

Effect of Foaming Agent on Pore Initiation and Growth of Aluminum Foam

Junji Ogi¹, Makoto Kobashi², Naoyuki Kanetake²

¹Graduate Student, Graduate school of Engineering, Nagoya University Japan

²Department of Materials Science and Engineering, Nagoya University, Japan

Al foam is expected to be used for wide range of industrial applications because it has various unique features, such as very low density, high energy absorption, and high stiffness. It is important to understand the foaming behavior from the pore initiation until the maximum expansion to control the pore morphology (pore size, pore shape and porosity). In this study, we observed the effects of foaming agent and Al alloy composition on pore initiation and growth of Al foam by a powder metallurgical (PM) method. We chose two kinds of Al alloys (pure Al or Al-7Si) and foaming agents (TiH₂, ZrH₂ and CaCO₃), and examined foaming behavior from an early stage of foaming to a highly expanded stage. As for the pure Al system, pore morphology was relatively large and flat at the early stage of foaming. In addition, Al/CaCO₃ system exhibited both high porosity and uniform pore distribution. In Al-7Si system, microscale pores (<100μm) were formed at the early stage of foaming process. When TiH₂ was used as the foaming agent, pores became larger even at the early stage of foaming. As for Al-7Si/CaCO₃ system, small pores resided during the entire foaming process. With increasing blending amount of CaCO₃, Al-7Si/CaCO₃ system showed high porosity more than 80% with microscale pore distribution.

Keywords: Porous material, Precursor method, Foaming agent, Aluminum alloy, Pore morphology

1. Introduction

Al foam is expected to be used for wide range of industrial applications because it has various unique features, such as very low density, high energy absorption, and high stiffness. Because the characteristic of the Al foam is largely affected by its pore morphology, it is important to establish foaming method to control the pore morphology [1]. Therefore, the foaming behavior from the pore initiation until the maximum expansion must be understood. In this study, we observed the effect of foaming agent and Al alloy composition on pore initiation and growth of Al foam by precursor method. The precursor method (Fig.1) is a well known production method for Al foam [2] [3]. This method begins with the mixing of metal powders with a foaming agent, followed by a compaction of the mixture to a dense pre-product (precursor). The precursor is foamed by heating and melting of the metal powder, which triggers the gas release from the foaming agent and the formation of porous. In general, TiH₂ is used as a foaming agent for producing porous aluminum.

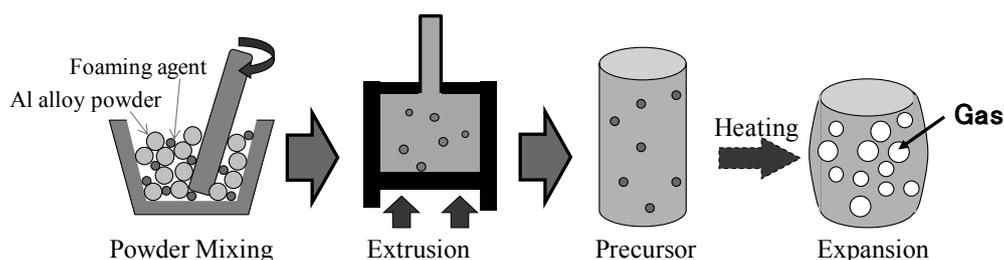


Fig. 1 Schematic illustration of precursor method procedure.

Various factors, such as viscosity of molten Al, surface tension of liquid film, and quantity or timing of gas release from the foaming agent, influence the pore morphology of Al foams. We chose two kinds of Al alloys (pure Al and Al-7Si) and three kinds of foaming agents (TiH₂, ZrH₂, and CaCO₃), and examined foaming behavior from an early stage of foaming to a highly expanded stage.

2. Experimental procedure

In this work, the precursor method was selected to fabricate Al alloy foams. Two kinds of Al-alloy powders (pure Al and Al-7Si) were used for preparing the precursor material. The alloy powders were mixed with foaming agents. Three kinds of powders were used as foaming agent (TiH₂ <45μm, ZrH₂ ave.5μm and CaCO₃ ave.1μm). Compositions of powder mixture used in this experiment are shown Table 1. The powder mixture was pre-compacted at room temperature to cylindrical-shaped samples and hot extruded at 400°C with extruded ratio 16. Cylindrical precursors (ϕ 8mm × 12mm) were cut off from extrusion bar. For producing foam specimens, these precursors were heated in a high-frequency induction furnace (Fig.2).

