

The Effect of Production Parameters on the Foaming Behavior of Spherical-shaped Aluminum Foam

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The effect of production parameters on the foaming behavior of spherical-shaped aluminum foam was studied. Elemental powders of Alumix 231 and 1% TiH₂ were mixed, compacted at 600 MPa pressure by using a uniaxial action press to produce blanks with 50×30×10 mm in dimensions. These blanks were pre-heated at 550 °C in a furnace for 180 min and then deformed by 10, 30, 50 and 70% by using an eccentric press. They were cut into square shape and foamed at temperatures between 650 °C and 710 °C. It was experimentally found that, the volume expansion rate of foam increases but the maximum foaming duration decreases with increasing the deformation rate and foaming temperature. In these studies 70% deformation and 3.5 minutes foaming duration were found to be the best for the production of spherical foams. This was determined by obtaining the maximum expansion, lower density and homogeneously distributed pores with spherical foams. It was also found that 10% deformation rate was not enough for foaming.

Keywords: APM foam, Al foam, powder metallurgy, porosity

1. Introduction

Metallic foams have extremely superior mechanical, physical and acoustic properties. They are a group of new materials whose production methods are rapidly developing¹. Combination of these properties provides that these structures to be widely used in structural and functional applications. Al-based foams have a great potential to be utilized in the fields of automobile, aerospace, shipment, railway and civil construction¹⁻⁴. Metallic foams have been produced using different manufacturing methods because of intensive research in this field and the developments in today's technology. Currently, the most commonly used production methods are the gas injection into mold, the addition of foaming agents and powder metallurgy⁵⁻⁷. In powder metallurgy method, aluminum foams are made by expansion of foamable precursor in foaming moulds. The mould is heated in a furnace until the expansion process of precursor. The foaming agent in structure during the foaming process decomposes and releases gas which expands the liquid metal. In this method for aluminum and its alloys as a foaming agent is used usually TiH₂ or ZrH₂. However, CaCO₃ and dolomite powders can be used effectively instead of TiH₂ as foaming agent. But the cell morphology varies with the foaming temperature^{8,9}. Homogeneous heat transfer into the precursor, foaming mould design and precursor geometry are most important for high quality near-net shape aluminum foam part production in moulds. If these parameters cannot be controlled non-uniform expansion can occurs^{10,11}. But the spherical-shaped metallic foam parts are produced without a mould. They are produced by

foaming a precursor material with APM (Advanced Pore Morphology) technology which is developed by IFAM in Germany¹². This technology consists of two main steps as the foam expansion and the foam shaping. The precursor materials are cut into small volumes that are foamed without molds in a continuous belt furnace in production^{6,13}. Surface tension of the metal melt shapes the elements spherical. Due to gravity force the geometry is not perfectly spherical^{10,11}. The result is a high reproducibility of the expansion level in contrast to foam expansion in moulds. The manufactured parts have a relatively small volume (volume <1 cm³). These parts are combined with a simple bonding technique (Figure 1). Therefore, APM foam parts manufacturers provide maximum flexibility for their users¹². They can be used as team members in front of vehicles by filling inside of steel pipes¹³⁻¹⁵. Recently, the researchers has focused on the mechanical properties of the single or hybrid APM foams^{16,17}. However, the researches on the effect of process parameters in production of these materials are still very limited. The aim of this study was to optimize spherical-shaped aluminum foam production parameters.

2. Materials and Experimental Process

In this study, 1 wt% TiH₂ powders (purity: 98%, particle size: <45 µm) supplied from Aldrich were added to Alumix 231 powder (purity: 99%, particle size: <200 µm) supplied from Eckart and were mixed in a three dimensional turbola for 30 min. Mixed powders were then compacted under 600 MPa single action pressure to produce blanks with 50×30×10 mm in dimensions¹⁸. These blanks were

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pre-heated at 550 °C in a furnace for 180 minutes due to the mismatch between the decomposition temperature of foaming agent (at about 400-600 °C)^[19,20] and then deformed by 10, 30, 50 and 70% by using an eccentric press. They were cut into shapes of square and foamed at various temperatures (650, 670, 690, 710 °C) from 2 to 5 minutes with the interval of 30 seconds and cooled to room temperature. Figure 2 shows the production stages of spherical-shaped aluminum foam. At least three and more samples for each configuration were investigated in experiments.

