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Oxidation kinetics of oxide film on bubble surface of aluminum foams produced by gas injection foaming process

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Abstract: In the range of 620−710 °C, air was blown into A356 aluminum alloy melt to produce aluminum foams. In order to study the influence of temperature on the thickness of oxide film on bubble surface, Auger electron spectroscopy (AES) was used. Based on the knowledge of corrosion science and hydrodynamics, two oxidation kinetics models of oxide film on bubble surface were established. The thicknesses of oxide films produced at different temperatures were predicted through those two models. Furthermore, the theoretical values were compared with the experimental values. The results indicate that in the range of 620−710 °C, the theoretical values of the thickness of oxide film predicted by the model including the rising process are higher than the experimental values. While, the theoretical values predicted by the model without the rising process are in good agreement with the experimental values, which shows this model objectively describes the oxidation process of oxide film on bubble surface. This work suggests that the oxidation kinetics of oxide film on bubble surface of aluminum foams produced by gas injection foaming process follows the Arrhenius equation.
Key words: aluminum foam; gas injection foaming process; oxide film; oxidation kinetics

1 Introduction

Researches on gas injection foaming process started from the end of 1980s [1]. Compared with other methods, gas injection process possesses some advantages such as low cost and the capability of continuous production. Its products can be processed as aluminum foam sandwiches and aluminum foam bricks, which are new materials used in the fields of impact resistance and energy absorption [2]. Nonetheless, a huge progress has been already made in a series of technical problems [1,3], and the issue of foam stability has been still under a lot of controversies until now. Although opinion varies from people to people, most researchers believe that the oxidation of bubble surface and the attachment of particles existing in the melt to the bubble surface are essential for foam stability. Therefore, the stabilization of foams is caused by at least two mechanisms, the segregation of particles to the interface and the oxide film covering the bubble surface [4].

In the past 20 years, the effects of particles on foam stability have become a hot topic. The relationships between wetting behavior, distribution of particles and foam stability were investigated deeply [5−8]. The possible effects of particles in stabilizing foams could be increasing viscosity, decreasing surface tension, modulating the interface and bridging between interfaces. However, the researches related to the effects of oxide film are less. We only know that the stability of foams with oxide film is much better than that of foams without oxide film [9]. Almost nobody has studied the oxidation kinetics of oxide film so far, which leads to the result that the understanding of the role of oxide film on bubble surface in foam stability is relatively superficial. Only BABCSÁN et al [9] analyzed the relationship between the thickness of oxide film and isothermal holding time at 680 °C. But they have not studied the oxidation kinetics deeply. Actually, the cognitions of the oxidation kinetics of directed melt oxidation process of Al−Si−Mg alloys are very profound at present, since the studies of preparation of MMC by directed melt oxidation method

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were very popular in 1980s [10,11]. This has laid a good foundation for the study of oxidation kinetics of oxide film. VLACH et al [12] studied the process of directed melt oxidation and suggested that the nominal activation energy of Al−Si−Mg alloy in the range of 1100−1300 °C was about 270 kJ/mol. Based on theoretical calculation, ZHOU et al [13] found that the nominal activation energy of aluminum alloy decreased significantly with the increase of Si content. When the content of Si was more than 7% (mass fraction) and the content of Mg was less than 1% (mass fraction), the nominal activation energy would decrease to be less than 100 kJ/mol. But the process of gas injection foaming method is special, the bubbles keep moving when they are in the melt. Whether the oxidation kinetics of oxide film of aluminum foams is consistent with that of directed melt oxidation process or not is still unknown. Our previous study showed that oxygen volume fraction of foaming gases had little effect on the thickness of oxide film [14], which was in agreement with NAGELBERG's work [15]. However, there are still some differences existing in the thickness of oxide film between our previous work and BABCSÁN's work [16]. Therefore, further studying the oxidation process of oxide film on bubble surface and identifying the factors that control the formation of oxide film on bubble surface should be tasks of top priority. It is impossible for us to explain the distinctions between different experimental results scientifically and understand the effects of oxide film in improving foam stability before the above problems are solved. Obviously, this study of the influence of temperature on the thickness of oxide film on bubble surface can help us not only gain a further scientific understanding of foam stability, but also improve the gas injection foaming process technique.

2 Experimental

The raw material used to produce aluminum foams was A356 aluminum alloy. 10% Al_2O_3 (volume fraction) particles, with an average size of 10 μm, were mixed into A356 aluminum alloy melt as foam stabilizer and fully dispersed by mechanical stirring. The orifice diameter of nozzle was about 0.5 mm, foaming depth (the distance between the nozzle and the surface of the melt) was 15 cm and the gas flow rate was 0.9−1.0 L/min. The gas chosen for foaming was compressed air, which was supplied by a professional manufacturer. 620−710 °C is a relative common temperature range for aluminum foam preparation. Accordingly, gas was blown into the formable precursor to prepare aluminum foams at 620, 650, 680 and 710 °C through an experimental platform built by ourselves [17]. Since the melt is enough, the changes of foaming depth during the preparation process of aluminum foams can be neglected. Besides, in order to control the oxidation time, aluminum foams were removed from the melt surface in 40 s.

The average thickness of cell walls was measured with the help of an image analysis software developed by our laboratory. More than 10 cell wall specimens produced under each experimental condition were selected to ensure the accuracy of the final results. In order to determine the thickness of oxide film on bubble surface, several cell wall specimens were randomly cut from aluminum foams and cleaned by ultrasonic. After that, these specimens were analyzed on a PHI−700 Auger electron spectroscope. The analyses only focused on the mole fraction of Al and O (regarding the total number of atoms of these two elements as 100%). Two or three cell walls of aluminum foams produced under each experimental condition were selected as analysis objects. The average composition of these specimens was regarded as the result.

3 Results and discussion

3.1 AES depth profiles of oxide films on bubble surface

Aluminum foam samples were processed by an electric discharging cutting machine and then scanned to acquire their vertical section images. A typical vertical section of aluminum foam produced at 680 °C is shown in Fig. 1. The average cell size measured by line method was 13.5−14.5 mm and the relative density of aluminum foam was 0.07−0.08. Cell wall specimens were observed with the help of SEM. A typical SEM microstructure of cell wall specimen is shown in Fig. 2. Obviously, all the cell wall surfaces are covered with an oxide film completely and almost no particle absorbs to the interface of cell wall, suggesting that the added Al_2O_3 particles will not interfere with the results of AES experiment. Moreover, according to the statistical results, the average thickness of cell walls is about 100 μm.

Fig. 1 Typical vertical section of aluminum foams produced at 680 °C