Table 1 Various combinations of Al and foaming agent powders used in this experiment.

		Powder Mixture					
		Al/TiH ₂	Al/ZrH ₂	Al/CaCO ₃	Al-7Si/TiH ₂	Al-7Si/ZrH ₂	Al-7Si/CaCO ₃
Amount of Foaming agent (mass%)	0.5	○	○	○	○	○	○
	1.0	/	/	/	○	/	○
	3.0	/	/	/	○	/	○
	5.0	/	/	/	○	/	○

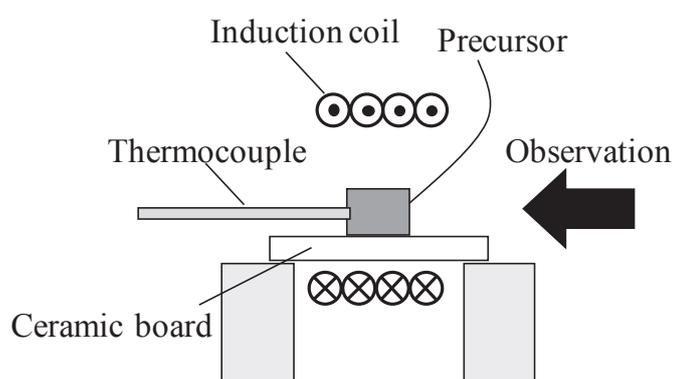


Fig.2 Schematic illustration of high frequency induction furnace.

As indicated in Fig.2, sequential change in shape of the precursor was recorded by a camera and the foaming behavior was evaluated by a relative projected area. The relative projected area was calculated by in the following equation:

$$\text{Relative projected area} = \frac{\text{Projected area; } A_t}{\text{Initial projected area; } A_0} \dots\dots\dots(1)$$

where A_0 is initial projected area (Fig.3a), A_t is apparent projected area (Fig.3b). As indicated in Fig.2, the temperature of the specimen was measured by a thermocouple embedded in the precursor. Some

specimens were taken out of the furnace at various temperatures and cooled in air for observing the pore morphology. Porosity was measured by an Archimedes method.

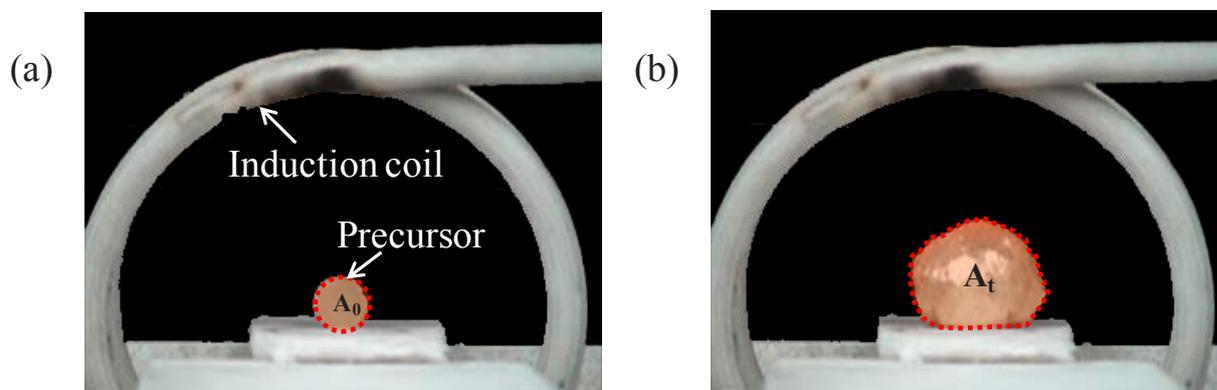


Fig.3 Relative projected area of specimen, (a) initial projected area and (b) apparent projected area.

