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Controlling Technique of Pore Morphology of Highly Reliable Aluminum Foam

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Abstract

Foamed Aluminum was fabricated by a powder processing route. Aluminum (pure Al or Al-7Si alloy) and titanium hydride (TiH_2) powders were mixed for the preparation of precursors. The Al(-7Si)/TiH_2 precursor was heated in an infrared furnace to melt aluminum and to decompose TiH_2, which resulted in the H_2 gas generation in molten aluminum. In this work, effects of processing parameters on the foaming behavior and also pore morphology were investigated. There was an adequate temperature range for a satisfactory blowing behavior. When the heating temperature was low, the precursor did not expand sufficiently. On the other hand, when the heating temperature was high, the precursor shrunk rapidly. The heating rate was an important factor to control pore size and circularity. When the Al-7Si/TiH_2 precursor was heated, the maximum expansion was sustained for a certain period of time.

1. Introduction

Foamed aluminum is a class of porous materials [1-6], in which closed pores are formed by a gas generation in liquid (or semi-liquid) aluminum alloys. The aluminum foam possesses unique properties which dense materials do not exhibit. High energy absorption [7], high sound absorption, low density (<1g/cm^3) are, for example, the typical properties of the aluminum foam. The powder-processing route is a typical processing technique to fabricate the aluminum foam. In the powder processing route, titanium hydride (TiH_2) powder as a blowing agent, which decomposes at the temperature near the melting point of aluminum and releases hydrogen gas, was blended with aluminum powder. The powder blend was then consolidated to make Al-TiH_2 precursors, and the precursor was heated in a furnace to induce melting of aluminum and decomposition of TiH_2. The H_2 gas released from TiH_2 successfully generates pores in aluminum by controlling processing parameters properly. To make reliable foam materials, the uniformity of both pore size and morphology is one of the most important factors [8,9]. In this work, the effects of processing parameters on the blowing behavior were observed in order to find some information to control the pore morphology. The processing parameters we focused on were heating rate, heating temperature, the aluminum composition (Al-7Si and pure aluminum) and the size of the precursor.

2. Experimental Procedure

Al-7Si and pure Al powders were used and the size distribution of these powders is listed in Table 1. Titanium hydride powder (TiH_2, <45μm) was used as a blowing agent. The TiH_2 powder was blended with Al powder by 0.5 or 1 mass %. The blended powder was, then, consolidated to make a precursor by hot compaction (773K, 160MPa). Two types of precursor with different sizes (Small: cubic 10 x 10 x 13mm, Large: cylindrical ϕ 40 x h 40mm) were prepared. The precursor was heated in an infrared furnace (Figure 1) and kept at 863-993K (Holding Temperature) for 0-1200s (Holding Time). The blowing behavior of the precursor was recorded by a camera and evaluated by a relative projected area (A_p).

$$Relative\ Projected\ Area\ (A_p) = \frac{Projected\ Area}{Initial\ Projected\ Area}$$

The pore morphology was observed and evaluated by scanning electron microscopy (SEM) and image analyzing software. Porosity was measured by an Archimedes method.

Table 1: Size distribution of pure Al and Al-7Si powders used in this experiment.

Pure Al powder

Size (μm)	-44	+44	+63	+75	+106	+150
mass%	77.6	9.7	5.0	5.0	2.6	0.1

Al-7Si powder

Size (μm)	-44	+44	+74	+114	+148	+296
mass%	21.4	20.3	14.8	13.0	25.8	4.7

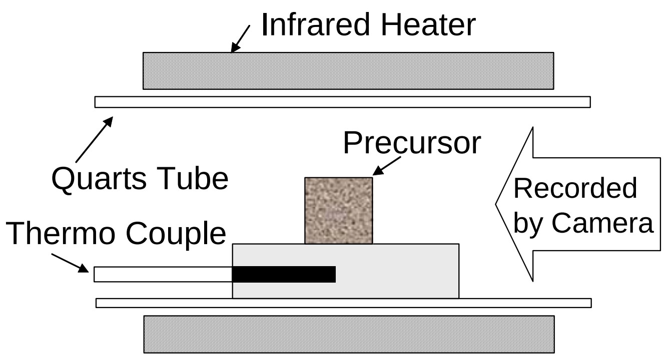

Figure 1: Schematic illustration of the experimental apparatus.

