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Fabrication of aluminum foam stabilized by copper-coated carbon fibers

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Abstract

Short copper-coated carbon fibers were used as novel stabilizer for aluminum foam. Aluminum foams containing 0.35, 1.0, 1.7 vol.% copper-coated carbon fibers were fabricated by a melt route. Foaming behavior and microstructure of these foams were observed. Results show that copper-coated carbon fibers can stabilize aluminum foam by preventing cell wall rupture and reducing coalescence. The fibers are mostly located inside cell wall and form a network structure, which can generate separating force and prevent cell wall from rupture. The volume fraction of copper-coated carbon fibers needed to stabilize aluminum foam is as low as 0.35 vol.%, and the foam is more stable when more fibers are used.

Keywords: Aluminum foam; Carbon fibers; Fiber stabilization; Separating force

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1. Introduction

Metal foams are highly porous materials, which possess outstanding properties and reason for the wide range of applicability such as sound insulation, energy absorption, structural application, etc. [1]. However, manufacture of these materials is very challenging as the system is quite complex involving solid, liquid and gaseous phases at high temperature [2].

Many approaches have been made to the stabilization of liquid metallic foams against collapse due to drainage and pore coalescence, and it is generally accepted that all the metal foams are stabilized by solid additions, e.g. particles [3]. However, which chemical and processing parameters are essential to obtain stable metal foam is still an open question, as both morphology and fraction of the particles created by different techniques are quite different [2,3].

The observation of Ip et al. indicates that a minimum amount of SiC particles is necessary to produce stable liquid-metal foam by blowing gas into a metallic melt [4]. Stabilization mechanism of these SiC particles was interpreted by the mechanism proposed by Kumagai et al. [5] who suggested that the particles could modify the curvature of film surface and results in a decrease in the pressure difference between Plateau border and liquid film. Kaptay evaluated the capability of six different defined structures which can in principle stabilize liquid foams, and concluded that loosely packed, clustered particles, or even their network are mainly responsible for the stabilization of liquid foams [6]. Gergely et al. stated that using higher particle content could damp the vertical motion of liquid by increasing viscosity [7]. While the results of microgravity experiments taken by Wübben et al. [8] show that the primary function of the solid stabilizer is to prevent films from coalescing while their influence on viscosity is less important. Körner et al. gave an explanation of metal foam stabilization by oxide network particles and suggested that mechanical barrier effect by particles is a universal stabilization mechanism for metal foams [9]. The research of Babcsàn et al. also shows that the oxide skin on the inner surface of the liquid cell walls when oxidizing gas was used can be an additional stabilization effect [10].

Though quite some categories of metal matrix composites (MMCs) were used to produce metal foam [11], little attention was paid to MMCs fabricated with short carbon fibers. It is obvious that short fibers with large aspect ratio can increase the viscosity of the melt more efficiently than the particles and much easier to form a network structure inside cell walls, so carbon fibers can be used as a novel stabilizer for metal foam.

It is known that carbon fibers cannot be wetted by molten aluminum under 1000 °C and harmful reaction may takes place at fiber–matrix interface. To solve these interface problems, various coating was deposited on carbon fibers before composite process. Researches have shown that copper layer plated on carbon fibers could improve the wetting property and avoid inter-

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face reaction, and the short fibers could be uniformly dispersed in the matrix [12,13].

In the present paper, copper-coated carbon fibers were used as a stabilizing component, and the stabilization mechanism of these fibers on liquid-metal foam is discussed.

2. Experimental procedure

2.1. Materials

Metal matrix composites used in the study were manufactured from molten aluminum admixed with copper-coated carbon fibers at 700 °C. An agitator with graphite paddle was used to make the fibers uniformly dispersed. The stirring time is 150 s and the stirring rate is 1000 rad/min, details in [13]. A typical microstructure of this MMC with 1.7 vol.% carbon fibers is shown in Fig. 1. The fibers are uniformly dispersed in the matrix, indicating the good wetting property at the fiber–matrix interface. The diameter of carbon fibers used is 7 μm, and the copper layer on the surface obtained by an electroplating method is 1.4 μm thick. Before composite process, these coated fibers were cut down to 5–8 mm in length. Commercially pure aluminum was used as the matrix, and the purity is 99.5 wt%. TiH_2 was used as a blowing agent, and the typical size distribution is shown in Fig. 2.