The density of the produced foam parts (ρ_s) is determined by Archimede's method. The volume expansion was then calculated by using Equation 1:

$$\text{Expansion} = \frac{(v^* - v)}{v} \times 100\% \quad (1)$$

Where; v^* and v are the specimen volume after and before foaming. The porosities of Al foam were calculated using the following Equation 2:

$$\text{Porosity} = \frac{(\rho - \rho^*)}{\rho} \times 100\% \quad (2)$$

Where; ρ^* and ρ_s are the densities of Al foams and the cell wall material respectively.

3. Results and Discussion

3.1. Volume expansion

Figure 3 shows the effect of foaming temperature on the volume expansion rate of precursor samples deformed by 10%. As seen in the graph, samples did not show any detectable volume expansion (under 40%) at any time. For example, the maximum expansion of 37% after 3.5 min at 690 °C was obtained in the precursor samples that were

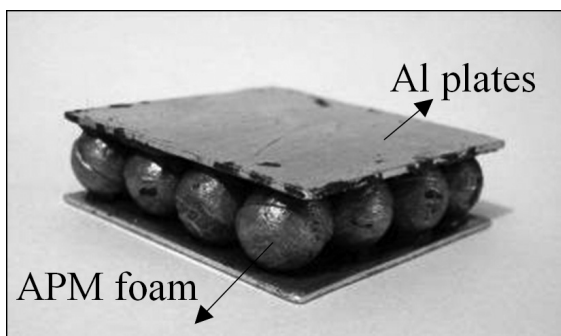


Figure 1. Sandwich structure with cellular core layer.

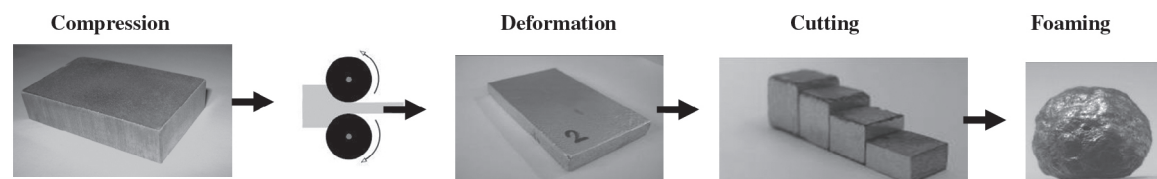


Figure 2. Production stages of spherical-shaped aluminum foam.

deformed by 10%. On the other hand, the foamed sample for 4 min at 650 °C exhibited maximum volume expansion rate of 29%. The results indicated that the foaming temperature was not effective for 10% deformed samples. This was attributed to the inadequate deformation rate which was not enough for retaining the entrapped gas during the foaming period.

Figure 4 shows the effect of foaming temperature on the volume expansion rate of samples deformed by 30%. As seen in the graph, the precursor samples foamed at 650 °C and 670 °C temperatures reached the maximum expansions in 4 min. During this period the volume expansion rates of 242% and 252% were obtained respectively. Moreover, the samples foamed at 690 °C and 710 °C exhibited expansion rates of 255% at 3.5 min and 204% at 3 min respectively. The volume expansion rates of samples were found to decrease after these periods were exceeded. The samples deformed by 50% and 30% exhibited similar foaming behavior as shown in Figure 5. However, the volume expansion rate of 50% deformed sample was higher than the sample deformed by 30%.

Figure 6 shows the maximum volume expansion rates of 70% deformed samples at different foaming temperatures. As seen in the graph, the samples foamed for 4 minutes at 650 °C exhibited maximum volume expansion rate of 449%. On the other hand, the foamed samples at 670 °C, 690 °C and 710 °C exhibited maximum volume expansion rates of 523%, 556% and 338% at 4, 3.5 and 3 min foaming durations respectively. According to the aforementioned results it can be said that high temperature reduced the foaming duration. This situation is based on the fact that hydrogen pressure (from the dissolution of TiH_2) is increased with increasing temperature. Thus, the acceleration in the releasing of hydrogen causes rapid coalescence of bubbles²¹. However, the volume expansion rates started to decrease again when these periods are exceeded the normal foaming duration and no more hydrogen gas is released and the foam begins to decay which leads to collapsing²².

Figure 7 shows the samples foamed for 3.5 min after being deformed at various rates. Spherical-shaped aluminum foam samples were obtained by means of free-form foaming in our previous studies. Because of the surface tension during foaming process, the precursor samples were put into spherical shape¹². However, the samples could not get exactly a spherical shape due to the mass of the melted samples. As seen in Figure 7, the 70 % deformed sample has the most spherical in shape. As mentioned previously, the blowing agent fails to be held in the structure properly with decreasing of deformation rate. The white dashed lines on the image indicate the cross section of samples before the foaming so that the foaming ratio can be understood easily.

