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Compressive properties of aluminum foam produced by powder-Carbamide spacer route

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ABSTRACT

Effects of cell shape and size, and relative density of aluminum foam on its compressive behavior have been investigated. Aluminum foams were produced via aluminum powder-Carbamide spacer route. The results show that angular cells significantly reduce mechanical properties of the foam. They also indicate that compressive properties of the foams, including plateau stress (σ_{pl}), densification strain (ε_D), and energy absorption, increase by cell size and relative density of the foams. Experimental results were compared with theoretical predictions; they were fairly corresponded to theoretical conceptions; this arises from near-ideal architecture of the foams with almost spherical cells, in this study. Constant values of C, n and α in theoretical modulus and densification strain equations wear calculated as 1.22, 2.09 and 0.95, respectively. The values indicate compressive behavior approaches to ideal morphology foam via employing spherical space holder.

1. Introduction

Metallic foams have attracted considerable attention as filtration, heat pipes, heat exchangers, sound absorbers, abradable tools, flow control devices, fortifying building and transport structures against buckling and impact, owing to their exceptional properties [1–3]. In the past decade, there have been a considerable number of investigations on their characteristics; in particular aluminum foam. One of their main and important performances is structural applications with a unique shape of compressive stress–strain response. This response consists of three distinct regions; an initial quasi-linear loading region where the compressive stress increases almost linearly with the strain, plateau region in which the cells collapse and finally densification zone with rapid rising of stress [4,5]. Three stages in compressive micro-deformation of closed-cell foam have been monitored and identified through a digital image correlation procedure. The first involves uniform localized plastic straining at cell nodes. The second comprises discrete bands of concentrated strain containing cell membranes that experience plastic buckling, elastically constrained by surrounding cells. Thirdly, coincident with a stress peak, so, one of the bands exhibits complete plastic collapse. As the strain increases, this process repeats, subject to small stress oscillations around so [6].

Several researchers have paid attention to the properties of metal foams and studied the influence of different parameters, such as sintering conditions, cell size, cell structure and morphology, on the mechanical properties, including yield strength, Young's modulus, shear modulus, strain rate sensitivity, crush and fatigue behavior as well as static and dynamic energy absorption [7–12]. Some researchers also attempt to model the mechanical properties [6,13,14]. It is generally argued that the advantage of spherical cell foam is that the cells are uniform and regular in shape and size, also that the mechanical properties are predictable by theoretical arguments. Foams with irregular cells make testing, interpretation and prediction of the mechanical behavior difficult. Also, irregular microstructures lead to inhomogeneous deformation and strange (e.g. jagged) flow curves [13], they knockdown the mechanical properties by factors ranging from 2 to 100 [14]. Therefore, metallic foams featuring fine, homogeneous microstructures; having near-spherical cell, are useful to capture the intrinsic average deformation behavior of this class of materials [13].

It is reported [15–20] that processing parameters of sintering-dissolution process (SDP) such as cell size, sintering time and temperature, solid or liquid phase sintering, and employing reinforcements (e.g. Y_2O_3 or Al_2O_3) have also significant effects on mechanical properties of aluminum foams. For instance, addition of Mg and Sn powders (~0.5 wt.%) to aluminum powder provides liquid phase sintering condition, and markedly improves properties of the foam after sintering, in especial, it increases the energy absorbing capacity of the foam up to 50% [21]. It is suggested that the optimum cell-size ranges are from 1.2 to 1.5 mm and from 0.71 to 0.80 mm for static and dynamic energy absorption, respectively [19].

The mechanical properties of foams have been modeled based on the mechanisms by which the cells deform and fail [21]. Under

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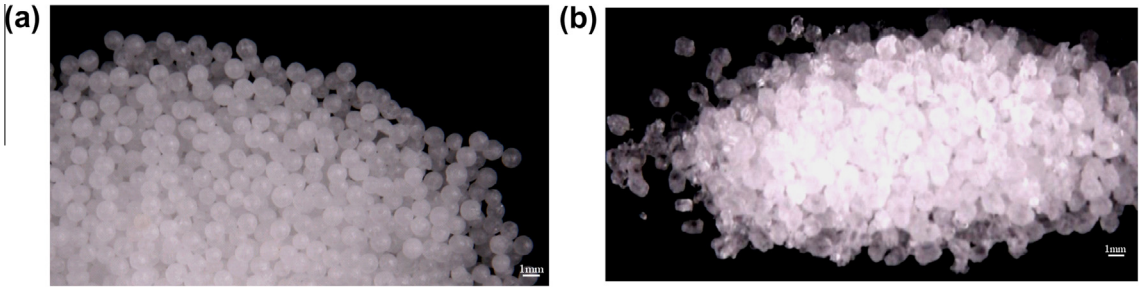

Fig. 1. Typical morphologies of Carbamide particles, (a) spherical, and (b) angular.

