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Comparison of aluminium foams prepared by different methods using X-ray tomography

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ABSTRACT

The cell structure and mechanical properties of aluminium foams prepared by melt foaming (MF) method are supposed to be better than the ones produced by gas injection (GI) method. Preparation processes of these two methods have been developed during the last recent years. Mechanical properties of aluminium foams depend strongly on characteristics of the cell structure. Therefore, it is necessary to compare cell structures of the foams fabricated with these two methods quantitatively using X-ray computed tomography and this is the purpose of the present paper. MF and GI foams have thus been prepared. True density measurements and cell structures indicate that the volume fraction of the closed cells of MF foam with high porosity is negligible. By contrast, the majority of cells of GI foam are closed. Results of cell structure analysis show that there are more micropores in cell walls of the foams prepared by MF method compared to the ones prepared by GI method, especially for the MF foams with low porosity. In addition, results of cell size study show that the cell size distribution is wide in dynamic GI foams, and there are usually big holes inside MF foams. GI method is more suitable to prepare aluminium foams with high porosity compared to MF method. Furthermore, the thickness difference between normal cell wall and Plateau border is greater in GI foams, in particular for the ones produced by the static injector.

1. Introduction

Melt foaming (MF) and gas injection (GI) are two important methods to prepare aluminium foams [1,2]. In the MF procedures, a blowing agent (e.g. TiH_2) is added into the thickened molten aluminium and the aluminium foam is obtained by decomposition of the blowing agent and subsequent solidification of the molten aluminium (this is the method used to produce the ALPORAS foams [3]). In the GI method, a gas jet is driven directly into the molten aluminium using a nozzle, and ceramic particles are contained in the molten aluminium for bubbles stability. There are two versions of this process, namely the dynamic and the static versions depending on the fact that the GI needle is moving or static. The first dynamic GI methods were developed by Alcan [4,5] and Norsk Hydro [6], and the static method by HKR [7,8]. The cells of aluminium foams prepared by these two ways are usually considered to be closed because they are originated from isolated gas bubbles [9]. Closed-cell aluminium foams have wide application prospects in aerospace, automobile and building industries due to their properties, e.g. low density, good energy absorption performance, effective noise reduction and fire resistance [10]. The MF is a simpler preparation process, especially for producing large foam blocks, so it is more popular in industry. GI is relatively low cost and has the advantage of continuous production [11]. Other researchers have compared aluminium foams prepared by different ways. Y. Sugimura et al. [9] found that the cell size and cell wall thickness of the Alporas foam were both smaller compared to the Alcan foam with a similar porosity. A.E. SIMONE et al. [12] concluded that Alporas foams had a better cell structure and mechanical properties compared to Alcan foams. A. Elmoutaouakkil et al. [13] characterised various aluminium foams using X-ray tomography and found that cells of Alporas foams and Norsk-Hydro foams were both closed, and Norsk-Hydro foams presented a bimodal cell size distribution. Most of the previous studies showed that MF foams are usually superior to GI foams concerning the homogeneity of both their structure and properties [1,9,12,13].

If the mechanical properties of aluminium foams could be improved, certainly their applications can be further expanded [3,10,14].

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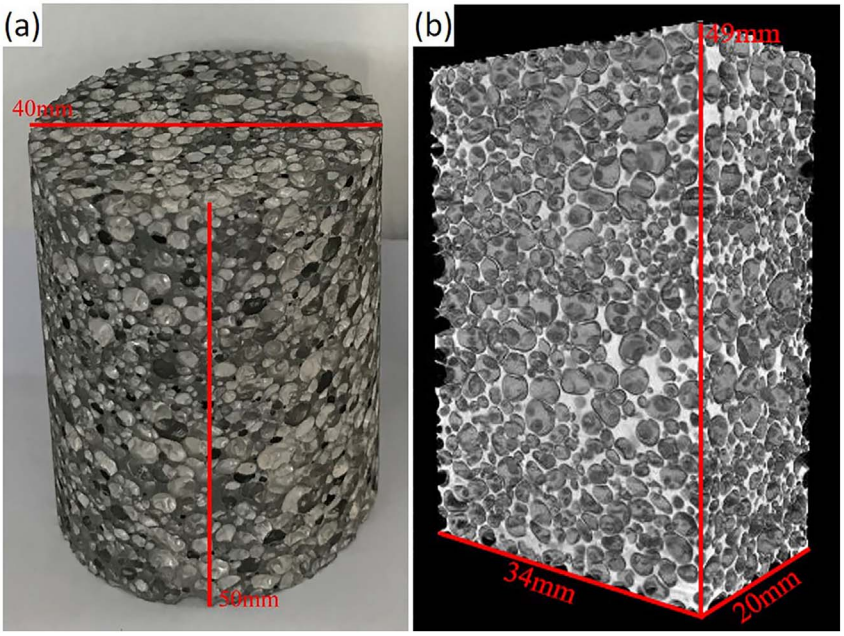

Fig. 1. (a) The macrographic photograph of a GI foam (sample No. 9 in Table 1), (b) 3D view of the corresponded sample after cropping.

