Processing and Mechanical Properties of Hollow Sphere Aluminum Foams

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ABSTRACT

Metallic foams exhibit unique combinations of excellent mechanical, thermal, electrical and acoustic properties that provide opportunities for a wide range of applications. Hollow sphere metallic foams are a new class of cellular material that possesses the attractive advantages of uniform cell size distribution and regular cell shape. These result in more predictable physical and mechanical properties than those of cellular materials with a random cell size distribution and irregular cell shapes. In the present study, single aluminum hollow spheres with three kinds of sphere wall thickness as 0.1 mm, 0.3 mm and 0.5 mm were processed by a new pressing method. Hollow sphere aluminum foam samples were prepared by bonding together single hollow spheres with simple cubic packing (SC) and body-centered cubic packing (BCC). Compressive tests were carried out to evaluate the deformation behaviors and mechanical properties of the hollow sphere aluminum foams. Effects of the sphere wall thickness and packing style on the mechanical properties were investigated. Results indicated that the hollow sphere aluminum foams exhibited the typical deformation behaviors of cellular metal materials. The relationship between the relative plateau stress and the relative density of the hollow sphere aluminum foams complies with the power-law that has the exponent n close to unity.

Keywords: Hollow spheres, Aluminum foams, Mechanical properties, Deformation behavior

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1. INTRODUCTION

Cellular metals have been of increasing interest as new engineering materials for lightweight construction and for use in sound and energy absorption devices, due to their unique combinations of physical, mechanical, thermal, electrical and acoustic properties [1,2]. Metallic hollow sphere structures are a new type of ultra-light weight material within the class of cellular metals. Hollow sphere cellular metals possess the attractive advantages of uniform cell size distribution and regular cell shapes. These result in more predictable physical and mechanical properties than those of cellular materials with a random cell size distribution and irregular cell shapes [3,4].

Cellular metals can be classified into closed-cell metals and open-cell metals according to the solid distribution of the material. Closed-cell metals have solid cell faces so that each cell is sealed off from its neighbors, whereas open-cell metals contain solid cell edges only. Hollow sphere cellular metals have a mixture of open and closed porosity. Hollow sphere cellular metals can be made from galvanically coated Styrofoam spheres [5] and fluidized bed coated Styrofoam spheres [6]. The Styrofoam acts as a volatilized core in these methods. The former method is limited to a few metals suitable for galvanic deposition, e.g. copper and nickel; the latter method is typically used for manufacturing stainless steel 316L and iron oxides hollow sphere structures. However, it is difficult to fabricate hollow sphere cellular aluminums by these methods because aluminum powders cannot be bonded completely by sintering.

The mechanical properties of cellular metal materials have been extensively investigated [7-10]. Normally, the compressive stress - strain curve for cellular metal materials shows an elastic region, where the flow stress increases with strain, and then a long plateau region, where the flow stress remains almost constant. They are followed by a densification region in which the flow stress rises rapidly. Sanders *et al* [11,12] theoretically modeled the mechanical behavior of hollow sphere cellular materials and indicated that hollow sphere cellular materials have the potential for improved mechanical properties compared to those cellular materials that have a randomly porous structure. However, there is still insufficient experimental data with which to understand the compressive behavior of this class of cellular materials with regularly packed hollow spheres.

Recently, hollow sphere cellular aluminum foam has been developed by a new pressing method [13]. This kind of aluminum foams is suitable for the precise investigation of the deformation behaviors and mechanical properties because the cell size, cell wall thickness and cell shape of each hollow sphere can be controlled. In the present study, four types of hollow sphere aluminum foam samples were prepared by bonding together single hollow spheres with different sphere wall thickness in a simple cubic packing (SC) and body-centered cubic packing (BCC). Compressive tests were carried out to evaluate the effects of the packing style and the sphere wall thickness on the deformation behavior and mechanical property.