3. Results

3.1 Blowing behaviour

3.1.1 Blowing behaviour of Al-7Si/TiH2 precursor

Figure 2 shows the relative projected area of the Al-7Si/TiH2 precursor(S) as a function of the holding time. The holding temperature was settled at 883K. The precursor started to expand at around 860K (close to the melting point of eutectic Al-Si alloy) and the maximum expansion was sustained in between 180-500s holding time To investigate the detailed foaming behaviour, the cross-section of the Al foam was observed by an optical microscope. As shown in Figure 3, the onset of pore formation was already observed by 60s holding. The pores grew gradually during the holding process. The drainage of aluminum and extinction of the pores were clearly visible by 900s holding. Figure 4 shows the relative projected area of the Al-7Si/TiH_2 precursor fabricated by different holding temperatures. The onset of the expansion was observed at 860K in every specimen. Once the projected area reached the maximum expansion, the specimen with 903K holding shrunk rapidly. Even though the maximum projected area of the specimen with 883K holding was lower, the stable maximum expansion was sustained for about 300s. The same tendency was observed when the holding temperature was settled at 863K. These results indicate that the high holding temperature brings high but unstable expansion.

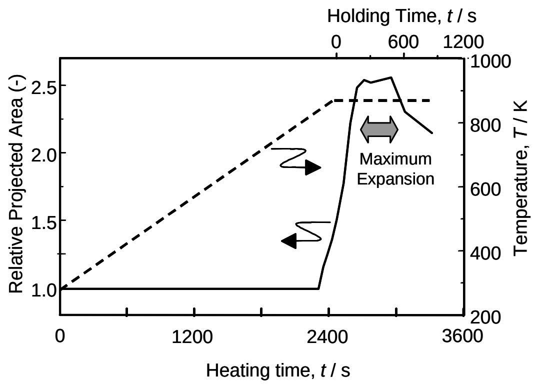

Figure 2: Relative projected area of Al-7Si/TiH_2 precursor (Holding Temperature: 883K).

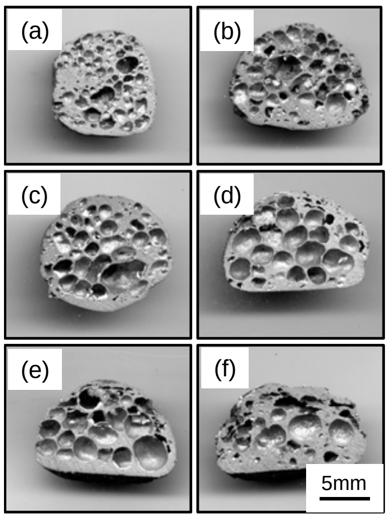

Figure 3: Cross sections of porous Al (Al-7Si/TiH_2 precursor), Holding Time (a) 60s, (b) 180s, (c) 300s, (d) 420s, (e) 600s, (f) 900s (Holding Temperature 883K).

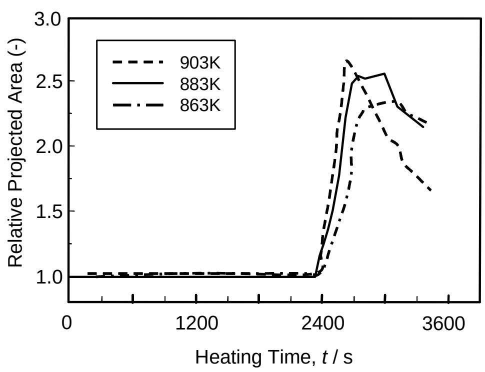

Figure 4: Relative projected area of Al-7Si/TiH_2 precursor (Holding Temperatures: 863-903K).

3.1.2 Blowing behaviour of pure Al precursor

The pure Al/TiH_2 precursor(S) started to expand at around 940K (close to the melting point of Al) and showed the sharp peak expansion. After the peak expansion, the precursor shrunk immediately. The pore morphology during the blowing process is shown in Figure 5. As seen in Figure 5(a), small pores were distributed over the whole specimen at the early stage of the holding process. The growth of pores already started from 60s holding, and the extinction of pores started with 600s holding. The most of the pores became irregular shape with 900s holding.

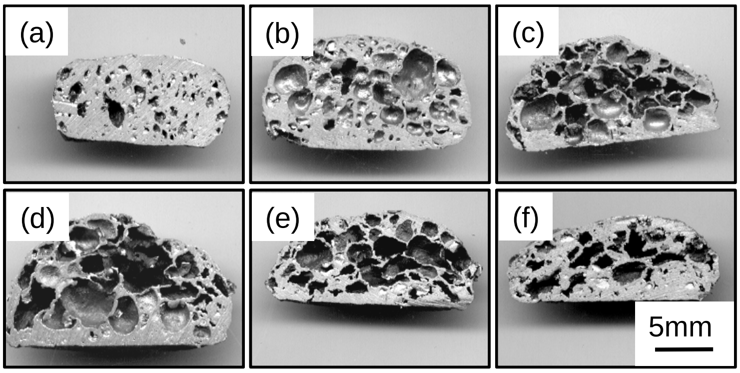

Figure 5: Cross sections of porous Al (pure Al/TiH_2 precursor), Holding Time (a) 60s, (b) 180s, (c) 300s, (d) 420s, (e) 600s, (f) 900s, (Holding Temperature: 973K)

