

DETERMINATION OF MECHANICAL PROPERTIES OF METAL FOAMS USING MICROSTRUCTURAL MODELS

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1. Introduction

Several different methods for determination of material characteristics have been developed as a result of efforts for cost reduction in cellular materials development and engineering use. This paper is aimed at the study of mechanical behaviour of aluminium metal foams by modeling their internal structure and analysis using finite element method. Firstly, the internal structure was modeled using voxel FE model created on the basis of series of CT scans. However, irregular cell shape and cell dimensions of selected reference material lead to huge and computationally demanding models with limited applicability. These considerations were motivation for subsequent discretization of the internal structure using Gibson-Ashby's equivalence.

2. Geometrical and mechanical modeling

Fundamentals of Gibson-Ashby's discretization are based on studies of beam deformation mechanisms considering that cell-wall bending is the principal mechanism of deformation of cellular materials. Deduction of macroscopic characteristics is thereby done by studying the bending of a beam, which represent the foam strut. This model was originally developed for discretization of open cell foams. In this study, the beam-only discretization is used intentionally to investigate its suitability for modeling of closed cell foams.

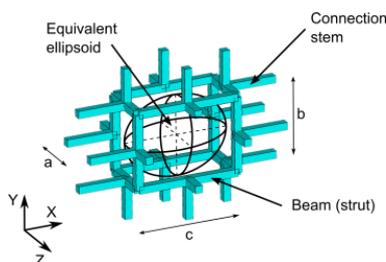


Fig. 1: Gibson-Ashby's cell with corresponding equivalent ellipsoid

The elementary cell is considered to have hexagonal or cubic form (that is used in this paper), and the whole structure is then modeled by periodical network of elementary cells [1].

Overall material characteristics of the foam were derived from tensile loading of the structure. The analysis was performed in ANSYS software in both elastic and plastic fields. Cell network was generated using linear hexahedral elements with 24 degrees of freedom.

Aluminium closed cell foam Alporas was selected as a reference material. Cell parameters were chosen to match real material characteristics [2], behavior of geometrically isotropic and anisotropic elementary cells was studied according to typical production parameters, where spherical cells become polyhedron at porosities over 70 %. Alporas is manufactured using special unnormalized alloy containing 97 % of aluminium, 1.5 % of calcium and 1.5 % of titanium [3]. Because material properties of this alloy are not provided by the manufacturer, the material models use mechanical properties of 98 % aluminium as stated in [4]:

- $E = 69 \text{ GPa}$
- $\mu = 0.33$
- yield strength $\sigma_y = 300 \text{ MPa}$
- tangential modulus $E_t = 1.725 \text{ GPa}$

Two variants of material model were used – linear elastic model and elasto-plastic material model with von Mises plasticity and bilinear isotropic hardening. Material characteristics in both elastic and plastic fields were derived from displacement controlled tensional loading. Investigated relations were particularly the evolution of overall elastic modulus according to different relative densities and in the plastic field the tensional stress-strain diagram.

3. Results

Firstly the dimensions of representative volume element (RVE) were determined from

evolution of elastic modulus vs. number of cells along each axis in the coordinate system. Substantial error was acquired at low number of cells and with growing number of cells the elastic modulus was decreasing. Cell network consisting of 12 cells along each axis was identified as RVE with equivalent real specimen dimensions $57.6 \text{ mm} \times 57.6 \text{ mm} \times 57.6 \text{ mm}$.

In the next step, parameters of the Gibson-Ashby's cell were assessed. Mechanical response of beam-like discretisation highly depends on relative lengths of the connection stems. Analyses show that elastic modulus increase with shorter connection stems and in this paper $1/8$ is considered as relevant value. Influence of cross-section shape was determined from comparison of rectangular and circular cross-section. Analysis of obtained relations indicate that the shape itself doesn't have any influence on results for relative densities lower than 0.12, for higher relative densities the circular shape model becomes stiffer.

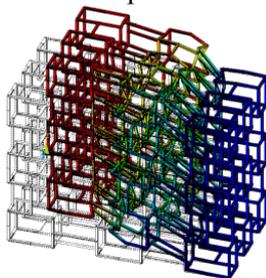


Fig. 2: Deformed cell network

Essential part of the analysis was determination of relations between mechanical response and beam cross-section parameters. For the geometrically isotropic cell, published elastic modulus of Alporas foam was acquired with model relative density in interval 0.12 - 0.185. For the geometrically anisotropic cell, the declared properties of Alporas were acquired with model relative density 0.08 – 0.13, which is consistent with real mechanical characteristics.

Analysis in plastic field was concentrated at determination of tensional stress-strain diagram in direction x . With respect to difficult convergence in geometrically nonlinear analysis, 10 % was selected as maximum strain value. Results were studied for geometrically linear or nonlinear simulation and also for statically definite or indefinite boundary conditions. Geometrically nonlinear simulation converged to real tensile

behavior of Alporas with plateau of constant stress in extensive range of deformation as can be seen in Fig. 3.

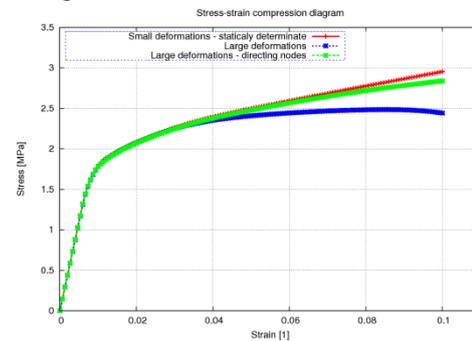


Fig. 3: Plastic field analysis - stress-strain diagram

4. Conclusion

This study shows that considered discretisation model can be used for numeric modeling of closed cell aluminum foams. Effects of beam parameters on total stiffness are highlighted and obtained results are in agreement with characteristics of real cellular materials. Increased length of connection stems decreases total stiffness, whereas increase in relative density increases total stiffness of the foam structure. Studies performed in plastic field are in agreement with plastic behavior of real specimens.

References

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