2.2. Foam preparation

Composites, with different fiber fraction of 0.35, 1.0, 1.7 vol.%, were melted in a crucible furnace and heated to 690 °C. After holding for 1 h, TiH_2 of 1.2 wt% was added into the melt. After stirring for 190 s at 1200 rad/min and holding for a certain period, the crucible was taken out of the furnace and cooled by air.

2.3. Sample characterization

Foam samples were sectioned longitudinally, along the mid-plane, using electro-discharge machining to minimize damage to the cell wall structure. The macroscopic images of foams were scanned using Unscan A30 at resolution of 300 dpi. A SSX-550 scanning electron microscope (SEM) was used to observe cell walls of carefully polished samples and cell surfaces of the samples. The minimum cell wall thickness was also determined by measuring the width of the thinnest point in individual cell wall using a measurement tool in the SEM. Cell walls with obvious defects were not selected for measurement. The density of foams is also measured by weighing cuboidal specimen, combined with measurements of dimensions with calipers.

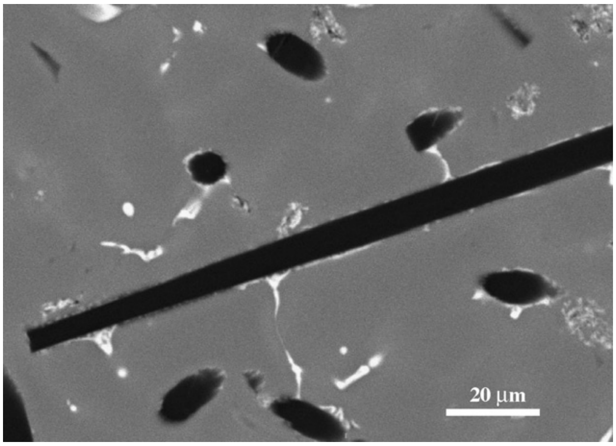

Fig. 1. SEM micrograph of Al–1.7 vol.%C_f composites.

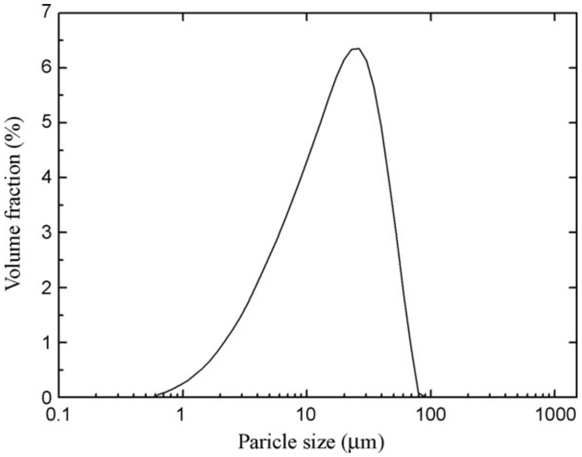

Fig. 2. Particle size distribution of TiH_2 particles used as blowing agent.

3. Results

3.1. Macrostructure

Fig. 3 shows macrostructural images of Al foams fabricated with 0.35, 1.0, 1.7 vol.% copper-coated carbon fibers and foaming for three different periods, 30, 120 and 260 s. The interruption of foaming at these particular times is an attempt to illustrate cell structure evolution of the foams during expansion.

A thick layer of metal is evident at the base of all Al foams with different composition, which exhibits obvious gravity-driven drainage during foaming process. This accumulation of metal is slightly slower for Al–1.7 vol.%C_f foam than the other two foams.

When foamed for 120 s, foam layer of all the three samples exhibit uniform structure consists of fine cells. The properties of these foams are shown in Table 1.

However, distorted or irregular cells are observed at the foam layer of Al–0.35 vol.%C_f and Al–1.0 vol.%C_f foam when the foaming time is 260 s, while that of Al–1.7 vol.%C_f foam remains a uniform structure with smaller cells.

Table 1
Densities of the Al–C_f foams foaming for 260 s

Material	Density ($g\,m^{-3}$)	Relative density (ρ/ρ_s)
Al–0.35 vol.%C_f	0.29	0.11
Al–1.0 vol.%C_f	0.25	0.09
Al–1.7 vol.%C_f	0.37	1.37