3.2 Controlling pore morphology

As already described in the former section, the stable maximum expansion of $Al\text{-}7Si/TiH_2$ precursor was sustained during the 180-500s holding. However, as shown in Figure 6 and 7, the pore morphology was not constant during this period of time. This suggests that the pore morphology can be controlled during this period of time without changing the porosity. For example, the relatively smaller pores are obtained by heating the precursor for a shorter period of time (Figure 6). Figure 7 (and also Figure 3) exhibits the morphological transition of the pores, showing that the spherical pores at the early stage of blowing process changes to the irregular-shaped cells.

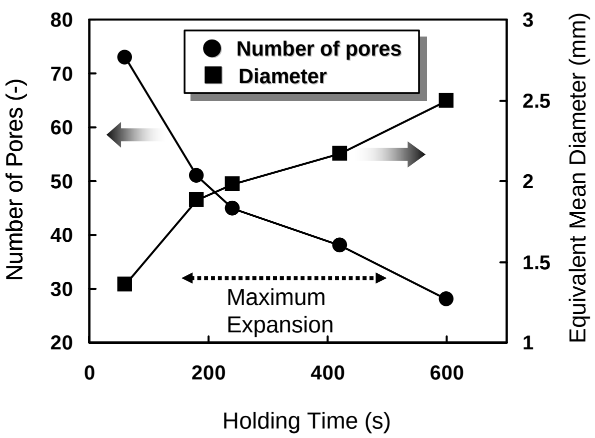

Figure 6: Number and mean size of pores of $Al\text{-}7Si/TiH_2$ precursor at different holding temperatures.

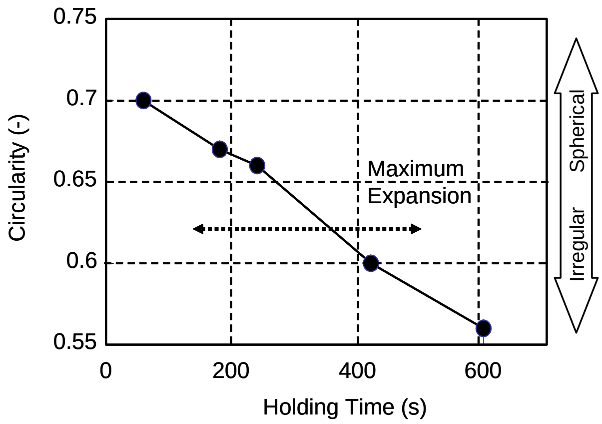

Figure 7: Circularity of pores of $Al\text{-}7Si/TiH_2$ precursor during holding process (Holding Temperature: 973K).

During the holding process, pores are born, grow and finally disappeared by sedimentation of molten aluminum (drainage). The life-span of the pore is strongly affected by the size of precursor because the drainage is dominated by the movement of pores caused by gravity. Therefore the size of the precursor is an important factor to determine the stability of pores. Figure 8 shows the porosity of the aluminum foam fabricated by different-sized precursors (S and L). By increasing the size of the precursor, the decrease in porosity can be restrained. However, the pore size increased during the holding time as shown in Figure 9. Hence, when the size of the precursor is large enough to maintain the stability of pores, the size of the pores can be controlled by controlling the holding time. The blowing behaviour was strongly affected by the heating process, which determines the temperature profile of the precursor. Figure 10 shows the cross-section (converted to a black-white image) of the Al-7Si foam made by different heating rates. It is clear that the smaller pores are obtained by the rapid heating. By increasing the heating rate, the exposure time of the precursor at a high temperature can be reduced. Therefore, the growth of the pores and the drainage hardly occurs and fine spherical pores were obtained. Figure 11 shows the typical pore structure of the Al foam, whose processing condition was well-controlled. The spherical homogenous pores (average diameter: 2-3mm) are visible.

