Journal of Alloys and Compounds 499 (2010) 227–230

Contents lists available at ScienceDirect

Journal of Alloys and Compounds

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

Compressive property and energy absorption characteristic of open-cell SiCp/$AlSi_9Mg$ composite foams

Yanru Luo[a,*], Sirong Yu[b], Jiaan Liu[b], Xianyong Zhu[a], Yanhe Luo[c]

[a] College of Mechanical Science and Engineering, Jilin University, Changchun 130022, China
[b] College of Materials Science and Engineering, Jilin University, Changchun 130022, China
[c] Tianjin Academy of Environmental Sciences, Tianjin 300191, China

ARTICLE INFO

Article history:
Received 8 January 2010
Received in revised form 14 March 2010
Accepted 18 March 2010
Available online 25 March 2010

Keywords:
Composite materials
Ceramics
Mechanical properties

ABSTRACT

Open-cell 4 vol.% SiCp/$AlSi_9Mg$ composite foams with different relative densities were fabricated by the infiltration process using NaCl preforms. The distributions of SiC particles in the cell wall were observed and compressive properties and energy absorption characteristic of the foams were investigated. The results show that the yield stress and the energy absorption capacities of open-cell 4 vol.% SiCp/$AlSi_9Mg$ composite foams increase with the rising relative density. And the stress–strain curves of open-cell 4 vol.% SiCp/$AlSi_9Mg$ composite foams are not as smooth as that of aluminum foams due to the addition of SiC particles. The theory model used to describe the energy absorption capacity of the foams in different strain region was induced.

Crown Copyright © 2010 Published by Elsevier B.V. All rights reserved.

1. Introduction

Recently, there has been a considerable increasing interest in using metal foams as lightweight structural components and energy absorption parts which can be utilized in the automobile, railway, shipbuilding and aerospace applications due to their outstanding mechanical and multifunctional characterization [1]. Important application for the metallic foams is in sacrificial crash boxes, which are absorbing deformable energy elements in automotive structures. The mechanical behaviors of foams are not only dictated by the microstructure of foams (described by relative density, cell shape, cell size, etc.) [2,3], but also dictated by the properties of the cell wall material [4,5]. While the mechanical behavior of cellular metallic materials has been widely studied, researches devoted to properties of the composite foams are limited. Prakash et al. studied the effect of microstructure on mechanical response of closed-cell Al–SiC foam, the results were the growth of cracks in the cell membranes is associated with a wide damage zone and the mechanical response is complex due to non-uniform distribution of particles [6]. Yu et al. found that the damping properties of ZA22/SiCp composite foams are obviously higher than those of ZA22 alloy and ZA22 alloy foams [7]. Esmaeelzadeh and Simchi drew a conclusion that there is a slight degradation in the mechanical properties of $AlSi_7$–3 vol.% SiC foams fabricated by powder compact [8]. Mondal et al. concluded that the influence of strain rate on the deformation responses of aluminum-fly ash particle composite foam is found to be very marginal [9]. However, Most of researches were carried on the preparation and characterization of closed-cell composite foams. Little investigation is taken on the characterizations of open-cell composite foams. Therefore, in this research, the compressive properties and energy absorption characteristic of open-cell SiCpAlSi_9Mg composite foams were investigated.

2. Experimental

2.1. Preparation

The open-cell 4 vol.% SiCp/$AlSi_9Mg$ composite foams produced by the infiltration process were used in the present study. To evaporate the moisture, the NaCl particles (0.9–4 mm in size) were heated to 500 °C for 1.5 h. Then the NaCl particles preforms were sintered at 700 °C for 3 h in a column to make a precursor. Raw materials of the cell wall were $AlSi_9Mg$ alloy (8.9 wt.% Si, 0.21 wt.% Mg, and Al balance) and SiC particles (0.28 wt.% C, 0.23 wt.% Si, 1.73 wt.% SiO_2, 0.56 wt.% Fe_2O_3, and SiC balance) in size of 28 μm. 4 vol.% SiCp/$AlSi_9Mg$ composite was prepared by conventional stir-casting technique, and then it was melted to 720 °C at a graphite crucible in an electric resistance furnace. To prevent sedimentation of SiC particles, the stir rate is up to 1200 rpm before the infiltration. Afterwards, NaCl preforms were infiltrated with molten 4 vol.% SiCp/$AlSi_9Mg$ composite under the pressure of 8 MPa quickly. After the complex solidified, NaCl particles were dissolved in water and the open-cell 4 vol.% SiCp/$AlSi_9Mg$ composite foams with different relative densities (defined as ρ^*/ρ_s, ρ^* is the density of foams, and ρ_s is the density of matrix metal) from 0.296 to 0.394 were obtained. The cell sizes of these 4 vol.% SiCp/$AlSi_9Mg$ composite foams are equal to the sizes of NaCl particles. An optical microscope was used for observing the cell structure and distribution of SiC particles in 4 vol.% SiCp/$AlSi_9Mg$ composite foams respectively. It can be found that the cell structure is uniform (Fig. 1(a)) and SiC particles distribute uniformly in cell wall (Fig. 1(b)).

