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Oxide film on bubble surface of aluminum foams produced by gas injection foaming process

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Abstract: Based on A356 aluminum alloy, aluminum foams were prepared by gas injection foaming process with pure nitrogen, air and some gas mixtures. The oxygen volume fraction of these gas mixtures varied from 0.2% to 8.0%. Optical microscopy, scanning electron microscopy (SEM) and Auger electron spectroscopy (AES) were used to analyze the influence of oxygen content on cell structure, relative density, macro and micro morphology of cell walls, coverage area fraction of oxide film, thickness of oxide film and other aspects. Results indicate that the coverage area fraction of oxide film on bubble surface increases with the increase of oxygen content when the oxygen volume is less than 1.2%. While when the oxygen volume fraction is larger than 1.6%, an oxide film covers the entire bubble surface and aluminum foams with good cell structure can be produced. The thicknesses of oxide films of aluminum foams produced by gas mixtures containing 1.6%−21% oxygen are almost the same. The reasons why the thickness of oxide film nearly does not change with the variation of oxygen content and the amount of oxygen needed to achieve 100% coverage of oxide film are both discussed. In addition, the role of oxide film on bubble surface in foam stability is also analyzed.
Key words: aluminum foam; gas injection foaming process; oxide film; foam stability mechanism

1 Introduction

Gas injection foaming process was developed firstly by the Aluminum Company of Canada (Alcan) [1] and the Norwegian Norsk Hydro Company [2] at the end of 1980s. Aluminum foams produced by gas injection foaming process can be processed into sandwich composite, which is a kind of ideal energy absorption material [3]. The aluminum foam plates also can be used in sound absorption and noise reduction field [4]. So, aluminum foams produced by gas injection foaming process became a hot research topic in 1990s. During the past two decades, great progresses were achieved in the studies of foaming requirements [5,6], foaming parameters [7], mechanical property of aluminum foams [8] and other aspects. But aluminum foams produced by gas injection foaming process still suffer from non-uniformity of cell size and poor repeatability of manufacturing process, which exert negative influence on their large-scale commercial production. Such an embarrassing situation is a result of the reality that most of the findings come from empirical experiences, which makes us fail to gain a profound scientific knowledge of foam stability. In fact, researches on foam stability have been going on for many years, so the understanding of foam stability is also in gradual progress. In the 1990s, almost all researches focus on the particles. JIN et al [1] proposed the famous particles size and volume fraction window for producing foam and suggested that about 10% (volume fraction) 10 μm particles should be added into the melt to achieve the best foaming effect. LEITLMEIER et al [6] studied the relationship between the travelling distance of bubbles and foam stability. They found that a minimum travelling distance was needed to ensure the stability of foams when the particle volume fraction of melt is fixed. Entering the 21st century, the experiments conducted by BABSCÁN et al [9] reflected the importance of oxide film in foam stability. Therefore, at present, most researchers have a unanimous consensus that at least two requirements are needed to ensure the stability of foams: the segregation of particles on the bubble surface and the formation of oxide film on the bubble surface [10].

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In recent years, both from experiments and simulations, the effects of particles on foam stability were investigated deeply by a lot of researchers and some models were proposed [11−14]. As shown in Fig. 1, HAIBEI et al [15] summarized and classified these models and then presented their idea that particles improved foam stability by creating surface elasticity and increasing the apparent viscosity (Fig. 1(f)). On the contrary, only a few researches related to the role of oxide film in foam stability. BABSCÁN et al [16] produced aluminum foams with nitrogen, air and oxygen respectively. They found there was a layer of oxide film on the surface of bubble produced by the latter two gases and their stability was much better. The thickness of oxide film on bubble surface [16] and the oxidation behavior of oxide film [9] were studied as well. However, further information about the morphology of oxide film, the coverage area fraction of oxide film on bubble surface, the critical oxygen volume fraction needed to produce aluminum foams with good cell structure and the role of oxide film in foam stability have not been reported. In order to improve the gas injection foaming technology, those issues are studied through preparing aluminum foams by gas mixtures containing different oxygen contents.

