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Micro–macro investigation of deformation and failure in closed-cell aluminum foams

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ABSTRACT

Macroscopic mechanical properties of metal foams originate from the deformation of forming cells which happens on a micro scale. In this sense, the geometry of cells as well as the thickness and property of cell walls play a role in determining overall mechanical properties. Using simulation methods combined with some experimental tests, the inter-relationship between the micro scale deformation and the macro scale properties is investigated in this paper. In the first part of the work, the effect of relative density on the mechanical properties of closed-cell aluminum foam is investigated by numerical methods, and the results are compared with analytical predictions and experimental data. In the second part, the effect of cell topology, including cell shape and cell size, on the material behavior is investigated for aluminum foams, regardless of relative density. It is shown that cell shape causes some changes in macroscopic material behavior, which can be explained by its effect on the pattern of deformation and local failure in the material. Different mechanisms of deformation at the cell level are considered in connection with closed-cell aluminum foams. And finally, in the third part, different patterns of failure are investigated on different scales. The deformation and failure at the cell level cause localization on the macro scale. The cell shape and the inhomogeneity of the foam structure are investigated as the primary factors affecting the deformation and failure modes, and the results give some deeper understanding about the effect of cell shape on mechanical behavior. Also, some experimental tests are carried out to validate the numerical results.

1. Introduction

Closed-cell metal foams are a group of materials which feature a number of closed pores evenly distributed inside materials. They are ultra-light in weight and are greatly valued for their high energy-absorbing performance [1]. These materials are mainly categorized by Low densities and novel physical, mechanical, thermal and acoustic properties. They offer capabilities for lightweight structures, for energy absorption, and for thermal management [2]. The solid foam often originates from the solidification of a liquid in which gas bubbles are finely dispersed [3]. In order to improve the energy absorbing process, it is very important to understand the deformation behavior and failure mechanism of these porous materials. Metallic foams are relatively unknown structural materials; however, they have enormous future potentials for applications where light weight combined with high stiffness and acceptable manufacturing costs are of prime interest [4].

The mechanical performance of closed-cell Al alloy foams accounts for their utility in various applications, such as cores for ultra-light sandwich panels/shells as well as crash or blast-absorbing systems [5]. Of particular interest to research about aluminum closed-cell foam is the usage of these structural foams in automotive components. Polymeric foams are currently being used as a filler material in bumpers and as reinforcement in roof and door beams. The objective is to reinforce these weak areas so that they respond effectively to impact loads. The energy-absorbing capacity of foams is derived from their ability to undergo large deformation, while maintaining a nearly constant stress value [6]. Beside excellent mechanical properties, foamed panels show low thermal conductivity and capacity, high resistance to humidity and UV-radiation, and they are good at noise attenuation and electromagnetic shielding. The unique properties of foamed panels for structural applications have drawn a considerable attention on the part of architects and furniture designers. Finally, foamed panels are ecologically harmless and fully recyclable [4]. Closed-cell aluminum alloy foams have a high strength-to-weight ratio. Under compression, foams can absorb a high amount of energy through the progressive collapse of their cellular structure; they display a low increase in instantaneous stress levels over a large region of strain. Also, aluminum foams can attenuate stress waves. Hence, they are becoming widely used in applications which require good crashworthiness properties [7]. Baumeister et al. [8] carried out a piece of research on the application of foam to absorb energy in

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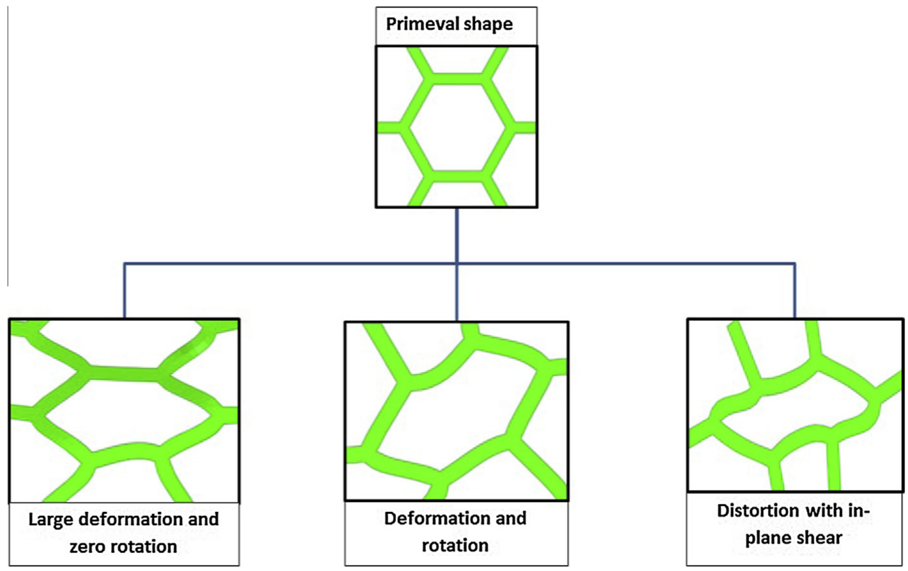

