements normal to the surface of cube faces, Fig. 1. In all numerical calculations the skeleton material is assumed as isotropic Cu – Young's modulus: 126 GPa, Poisson's ratio: 0.3 and yield limit: 20 MPa. The computational methods and procedures applied in the analysis of the micro tomography observations and numerical simulations of deformation process are presented in detail. An example is displayed in Fig. 1, where



a)



b)

Figure 1: a) Initial configuration of the skeleton of the convex open-cell Cu foam of 94% porosity, b) finite element model with the scheme of displacement boundary conditions.

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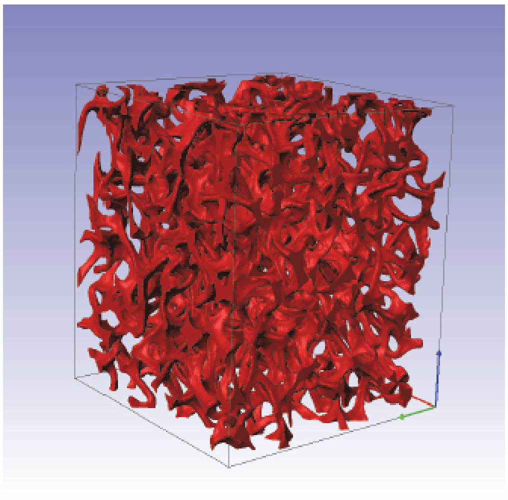
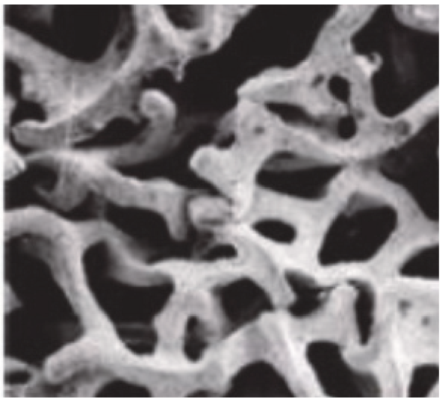
the initial configuration of the skeleton of the convex open-cell Cu foam of 94% porosity is presented and the finite element model of the foam cube with the edge of 800 voxels is depicted. The dimension of a finite element corresponds to the dimension of a single voxel and is equal to $2.52\ 10^{-6}\ m$. The finite element mesh is obtained with use of ABAQUS/CAE.

3. Presentation of the results

Presentation of the results of numerical simulation is given in Figure 2.



a)



b)

Figure 2: a) The resulting structure of the virtual auxetic foam with the estimated Poisson's ratio: - 0.3, b) the picture of real Cu skeleton with reentrant cells obtained in [6]

Figure 2 compares a configuration of the structure of the virtual auxetic Cu foam resulting from numerical simulations with the picture of real Cu skeleton with re-entrant cells obtained experimentally by Lakes [6]. Both pictures reveal a striking similarity of topology and geometry of the skeleton. The results presented in [7] show that the similar re-entrant skeleton structure can be obtained also for other materials, e.g. polyether foams

4. Conclusions

The results of the above analysis can be applied for the prediction and optimisation of manufacturing requirements. Repeating the process of three-axial compression for different displacement boundary conditions the optimal values of the face displacements can be obtained with respect to the required structure of the auxetic foam skeleton. Analysis of the sequence of calculated deformation processes of the virtual cube leads to the required displacements of the faces of real Cu specimen and enables fabrication of auxetic foam without any damage or crushing of the skeleton ribs, what is quite frequently observed in real manufacturing processes. The proposed procedure of virtual experiments can be applied for convex cell foams of diverse skeleton materials and provides the possibility of omitting the expensive trial and error experiments leading very often to the total damage of real skeleton of the investigated metallic foam.

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