Available online at www.sciencedirect.com
ScienceDirect
Trans. Nonferrous Met. Soc. China 27(2017) 1569−1579
Transactions of Nonferrous Metals Society of China
www.tnmsc.cn

# Effects of foaming parameters on microstructure and compressive properties of aluminum foams produced by powder metallurgy method

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Received 3 June 2016; accepted 28 February 2017

**Abstract:** Semi open-cell aluminum foams having channels between individual cells were produced using low cost $CaCO_3$ foaming agent and applying the powder compact melting process. To this end, the aluminum and $CaCO_3$ powder mixtures were cold compacted into dense cylindrical precursors for foaming at specific temperatures under air atmosphere. The effects of several parameters including precursor compaction pressure, foaming agent content as well as temperature and time of the foaming process on the cell microstructure, linear expansion, relative density and compressive properties were investigated. A uniform distribution of cells with sizes less than 100 μm, which form semi open-cell structures with relative densities in the range of 55.4%−84.4%, was obtained. The elevation of compaction pressure between 127−318 MPa and blowing agent up to 15% (mass fraction) led to an increase in the linear expansion, compressive strength and densification strain. By varying the foaming temperature from 800 to 1000 °C, all of the investigated parameters increased except compressive strength and relative density. The results indicated the optimal foaming temperature and time as 900 °C and 10−25 min, respectively.

**Key words:** aluminum foam; powder metallurgy; $CaCO_3$; foaming agent; semi open-cell microstructure; expansion; compressive properties

## 1 Introduction

Since the first production of metallic foams in 1948 by SOSNICK [1], much attention has been paid to these materials with different compositions, cell microstructures and cell sizes. Their unique properties such as low density, high specific strength, high energy absorption, sound absorption and heat resistance make these materials appropriate for many structural and functional applications such as automotive, aerospace, building industry, filtration, fluid flow control, water purification and acoustic control [2,3].

There are numerous methods to produce metallic foams including sintering of the metal powders or fibers, sintering the metallic hollow spheres, gas injection to the molten metals, casting the molten metals into the polymer foams, powder compact melting, metal vapor deposition on cellular preform, and electro-deposition [2−5]. Among these foaming methods, the powder compact melting process has been widely applied to producing aluminum foams, due to the advantages such as high uniformity of the cells, flexibility in alloy choice without requiring any stabilizer particles and production possibility of near-net shaped parts with complex geometries as well as composite foams [6,7]. This process was first introduced by ALLEN [8] and developed by the Fraunhofer Institute [9,10]. All reports demonstrated that this procedure results in closed-cell foams [6,7,11−18]. Recently, researches have been focused on the control of this process in order to produce foams with improved cell structure, enhanced properties and lower costs. YOU et al [11] investigated the effects of foaming temperature and content of $TiH_2$ foaming agent on the cell structure of aluminum foams produced by powder compact melting process. Their results showed that adjusting these two key factors could lead to the formation of closed-cell foams with uniform cell structure and high porosity. Moreover, SURACE et al [12] investigated the effects of three parameters, i.e., compaction pressure, temperature and SiC content on morphology and compressive properties of aluminum foams produced with $TiH_2$ foaming agent by a powder metallurgy technique. Considering linear expansion, relative density and compressive strength of samples, the optimum set-up

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DOI: 10.1016/S1003-6326(17)60178-X

parameters in their experiments were recognized as compaction pressure of 430 MPa, foaming temperature of 750 °C and stabilizer content of 3% SiC (mass fraction). KEVORKIJAN et al [13] used $CaCO_3$ and dolomite particles as foaming agents to produce aluminum foams by either powder metallurgy or melt rout. In their experiments, the effects of porosity and density of precursors as well as concentration and morphology of foaming agents on foaming efficiency, relative density and structure of aluminum foams were investigated.

Till now, a large number of studies have been done on the properties of aluminum foams using $TiH_2$ foaming agent and powder metallurgy while $CaCO_3$ foaming agent is cheaper and more controllable. Since there are a few reports on aluminum foams using $CaCO_3$ foaming agent [6,14,15], there is a need to investigate the correlations between processing parameters and final properties of foams produced using $CaCO_3$ as a foaming agent.

