Numerical simulations of mechanical properties of alumina foams based on computer tomography

Zdzisław Nowak[1], **Marcin Nowak**[2], **Ryszard B. Pęcherski**[3], **Marek Potoczek**[4], **Romana E. Śliwa**[5]*
[1,2,3]*Institute of Fundamental Technological Research, Polish Academy of Sciences*
Pawińskiego 5B, 02-106 Warszawa, Poland
e-mail: znowak@ippt.pan.pl [1], nowakm@ippt.pan.pl [2], rpecher@ippt.pan.pl [3]
[4]*The Faculty of Chemistry, Rzeszów University of Technology*
al. Powstańców Warszawy 6, 35-959 Rzeszów, Poland
e-mail: potoczek@prz.edu.pl
[5]*The Faculty of Mechanical Engineering and Aeronautics, Rzeszów University of Technology*
al. Powstańców Warszawy 8, 35-959 Rzeszów, Poland
e-mail: rsliwa@prz.edu.pl

Abstract

The aim of the paper is to apply the results of microtomography of alumina foam to create the numerical model and perform the numerical simulations of compression tests. The geometric characteristics of real foam samples are estimated from tomographic and scanning electron microscopy images. The performance of the reconstructed models is compared to experimental values of elastic moduli and strength in the uniaxial compression test.

Keywords: compression test, alumina open-cell foam, Young's modulus, compressive strength of alumina foams

1. Introduction

The mechanical properties and numerical model of real alumina foam, which is produced in the gelcasting process are studied. The finite element models of alumina open-cell foams are developed. Elastic properties and compressive strength are predicted and compared with experimental results. The numerical parameters which are needed to build the unit cell model are based on the data obtained from microtomography images of real foam. Alumina foams are studied also with the use of periodic models based on the crystallographic systems: simple cubic (*sc*), body centered cubic (*bcc*) or face centered cubic (*fcc*). Each lattice point is replaced by a bubble, whose radius corresponds to the mean value of cell radius distribution of alumina foam. In these models the interconnection radius between two bubbles is equal to the mean value of distribution of window radius for a real porous material. Using the procedures described in Ref.[4] the analysis of the microtomography images shows that the alumina foams are composed of approximately spherical cells interconnected by circular windows Ref. [6].

The porosity, cell radius distribution, and window radius distribution of an individual foam sample is computed and the geometry of a unit cell is proposed. Dimension of a finite element corresponds to the dimension of a single voxel and is equal to 16μm. In all numerical calculations the cube-shaped sample of the foam with dimensions of 400×400×400 voxels was considered. This assumption gives a representative volume element (RVE) of size 4×4×4 mm. To assure the better convergence of the numerical simulations the microtomography images of alumina foams were rendered by ScanIP software, Fig. 1.

The material of skeleton of the alumina foam is assumed to be isotropic and linearly elastic. The bottom surface of the sample is fully constrained and the top surface of the sample is moved parallel to the z-axis. As a result of numerical simulation of compression test of alumina foam for different values of porosity, the Young's modulus and the strength of such foams are estimated. The comparison of experimental data Ref. [6] with numerical and analytical predictions Ref. [3] of Young modulus for Al_2O_3 ceramic foams of different porosity is presented. The analytical estimation shows good correlation with the results of experiment and simulation for the range of porosity (84%-90%).

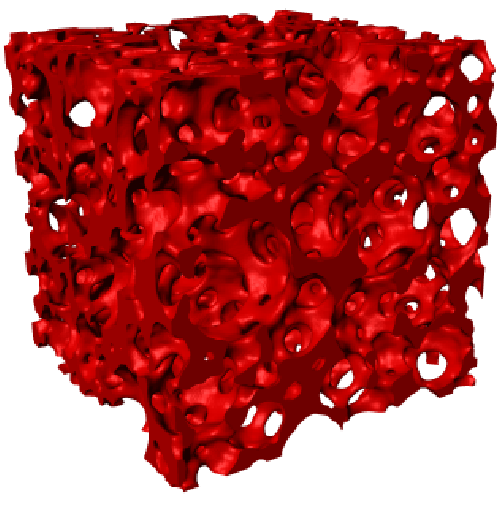

Figure 1: The example of rendered alumina 86% porosity foam used in simulations.