3. Results and Discussion

Fig. 4 shows the relative projected area and the specimen temperature of precursors as a function of the heating time. Each precursor contains 0.5mass% foaming agent. In pure Al system, the precursors started to expand at the melting point of Al and reached maximum expansion regardless of the type of foaming agent. In Al-7Si system, the precursors started to expand at eutectic temperature.

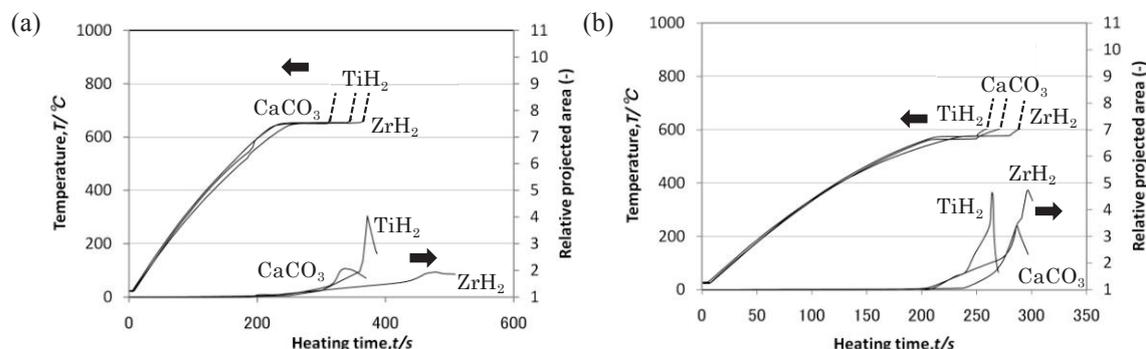


Fig.4 Comparison of relative projected area and specimen temperature in various kinds of powder mixtures, (a) pure Al system and (b) Al-7Si system.

We defined early stage of foaming as relative projected area value of 1.5, and cross-section at the early stage of foaming was shown in Fig.5 (a). Pore shape was affected by the kind of Al alloys. In pure Al system, pore shape became flat platelet. It is well known that flat shape pores, the kind of perpendicular to compression axis, are observed at the early stage of foaming. One reason is that foaming agents release gas at temperatures below the melting point of aluminum. Another reason is that due to compaction history the strength of the precursor is anisotropic [4]. The SEM images of cross section of Al-7Si system is shown in Fig.5 (b). Fig.5 (b) shows that many microscale pores (<100 μ m) existed at an early stage in Al-7Si system.

The cross-section of highly expanded foam is shown in Fig.6. In pure Al system, both high porosity and uniform pore distribution were achieved by TiH₂ addition, although pores had irregular shapes. On the other hand, high porosity could not be achieved by ZrH₂ and CaCO₃ addition. Pores of these foams were located at center of cross-section. In Al-7Si system, uniform pore distribution was achieved by all foaming agents. Al-7Si/ZrH₂ system exhibited both high porosity and smaller pores

than that of Al-7Si/TiH₂ system. Although Al-7Si/CaCO₃ system showed low porosity than the others, pore size was the smallest in Al-7Si system.

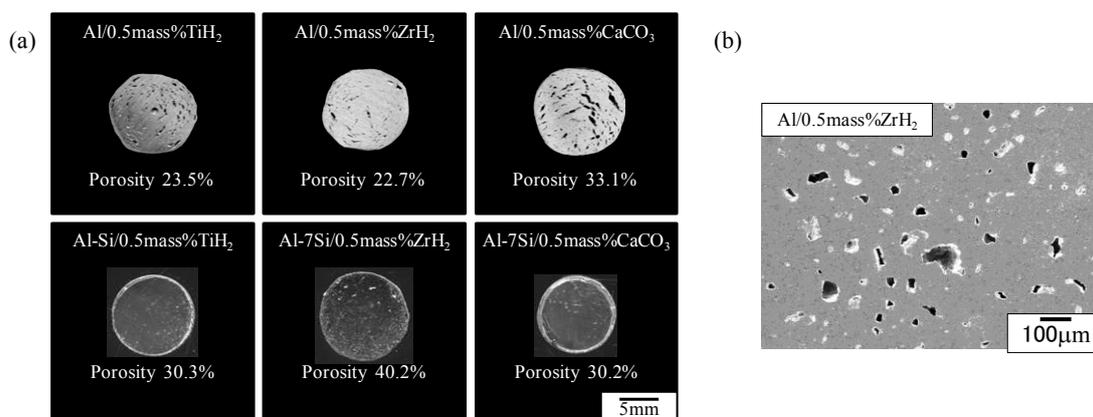


Fig.5 Cross section of early stage of foaming, (a) macroscopic cross section and (b) SEM image.