* Corresponding author at: College of Mechanical Science and Engineering, Jilin University at Nanling Campus, Renmin Street 5988, Changchun 130022, China. Tel.: +86 431 85095357; fax: +86 431 85095288.
E-mail address: luoyr@jlu.edu.cn (Y. Luo).

0925-8388/$ – see front matter. Crown Copyright © 2010 Published by Elsevier B.V. All rights reserved.
doi:10.1016/j.jallcom.2010.03.172

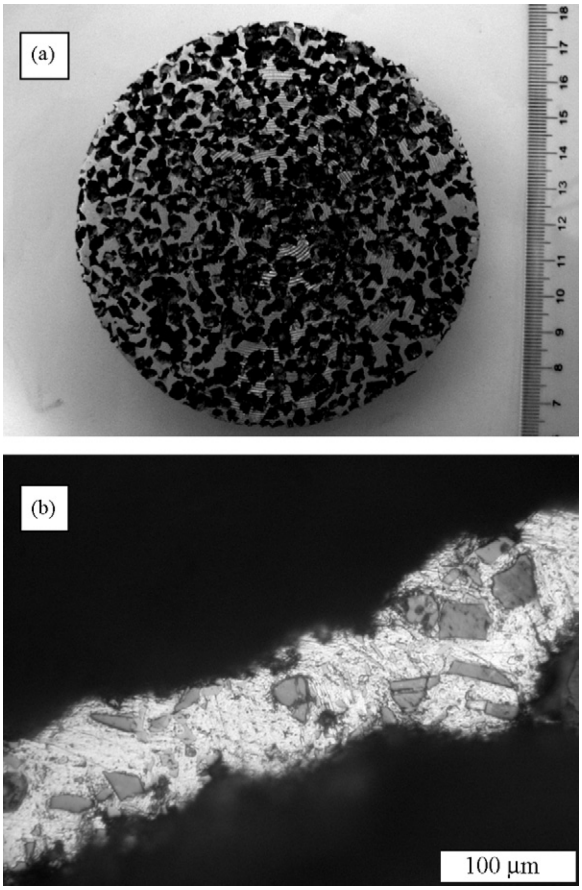

Fig. 1. Photographs of 4 vol.% SiCp/$AlSi_9Mg$ composite foams: (a) optical photograph; (b) photograph of cell wall.

2.2. Compression tests

The compressive specimens with the dimensions of 15 mm × 15 mm × 35 mm were prepared. The compressive tests were carried out on a CMT5205 electron universal testing machine at strain rate of 10^{-3} s^{-1}.

3. Results and discussion

3.1. Compressive behaviors

The compressive stress–strain (σ–ε) curves of open-cell 4 vol.% SiCp/$AlSi_9Mg$ composite foams with different relative densities are shown in Fig. 2. The curves in Fig. 2 are not as smooth as the aluminum foams due to the addition of SiC particles [4]. It can be seen that all the stress–strain curves exhibit typical three distinct regions: linear elastic deformation region, collapse plateau region and densification region. The linear elastic deformation regions of 4 vol.% SiCp/$AlSi_9Mg$ composite foams appear only at a low strain about 0.04. And in this region, the flow stress increases sharply with increasing strain. The deformations of open-cell foams at this stage are mainly controlled by the cell wall bending and fracture [10]. With the relative density increase, the yield stress increases. The yield stress of 4 vol.% SiCp/$AlSi_9Mg$ composite foams with the relative density of 0.394 is nearly up to 13 MPa, while the yield stress of the foams with the relative density of 0.296 is only 7 MPa. The main reason for that is the compression of cell wall become more and more notable with the increase of relative density. In the collapse plateau region, the cell wall buckles and the foams collapse layer by layer. Differ from the yield stress, the densification strain (ε_d) of 4 vol.% SiCp/$AlSi_9Mg$ composite foams decreases with the increase of relative density. In this strain all the cells were compacted, so the larger relative density foams enter into this strain earlier than the low relative density foams. The second region is followed by the third region after the densification strain reaches. The smooth curves with obvious slope can be observed. The greater the relative densities are, the steeper the curves appear.

