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DYNAMIC COMPRESSION STRENGTH OF COPPER OPEN-CELL FOAMS

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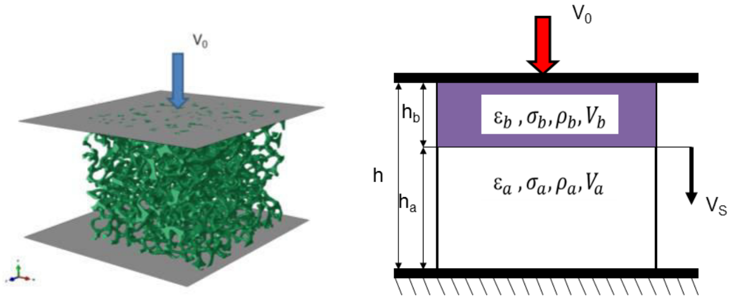
Abstract

Metal foams in view of their structural strength and mechanical energy absorption capability under high speed impact can be utilized as energy absorbers. It is important to understand the propagation of compaction waves in the foams. Most commercially available metal foams are made of aluminium, nickel, copper, and metal alloys. Two kinds of foams exist, namely the open-cell and the closed-cell foams. Typically, the pore density of uncompressed open-cell foams varies between 5 to 100 PPI (pores per inch), while the porosity is in the range from 70% to 95%. Literature provides several examples of metal foams solutions for energy absorption applications, dealing with both experimental, numerical and analytical studies e. g., [1], [2].

The subject of the study are the models based on digital microstructures, in particular open cell metallic foams characterised with the skeleton formed of convex or re-entrant cells. The re-entrant materials revealing negative Poisson's ratio have attracted increasing attention in the context of modern materials applications, [3]. The goal of the presented investigations is to study the impact limits and absorption energy of these two kind of open cell metallic foams. To simulate the deformation processes the finite element program ABAQUS is used, [4]. The computer tomography made the basis for the formulation of computational model of the foam and the finite element discretization of the skeleton, [5], [6].



$$V_b - V_a = V_S(\varepsilon_b - \varepsilon_a) \quad (1)$$

$$\sigma_b - \sigma_a = \rho_0 V_S (V_b - V_a) \quad (2)$$

$$U_b - U_a = \frac{1}{2}(\sigma_b + \sigma_a)(\varepsilon_b - \varepsilon_a) \quad (3)$$

Fig. 1. The uniaxial impact loading conditions of metallic open-cell foam sample (left) and the schematic diagram of shock front for the striker-wall impact scenario (right). The location h_b of the shock front and its speed V_S are presented.

From each reconstructed volume, a representative cubic volume element was extracted. For numerical simulations the constitutive elasto-viscoplasticity model is applied that defines the dynamic behaviour of oxygen-free high conductivity (OFHC) Cu using the experimental data reported in the literature. The chosen material model for the numerical simulation is the Cowper-Symonds model. The model is able to predict the mechanical behaviour of the materials under different loading conditions and it is implemented in many FEM codes in order to investigate and describe problems such as ballistic impacts or problems in which the strain-rates component are relevant. In numerical simulations the bottom displacements in the impact direction are fixed and initial velocity V_0 on the top surface and general contact (steel wall-Cu foam and selfcontact Cu foam) with the friction coefficient 0.35 is assumed, Fig. 1(left). The numerical predictions of axial force (crushing force) within the wide range of velocity: from 50 to 300 m/s are discussed.

Using the numerical models, a parametric study has been carried out to examine the effect of impact velocity on the absorbed energy of both types of foams.

The equations (1)–(3) describe the shock compression of the metal foam above a critical impact velocity. In Eqs. (1)-(3) V, ε, σ, U, ρ_0 are material velocity, engineering strain, engineering stress, internal energy density and initial density of the foam, respectively. The subscript s, a and b denote the shock front, the material ahead of the shock front and the material behind the shock front, respectively, Fig. 1(right). The shock state variables derived from Hugoniot relation and the conservation laws are used for comparison with FEM simulations.

The main observation is following: the re-entrant foam yields lower final axial displacement for the same compression time and velocity of the impact than the metallic foam with conventional convex cell skeleton. The advantage of re-entrant foam becomes larger as the impact velocity decreases. The multiscale character of deformation process is discussed and the mechanisms of the deformation of skeleton struts are visualised.

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