Fig. 1. Deformation mechanisms in close cell foam.

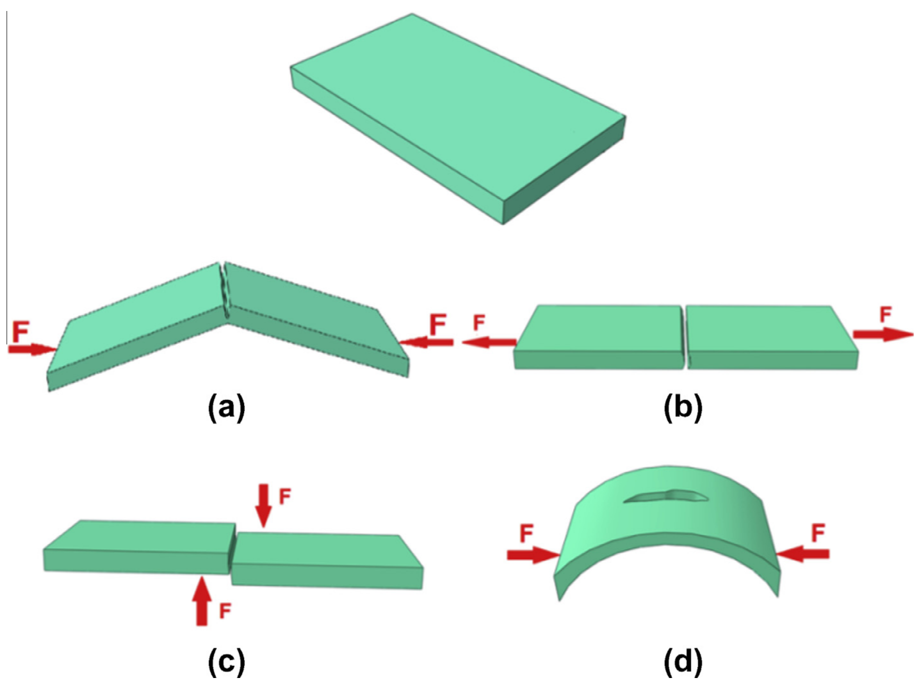

Fig. 2. Schematic draw of four failure modes at the cell wall, to represent better imagine about failure mechanisms.

vehicle bodies. Many studies [9–19] have been done on the mechanical behavior of metallic foams, especially on plateau stress, compressive yield strength, Young's modulus and hardening. Batawros et al. [5] experimentally investigated the deformation mechanisms of closed-cell metallic foams subjected to different loadings. The observation and measurement of cell-level distortions and rotations accompanying the pattern of deformation bands have established some factors that govern the inelastic response of commercial closed-cell metal foams. Markaki and Clyne [20] experimentally studied the cell wall microstructures and cell wall morphology of three different closed-cell Al alloy foams under SEM. They found that microstructures can substantially affect the macroscopic deformation behavior and failure types of metallic foam walls (ductile or brittle failure). Jeon et al. [21] conducted a study on closed-cell Alporas® foam using the finite element method and tomographic images. The macroscopic mechanical properties obtained from uniaxial compression experimental tests agree well with the finite element results.

The current study presents an FE simulation approach for investigation of closed-cell foams to predict their compressive mechanical properties. The simulation results provide a deeper understanding of the cell deformation pattern and its effect on macroscopic behavior. Based on our observations and careful study of the geometrical characteristics in foam, four-modified-unit-cells models are developed. Different cells that can be assembled next to one another are created to encompass the entire existing geometries of real aluminum foam. Compressive deformation behavior and failure mechanisms of cell walls are investigated using final