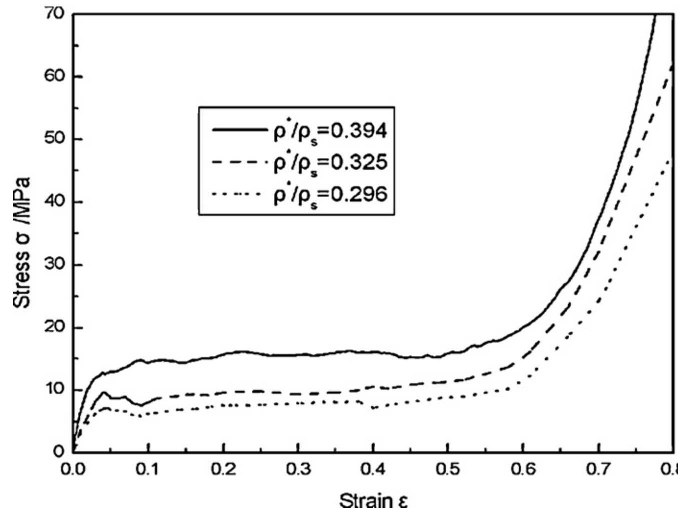

Fig. 2. Stress–strain curves of open-cell 4 vol.% SiCp/$AlSi_9Mg$ composite foams.

The relations between the relative stress and relative density for open-cell 4 vol.% SiCp/$AlSi_9Mg$ composite foams are plotted in Fig. 3. The relative stress of 4 vol.% SiCp/$AlSi_9Mg$ composite foams increases with the increase of relative density. According to Gibson and Ashby model for open-cell foams [10,11]:

$$\sigma_y = 0.3\sigma_m \left(\frac{\rho^*}{\rho_s}\right)^{3/2} \tag{1}$$

Where σ_m is the stress of 4 vol.% SiCp/$AlSi_9Mg$ composite and σ_y is the yield stress of SiCp/$AlSi_9Mg$ composite foams. As shown in Fig. 3, the result of open-cell 4 vol.% SiCp/$AlSi_9Mg$ composite foams in current investigation is in close agreement with the theory model of Gibson and Ashby.

3.2. Energy absorption characteristic

The work acting on the foams is dissipated in the form of energy during compressive loading. The work per unit volume in defor-

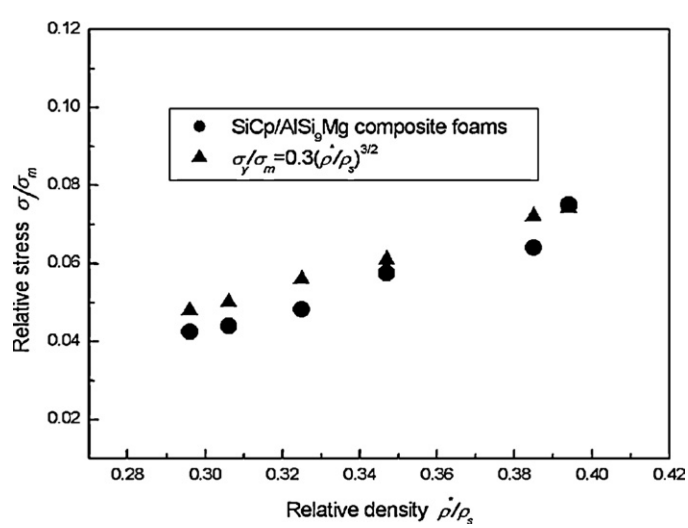

Fig. 3. Relation between the relative stress and relative density for different 4 vol.% SiCp/$AlSi_9Mg$ composite foams.

