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# The numerical analysis of cantilever beam structures filled using aluminium foam

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The design trends in the field of civil engineering, mechanical engineering, but especially the automotive industry increasingly apply thin-walled structural components filled with foam structures mainly due to relatively low weight, possibility of achievement of the required stiffness, and also their excellent ability to absorb energy. Structural components have different shapes and are subject to different loads depending on their shape.

The beam constructions are generally classified as the most used and the most important constructions in the field of mechanical engineering. For these reasons, the specific beam structures with improved properties in terms of weight, stiffness and damping are currently being developed, which will also meet economic requirements. One of the design approaches that could meet the mentioned requirements is the creation of a beam structure with a closed cross-section, while its inner space is filled with a material with a specific structure created as aluminium foam.

The Al-foam and its material properties depend on the conditions and parameters of technological process. The global as well as the microstructural material properties of aluminium foam depend on the conditions and parameters of the technological process by which the creation of aluminium foam is achieved. From a global point of view, the properties as mass and stiffness of aluminium foam, which are crucial for the design of constructions from components filled using aluminium foam, are dominantly dependent on the size and distribution of cavities in structure of aluminium foam. On the basis of knowledge, it can be concluded that when using existing technological procedures, it is not possible to achieve either the same size of cavities or a deterministically arranged distribution of cavities in the volume of aluminium foam. However, this fact significantly complicates the possibilities for creating computational models and performing numerical simulations on virtual models of structures made of components with an aluminium foam structure. In principle, it is not possible to practically carry out computational simulations with the fact that the computational models of the foam structure would contain cavities created in detail in the volume of aluminium foam [1], [2]. This is due to the stochastic nature of the shape and also the distribution of cavities, but mainly due to the size of the computational model of the given structure. One of the possibilities to overcome these complications is the homogenization of the properties of the foam structure [3], i.e. determine the necessary equivalent mechanical properties of the homogenized volume without cavities, which replace the volume of the foam structure with cavities. The method of determining the equivalent mechanical properties of the homogenized aluminum foam structure is presented in the article. Due to the stochasticity of the aluminum foam structure (Fig. 1), the homogenization of these mechanical properties will be performed for the deterministic structural arrangement of the cavities. The basis for performing the homogenization of mechanical properties is the assumption of elastic behavior of aluminum foam.

a b

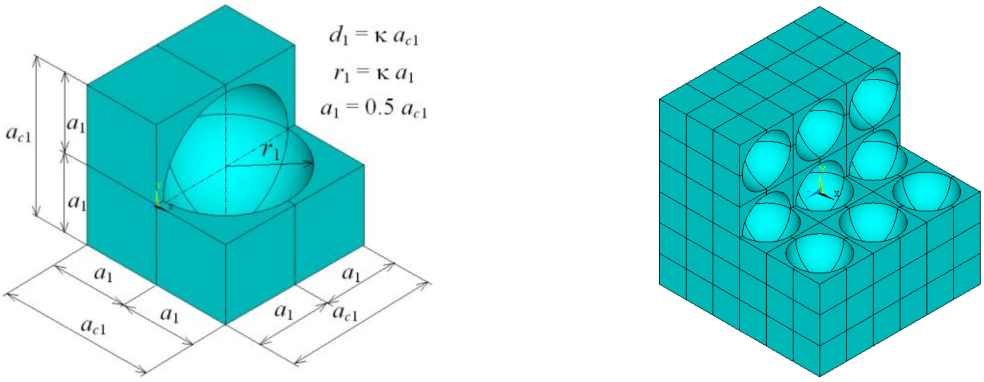
Fig. 1. Aluminium foam; a - structure of aluminium foam; b - profile filled using aluminum foam

The homogenization of the mechanical properties of the foam structure with a deterministic distribution of cavities and with a specified dimension of the cavities is based on the creation of a basic cell with a cavity inside the cell (Fig. 2). By using these cells representing part of the foam structure, the internal space of the beam structure is filled.

The mutual dimensional parameters of the cell and the cavity are specified, considering what part of the cell volume is occupied by the cavity, which is expressed by the ratio κ of the dimensions of the cell and the cavity

$$\kappa = \frac{d_1}{a_{c1}} = \frac{r_1}{a_1}, \tag{1}$$

where $d_1$ is cavity diameter and $a_{c1}$ is length of the cell edge (cube shape).

