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Research Note

Effect of SiC on microstructural features and compressive properties of aluminum foam

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Abstract. Composite aluminum-SiC foam was manufactured by injection of air and addition of reinforcement particles into the liquid aluminum. Microstructure and mechanical properties of the Al/SiC foams were investigated by scanning electron microscopy and compression tests. Results showed that both the cell size and the wall thickness augmented with increasing of the SiC reinforcement particles, while SiC particles resulted in the reduction of the plateau border length. With more SiC particles, plateau stress became larger, but maximum plateau strain became smaller. The stress-strain curves exhibited serrations in the plateau region due to addition of the SiC particles.

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1. Introduction

Al/SiC foams are light-weight structural materials with high strength, low thermal expansion, high abrasion resistance, large stiffness and capability of absorption of impact energies [1-4]. Their diverse applications have attracted attention of many advanced materials investigators [4,5]. They can be produced by injection of gas into molten aluminum containing ceramic hard particles. The injected air produces bubbles, which rise towards top of the melt. The bubbles accumulated on the top can be collected and molded for fabrication of desirable foamy objects. Attainment of uniform cellular structure with controlled foam architecture is, however, a major challenge. Perfect reproducibility is important, too.

Direct foaming has been investigated by D. Leitmeier and coworkers at LKR, Austria in the year

2000 [6]. They developed Al foams with uniform cell-size distribution called METCOMB [6]. In order to develop a reliable manufacturing technology for production of stable and reproducible foams with improved cellular structure without any rupture due to drainage of liquid, the process has to be theoretically well-understood and practically full-controlled.

A foamy liquid can be produced by vigorous gas bubbling. It can be stabilized by ceramic particles injection. The particles can transfer toward and reside within the walls of the solidified cells. The stabilized liquid can 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 [7,8]. 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 investigation of the effect of the percentage of the SiC particles on the cell structure and mechanical properties of the produced foam.

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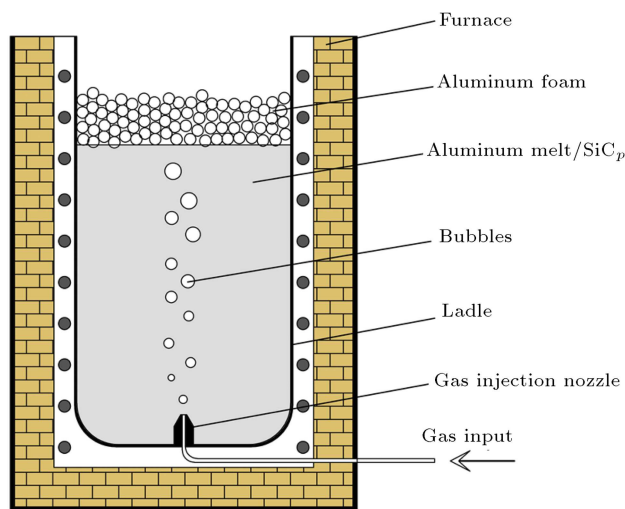


Figure 1. Schematics of the gas injection system.

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 wettability, 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

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

foam was calculated using the equation:

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

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 $\times$ 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/SiCp composite foams. A digital caliper with 1 μm resolution was used to measure the cell size. Each value represented the average of sizes measured for 20 cells. The plateau-border size and the cell wall thickness were determined by an optical microscope. Sample distortion caused by sectioning angle was avoided. Existence of correlation between the wall thickness and the plateau-border size was assessed from the measurements.

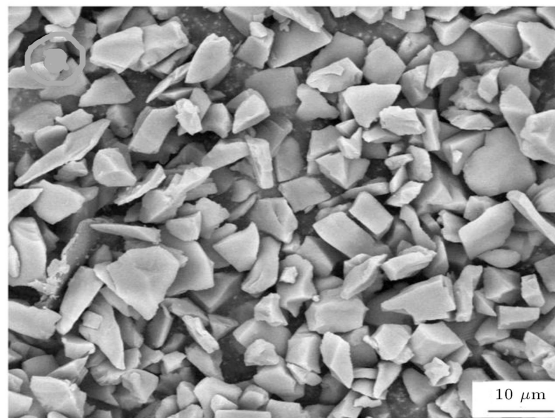
Compression-test specimens were wire-cut out of the foamy composite slabs. Their dimensions were selected to be 50 $\times$ 50 $\times$ 60 mm so that at least six cells in each direction could exit. Zwick Z250 universal testing machine controlled by computer with a cross-head speed of 1 mm/min was used for compression measurements [6–9].

3. Results and discussion

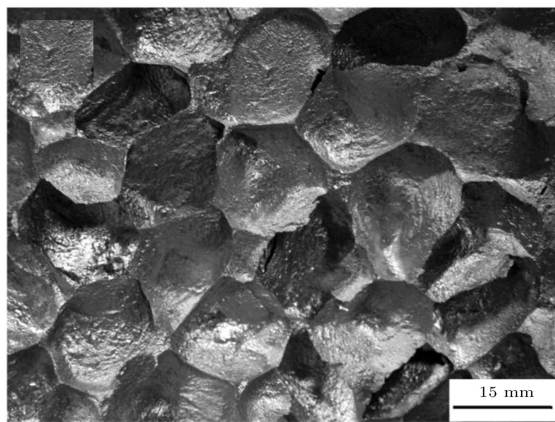
3.1. Microstructural features

SEM micrograph of the heat-treated SiC particles raw material is shown in Figure 2(a). Figure 2(b) 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 2(c) 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.

