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MICRO-INERTIA EFFECT AND DYNAMIC POISSON'S RATIO OF CLOSED-CELL METALLIC FOAMS UNDER COMPRESSION

C.F. Wang, Z.J. Zheng*, and J.L. Yu

ABSTRACT

A significantly decreasing influence of lateral constraint on the crushing stress with increasing loading rates has been found for a closed-cell aluminum foam. This interesting phenomenon may be interpreted by the micro-inertia effect and/or the decrease of Poisson's ratio in dynamic compression. In this paper, the three-dimensional Voronoi technique and the explicit finite element method are utilized to investigate the micro-inertia effect and dynamic Poisson's ratio of closed-cell metallic foams. The simulation results indicate that the micro-inertia effect plays little role in enhancing the plateau stress of metallic foams. The Poisson's ratio varies with the nominal strain and its peak value decreases as impact velocity increases.

Key Words: Voronoi structure; Metallic foam; Micro-inertia; Poisson's ratio

INTRODUCTION

Metallic foams have been extensively used as impact energy absorbers, but the comprehensive understanding of their dynamic crushing behaviors is still very limited. The multi-axial crushing behaviors of metallic foams are important for their engineering application. Recently, Yu et al. [1] reported an interesting phenomenon of metallic foams in dynamic crushing with side constraint. A significantly decreasing influence of lateral constraint on the collapse stress with increasing loading rates has been found for a closed-cell aluminum foam. The study on the micro-inertia effect and the behavior of Poisson's ratio in dynamic compression may help to understand the inherent mechanisms.

For this purpose, a mesoscopic finite element method is employed to investigate the mechanical behavior of closed-cell metallic foams. The micro-inertia effect and the plastic Poisson's ratio are quantitatively studied.

CAS Key Laboratory Mechanical Behavior and Design of Materials, University of Science and Technology of China, Hefei, Anhui 230026, China
*Email: zjzheng@ustc.edu.cn

METHODS AND MATERIALS

The mesoscopic models of closed-cell foams are constructed using a 3D Voronoi technique. N nuclei are randomly generated in a given box with a distance constraint of any two nuclei as done for constructing the 2D Voronoi honeycombs [2]. Similarly, the irregularity of 3D closed-cell metallic foam is defined as $k=1-\delta/d_0$, where d_0 is the minimum distance between any two adjacent nuclei of regular tetrakaidecahedral structure [3] and δ is the minimum distance between any two nuclei. The irregularity of the models in this paper is taken to be 0.5.

The relative density of the specimens is 0.2 and their geometric parameters are 30mm×25mm×25mm. Every specimen has 300 nuclei. Cell-walls are simulated by shell elements with 0.2749mm thickness. Through a convergence analysis, the elements of these models are meshed with the characteristic length of 0.3mm. To save computing time, any adjacent nodes with very small distance are combined to one node. The mechanical property of cell wall material is elastic-perfectly plastic with Yang's modulus, yield stress and Poisson's ratio being 69GPa, 170MPa and 0.3, respectively.

The finite element code ABAQUS/Explicit is used to study the dynamic crushing behavior of the 3D Voronoi models. The models are loaded uniaxially in the longer direction by two rigid walls. The bottom rigid wall is fixed in all directions; the top rigid wall is fixed except in the impact direction. A constant velocity is applied to the top rigid wall.

RESULTS OF SIMULATION

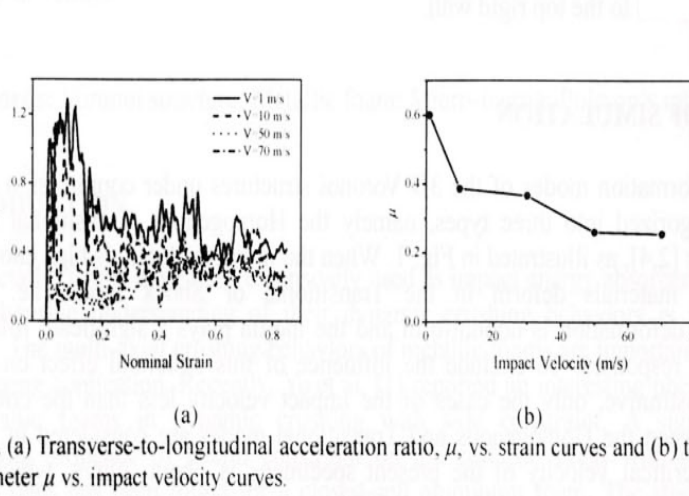
The deformation modes of the 3D Voronoi structures under compression can also be categorized into three types, namely the Homogenous, Transitional and Shock modes [2,4], as illustrated in Fig. 1. When the impact velocity is high enough, the cellular materials deform in the Transitional or Shock mode, i.e. the macroscopic deformation is nonuniform and the inertia plays a significant role in the dynamic responses. To exclude the influence of this structural effect on the dynamic constitutive, only the cases of the impact velocity less than the critical velocity between the Homogenous and Transitional modes are considered in this paper. The critical velocity of the present specimens is about 70m/s, which is determined by evaluating the uniformity of plateau stress [4].

