CELLMAT2012

Certificate

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Herewith we certify that the papers with the titles

"Effect of SiC on microstructural features and compressive properties ofaluminum foam"
M. Malekjafarian, M. S. Abravi, M. Golestanipour, A. Sadeghi, H. Amini Mashhadi, A. Babakhani,

"Effects of density on the bending and compressive properties of closed-cell aluminum foam"
M. Malekjafarian, M. S. Abravi, M. Golestanipour, A. Sadeghi, H. Amini Mashhadi, A. Babakhani

“Ceramic particles stabilized aluminum foams produced by melt gas injection”
M. Malekjafarian, M. S. Abravi, H. Amini Mashhadi, M. Golestanipour, A. Sadeghi, A. Babakhani,

have been published at the Proceedings CD of the conference

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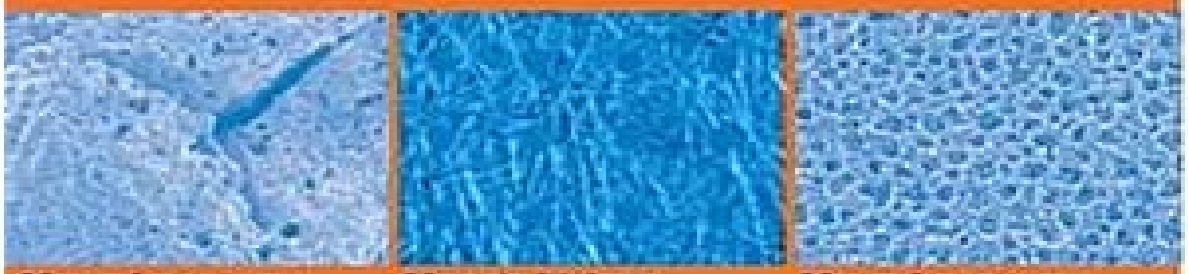

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Ceramic Particles Stabilized Aluminum Foams Produced by Melt Gas Injection

Abstract

Composite aluminum foams reinforced with SiC particles were manufactured by injecting gas into the liquid. Microstructure and mechanical behavior of the aluminum foam were investigated by scanning electron microscopy and compression test. The results show that the both cell size and wall thicknesses augmented with increasing SiC particles content while the plateau border size decreased. With greater SiC particles content, plateau stress was larger but maximum plateau strain was lower. The stress-strain curve exhibited serrations in the plateau region.

Keywords: Aluminum; Foam; Particulate reinforced composites; Melt spinning; Compression test

1. Introduction

Aluminum foams are useful material for light weight structural application and for absorbing energy of impact due to its high specific strength, high specific stiffness and high energy absorbing capacity with good absorption efficiency [1–2]. The gas injection foaming process is an important method to produce aluminum foams. In this process, gas is injected through a special injecting device into aluminum melt containing some ceramic particles to form bubbles, and then the bubbles accumulating on the surface of the melt are collected and molded to fabricate aluminum foam parts. The main challenge of recent research is to achieve a uniform cellular structure, to perfect the reproducibility in manufacture and to control foam architecture. In 2000 D. Leitlmeier and coworkers at LKR, Austria, reinvestigated the direct foaming process and successfully developed aluminum foams with a homogeneous cell size distribution now called METCOMB® [3]. In order to improve the cellular structure of the materials and also make the production technology more reliable and reproducible, foam stability (avoidance of rupture and of drainage) of liquid metals has to be understood and controlled, since without a clear scientific understanding of foam stability further improvement in foam quality and process control is impossible.

The injected air produces bubbles, which rise towards the surface of the melt. A foamy liquid in this way is produced, which can be stabilized by injection of solid ceramic particles into the gas-liquid interface. These particles can reside inside the walls of the solidified cells. The stabilized liquid can mechanically be conveyed to the surface of the melt and allowed to cool down and solidify into a foamy aluminum slab. The aluminum foam structure (cell size and cell wall thickness) is controlled by the process variables such as the volume fraction of the solid particles; foaming temperature, air flow rate and impeller design of the foam making process [4]. No publication has yet been accessible on the influence of the process variables on the cell-structure of the aluminum foam. The present study is aimed at investigating of the effect of the percentage of the SiC particles on the cell structure and mechanical properties of the produced foam.

2. Materials and experimental techniques

2.1. Materials

Commercial A356 cast aluminum alloy and SiC particles with 98.0 wt % purities were raw materials used in this research. The mean particle size of the reinforcement SiC particles was 10 μm. Heating SiC particles at 950 °C for 1 h and then at 650 °C for 2 h was performed to improve the wetting properties by removing the adsorbed gases from their surfaces.