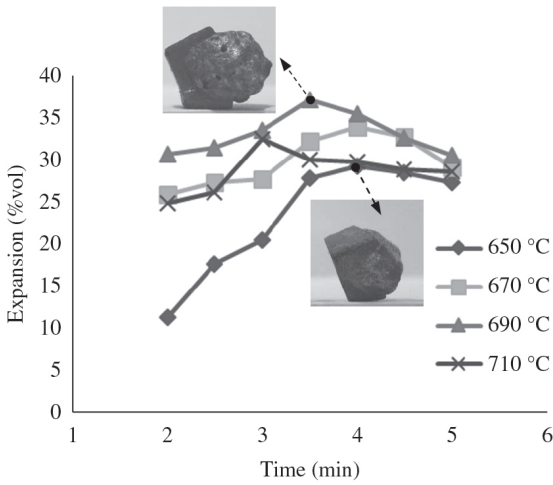


Figure 3. Expansion rates of 10% deformed samples at various foaming temperatures.

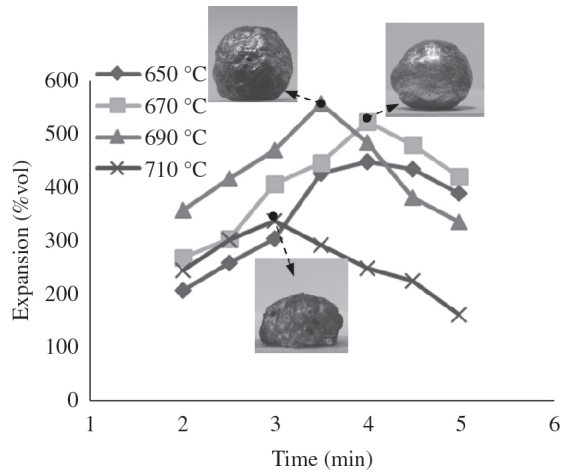


Figure 6. Expansion rates of 70% deformed samples at various foaming temperatures.

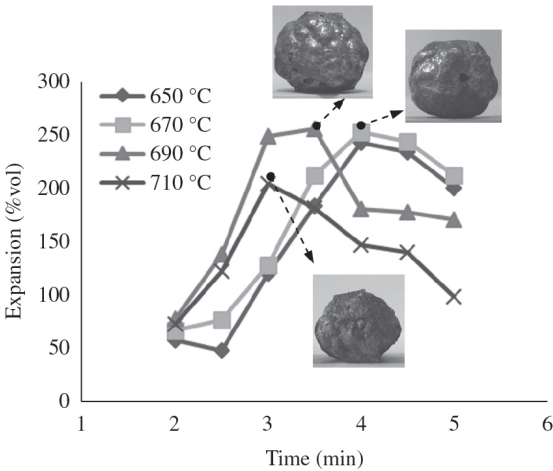


Figure 4. Expansion rates of 30% deformed samples at various foaming temperatures.

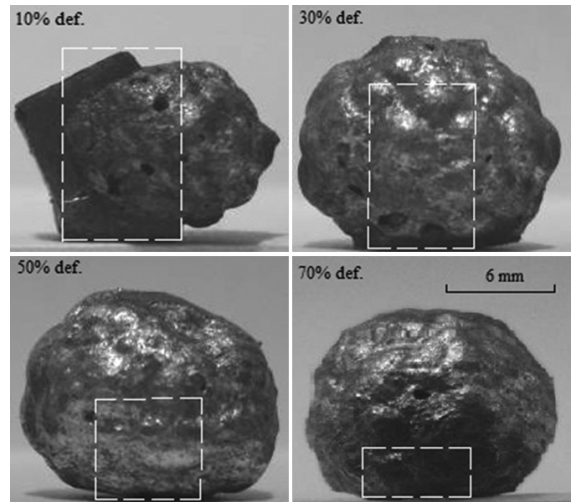


Figure 7. The appearance of the samples foamed for 3.5 min after being deformed at various rates.

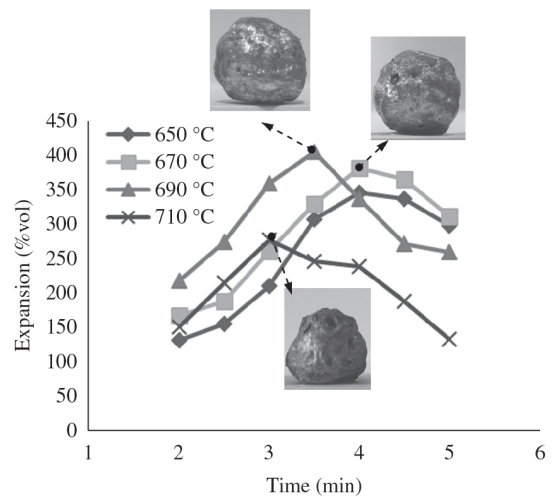


Figure 5. Expansion rates of 50% deformed samples at various foaming temperatures.