2 Experimental

A356 aluminum alloy was used as raw materials. 10% Al_2O_3 particles, with an average size of 10 μm, were mixed into A356 alloy melt as foam stabilizer and were fully dispersed by mechanical stirring. In order to remove the engulfed air induced by stirring from the composite melt, the melt was refined and degassed by pure nitrogen. During the whole preparation process, foaming temperature was kept at 680−690 °C, the gas flow was 0.9−1.0 L/min. The orifice diameter of nozzle was about 0.5 mm. Compressed air and nitrogen were selected as foaming medium. The purity of nitrogen was over 99.99% (volume fraction). Gas flows of air and nitrogen were controlled by mass flowmeters independently. Thus, compressed air and nitrogen could be mixed at a given volume proportions by adjusting the gas flows of gas and nitrogen, ensuring the oxygen volume fraction of gas mixtures meet the requirements of tests. The selected nominal flows were injected into the melt to make aluminum foams. In order to control the oxidation time, aluminum foams were removed from the surface of the melt in 50 s. In our experiments, aluminum foams were produced by pure nitrogen, air and gas mixtures at the platform built by ourselves [17]. Since the foam stability under some experimental conditions was poor, an auxiliary measure of lifting the aluminum foams was adopted during the sample collection process. Nitrogen, air and gas mixtures containing 0.2%−8.0% oxygen were used to represent those experimental gases hereinafter.

According to ISO standard 2896−86, the average cell size was obtained by line method. Chord lengths of three-dimensional directions were firstly measured by a ruler, and then the average cell size could be calculated by

$$D=L/0.616 \tag{1}$$

where D is the average cell size and L is the average chord length. The relative densities of aluminum foams were measured as well. The data could be obtained by

$$\rho_r=m_f/(V_f\,\rho_s) \tag{2}$$

where ρ_r is the relative density, m_f is the mass of aluminum foam, V_f is the volume of aluminum foam and ρ_s is the density of A356 aluminum alloy.

In order to observe the original macro and micro morphology of cell walls, several cell wall specimens were randomly cut from aluminum foams and their images were obtained by Axio scope a1 optical microscopy and Quanta 200 scanning electron microscopy. The elements content depth profile analyses

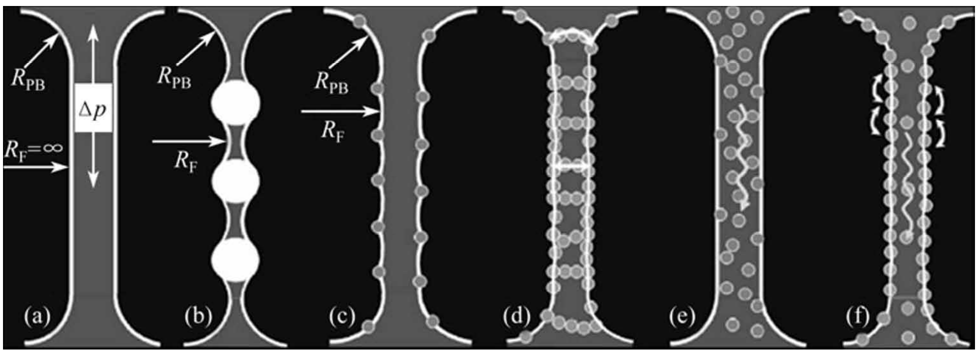

Fig. 1 Summary of effects of particles on different models for foam stability [15]: (a) Liquid film in foam; (b) Adsorbed particles bridged by film; (c) Interfaces modulated by adsorbed particles; (d) Particle layers at interfaces mechanically connected by bridges; (e) Drainage reduction by particles; (f) Creating surface elasticity and increasing viscosity