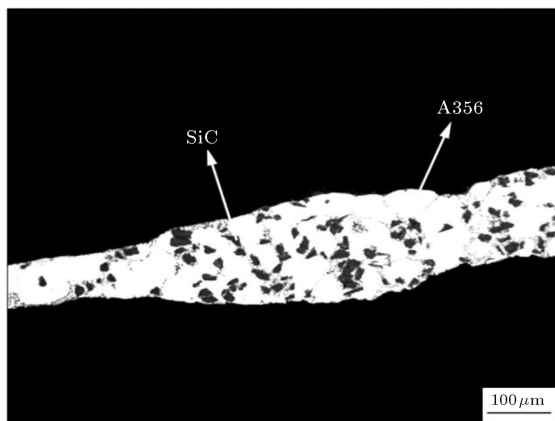
Two important factors that affect the stability of the aluminum foam are wettability of the ceramic



(a)



(b)



(c)

Figure 2. (a) SEM micrograph of the SiC particles. (b) Macrostructure of aluminum foam prepared by gas injection method. (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.

particles by the melt, 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

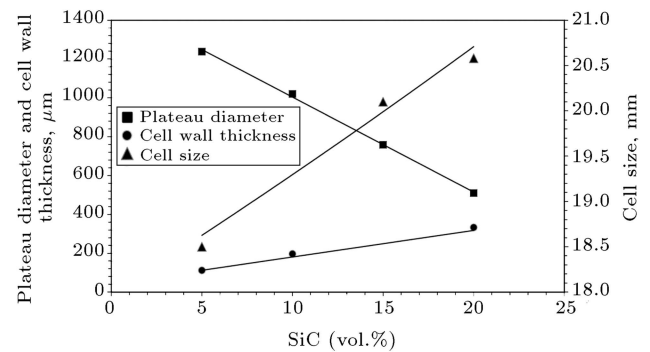


Figure 3. Effect of SiC volume percentage on the cell size▲, cell wall thickness ● and plateau diameter ■.

solidification [10,11]. 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 [12,13]. 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 [12]. 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 [10].

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 [11–14].

3.2. Compressive properties

Compressive stress-strain curves of composite foams having different amounts of SiC additive are compared in Figure 4(a). 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 [15].

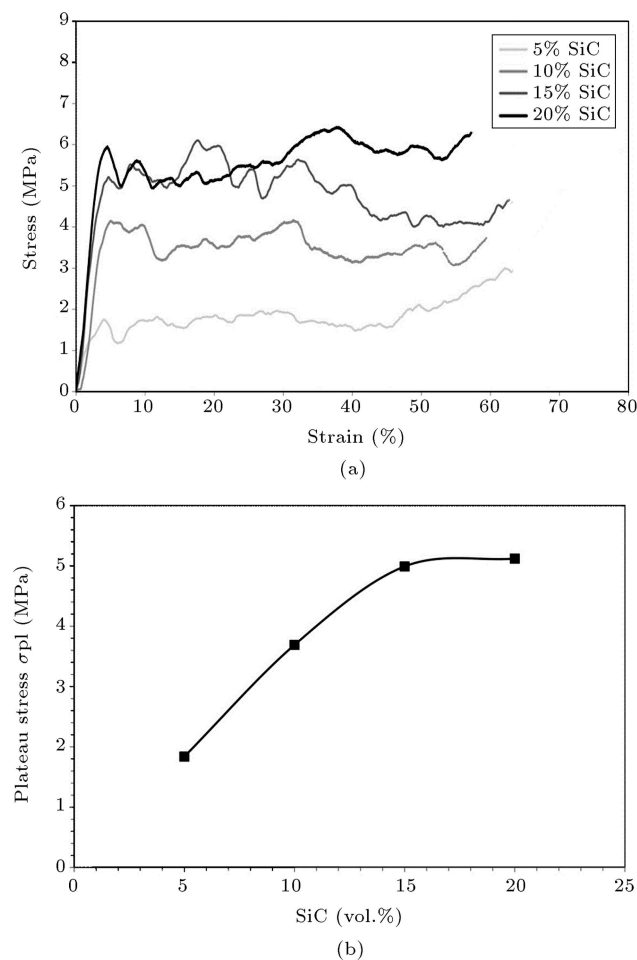


Figure 4. (a) Stress-strain curves of aluminum foams obtained from compression test at various SiC volume percentage. (b) Effect of SiC volume percentage on the plateau stress of aluminum foam.

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 [16].

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 4(a) 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 [17]. Brittleness of Al/SiCp composites is generally more than that of Al alloys [18]. In order to categorize, Al/SiCp composite foams belong to brittle foams.

When stress on Al/SiCp 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/SiCp composite foams [19].

Effect of SiC volume percentage on compressive behavior of composite foams is shown in Figure 4(b). 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

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. At a specified temperature, cell size of the Al/SiC foamed sample increases with SiC particle content. With increasing of SiC particle content, the cell wall drainage retards, and as a result, cell wall thickness increases and plateau border size decreases. Finally, 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 SiC volume percentage.

Acknowledgements

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Biographies

Mostafa Malekjafarian graduated from Sharif University of Technology in Tehran, Iran with an MSc degree in Materials Science and Engineering. At the moment he is faculty member of the Advanced Materials research group of Iranian Academic Center for Education, Culture and Research. His activities cover the broad areas of cellular materials, metal matrix composites, biomaterials and functional materials. During the last 3 years, he has been the author and co-author of four patents and about 30 papers.

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