The density of samples increased with increasing the rate of deformation which is also indicated in the literature²³. Thus, the blowing agent cannot escape from the structure during the foaming process. The densities of precursor samples depend on the amount of deformation rates given in Table 1.

3.2. Density, porosity and structure of pores

In this section, the densities of samples that exhibited maximum volume expansion at 690 °C were compared and the graph was obtained (Figure 8). As seen in the graph, the lowest density and the maximum expansion rate were reached after foaming for 3.5 min. In the same period of exposure the densities of samples deformed by 70%, 50%, 30% and 10% were calculated to be 0.40, 0.52, 0.75 and 1.99 g/cm³ respectively. But the densities of samples increased after that time up to 5 minutes. Some samples that deformed by 70% exhibited some cracks. The deformation

Table 1. The densities of precursor samples depending upon the amount of deformation rates.

Deformation Rate (%)	10	30	50	70
Average Density (g/cm ³)	2.42	2.48	2.53	2.68

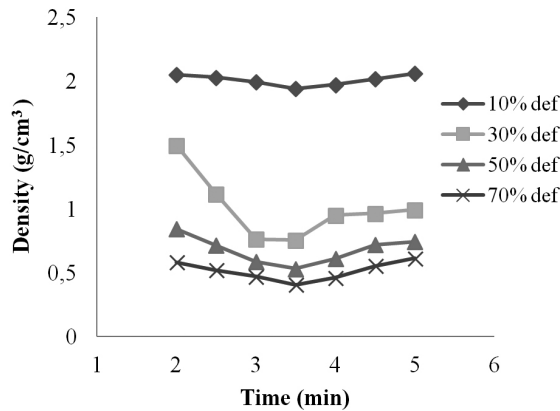


Figure 8. Density of samples foamed at 690 °C.

process was controlled with structural defects, which was believed to have resulted in some cracks.

The increase in the density is due to the escaping of the trapped gas from the pores particularly on the highly deformed samples. This process also results in the collapsing of the foamed materials due to the escaping of entrapped gas from the molten metal easily. In addition, significant differences in the pore structure of samples were formed. Figure 9 shows the structure of pores of foam samples exhibited the maximum volume expansion at 690 °C. When we increased the foaming duration to 3.5 min, small amount of porosity (27%) was seen on the sample deformed by 10% as shown in Figure 9. However, 50% deformed sample exhibited more pores (80%) which were smaller than those seen in the sample deformed by 70% which exhibited homogeneously distributed spherical porosity (84%).

4. Conclusions

The foaming behavior of spherical-shaped aluminum foam depending on the production parameters was

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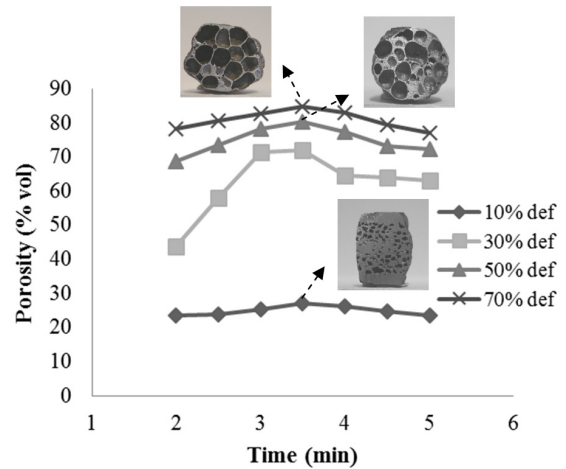


Figure 9. The structure of samples foamed 690 °C.

investigated. It was experimentally found that, the volume expansion rate of foam increases but the maximum foaming duration decreases with increasing the deformation rate and foaming temperature. In these studies 70% deformation and 3.5 minutes foaming duration were found to be the best for the production of spherical foams. This was determined by obtaining the maximum volume expansion, lower density and homogeneously distributed pores with spherical foams. It was also found that 10% deformation rate was not enough for foaming, 50% deformation on the other hand, showed some pores after 3.5 min foaming, but they were not homogeneously distributed although the foamed sample was almost spherical in shape. It was found that the foaming duration shortened with increasing foaming temperature.

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