Journal of Alloys and Compounds 476 (2009) 220–225

Contents lists available at ScienceDirect

Journal of Alloys and Compounds

journal homepage: www.elsevier.com/locate/jallcom

Correlation between ceramic additions and compressive properties of Zn–22Al matrix composite foams

Jiaan Liu[a], Sirong Yu[a,*], Xianyong Zhu[b], Ming Wei[a], Yanru Luo[b], Yaohui Liu[a]

[a] Key Laboratory of Automobile Materials (Jilin University), Ministry of Education, and College of Materials Science and Engineering, Jilin University, Changchun 130025, China
[b] Institute of Mechanical Science and Engineering, Jilin University, Changchun 130025, China

ARTICLE INFO

Article history:
Received 18 July 2008
Received in revised form 8 September 2008
Accepted 12 September 2008
Available online 1 November 2008

Keywords:
Metal matrix composites
Zn–22Al alloy
Ceramics
Microstructure
Compressive behavior

ABSTRACT

The compressive behaviors of Zn–22Al composite foams using SiC particles as reinforcement and stabilizing agent (ZA22/SiCp composite foams) were investigated in this study. To observe the deformation mechanisms, the deformation processes of the composite foams were recorded, and the cracks under the compressive load were observed by scanning electron microscope (SEM). Owing to the presence of the particles, ZA22/SiCp composite foams show more brittle compressive behavior with a large stress fluctuation than Zn–22Al alloy foams (ZA22 foams). The compressive processes of composite foams are characterized by the formation and propagation of the localized deformation band. The photomicrographs of the cracks indicate that a complicated effect of SiC particles on the compressive properties of the foams result in a high compressive strength. As a consequence, ZA22/SiCp composite foams exhibit slightly high energy absorption capacities, although low energy absorption efficiencies, as compared with ZA22 foams.

1. Introduction

Metallic foams have received extensive interest as new structural and functional materials because of their energy absorption, flame resistance, vibration reduction, and acoustic insulation [1]. In particular, they can absorb most of the plastic deformation energy at low constant stress during compression. They are adopted for protective aim in traffic and packing industry [2,3]. Therefore, the compressive property is an important characteristic of metallic foams.

Generally, the compressive properties of metallic foams depend on the property of cell wall material [4–7], the relative density [1–3], the cell structure (e.g., shape, orientation and defect of cell) [8,9], and the type of load (e.g., static or dynamic, free or constrained compression) [10,11].

Secondary phase or component in cell wall materials is an important factor affecting the mechanical response of the foams [5,11–17]. SiC particles commonly utilized as the stabilizing agent for the fabrication of metallic foams can dramatically change the mechanical properties of metallic foams [5,14–17]. Parkash et al. [14] found that the localized deformation took place in Al/SiCp composite foams due to SiCp dispersed in cell structure. Yu et al. [5] also denoted that the presences of SiC particles in Zn–22Al/10 vol.% SiCp composite foams resulted in a large compressive stress fluctuation. Moreover, the studies on the composite foams fabricated by powder metallurgy process also demonstrated that the composite foams showed a brittle deformation behavior and a slight degradation in the compressive properties as compared with Al alloy foams [15,16]. However, the studies on the correlation between ceramic particles and compressive property of metallic foams, especially on the nucleation and propagation of cracks, are limited. Therefore, in present study, the deformation process and the cracks of ZA22/SiCp composite foams were observed in order to understand the compressive deformation mechanisms of composite foams.

2. Experimental

2.1. Raw materials

The raw materials for preparing composite foams included ZA22 alloy (22.0 wt.% Al, 1.0 wt.% Cu, 0.03 wt.% Mg, and Zn balance), SiC particles (98.0 wt.% in purity, about 28 μm in size), and $CaCO_3$ powders (99.5 wt.% in purity). SiC particles and $CaCO_3$ powders were used as stabilizing agent and blowing agent, respectively. To improve the wettability between SiC particles and ZA22 melt, SiC particles were heat-treated at 930 °C for 6 h and at 420 °C for 2 h, respectively.

2.2. Fabrication of composite foams

Zn–22Al composite slurry with 7 vol.% SiCp was prepared by conventional stir-casting technique [18], and then $CaCO_3$ powders were added into the melt.

* Corresponding author. Tel.: +86 431 85095862; fax: +86 431 85095876.
E-mail addresses: yusr@jlu.edu.cn, yusirong4179@163.com (S. Yu).

0925-8388/$ – see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.jallcom.2008.09.069

Afterwards, the composite slurry was stirred for 2 min with a steel stirrer at a rate of 900 r/min and then held at 700–720 °C to allow the blowing agent to release gas bubbles.

2.3. Compression test

Size effect is an important issue in the mechanical testing of metallic foams [19–21]. That means the value of the specimen size relative to the mean cell size has great influence on the mechanical properties of the metallic foams. The specimen with insufficient number of cells (<6) can cause a significant loss of the mechanical properties. When a specimen contains more than 6 cells, the size effects can be ignored [19,20]. Therefore, the large specimens used for compression test are favoring for eliminating the size effects. But large specimens are discommodious for observation in SEM. A small specimen is required for the observations on the microstructure failure. Song et al. [21] found that the failure process of a specimen with insufficient cell is homologous to that of a specimen with many cells. Both of them are defect-directed or weakness-directed processes. That means that the failure mechanisms of small and large specimens are homologous. Therefore, in this work, we selected the large specimen used for compression test and the small specimen used for the observation on the microstructure failure.