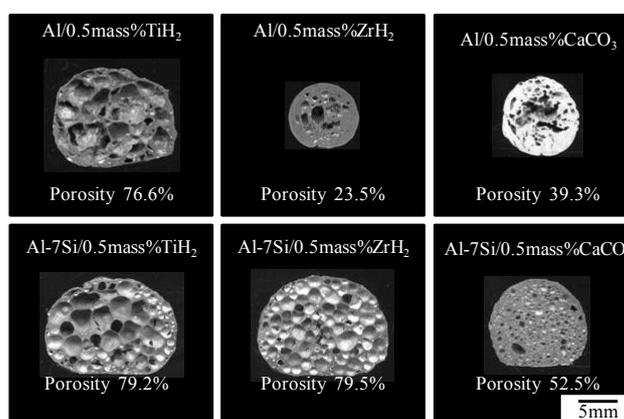


Fig.6 Cross section of fully expanded foam.

Table 2 Gas yield amount of precursor with different foaming agent.

foaming agent	TiH ₂	ZrH ₂	CaCO ₃
*gas yield (cm ³ /precursor)	4.48	2.40	2.24

(* precursor weight=2.0g)

Table 2 shows comparison of quantity of gas from foaming agent. Since gas amount released from foaming agent is lower than that of Al/TiH₂ in Al/ZrH₂ and Al/CaCO₃ systems, porosity becomes low in these systems. So we made the precursor which contained higher amount of foaming agent in Al-7Si/CaCO₃ system, and fabricated fully expanded foam. These results are displayed in Fig.7. With increasing amount of CaCO₃, Al-7Si/CaCO₃ system showed high porosity. The porosity of Al-7Si/3mass%CaCO₃ showed the highest value. Increasing amount of CaCO₃, gas emission became too large to keep it inside a foam.

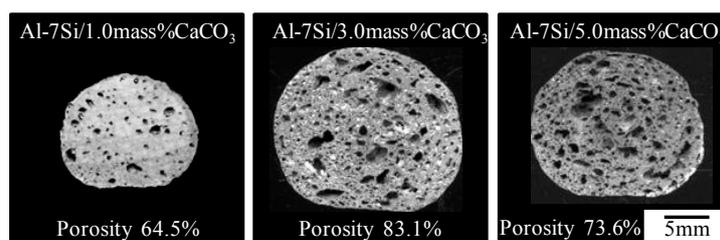


Fig.7 Cross-section of fully expanded foam with various foaming agent in Al-7Si/CaCO₃ system

In Al-7Si/3mass%CaCO₃ system, we examined foaming behavior from an early stage of foaming to a highly expanded stage in more detail. We observed two pieces of cross section to describe the pore morphology. We defined them transverse cross-section and longitudinal cross-section as shown in Fig.8.

