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Compressive behavior and damping property of ZA22/SiC_p composite foams

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Abstract

The ZA22 alloy composite foams reinforced by 10 vol.% SiC particles (ZA22/SiC_p composite foams) were fabricated with the melt foaming route using $CaCO_3$ blowing agent in this paper. The compressive behavior and damping property of the composite foams were investigated. The results show that SiC particles dispersing in cell walls can alter the deformation mechanism of ZA22 foams. The plateau stress of the composite foams, therefore, fluctuated continually. The damping properties of ZA22/SiC_p composite foams are obviously higher than those of ZA22 alloy and ZA22 foams. The addition of SiC particles can improve the damping capacity of ZA22 foams because SiC particles introduce multifarious interfaces and high-density dislocations in composite foams.

Keywords: ZA22 alloy; SiC particles; Metal foams; Compressive behavior; Damping property

1. Introduction

Recently, metallic foams have received extensive interest as new structural and functional materials because of their high specific strength, energy absorption, flame resistance, vibration reduction, and sound absorption [1]. Therefore, they can be widely used in construction, transportation and aerospace industry [1,2]. Metal can be foamed in many methods [1,4–7]. Direct foaming methods of metal melts are quite suitable for industrial production because of their handleability and low cost [1,3], but the cell structure of metallic foams is irregular and the cell size is inhomogeneous. So, it is necessary to increase the viscosity of metal melts in order to prevent gas bubble from escaping and coalescing. Addition of ceramic particles such as SiC, MnO_2, and Al_2O_3 to metal melts is a good approach for increasing the viscosity [1,3]. For example, the recently developed FORMGRIP/FOAMCARP process, which was based on the remelting of metal matrix composites (SiC_p/Al), is suitable for producing metal foams [5,6]. Most of previous researches about the effects of solid additive on the manufacture of metal foams were focused on the foaming physics. It was thought that ceramic particles changed the curvature of gas/liquid interface, increased the viscosity of melts, and stabilized the cell wall [7–9]. However, the studies about the effects of the ceramic particles on the structure and properties of metal foams were very few. Sigimura et al. [10] confirmed that the microstructures of Al matrix composite foams were similar to those of ceramic particle reinforced Al matrix composites. Parkash et al. [11] investigated the compressive characteristics of Al/SiC_p composite foams and found that the localized deformation took place due to the existence of SiC_p in cell wall. Gui et al. [12,13] found that A356/SiC_p composite foams exhibited a typical brittle characteristic and had better damping and sound absorption properties than Al foams because of the existence of Al/SiC_p interfaces.

Zn and Zn alloy foams possess excellent mechanical behaviors and damping properties at room temperature [14–16]. However, the work on closed-cell Zn foams prepared with the direct foaming method of melt, to date, is few, and the study on Zn matrix composite foams has not been reported yet. Consequently, it is necessary to investigate various characters (especially functional properties) of Zn and Zn matrix composite foams in order to widen the applying field of metallic foams.

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The purpose of this work is to study the compressive behavior and damping property of ZA22/SiC_p composite foams and reveal their mechanisms.

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), ZA22 alloy powders (about 40 μm in size), SiC particles (98.0 wt.% in purity, about 28 μm in size), and $CaCO_3$ powders (99.5 wt.% in purity, about 44 μm in size). SiC particles and $CaCO_3$ powders were used as reinforcement and blowing agent, respectively. To improve the wettability between SiC_p and ZA22 melt, SiC particles were heat-treated at 930 °C for 6 h and then at 420 °C for 2 h.

2.2. Measure of decomposition temperature of blowing agent

The decomposition reaction of $CaCO_3$ blowing agent can be written as [19]:

$$CaCO_{3(s)} = CaO_{(s)} + CO_{2(g)} \quad (1)$$

In order to determine reasonable foaming temperature of ZA22 melt, the decomposition temperature of $CaCO_3$ blowing agent has to be measured. So, $CaCO_3$ blowing agent was studied with Thermogravimetric Analysis (Model DTA/TG-Rigaku-8150, Japan) under a protection of high pure argon. The heating rate was 20 °C/min.

2.3. Fabrication of composite foams

In order to make SiC_p and $CaCO_3$ powders enter ZA22 melt easily, powder preforms containing SiC_p, ZA22 alloy powders, and $CaCO_3$ powders (the mass ratio is 4:4:1) were prepared. Firstly these powders were blended for 5 h using a ball mill in a stainless steel container. Then the powder mixture was mechanically pressed into a cylindrical die at 20 MPa. The size of the compact preform is Ø 22 mm × 20 mm. Finally cylindrical preforms were baked at 150 °C for 3 h in a vacuum drying oven to remove moisture.

According to the thermogravimetric analysis curve of $CaCO_3$ powders (Fig. 1), the beginning temperature of CO_2 evolution is about 650 °C. Therefore, when performs were added to ZA22 melt, the temperature of ZA22 melt cannot be more than 650 °C in order to avoid the premature release of CO_2 gas.

ZA22 alloy was melted to 510 °C in a crucible furnace, and then performs, whose adding amount was determined according to the designed volume fraction (10%) of SiC_p in cell wall, were added to the melt. After that, the slurry was stirred for 10 min with a steel stirrer at a rate of 900 r/min to disperse SiC and $CaCO_3$ particles homogeneously and then held at 700–710 °C for 12 min to allow blowing agent to release gas bubbles. Finally the composite foams were cooled down in air.

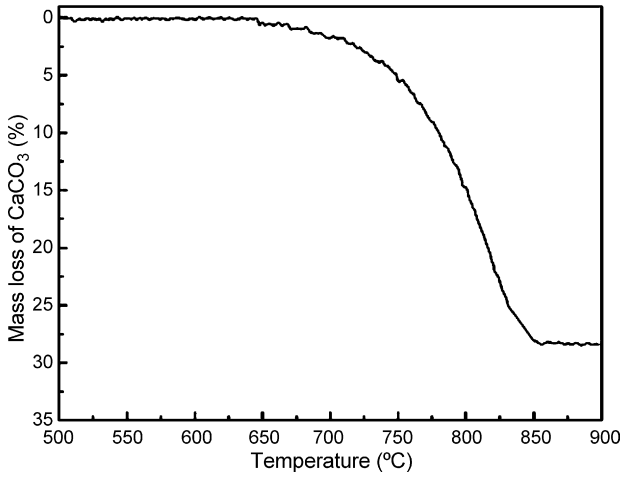

Fig. 1. Thermogravimetric analysis curve of $CaCO_3$ powders.

2.4. Characterization of composite foams

Microstructure and phases of the composite foams were analyzed by means of scanning electron microscopy (SEM) (Model JSM-5310, Japan) and X-ray diffraction (XRD) (Model D/Max 2500PC Rigaku, Japan).

The porosities of composite foams were calculated using the following equation:

$$P = \left(1 - \frac{\rho^*}{\rho_s}\right) \times 100\% \quad (2)$$

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

2.5. Compression and damping test

Specimens with the dimensions of 15 mm × 15 mm × 30 mm (used for compression test) and Ø 70 mm × 10 mm (used for damping test) were prepared with a wire cutting machine. The size of compressive specimens was chosen to guarantee at least six cells in each direction because samples with smaller dimension can cause a significant loss of mechanical properties [17].

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 damping characteristic values were measured using free vibration method. The signal frequency was 400 Hz. The logarithmic decrement δ was used to describe the damping capacity of materials. δ is expressed as [18]:

$$\delta = \ln \frac{x_n}{x_{n+1}} \quad (3)$$

where x_n and x_{n+1} are amplitudes of successive cycles.