2.2. Processing methodology

Conventional stir-casting technique was employed to produce SiC reinforced Al-matrix composite foam. Molten slurry containing Al and SiC was stirred at 650-680 °C by a rotational speed of 1400 rpm and then poured into steel moulds. To improve wetability, 1 wt% magnesium was added to the melt. Solidified ingots were then re-melted and stirred at 700 °C to attain sufficient viscosity.

Stirred-heating of the mixture continued until molten phase reached the foaming temperature of 730 °C. It was then poured into the foam making ladle illustrated in Figure 1. Resistance heating helped preservation of the ladle temperature. The ladle was made of low carbon steel protected with zirconia coating guard. When the top level of the molten composite was about 15 cm below the foaming spout, compressed air was blown into the melt from bottom nozzle. A rotameter controlled flow rate of the air (2 and 4 l/min at 0.2 MPa). Different amounts of SiC particles (5, 10, 15 and 20 Vol. %) was added to the melt to obtain composite foams with different relative densities and mechanical properties. Blowing was stopped whenever foam was about to overflow.

After cooling, the solidified composite foam was removed from the ladle and sectioned for evaluation of cell structure and mechanical strength. Porosity of the foam was calculated using the following equation:

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

P is porosity of the foam; ρ is density of the foam; ρ_s is density of the cell wall material and ρ/ρ_s is the relative density of the composite foam with respect to the cell wall material. Quantities of these parameters are listed in Table 1.

2.3. Materials characterizations

Specimens with cross-section of 50 mm × 50 mm and height of 30-40 mm were cut out of foam slabs to determine their cell structure. Scanning electron microscopy (LEO 1450VP 35 kV) and conventional optical microscopy (Olympus PM3) were used to elucidate microstructure of the cells and distribution of SiC particles in Al/SiC_p composite foams. Mean intercept length technique of at least 30 cells were used to determine the cell size of different foam samples. Cells of average size were chosen for measurement of their wall thickness and the plateau-border size under microscope. Existence of correlation between the wall thickness and the plateau-border size was hence revealed from these measurements.

Compression-test specimens were wire-cut out of the foamy composite slabs. Their dimensions were selected to be 50×50×60 mm so that at least six cells in each direction could exit. Zwick Z250 universal testing machine controlled by computer with a cross-head speed of 1 mm/min was used for compression measurements [3,5].

3. Results and discussion

3.1. Microstructural features

SEM micrograph of the heat-treated SiC particles raw material is shown in Figure 2a. Figure 2b shows relatively uniform cell structure of the composite foam produced in this research. This material is as light as 0.20 g/cm^3. Figure 2c represents SiC particles distributed within a typical wall of a cell. Changes of the cell size with SiC volume percentage is demonstrated in Figure 3.

Two important factors that affect the stability of the aluminum foam are wetability of the ceramic particles by the melt and the drainage and rupture of the cell walls separating them from air bubbles. Presence of solid particles has increasing effect on bulk viscosity of the melt. Viscosity increase results in slow-down of the melt which retards the cell wall drainage before solidification [6,7]. Ceramic particles have another important impact on foam stability through their attachment to the gas/liquid interface which changes the interfacial curvatures and reduces the capillary pressure difference between the plateau border and the cell wall of the aluminum foam [8,9]. For a given type of ceramic particle, volume percentage of the added particles has critical effect on stability of the foaming process.

Volume percentage of SiC for a stable foaming process largely depends on the immersion depth of the air jet because the number of SiC particles entrapped by the gas bubbles depends on the height that bubbles ascend [8]. The rising bubbles become stable only when their surface achieves critical coverage by SiC particles. The longer the path that bubbles travel, the lower the critical volume percentage of SiC particles is required to produce stable foam. The affinity of the ceramic particles for the aluminum melt also plays an important role in the amount of particle addition for appropriate foaming of the melt [6].

Figure 3 indicates the thickness-increase of the cell wall and illustrates the diameter decrease of the plateau border versus SiC particle percentage. With certain particle size used in the tests, the increase in the thickness of the cell wall shows that the viscosity of the composite melt increases with incorporation of more particles into the liquid melt. Increasing of the cell wall thickness means more aggregation of particles in the particle/liquid interface. This creates more tortuous path for the liquid and acts as a liquid flow barrier from the cell wall towards the plateau border. As a result, the cell wall drainage retards causing the increase of the cell wall thickness and the decrease of the size of the plateau border [7,9,10].

3.2. Compressive properties

Compressive stress–strain curves of composite foams having different amounts of SiC additive are compared in Figure 4a. During compression loading, the strain applied to

foams with closed-cells tends to localize into a thin band. This causes buckling of the cell walls [11]. A consequence of this topology of the cell structures is a tendency to non-uniform local distribution of strain. The sites for onset of local plastic deformation depend thus on structure of the cells [12].