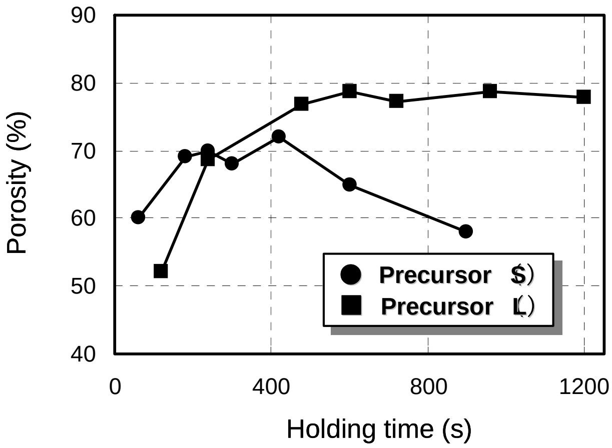

Figure 8: Porosity of the precursors (S) and (L).

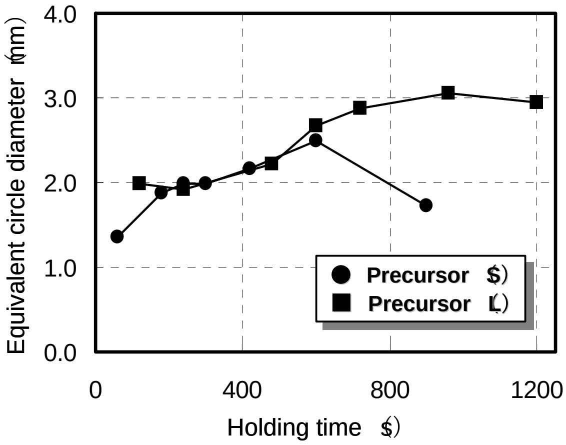

Figure 9: Mean size of the pores of precursors (S) and (L).

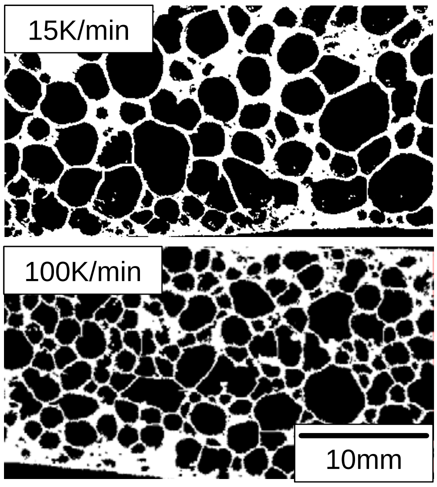

Figure 10: Black and white images of the cross-section of aluminum foams fabricated by different heating rates

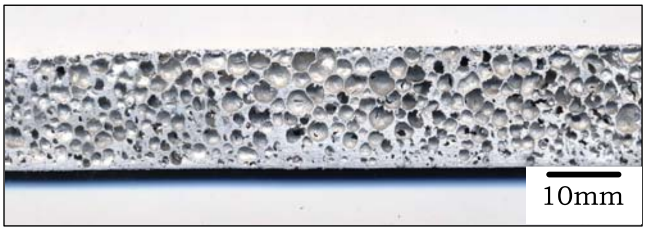

Figure 11: Cross-section of Al foam fabricated by powder processing technique.

4. Summary

Aluminum foam was fabricated by a powder processing technique. TiH_2 powder and aluminum (Al-7Si and pure Al) powder was blended and consolidated to make a precursor. The processing parameters which affected the blowing behaviour were estimated and investigated. The following results were obtained from this work.

1. Using Al-Si alloy was more effective to sustain stable pores than to use pure Al.
2. While the maximum expansion (stable porosity) of Al-7Si precursor was sustained for a certain period of time, the pore morphology was not constant.
3. When the size of the precursor was large enough to sustain stable pores and restrain drainage, the size and shape of the pores are relatively easier to control.
4. The blowing behaviour was strongly affected by the heating profile. By increasing the heating rate, the exposure time of the precursor at high temperature can be reduced and the drainage hardly occurs. As a result, fine spherical pores can be obtained.

References

[1] G.J.Davis, S.Zhen: Journal of Mater. Science, 18(1983), 1899.
[2] V.Shapovalov: MRS Bulletin, April(1994), 24.
[3] J.Baumeister, J.Banhart, M.Weber: Mater. & Design, 18(1997), 217.
[4] H.P.Degischer: Mater. & Design, 18(1997), 221.
[5] A.E.Simone, L.J.Gibson: Mater. Sci. and Eng. A229(1997), 55.
[6] C.J.Yu, H.Eifert, J.Banhart, J.Baumeister: Advanced Mater. and Processes, 154(1998), 45.
[7] K.A.Dannemann, J.Lankford: Mater. Sci. and Eng., A293(2000), 157.
[8] L.Ma, Z.Song: Scripta Mater., 39(1998), 1523.
[9] Y.Sugimura, J.Meyer, M.Y.He, H.Bart-Smith, J.Grenstedt and A.G.Evans: Acta Mater., 45(1997), 5245.