uniaxial compression stress, open cell foams are deformed by bending, followed by formation of plastic hinges within the cell walls. Simple dimensional arguments give the Young's modulus, and plastic collapse strength, as [7,9]:

$$\frac{X_f}{X_s} \approx C\left(\frac{\rho_f}{\rho_s}\right)^n \tag{1}$$

where X and ρ are main mechanical properties (such as strength or Young's modulus) and density, respectively. Indices of f and s stand for foam and solid. The values of C and n are 1 and 2 to predict Young's modulus, respectively, while they are 0.3 and 1.5 in prediction of plastic collapse strength. In addition, bending of the cell edges in closed-cell foams is accompanied by stretching of the cell faces and a linear density term is added to Eq. (1), as follow [7,9]:

$$\frac{E_f}{E_S} = 0.32\left(\frac{\rho_f}{\rho_s}\right)^2 + 0.32\left(\frac{\rho_f}{\rho_s}\right) \tag{2}$$

$$\frac{\sigma_{\mathrm{pl}}}{\sigma_{\mathrm{ys}}} = 0.33\left(\frac{\rho_f}{\rho_s}\right)^2 + .0.44\left(\frac{\rho_f}{\rho_s}\right) \tag{3}$$

where E and σ_{ys} are elastic modulus and yield stress, respectively. Ashby et al. [4] have reported that the densification strain for both open- and closed-cell plastic foams can be described by the following equation:

$$\varepsilon_D = \alpha \times \left(1 - 1.4\left(\frac{\rho_f}{\rho_s}\right) + 0.4\left(\frac{\rho_f}{\rho_s}\right)^3\right) \tag{4}$$

where ε_{D} is the densification strain, and α is the material constant being between 0.9 and 1.0 for open- and closed-cell aluminum foams, respectively [5].

It is suggested [14] that the mechanical properties of metal foams with ideal or near-ideal morphologies (i.e., those with equiaxed cells having straight wall and boarders with uniform thickness) should approach the predicted mechanical properties. Based on these conceptions, this article investigates the effect of three parameters; cell-shape, cell-size, and relative density on compressive properties of aluminum foams. Then, it compares experimental results with theoretical predictions for spherical cell

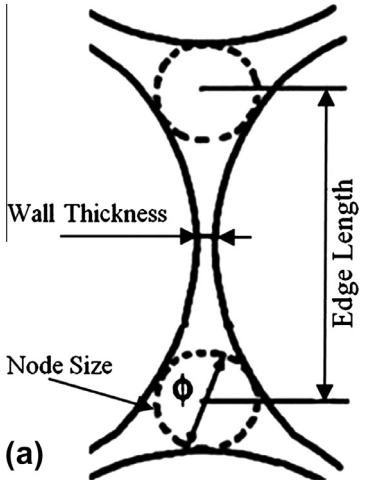

Fig. 2. A typical cell wall showing different features of wall thickness, node size, and edge length.

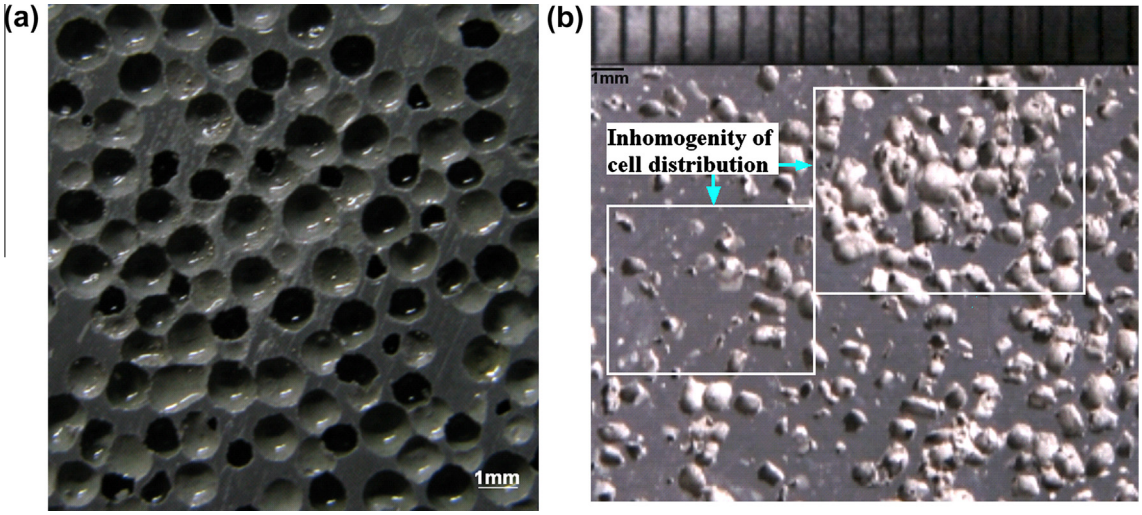

Fig. 3. Macrostructure of the Al foams with, (a) spherical, and (b) angular cells.