In this study, the semi open-cell aluminum foams were produced by powder compact melting process and low cost $CaCO_3$ foaming agent via adjusting the critical processing parameters. Moreover, the effects of these critical parameters including compaction pressure, foaming agent content, foaming temperature and time on linear expansion, relative density, cell microstructure and compressive properties were studied.

## 2 Experimental

### 2.1 Materials

Aluminum (Merck, Germany, >99% purity, <15 μm) and $CaCO_3$ (Farzan Powder, Iran, >99.5% purity, <50 μm) powders were used as aluminum source and foaming agent, respectively.

### 2.2 Samples production

According to "powder compact melting" method, aluminum and $CaCO_3$ powders were mixed together for 20 min with different $CaCO_3$/Al mass ratios (5%, 10%, 15% and 20%) to obtain homogeneous mixtures. The mixed powders were then compacted using uniaxial cold pressing with different pressures (127, 191, 255 and 318 MPa) to form dense cylindrical components called "foamable precursors" with 20 mm in diameter and different heights and densities. The precursors were placed in a cylindrical steel mold (20 mm in inner diameter, 100 mm in height), which was open only at the top. Heat treatment was done in a preheated furnace at different temperatures (800, 900 and 1000 °C) for different time (5, 10, 15, 25 and 30 min) in air atmosphere. The processing parameters of the samples were listed in Table 1. Since the precursors and the mold had the same diameters, expansions occurred only in the height direction. After the foaming process, the samples were removed from the furnace and natural cooling in the air was employed to solidify the foams. The densities of precursors and foam samples were calculated from their mass and geometry. Furthermore, relative density of precursors and foams ($\rho_R$), linear expansion ($\alpha_{LE}$) and porosity of foams ($P$) were calculated using the following equations [12,19]. It is important to note that all the calculations are in comparison with the bulk aluminum.

$$\rho_R = \frac{\rho_1}{\rho_2} \times 100\% \quad (1)$$

$$\alpha_{LE} = \frac{h_1 - h_2}{h_2} \times 100\% \quad (2)$$

where $\rho_1$ and $\rho_2$ are densities of precursor or foam and bulk aluminum, respectively; $h_1$ and $h_2$ are heights of foam and precursor, respectively.

**Table 1** Processing parameters of produced samples

| Sample code | Compaction pressure/ MPa | $w(CaCO_3)$/ % | Foaming temperature/ °C | Foaming time/ min |
|---|---|---|---|---|
| F04 | 127 | 10 | 900 | 15 |
| F06 | 191 | 10 | 900 | 15 |
| F08 | 256 | 10 | 900 | 15 |
| F10 | 318 | 10 | 900 | 15 |
| C05 | 318 | 5 | 900 | 15 |
| C10 | 318 | 10 | 900 | 15 |
| C15 | 318 | 15 | 900 | 15 |
| C20 | 318 | 20 | 900 | 15 |
| D800 | 318 | 15 | 800 | 10 |
| D900 | 318 | 15 | 900 | 10 |
| D1000 | 318 | 15 | 1000 | 10 |
| M05 | 318 | 15 | 900 | 5 |
| M10 | 318 | 15 | 900 | 10 |
| M15 | 318 | 15 | 900 | 15 |
| M25 | 318 | 15 | 900 | 25 |
| M30 | 318 | 15 | 900 | 30 |

### 2.3 Characterization

In order to determine the decomposition temperature range of the foaming agent ($CaCO_3$), differential thermal analysis (DTA) was performed. The pattern was recorded on BAHR Thermo Analyse 703 machine from 25 to 1000 °C with a heating rate of 10 °C/min in argon atmosphere. The $CaCO_3$ (35 mg) and alumina (35 mg) powders were used as foaming agent and the reference material, respectively. In order to compare the compressive data, samples were cut into cylindrical parts with 20 mm in diameter and height to diameter ratios in the range of 1.5−2.0. The minimum