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The starting materials are commercially available aluminum sheets A1050 with compositions (wt.%): Al 99.5; Si 0.25; Fe 0.40; Cu 0.05; Mn 0.05; Mg 0.05; Zn 0.05. Aluminum sheets with three kinds of thickness as 0.1 mm, 0.3 mm and 0.5 mm were prepared. These aluminum sheets were then pressed into hollow hemispheres with the same outer sphere diameter of 4 mm. Single hollow spheres were fabricated by bonding together two hollow hemispheres. Hollow sphere foam samples were prepared with three kinds of sphere wall thickness as 0.1 mm, 0.3 mm and 0.5mm and in two kinds of packing styles as simple cubic packing and body-centered cubic packing. The optical micrograph of the single hollow aluminum spheres is shown in Fig. 1. Cyanoacrylate instant adhesive Aron Alpha (Toagosei Co., LTD.) was used for bonding in the present study. The hollow sphere aluminum foam sample with body-centered cubic packing and simple cubic packing are shown in Fig. 2 (a) and (b), respectively. The dimensions of the hollow sphere aluminum foam sample with simple cubic packing were 20 mm x 20 mm x 20 mm (i.e., 25 hollow sphere x 5 layers, totally 125 hollow spheres). The dimensions of the hollow sphere aluminum foam sample with body-centered cubic packing were 16.1 mm x 20 mm x 20 mm (i.e., 25 hollow sphere x 3 layers plus 16 hollow sphere x 2 layers, totally 107 hollow spheres). The densities and relative densities of the hollow sphere aluminum foam samples with various wall thicknesses and packing styles were listed in Table 1.

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3. RESULTS AND DISCUSSIONS

Compressive tests were performed on the hollow sphere aluminum foam samples with three kinds of wall thickness as 0.1 mm, 0.3 mm and 0.5 mm and two kinds of packing style as body-centered cubic packing (BCC) and simple cubic packing (SC). The nominal stress - nominal strain curves are shown in Fig. 3. It can be seen that, for all of the hollow sphere aluminum foam samples, the nominal stress - nominal strain curves under compressive loading exhibit a linear elastic regime, a rounded shoulder at the onset of yield followed by a long plateau regime with a nearly constant flow stress to a large strain, and a densification regime where the flow stress rapidly increases. Although the sphere wall thickness and the packing style were different with one another, these hollow sphere aluminum foam samples deformed in a similar manner with three deformation regimes, which is the typical deformation behavior cellular metals [7-9]. The nominal stress increases with the increasing of the sphere wall thickness, as shown in Fig. 3. This is because the density of the hollow sphere foam samples increases with the increasing of the wall thickness as listed in Table 1. It should be noted that for sample B and sample C, the stress - strain curves were relatively close to each other, though the two samples have the same density but different sphere packing style as simple cubic packing and body-centered cubic packing. The plateau stress of sample B with SC packing was slightly lower than that of sample C with BCC packing.

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Fig. 5 and Fig. 6 show the frames taken by video camera during compression tests of the hollow sphere foam samples with body-centered cubic packing and simple cubic packing, respectively. Observations on all the compressive processes found that the deformation is dominated by sphere wall bending.

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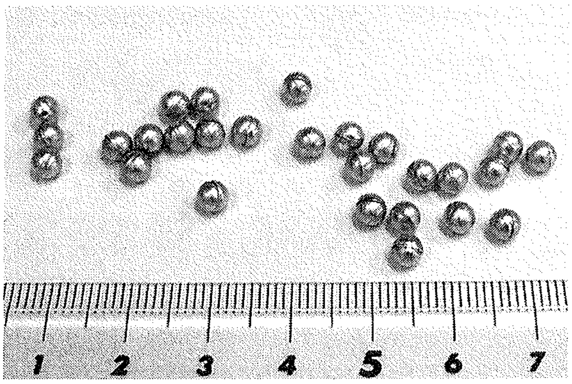

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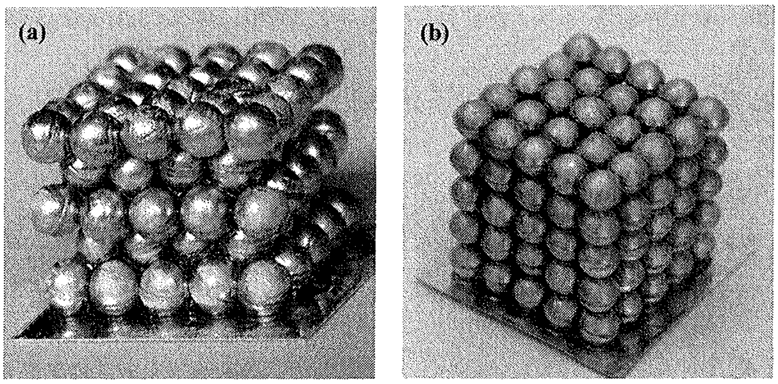