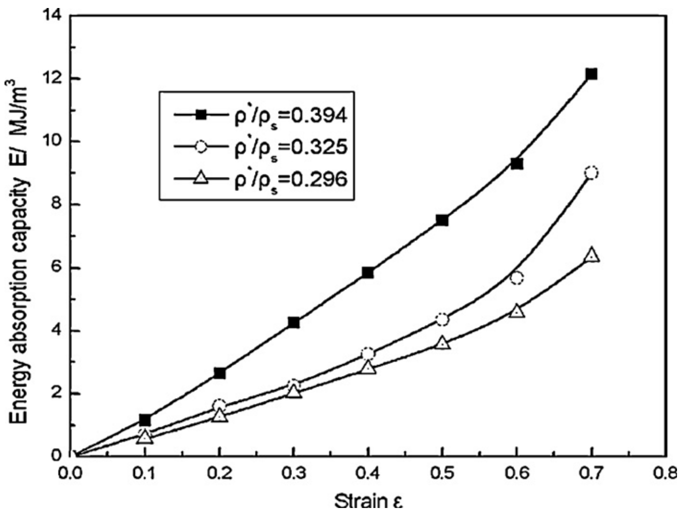

Fig. 4. Energy absorption capacity of 4 vol.% SiCp/AlSi$_9$Mg composite foams.

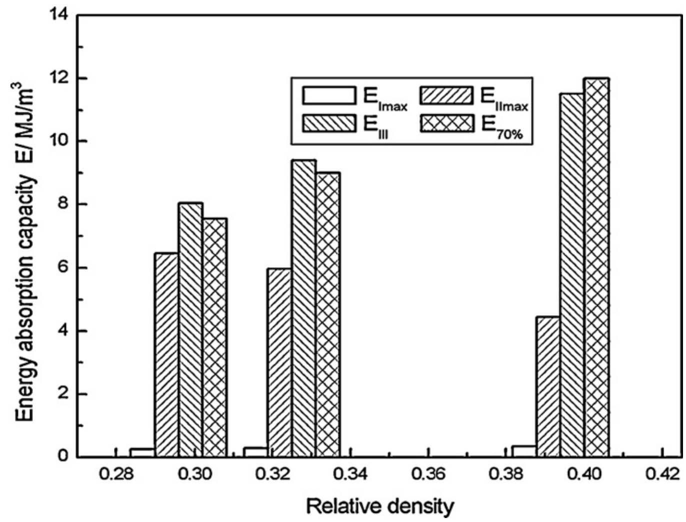

Fig. 5. Relationship between relative density and energy absorption capacity of 4 vol.% SiC$_P$/AlSi$_9$Mg composite foams in different strain field.

mation at certain strain is the area under the stress–strain curve, which is called the energy absorption capacity (E) and the E is given by [10]:

$$E = \int_0^{\varepsilon} \sigma d\varepsilon \tag{2}$$

The energy absorption capacities of open-cell 4 vol.% SiCp/AlSi$_9$Mg composite foams with different relative densities at compressive strain of 10–70% are shown in Fig. 4. The energy absorption capacity is strongly depended on the relative density for the SiCp/AlSi9Mg composite foams. The energy absorption capacity rises with the increasing relative density and compressive strain. The energy absorption capacity of open-cell 4 vol.% SiCp/AlSi$_9$Mg composite foams is 7.5 MJ/m^3 at strain of 50% with the relative density of 0.394, while it is only 3.6 MJ/m^3 at the same strain with the relative density of 0.296. The former is twice as much as the latter. Therefore, it can be concluded that the energy absorption capacity is a function of the relative density.

To describe the energy absorption capacity in different strain region, the energy absorption can be divided into the corresponding three regions according to the three regions of compressive curves.

In the linear elastic region, the approximate energy (E_{I}) dissipated by elastic deformation is [12]:

$$E_{\text{I}} = 0.5\sigma\varepsilon (0 < \varepsilon < 0.04) \tag{3}$$

For the 4 vol.% SiCp/AlSi$_9$Mg composite foams in this investigation, the yield strain(ε_y) is about 0.04.

$$E_{\text{Imax}} = 0.15\sigma_m \varepsilon_y \left(\frac{\rho^*}{\rho_s}\right)$$