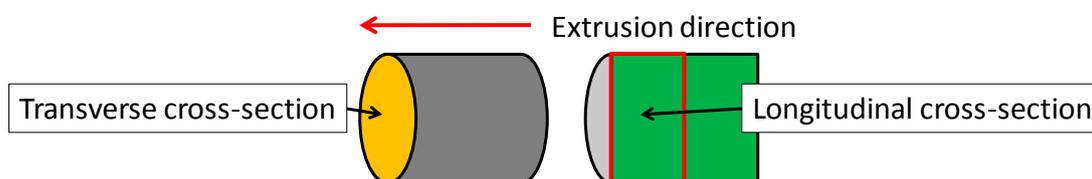


Fig.8 Schematic illustration of two pieces of cross section

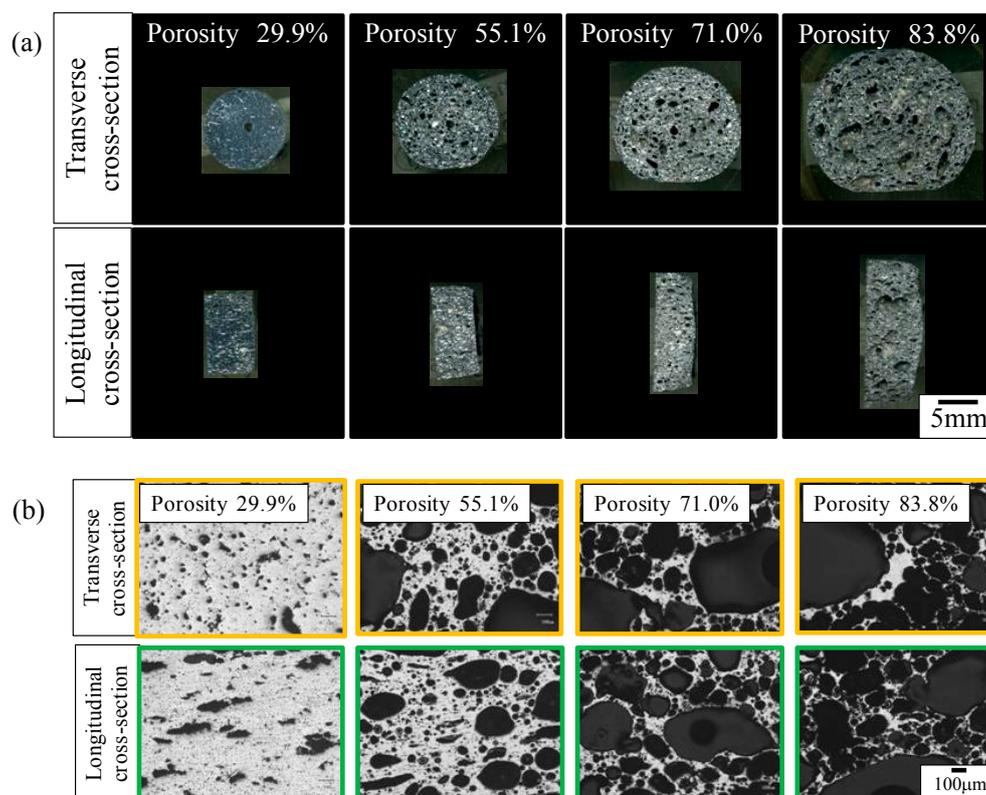


Fig.9 Cross-section of Al-7Si/3mass%CaCO₃ system, (a) macroscopic cross section and (b) optical microscopic images

The pores of Al-7Si/3mass%CaCO₃ system were smaller than those of other Al-7Si systems. In addition, small pores resided during the entire foaming process. In longitudinal cross-section, flat

shape pores were observed at the early stage of foaming. Because foaming agents exist in powder grain boundary, pores are formed by tearing the powder grain boundary, and become flat shape. These pores become spherical shape by growing and coalescence. [5]

4. Conclusion

Various kinds of Al foams were fabricated by precursor method. It was revealed that the foaming behavior was characterized by the kind of Al alloy or foaming agent. The foaming behavior by the relative projected area and pore morphology in the cross section was observed. The following results were obtained from this work.

1. In pure Al system, high porosity couldn't be achieved by adding ZrH_2 and $CaCO_3$, because total amount of gas released from these foaming agents is lower than that of TiH_2 .
2. In Al-7Si system, the pore morphology becomes more uniform than that of Al system. The reasons for this are that these might be a plenty of liquid phase due to a low solidus temperature at the early stage of foaming.
3. With increasing blending amount of $CaCO_3$, Al-7Si/ $CaCO_3$ system showed high porosity with microscale pore distribution.
4. In longitudinal cross section of Al-7Si/3mass% $CaCO_3$ system, flat shape pores were observed at the early stage of foaming. Since foaming agents exist in powder grain boundary, pores form like tearing powder grain boundary, and become flat shape. These pores become spherical shape by growing and coalescence of pores.

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