(a) 1 m/s (b) 90 m/s (c) 110 m/s

Figure 1. Three deformation modes of foams. (a) Homogenous mode; (b) Transitional mode; (c) Shock mode.

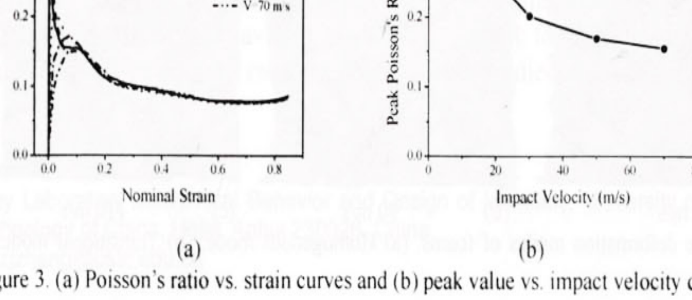
Micro-inertia effect is favored by many researchers [5][6] to explain the dynamic responses of cellular materials. But some conflicting views exist in the literature. Some researchers think the micro-inertia effect plays an important role in enhancing the dynamic crushing strengths of metallic foams [6], but some others believe the effect is little [5]. To quantitatively investigate the micro-inertia effect, a parameter μ defined as the ratio of mean square acceleration in lateral and longitudinal directions has been introduced by Liu et al. [4]. This micro-inertia parameter was named the transverse-to-longitudinal acceleration ratio. Its value for the present specimens under different impact velocities is shown in Fig. 2a. The corresponding means from the zero strain to the densification strain are plotted in Fig. 2b. The results show that the micro-inertia parameter of specimens decreases with increasing impact velocity and is close to that of solid material. It transpired that μ is much smaller than that for a Type II structure [5], indicating the micro-inertia effect is relative weak for 3D Voronoi structure.

The plastic Poisson's ratio ν_p is defined as the negative ratio of the transverse strain (average of ε_x and ε_y) to the axial strain ε_z. The deformations Δx and Δy are calculated from the average of lateral displacements of all nodes n_i in specific directions. The Poisson's ratio varies with the nominal strain, see Fig. 3a. For a low impact velocity, a sharp peak value of Poisson's ratio appears at a small nominal strain, and then it decreases with the increase of nominal strain. With the increase of impact velocity, the peak value of Poisson's ratio decreases, as shown in Fig. 3b.



(a) (b)

Figure 2. (a) Transverse-to-longitudinal acceleration ratio, μ, vs. strain curves and (b) the average of parameter μ vs. impact velocity curves.



(a) (b)

Figure 3. (a) Poisson's ratio vs. strain curves and (b) peak value vs. impact velocity curves.

DISCUSSION

Our simulation results reveal that the micro-inertia effect plays little role for metallic foams deformed under Homogenous mode. The Poisson's ratio varies with the nominal strain and its peak value decreases as impact velocity increases.

The decrease of the Poison's ratio can be explained by the following mechanism. Under quasi-static uniaxial compression, macroscopic transverse displacement of the material takes place due to the Poison's effect. When impact velocity is low, the foam has sufficient time to deform transversely even in the initial stage. But at higher impact velocities, the deformation in the transverse directions is limited due to the inertia effect. So the peak value of the Poisson's ratio decreases with increasing impact velocity.

The above mechanism can explain the experimental phenomenon found in Ref. [1]. When side constraints are applied, the higher peak value of the Poison's ratio causes a lateral compressive stress which enhances the initial axial crushing stress of foams under low velocity impact. However, this constrains becomes weak under high velocity impact.

The relative densities of foams may influence the Poisson's ratio and it is necessary to clarify the influence in the further work.

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