Deformation initiates in a single band, which is in contact with the loading surface, and proceeds to other layer one after the other. The plateau region of the compressive stress-strain curve of composite foams shown in Figure 4a is not very smooth and exhibits some serrations. The main reason is the addition of SiC particle to Al alloy. According to the mechanical properties of matrix materials, metallic foams are three types: elastic, plastic and brittle materials [13]. Brittleness of Al/SiC_p composites is generally more than that of Al alloys [14]. In order to categorize, Al/SiC_p composite foams belong to brittle foams.

When stress on Al/SiC_p composite foams reaches its maximum, the plateau region collapses. By increasing of the compressive strain, cracking of the cell walls and their brittle rupture then suddenly occur. The space inside these cells decreases and the stress is released. With increasing of the strain, the stress rises again. The next decrease of stress, which results from sudden rupture of other cell walls, occurs by increasing of the strain. During straining, some fragments of the cell walls eject from the boundary cells indicating the local brittle fracture of the Al/SiC_p composite foams [15].

Effect of SiC volume percentage on compressive behavior of composite foams is shown in Figure 4b. It is seen that when the relative density is constant, the yield stress of the composite foams increases with SiC volume percentage. This indicates that SiC has strengthening effect on compressive properties of composite foams.

4. Conclusions

(1) Stable foam does not occur until SiC particle content reaches a critical level, while the excessive addition of the particles will lead to unstable foaming.
(2) At a specified temperature, cell size of the Al/SiC foamed sample increases with SiC particle content.
(4) With increasing of SiC particle content, the cell wall drainage retards, and as a result, cell wall thickness increases and plateau border size decreases.
(5) The compressive stress-strain curves of composite foams have three distinctive sections: elastic, plateau and densification regions. The stress of the plateau region increases with the relative density and the SiC volume percentage.

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Table 1. Properties of composite foams produced in this research.

Property	Sample			
	AS5	**AS10**	**AS15**	**AS20**
SiC particles (Vol. %)	5	10	15	20
Density (g/cm^3)	0.1	0.16	0.25	0.32
Porosity (%)	96.0	94.0	90.0	88.0

Figure Captions:

Fig. 1. Schematics of the gas injection system.

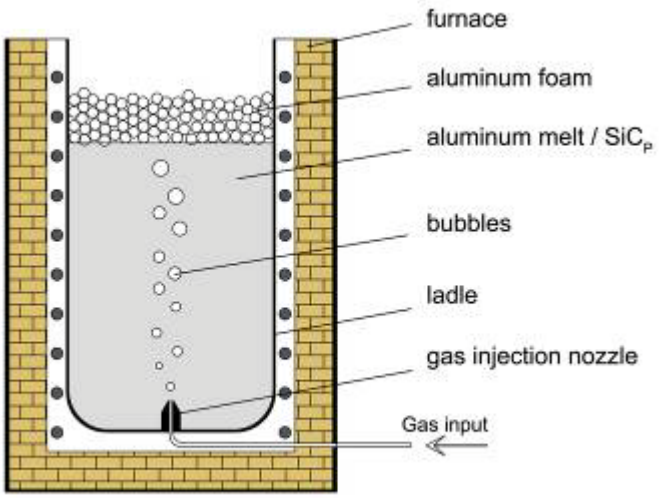

Fig. 2. (a) SEM micrograph of the SiC particles, (b) macrostructure of aluminum foam prepared by gas injection method and (c) optical micrograph of cell walls of the aluminum foam with SiC particle additions. Segregation of particles at the gas/liquid interface is also shown.

