The foamed structures in numerical testing

Antoni John[1]* and Małgorzata John[2]

[1] *Faculty of Mechanical Engineering, Institute of Computational Mechanics and Engineering, Silesian University of Technology*
Konarskiego 18A, 44-100 Gliwice, Poland
e-mail: antoni.john@polsl.pl

[2] *Faculty of Mechanical Engineering, Institute of Fundamentals of Machinery Design, Silesian University of Technology*
Konarskiego 18A, 44-100 Gliwice, Poland
e-mail: malgorzata.john@polsl.pl

Abstract

In the paper numerical simulation of the foamed metal structures using numerical homogenization algorithm is prescribed. From the beginning, numerical model of heterogeneous porous simplified structures of typical foamed metal, based on the FEM was built and material parameters (coefficients of elasticity matrix of the considered structure) were determined with use of numerical homogenization algorithm. During the work the different RVE models of structure were created and their properties were compared at different relative density, different numbers and the size and structure of the arrangement of voids. Finally, obtained results were used in modeling of typical elements made from foam metals structures - sandwich structure and profile filled with metal foam. Simulation were performed for different dimensions of cladding and core. Additionally, the test of influence material orientation (arrangement of voids in RVE element) on the maximum stresses and displacement during bending test was performed.

Keywords: foam metal structures, multi-scale modelling, numerical homogenization, RVE, FEM, sandwich structure

1. Introduction

The foam metal structures are widely used in many industries. One can denoted that expanded metal is used often as components of a vibration damping or impact-absorbing casing. This is due to the high energy absorption property of the metal foam, many times larger than the native material. They are also used in many types of machine tools for impact protection as vibration isolators, in other equipment and sometimes components. Many applications one can observe in automotive, wherein the foam metal used to reinforce the hollow profile in the design of safe crumple zones. Crumple zones safe are responsible for absorbing the energy created during impact.

However, in the literature we can find many papers on the metal foam but few of them concerns the numerical simulation. Most of these concern the fluid flow in porous materials [2,4] or heat transfer [4,6]. Modeling is focused on the structure with open cells De Jaeger at al. in [3] present numerical model as trabecular structure. Sadovskaya in [8] presents numerical simulation of deformation of a metal foam but in the theoretical domain only. We can find the works using numerical homogenization of the bone scaffold structures [7], of materials with internal cracks or in analysis of composite with inclusions [1].

Presented here a new approach to the modeling of the metal foam consists of closed cells ball-shaped and cylindrical voids represented by means of RVE elements with different number, size and distribution of the pores (voids). Numerical homogenization method is applied to calculate material coefficient matrix of simulated structures.

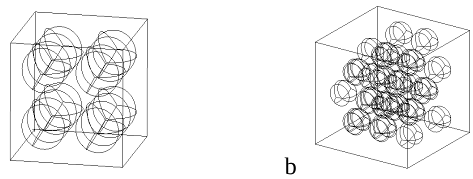
2. Numerical homogenization

Numerical homogenization is used for modelling the materials with repetitive internal structure.

The elements which represent the structure of the micro call RVE. RVE models should represent the microstructure to the extent possible to identify the properties of the medium in composition. It is important RVE small enough to make it simple as possible so that we can carry out its detailed analysis, yet large enough to be able to represent the microscopic structure of the tested structure. There are three types of approaches to the use RVE. Here, the adoption of a constitutive law at the macro level, testing of material parameters is applied.

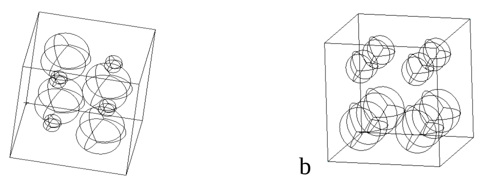
The simplified models of foam metal structures were prepared using FEM. The MSC.Software system was used. In RVE elements the size of voids, the number of voids (density) and position were changed. As a basic material assumed pure aluminum (Young modulus E = 69 GPa, Poisson ratio ν = 0.33). During numerical simulations 13 models of RVE elements were prepared.

Each RVE element was modeled as a cube measuring 5x5x5 mm. The simplest element had one void with a radius of 2.25 mm centrally positioned. The next four RVE elements are regular, further 5 elements are irregular and 3 last elements are with cylindrical voids. The selected examples of each type of RVE elements are showed in Fig. 1-3. As a result of numerical analysis the values of the coefficients of elasticity matrix for defined materials can be determined. More details concern numerical calculations and final form of the elasticity matrix for another RVE elements one can find in [5].



a b

Figure 1: Regular RVE models: a -model 2, b - model 3



a b

Figure 2: Irregular RVE models: a - model 7, b - model 8

*The research is partially financed by research project no. BK-220/RMT-4/2017 (10/040/BK17/0045).

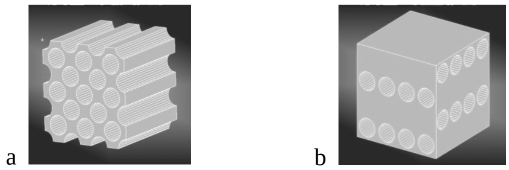


Figure 3: Cylindrical RVE models: a - model 11, b - model 12

3. Numerical simulation and discussion

In this study developed 3D model of RVE elements and the coefficients of elasticity matrix were determined for different number and size of voids and their various positions. It means that influence of geometrical features on material parameters was tested. Next, using results obtained from numerical homogenization a numerical simulation of three-point bending test was proposed. Sample used in a test was prepared as a sandwich structure where core and claddings were made from pure aluminium. During the test it was investigated the effect a change in thickness of the core and claddings on the displacement and stresses values. Displacement and stresses have been shown with respect to the total weight of tested sample. Finally, using the same sample, the test of influence material orientation (arrangement of voids in RVE element) on the maximum stresses and displacement during bending was performed.