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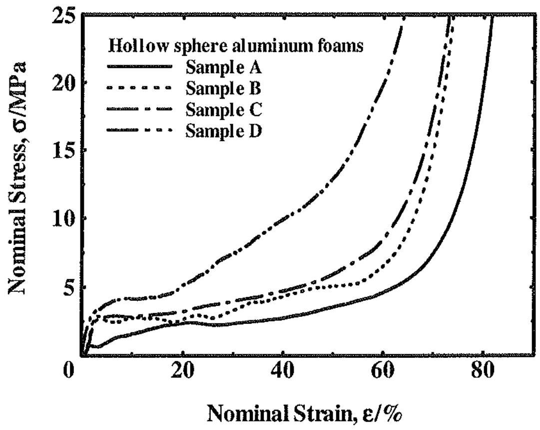
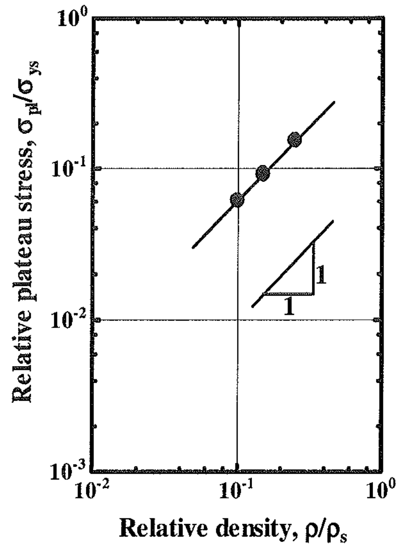


Fig. 3 The nominal stress - nominal strain curves for the hollow sphere aluminum foam samples



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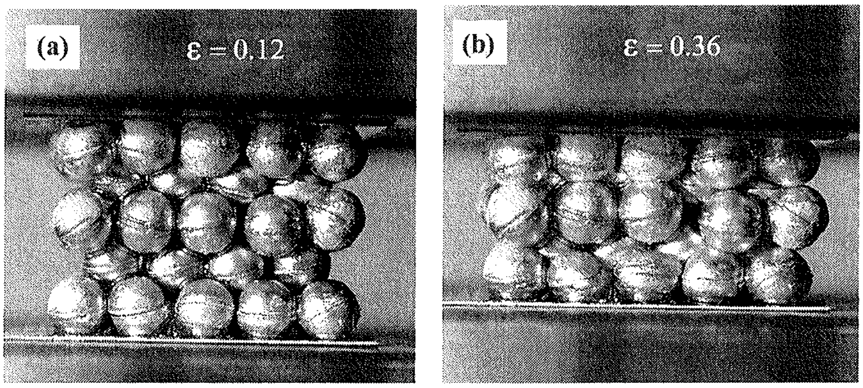
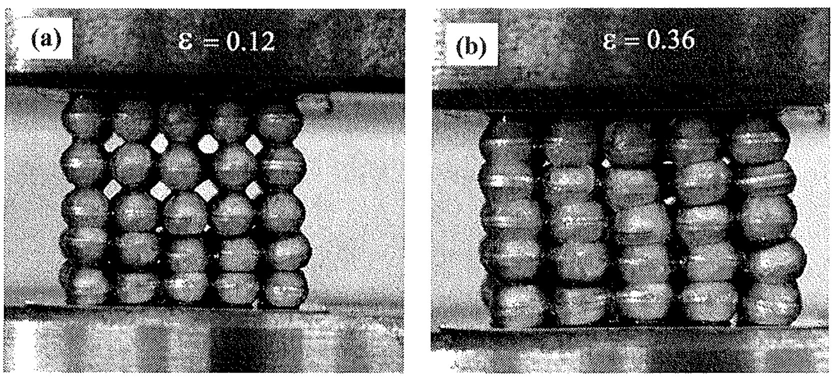


Fig. 5 Deformation behavior of the body-centered cubic packing hollow sphere foam sample (sphere wall thickness 0.3 mm)



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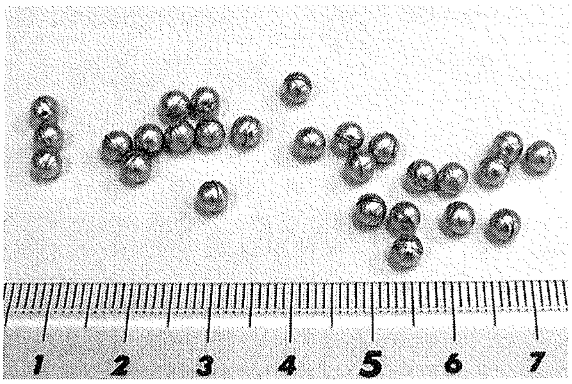