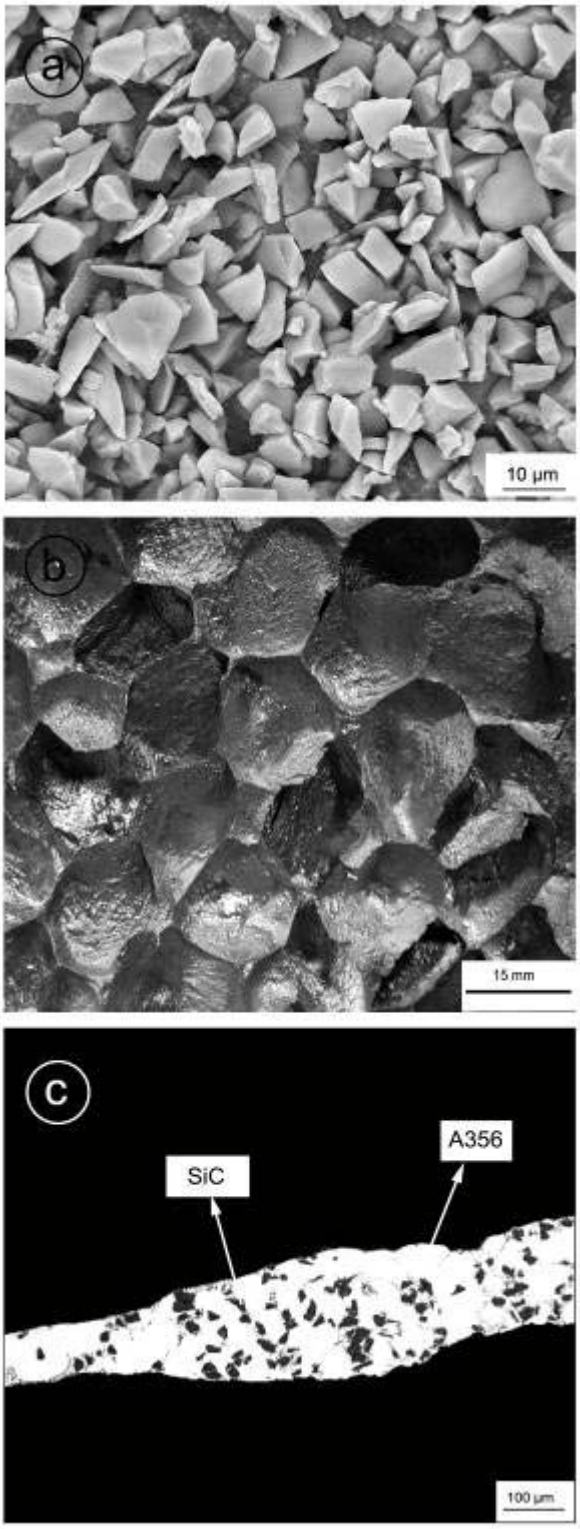

Fig. 3. Effect of SiC volume percentage on the cell size▲, cell wall thickness ● and plateau diameter ■.

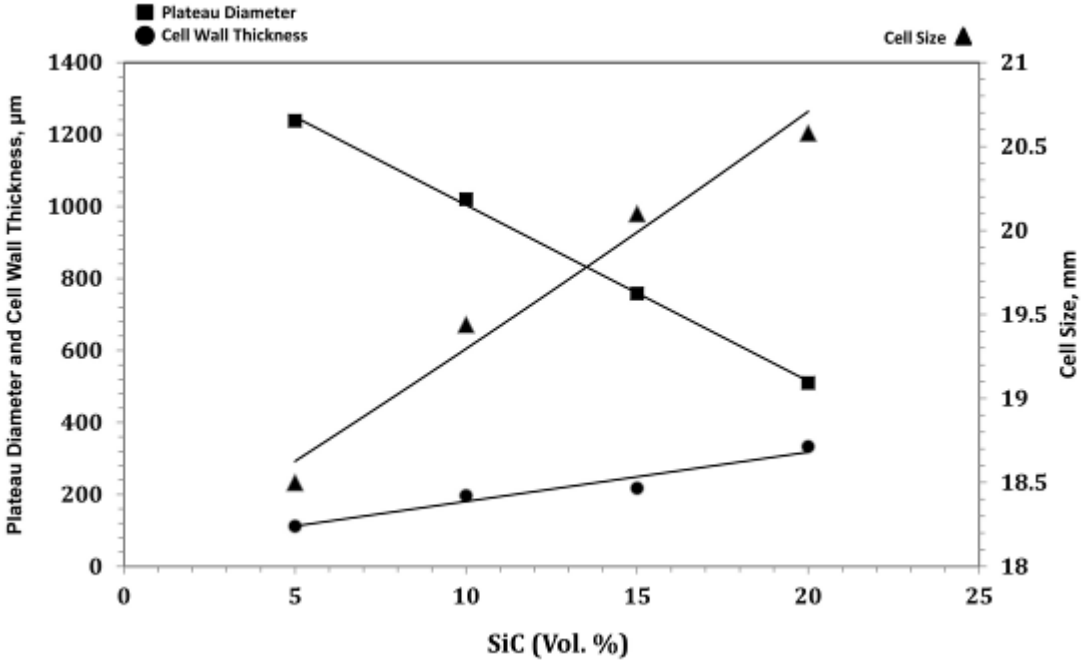

Fig. 4. (a) Stress-strain curves of aluminum foams obtained from compression test at various SiC volume percentage and (b) effect of SiC volume percentage on the plateau stress of aluminum foam.