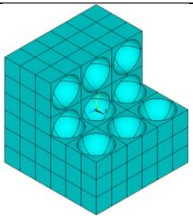
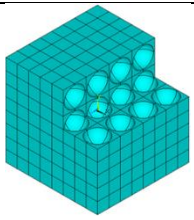
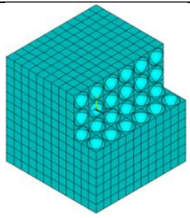


a b

Fig. 2. Computational models for homogenization of mechanical properties; a- fundamental geometry of cell with cavity; b-structural model of deterministic foam structure

The basic mechanical properties that need to be determined for the homogenized structure are Young modulus and Poisson's number. It is obvious that the homogenized mechanical properties of porous structures (Fig. 2b), which are created using deterministically arranged cells with a cavity (Fig. 2a), are dependent on the ratio κ and the number of cells in the porous structure. Therefore, computational models porous structure with the same global geometric dimensions and with different numbers of cells with cavities were created (Table 1).

Table 1. Models of porous structures

| Type of structure | | |
|---|---|---|
| T1 | T2 | T3 |
|  |  |  |

Uniaxial loading was applied to these porous sample models. Subsequently, a change in the global dimensions of the porous sample, i.e. elongation in the load direction and contraction perpendicular to the load direction. The calculation of the homogenized mechanical properties of porous structures is performed using well-known standard expressions from the theory of elasticity, so they can be expressed in the following form

- homogenized Young modulus $$E_h = \frac{F}{S}\frac{1}{\varepsilon_{x,p}}, \tag{2}$$

- homogenized Poisson´s number $$\mu_h = \frac{\varepsilon_{y,p}}{\varepsilon_{x,p}} = \frac{\varepsilon_{z,p}}{\varepsilon_{x,p}}, \tag{3}$$

where $F$ - loading force,
S - surface on which the loading force acts,
$L_x$ - length of the porous sample in the x-axis direction,
$\Delta L_{x,p}$ - elongation of the porous sample in the x-axis direction,
$\varepsilon_{i,p} = \Delta L_{i,p}/L_i$ - strain of the porous sample in the „$i$” axis direction ($i \approx x, y, z$).

The dependences of the homogenized Young modulus $E_h$ and the homogenized Poisson's number $\mu_h$ of aluminium on volume ratio $\kappa_V$ for different types of cavities arrangement are shown on Fig. 4 and Fig. 5.

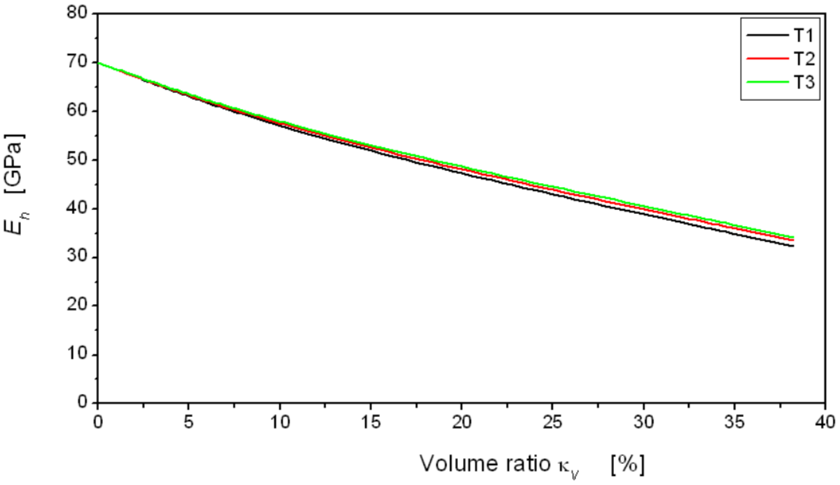


Fig. 3. Dependence of the homogenized Young modulus $E_h$ of aluminum on the volume ratio $\kappa_V$ for different types of cavity arrangement