In the collapse plateau region, the approximate energy (E_{II}) is:

$$E_{\text{II}} = \sigma_y(\varepsilon - \varepsilon_y) + E_{\text{I}}(0.04 < \varepsilon < \varepsilon_d) \tag{4}$$

$$E_{\text{IImax}} = 0.15\sigma_m \left(\frac{\rho^*}{\rho_s}\right)(2\varepsilon_d - \varepsilon_y)$$

where ε_d is the densification strain and equal to $[1 - 1.4(\rho^*/\rho_s)]$ [10]. E_{IImax} is a quadratic function according to the function expression, and it has the maximum value when the relative density is equal to 0.175. The relative density of open-cell 4 vol.% SiCp/AlSi$_9$Mg composite foams in this investigation are all greater than 0.175, therefore the E_{IImax} decreases with the relative density increase.

In the densification region, the approximate energy (E_{III}) dissipated is:

$$E_{\text{III}} = 0.5(\sigma + \sigma_d)(\varepsilon - \varepsilon_d) + E_{\text{II}}(\varepsilon_d < \varepsilon) \tag{5}$$

σ_d is the corresponding stress and equal to σ_y.

Fig. 5 shows the calculated values (E_{Imax}, E_{IImax}, E_{III} (ε = 70%)) and the actual value ($E_{70\%}$ (ε = 70%)) of open-cell 4 vol.% SiCp/AlSi$_9$Mg composite foams with different relative densities (0.296, 0.325 and 0.394). E_{Imax} of these foams with different relative density are much the same on the whole. However, E_{IImax} of these foams decrease with the increase in relative density. And the calculated value E_{III} (ε = 70%) are close to the actual value $E_{70\%}$. The results proved that the energy absorption capacity of foams with different relative density under compressive loading can be described using the theory model mentioned above. In practical application, the compression of foams cannot get a complete process and the strain of foams does not reach the densification strain. Therefore, this model can be used to estimate the probable value of energy absorption capacity of foams.

4. Conclusion

Open-cell 4 vol.% SiCp/AlSi$_9$Mg composite foams with different relative densities were fabricated by the infiltration process. The yield stress and the energy absorption capacity of open-cell 4 vol.% SiCp/AlSi$_9$Mg composite foams increase with the increasing relative density, but the densification strain of these foams decrease when the relative density increase. And the stress–strain curves of open-cell 4 vol.% SiCp/AlSi$_9$Mg composite foams are not as smooth as that of aluminum foams due to the addition of SiC particles. The theory model of energy absorption capacity in three regions was used to describe the energy absorption in different strain field. E_{Imax} of open-cell 4 vol.% SiCp/AlSi$_9$Mg composite foams with different relative density are much the same on the whole, however, E_{IImax} of foams decrease with the increasing relative density, and E_{III} (ε = 70%) of foams are near to the actual value $E_{70\%}$ of foams.

Acknowledgement

This work was supported by Program of Jilin Provincial Science & Technology Department of PR China.

References

[1] L. AFuganti, A.G. Lorenzi, Hanssen, et al., Adv. Eng. Mater. 2 (2000) 200.
[2] F.P. Chiang, Y. Ding, Compos. Part B: Eng. 39 (2008) 42–49.
[3] C. Chen, N.A. Fleck, J. Mech. Phys. Solids 50 (2002) 955–977.
[4] S.R. Yu, Y.R. Luo, J.A. Liu, Mater. Sci. Eng. A 48 (2008) 394–399.
[5] O. Gerbaux, T. Vercueil, A. Memponteil, et al., Chem. Eng. Sci. 64 (2009) 4186–4195.
[6] O. Prakash, H. Sang, J.D. Embury, Mater. Sci. Eng. A 199 (1995) 195–203.
[7] S.R. Yu, J.A. Liu, Y.R. Luo, Mater. Sci. Eng. A 457 (2007) 325–328.
[8] S. Esmaeelzadeh, A. Simchi, Mater. Lett. 62 (2008) 1561–1564.
[9] D.P. Mondal, M.D. Goel, S. Das, Mater. Sci. Eng. A 507 (2009) 102–109.
[10] L.J. Gibson, M.F. Ashby, Cellular Solids, Structure and Properties, 2nd edition, Cambridge Press, Cambridge, UK, 1997.
[11] P.H. Thomton, C.L. Magee, Metall. Trans. 6 (1975) 1253–1263.
[12] Z.H. Song, S. Nutt, Adv. Eng. Mater. 2 (2000) 73–77.