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2. The quasi-brittle material model for Al_2O_3 foams

The model describing behaviour of considered alumina foam is defined in elastic range by Hooke's law and inelastic range by the associated plasticity theory. The limit surface is defined by Burzyński paraboloid yield condition, see Refs. [1, 2, 8, 9]. The additive decomposition of strain tensor into elastic and inelastic part is given

$$\varepsilon = \varepsilon^{e} + \varepsilon^{in} \tag{1}$$

The Burzyński paraboloid yield condition is given in a form

$$F = \frac{1}{2k}\left\{3(1-k)\,\sigma_m + \sqrt{9(k-1)^2\,\sigma_m^2 + 4kq^2}\right\} + - \sigma_Y^T = 0 \tag{2}$$

where $k = \sigma_Y^C/\sigma_Y^T$, σ_Y^C and σ_Y^T are the initial yield stress in uniaxial compression and tension test, respectively, and σ_m is the mean stress $\sigma_m = (\sigma_1 + \sigma_2 + \sigma_3)/3$, while $q = \sqrt{3/2\,\mathbf{s} : \mathbf{s}}$ and $\mathbf{s}$ is the deviatoric stress tensor.
In addition the scalar damage parameter d is introduced.

$$\sigma = (1-d)D^{e} : \left(\varepsilon - \varepsilon^{in}\right) \tag{3}$$

The inelastic part of strain rate is given by classical associated flow rule where F represents limit surface given in Eqn (2)

$$\dot{\varepsilon}^{in} = \dot{\gamma}\frac{\partial F}{\partial \sigma} \tag{4}$$

In Eqn (5) parameter d describes the damage in skeleton material. The evolution of the damage parameter d is described by function $\eta(\bar{\varepsilon}^{in})$, where $\bar{\varepsilon}^{in}$ is the equivalent inelastic strain, cf Ref. [5]. In the calculations the function η is linear function of $\bar{\varepsilon}^{in}$ with the limits:

$$\eta(0) = 0\,,\ \ \eta(\bar{\varepsilon}_k^{in}) = 0.9 \tag{5}$$

The system of equations describing the deformation process of the open-cell foam is solved by algorithm using the return mapping procedure. The proposed algorithm is implemented in commercial FEM software ABAQUS/STANDARD with developed own UMAT subroutine, Ref. [5].

The ceramic foam is assumed isotropic. The bottom surface of the sample is fully constrained and the top surface of this sample is moved parallel to the z-axis.

Material data for Al_2O_3 are as follows: Young's modulus E = 370 GPa, Poisson ratio ν= 0.22, the initial compression yield stress σ_Y^C= 2400 MPa, the initial tensile yield stress σ_Y^T= 105 MPa, density ρ = 3.92g/cm^3.

3. Summary and Conclusions

The model outlined in Section 2 is used to predict the response of alumina foam in the uniaxial compression. The calculations is terminated after the expected initial load maximum representing the strength of the foam skeleton. The material is quasi-brittle with the stress-strain response of the Al_2O_3 ceramic measured in a tests. The initial part of the response is nearly linear with Young's modulus E in a good agreement with the measured values. An example of the comparison of normalized Young's modulus with the experimental data (Ref. [7], [10]) and numerical predictions for the periodic models (*sc*, *bcc* and *fcc*) are presented in Fig. 2.

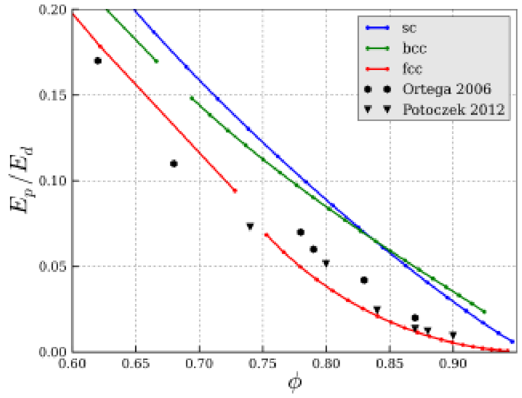

Figure 2: The comparison of predicted numerically normalized Young modulus for the periodic models (*sc*, *bcc* and *fcc*) with the experimental data (Ref. [7], [10]) as a function of porosity.

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