Mechanical properties of aluminium foams could be improved from the matrix alloy [15] or cell structure, which includes relative density, cell morphology and cell size, and their influences are usually not independent of each other [16,17]. In recent years, reducing the cell size of aluminium foams is an effective and extensive way to improve mechanical properties, both in MF [18,19] and dynamic GI [20–24] methods. With the developments of aluminium foam preparation technology and characterising technique in the last few years, it is necessary to systematically inspect the cell structure differences of aluminium foams prepared by different methods, especially when the average cell diameter is decreased to around 1 mm [19,23]. If this is achieved, the effect of cell structures could be quantitatively analysed in the mechanical property study of different aluminium foams [25], then the application of aluminium foams prepared by different ways could be better carried out according to their different cell characteristics.

X-ray computed tomography (XRCT) is a nondestructive and effective way to characterise the cell structure of aluminium foams [26–29]. The acquisition of 3D images helps to analyse the morphology of the foams quantitatively and accurately. Gas trapped in the closed cells influences the compressive performance [30], especially in the dynamic response [31]. So it is necessary to try to detect the micro connections between the cells and measure the amount of closed and open porosity accurately, which is beneficial to the prediction and study of mechanical properties of different aluminium foams. Micropores in cell walls and Plateau borders would affect the failure process of aluminium foams under compressive loads [32]. Moreover, M. Mukherjee et al. [33] defined microporosity and pointed out that micropores promote the generation of macro defects, such as broken cell walls. The cell size distribution is also an important parameter [8,13], which can affect the energy absorption ability of aluminium foams [34]. The sphericity of pores affects the effective conductivity (both thermal and electrical) and Young's modulus of closed cell metallic foams [35]. Distribution of the cell wall thickness depends on the preparation of aluminium foams; it certainly influences the deformation and failure of cells [36–38]. Therefore, the above parameters are worth studying in the comparison of aluminium foams prepared by different methods.

In this paper, aluminium foams prepared by MF method [19], static GI [39] and new dynamic GI methods [23] are studied by X-ray tomography. Closed porosity, micropores distribution, cell size and solid material thickness distributions of these foams are compared quantitatively. The comparison of aluminium foams prepared by different ways is significant for optimizing the mechanical property and extending the future application of aluminium foams.

2. Experimental

Fourteen aluminium foam specimens, which were all prepared by the authors, were used for X-ray tomography experiments in this paper. In the case of the MF method, five samples with different cell sizes were selected, and the cell size was reduced by mixing the pre-oxidized TiH_2 with Cu powder. A more detailed description is given in literature [19]. In the case of the static GI method, three samples with different cell sizes were chosen. A foam sample with the minimum cell diameter (around 5 mm) was obtained by the optimization of orifice diameter and chamber pressure during the static GI process, as described in detail in literature [39]. In the case of the dynamic GI method, six samples with different cell sizes were chosen. A self-developed high-speed horizontal oscillation system was used in the preparation procedure [40], and a specimen prepared by the combination of high-speed horizontal oscillation and improved melt preparation methods (smaller particle size and less particle addition) was also scanned [23]. In order to improve the scanning resolution and facilitate the analysis of cell wall structure, samples were cut to certain sizes. For the reliability of average cell parameters, the dimensions of the scanning samples were determined by ensuring a sufficient number of cells (at least ten cells) in each direction. The foam samples are all cylindrical, as shown in Fig. 1(a). They were weighed by an electronic balance. Then, the porosity of the foam could be obtained by Eq. (1).

$$P = 1 - \frac{4m}{\pi d^2 \cdot h \cdot \rho_s} \tag{1}$$

where P is the measured porosity according to the relative density of the aluminium foam specimen, m the weight, ρ_s the solid density, d and h the diameter and height of the cylindrical foam sample, respectively. For simplicity in this paper, the solid densities were taken as the expected densities of the aluminium alloy matrices (pure aluminium 2.7 g/cm^3 and A356 aluminium alloy 2.685 g/cm^3 for MF and GI foams, respectively). We are aware however of the fact that this density also actually slightly depends on the additives, but we will neglect this small