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MODELING OF MACROSCOPIC ELASTIC PROPERTIES OF ALUMINIUM FOAM

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Abstract: *This paper is focused on the prediction of macroscopic elastic properties of highly porous aluminium foam. Intrinsic material properties of cell wall constituents are assessed with nanoindentation whereas analytical homogenizations are employed for the assessment of the cell wall elastic properties. Two-dimensional microstructural FEM model was applied to obtain effective elastic properties of the upper material level, for which the Young's modulus reached 1.11 GPa. The value is by ~30% lower than the range of experimental values obtained from experimental compression tests.*

Keywords: ***metal foam, porous system, nanoindentation, micromechanical properties, homogenization.***

1. Introduction

Two-scale microstructure-based model for the assessment of overall elastic properties on highly porous aluminium foam (Alporas®) is proposed in the paper. The model utilizes the micromechanical approach (Zaoui, 2002) that is used for upscaling of mechanical properties (e.g. elastic modulus) on microscopically inhomogeneous composites to the upper level. The material is characterized by a stochastically distributed closed pore system with very thin cell walls (defined by the mean midspan wall thickness *L_mean*=61um) and large pores (0.2 - 6 mm in diameter). In the analysis, the pores were replaced by equivalent ellipses in 2-D image. Further, a shape factor computed as the ratio between the longer and shorter axes of the ellipse was obtained. The mean value of the shape factor was 1.15. This value indicates that the shape of the pores is nearly circular with a small flattening. Relative density and porosity (Gibson, 1997) were detected by weighing of a sufficiently large sample. The relative density was assessed as 0.0859 and porosity reached 0.914. Two characteristic length scales can be at least distinguished: the cell wall level and the foam level. Therefore the proposed micromechanical model separates the foam microstructure into two levels.

Level I (the cell wall level) consists of prevailing aluminium matrix (Al-rich area) with embedded heterogeneities in the form of Ca/Ti-rich areas. Intrinsic elastic properties of the microstructural constituents were assessed by nanoindentation at this level. Two-phase system was assumed in the statistical deconvolution algorithm (Constantinides et al., 2006). Application of analytical homogenization schemes showed very similar results (Tab.1) of effective cell wall elastic properties ($E_{Level\text{-}I} \approx 70$ GPa). Detailed description of this experimental part can be found in Němeček et al., 2011.

Level II (the foam level) includes the Level I and large pores (average diameter ~2.9 mm). In this level, cell walls are considered as homogeneous having the properties that come from the Level I

Tab. 1: Effective values of Young's modulus by different homogenization schemes

Homogenization technique	Mori-Tanaka	Self-consist. scheme	Voigt bound	Reuss bound
Young's modulus Level I [GPa]	70.076	70.135	71.118	69.195
Young's modulus Level II [GPa]	3.151	0.001213	6.02	0.00109

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homogenization. At first, effective elastic properties of Level II were estimated with the same analytical schemes used in Level I. However, the analytical methods do not give satisfactory results (compared to experimental values) in this case. Nevertheless, the correct solution should lie between Voight and Reuss bounds that are, in this case, quite distant (Tab. 1).

At second, more appropriate two dimensional microstructural FEM model was applied. The model geometry was generated from high resolution 2-D optical images of Al-foam in which pore centroids were detected. From these points, Voronoi cells and equivalent 2D-beam structure were generated. As a first estimate, uniform cross-sectional area was prescribed to all beams (~8.59 % of the total). The size of our domain (120×120 mm) allowed us to solve the problem with kinematic boundary conditions (Fig.1). The influence of the boundary conditions on microscopic strains and stresses in the domain was decreased by using smaller inner region (20×20 mm) for homogenization. The whole domain (120×120 mm) was subjected to homogeneous macroscopic strain in one axial direction ($\mathbf{E}=\{1,0,0\}^T$) by imposing prescribed displacement to one domain side (Fig. 1). Strains and stresses inside the smaller area were averaged and used for computation of the homogenized Young's modulus. The solution gave E_{hom} = 1.11 GPa for the tension in x-direction (Fig.1). Such stiffness is by 30% lower than results obtained from our experimental measurements (uniaxial compression test on 30×30×60 mm Alporas blocks) that indicate E≈1.45 GPa.

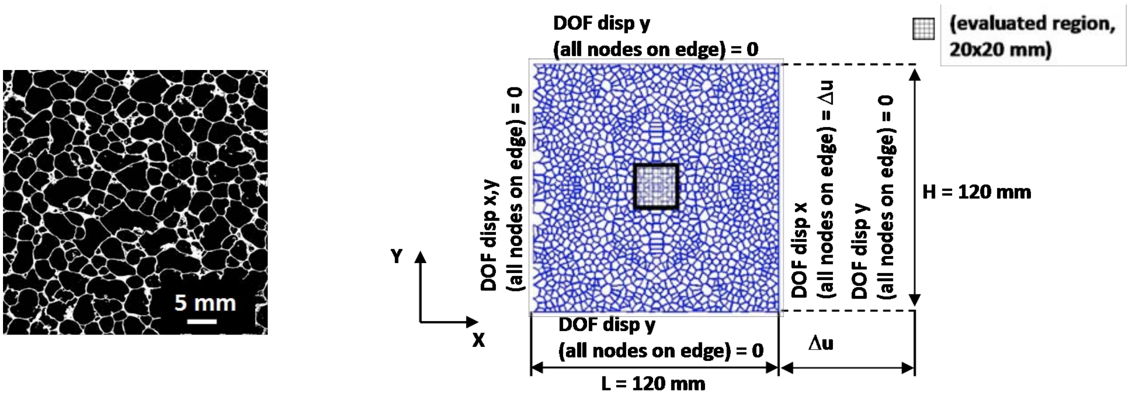

Fig. 1. Foam microstructure (left) and 2D-beam structure with prescribed deformation boundary conditions (right).

2. Conclusions

The microstructure of Al-foam was studied by image analysis and phase properties assessed with nanoindentation. Application of analytical homogenization schemes showed very similar results of effective cell wall elastic properties ($E_{Level\text{-}I} \approx$ 70 GPa). Therefore more appropriate two dimensional microstructural FEM model was applied. Homogenized Young's modulus reached 1.11 GPa. The lower stiffness obtained from 2-D model can be explained by the lack of additional confinement present in the 3-D case and leads to the necessity to solve the structure in 3-D which is the future goal of our work.

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