Specimens with the large dimensions of 15 mm × 15 mm × 30 mm were prepared for the compressive test in order to eliminate size effects [5]. The compressive tests were carried out on a universal mechanical testing machine at a nominal strain rate of $2.2 \times 10^{-3}\ s^{-1}$. The obtained data were used for drawing the compressive stress–strain curves. The deformation processes of the large foam samples were recorded by a numeral camera to study the deformation mechanism of the macrostructure in the composite foams.

The rectangular sections of small foam samples (10 mm × 10 mm × 12 mm) were polished, and then the samples were compressed at certain strain. Afterwards, the polished sections of the samples were observed immediately without further metallographic treatment.

2.4. Characterization of composite foams

The cracks of the deformed foams were observed by means of scanning electron microscopy (SEM) (Model JSM-5310, Japan).

The porosities of the composite foams were calculated using the following formula [2]:

$$P = \left(1 - \frac{\rho^*}{\rho_s}\right) \times 100\% \quad (1)$$

where P is the porosity of the composite foams, ρ^* and ρ_s are the densities of the composite foams and the cell wall material, respectively, and (ρ^*/ρ_s), which is called the relative density of the composite foams, indicates the ratio of the density of the composite foams to the density of cell wall material.

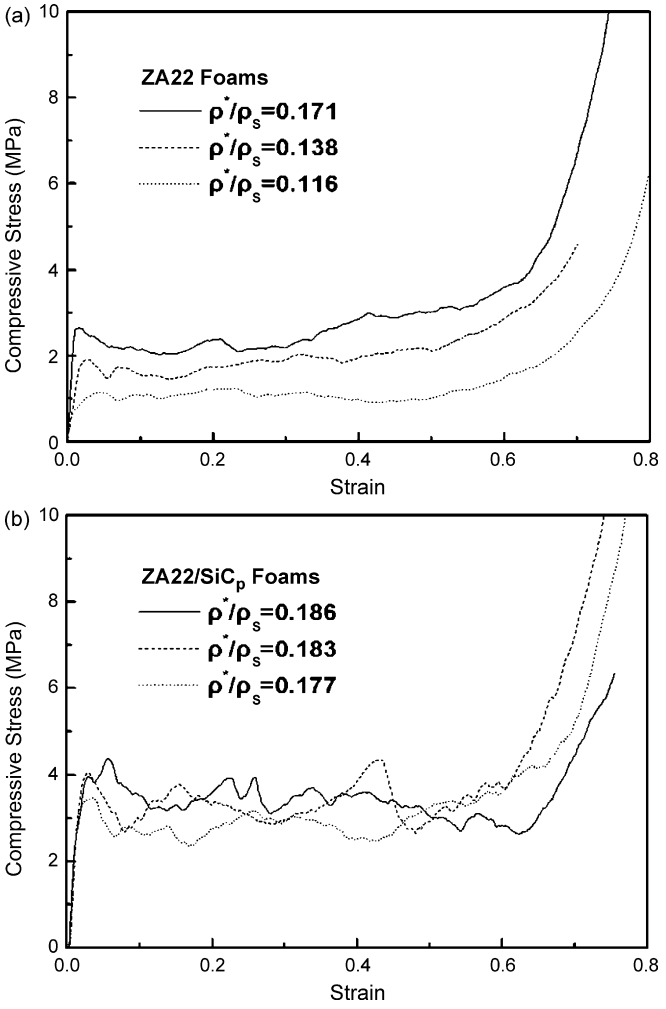

Fig. 1. Compressive stress–strain curves of (a) ZA22 foams and (b) ZA22/SiCp composite foams.

3. Results and discussion

3.1. Compressive curves of the foams

Fig. 1 shows the compressive stress–strain curves of ZA22 foams and ZA22/SiCp composite foams with various relative densities. It can be seen that all the stress–strain curves exhibit three distinct regions [7,10]: a linear-elastic region at very low strain, a collapse plateau region, and a densification region where the stress rises rapidly.

Owing to the presence of ceramic particles, ZA22/SiCp composite foams have a complex mechanical response as compared with ZA22 foams. It can be found that the curves of composite foams continually fluctuated with increasing strain, and the stress peak appeared time and again (Fig. 1(b)). As is generally accepted, the brittle foams exhibit a serrate compressive stress–strain curve, while the plastic foams show a smooth stress–strain curve [2,3]. It can be found that from Fig. 1, the composite foams show more brittle compressive behavior than Zn–22Al alloy foams.

3.2. Deformation mechanisms of composite foams in macrostructure and microstructure

To observe the deformation mechanisms, the deformation processes of the composite foams with different strains were recorded (Fig. 2). The formation and propagation of the localized deformation band, which is approximately perpendicular to the compression direction, can be observed. This deformation process is in accordance with the universal investigations on the deformation of metallic foams with closed-cell structure [3,4,7,9,14,16]. The position of the initially local deformation and the propagation of the deformation band rely on the cell structure. It seems to be that the isolated large pore and deep pore are easy to deform because they are thought to be a weak portion in the foam structure. There are two different categories of alloy foams: One is ductile foams, and another is brittle foams. It is generally accepted that the compressive failure of ductile foams is controlled by the cell edge buckling and cell wall bending, whereas the compressive failure of brittle foams is governed by the cell edge fracture and cell wall tearing [3,4,16]. The ductile foams were characterized by a smooth curve in compressive response. On the contrary, the brittle foams were characterized by a large fluctuation in plateau region [2]. Figs. 1 and 2 further indicated that composite foams show a partly brittle deformation behavior because some pores were crushed. Therefore, the deformation mechanism of composite foams can be summarized as follows: the deformation starts from an elastic one of cell structure. Then the cell structure collapses, and a localized deformation band occurs per-