For testing the mechanical parameters of sandwich structures numerical simulation of tree point bending test was performed. The sample with a length of 220 mm, a height of 30 mm and 50 mm wide was modelled. Cladding and core were made from pure aluminium (Young modulus 69 GPa, Poisson's ratio 0.33). Acting force equals 100 N.

The first test was investigated the effect a change in thickness of the claddings at a constant thickness of the core on the displacement and stresses values. Figs. 4 and 5 show obtained results.

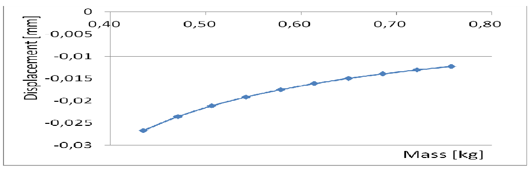


Figure 4: The maximum displacement of structure as a function of the mass with the constant thickness of the core

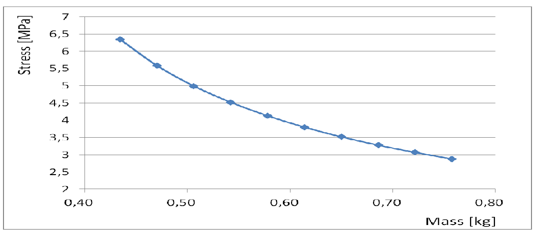


Figure 5: The maximum stresses of structure as a function of the mass with the constant thickness of the core

In the next step thickness of the claddings was constant and a thickness of the core changed. The results are presented in Figs. 6 and 7. Displacement and stress values are shown on the total weight of the system under study. In the first case, it was observed that increasing the share of the claddings increases the rigidity of the structure, but the layer is thicker the rapidly increasing mass model. In the second case it was found that, at constant thickness claddings (2 mm) too greatly increasing the thickness of the foam layer (over 20 mm) is uneconomical because it does not introduce any significant changes in the properties of the structure.

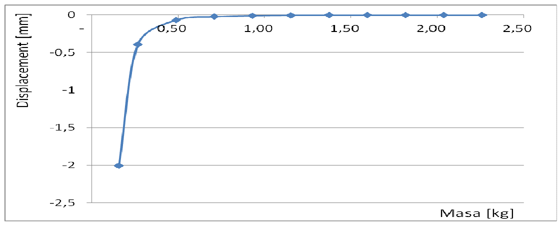


Figure 6: The maximum displacement of structure as a function of the mass with the constant thickness of the claddings

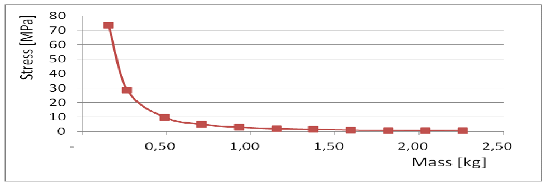


Figure 7: The maximum stresses of structure as a function of the mass with the constant thickness of the claddings

Changing the orientation of the material associated with deploying voids in the element RVE little effect on the determined value of stresses and displacements. Only for significant irregularities of voids in the RVE and the directional orientation of cylindrical voids the differences are significant.

In further studies, the results (material constants) will be used to develop and stress analysis of complex systems containing elements made from foamed metal type structures. This approach should result in significantly shorten the time of calculation.

References

[1] Beluch W., Burczyński T. and Długosz A., Evolutionary multi-objective optimization of hybrid laminates. *Computer Assisted Mechanics and Engineering Sciences,* 14(4): pp. 569-578, 2007.

[2] Boomsma K., Poulikakos D. and Ventikos Y., Simulations of flow through open cell metal foams usingan idealized periodic cell structure. *Int. J. of Heat and Fluid Flow* 24, pp. 825–834, 2003.

[3] De Jaeger P., T'Joen P., Huisseune H., Ameel B. and De Paepe M., An experimentally validated and parameterized periodic unit-cell reconstruction of open-cell foams. *J. Appl. Phys.*109, 103519, pp. 1-10, 2011.

[4] Dukhan N., *Metal Foam: Fundamentals and Applications.* DEStech Publications, Inc., Lancaster, Pensylvania, 2013.

[5] John A., John M. and Bartela A., Numerical homogenization of the foamed metal structures. *Mechanika.,* v. 22(5), pp. 343-348, 2016.

[6] Kopanidis A.; Theodorakakos A.; Gavaises E.; Bouris D., 3D numerical simulation of flow and conjugate heat transfer through a pore scale model of high porosity open cell metal foam. *Int. J. of Heat and Mass Transfer* 53, 2539–2550, 2010.

[7] Makowski P., John A., Kuś W. and Kokot G., Multiscale modeling of the simplified trabecular bone structure, *Mechanika, Proc. of the 18th Int. Conf. Mechanika 2013,* Kaunas, pp. 156-161, 2013.

[8] Sadovskaya O.V. Numerical simulation of deformation of a metal foam. *Proceedings of XLI International Summer School–Conference APM 2013*, pp. 485-491, 2013.