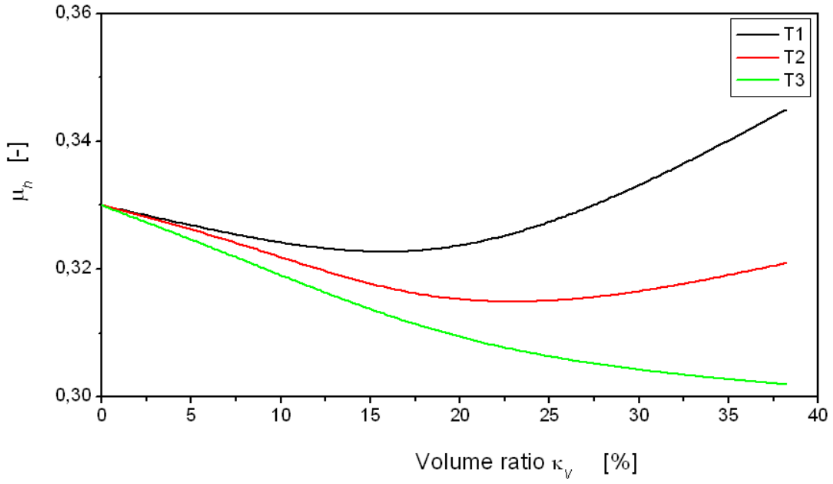
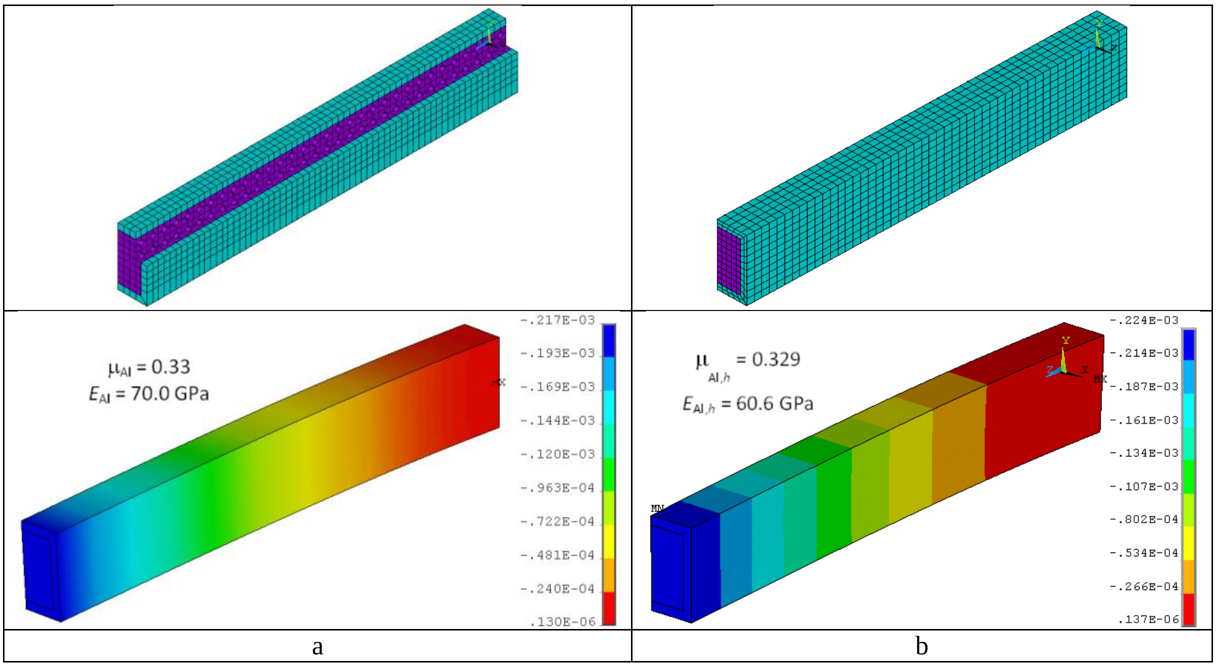


Fig. 4. Dependence of the homogenized Young modulus $E_h$ of aluminum on the volume ratio $\kappa_V$ for different types of cavity arrangement

To investigate the effect of the cavities size on the mechanical properties, the coefficient $\kappa_V$ is defined, which represents the ratio of cavities volume $V_c$ to the full material volume $V_{full}$

$$\kappa_V = \frac{V_c}{V_{full}} . \tag{4}$$

Comparison of the deformations of the cantilever beam structure filled with aluminum foam (porous material), which in the first case was modeled as a porous structure with deterministically arranged cavities and in the second case the beam filling was modeled from a non-porous material with homogenized mechanical properties, are shown in Fig. 5.



a

b

Fig. 5. Deflection of cantilever beam filled aluminium foam; a-porous model; b-homogenized model

Based on the obtained results, it can be concluded that a good agreement was obtained for the bending of the beam filled with aluminum foam, which was modeled in the first case as a porous material and in the second case as a model with homogenized mechanical properties. The above-mentioned methodology for modeling mechanical structures filled with porous material by homogenizing the filling and replacing it with homogenized mechanical properties provides, in addition to good agreement of results, a significant reduction in the size of the simulation models and the resulting reduction in calculation times.

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