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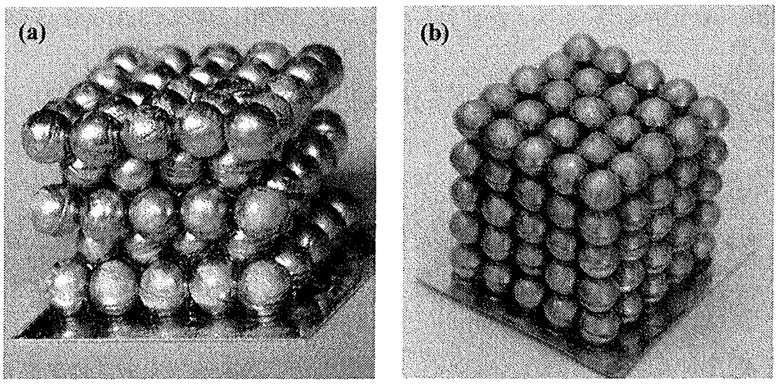

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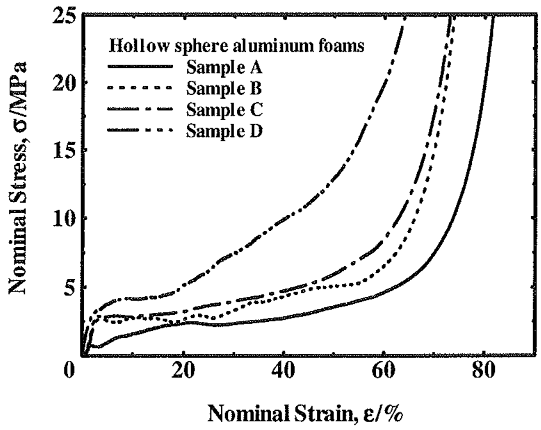

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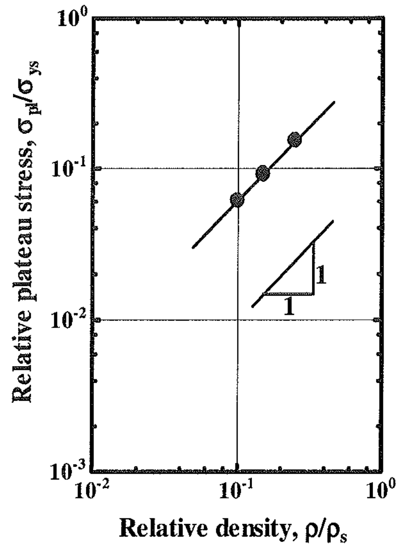

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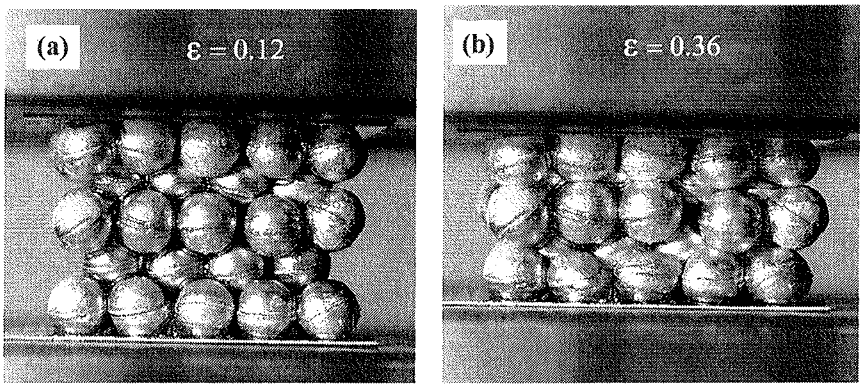

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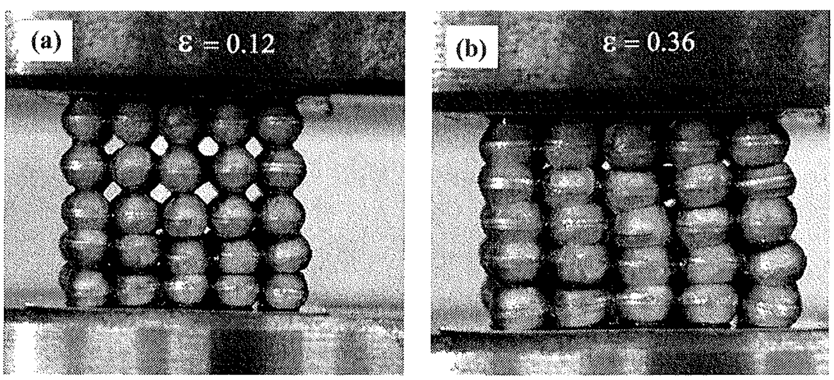

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