Fabrication of lotus-type porous aluminum using thermal decomposition of magnesium hydroxide

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Abstract. Lotus-type porous aluminium was fabricated using a thermal decomposition of magnesium hydroxide in a vacuum. The effect of addition of magnesium hydroxide on the porosity and the average pore diameter were investigated. The hydrogen dissolved in molten aluminum through thermal decomposition of magnesium hydroxide when the melt solidified evolves pores. Furthermore, magnesia formed through thermal decomposition of magnesium hydroxide in the melt serves as nucleation sites for the pores. The porosity and the number of the pores increase with increasing amount of magnesium hydroxide, and the average pore diameter is not much varied with amount of magnesium hydroxide.

1. Introduction
Porous and foamed metals have been the focus of great interest due to their special features that include low density, high surface area, sound absorption and so on. Thus, these metals are expected to be utilized as light-weight materials, catalysts, electrodes, vibration and acoustic energy damping materials, impact energy absorption materials and so on[1,2]. Especially, porous Al alloys are expected to be used for lightweight structural applications because of low specific weight, high stiffness and high energy absorbing capacity.

One class of the porous metals, lotus-type porous metals possess long cylindrical gas pores aligned in one direction. These have superior mechanical properties originating from unidirectional pores compared with other porous metals with isotropic and spherical pores[3], so that they are attracting attention as new light-weight structural materials.

In many fields of industry such as aircrafts and automobiles, aluminum and its alloys have been developed to be used as structural materials which have good advantages such as light weight and corrosion resistance. If the aluminum and its alloy with the lotus-type structure can be fabricated, light weight structural applications become possible. However, it is difficult to fabricate lotus-type porous aluminum with high porosity utilizing hydrogen gas solubility gap between solid and liquid, since the solubility of the aluminum is small[4]. In order to fabricate the lotus-type porous aluminum with a higher porosity, the new fabrication technique is necessary.

Recently, Nakajima and Ide[5] developed a new fabrication technique using a thermal decomposition method (TDM) of compounds containing gas elements in a non-hydrogen atmosphere under nearly atmospheric pressure. They reported that the metallic oxide particle formed by the thermal decomposition of the compound may serve as the nucleation sites for the hydrogen pores in the solid/liquid interface during unidirectional solidification. It is expected that the pore size and
porosity become homogeneous by uniformly distributed nucleation sites. Thus, the TDM is expected to the new fabrication of the lotus-type porous aluminum.

In this study, we fabricated the lotus-type porous aluminum using the thermal decomposition of magnesium hydroxide in order to investigate an effect of the magnesium hydroxide on the porosity and the pore morphology.

2. Experimental procedure

The mold casting apparatus for lotus-type porous aluminum used in this study is shown in figure 1, which consists of melting in the upper part and casting in the lower part. Pure aluminum (99.99%) of about 80 g was melted in a graphite crucible by an induction heating coil in vacuum. The bottom of the mold was copper plate cooled down by circulated water chiller, while the side wall was made of a stainless steel sheet of 0.1 mm in thickness to avoid solidification from the side surface. Magnesium hydroxide was usually wrapped with aluminum foils and was set on the bottom plate of the mold.

The temperature of the liquid in the graphite crucible was monitored by an infrared pyrometer (model IR-AP, Chino Co.). After pouring the molten aluminum at 1173 K in the crucible into the mold, hydrogen decomposed from magnesium hydroxide dissolves in the melt, which is then solidified so that insoluble hydrogen precipitates to evolve the hydrogen pores. Amount of magnesium hydroxide was added from 0.1 g to 0.4 g. The experiments were carried out 3 times for each mass condition.

The fabricated lotus-type porous aluminum was cut using a spark-erosion wire cutting machine (Model LN1W, Sodick Co.) in directions parallel and perpendicular to the solidification direction. Each cross-section was polished with a series of emery papers and was observed using an optical microscope. The pore diameter was measured in the cross-section perpendicular to the solidification by image analyzer (Win ROOF, Mitani Co.). The porosity ($p$) was evaluated from the following expression:

$$p \, (\%) = \left(1 - \frac{\text{Apparent density of porous aluminum}}{\text{Density of nonporous aluminum}}\right) \times 100 \quad (1)$$

The apparent density of the individual specimen was calculated by measuring both the weight and the apparent volume of each sample.
3. Results and discussions

Figure 2 shows the cross-sectional views of the lotus-type porous aluminum fabricated by the mold casting technique in the mass range of the magnesium hydroxide from 0.1 to 0.4 g in vacuum. The upper and lower views are parallel and perpendicular to the solidification direction, respectively. The pores are aligned in one direction parallel to the solidification direction, and the number of the pores seems to increase generally with an increase in the amount of magnesium hydroxide.

The porosity measured in each sample are shown in Figure 3. The porosity increases with increasing amount of magnesium hydroxide. On the other hand, the variation of the porosity decreases with an increase in the amount of magnesium hydroxide.

Figure 4 shows the average pore diameter of the lotus-type porous aluminum fabricated in the mass range of the magnesium hydroxide from 0.1 to 0.4 g. Although the average pore diameter has large
standard deviations, the pore size is not varied so much. The results on both the porosity and the average pore diameter in the lotus-type porous aluminum fabricated through the thermal decomposition of magnesium hydroxide are in good agreement with that in the lotus-type porous copper fabricated through the thermal decomposition of titanium hydride reported by Nakajima and Ide[5].

The porosity in the lotus-type porous metals mainly depends on the amount of the insoluble hydrogen rejected from the solid during unidirectional solidification[3,6]. Since the hydrogen dissolved in the liquid aluminum through the thermal decomposition of magnesium hydroxide increases with an increase in the amount of magnesium hydroxide, the porosity also increases because the amount of the insoluble hydrogen rejected from the solid during the solidification process increases. On the other hand, it is reported that the pore size in the lotus-type porous metals is affected by the undercooling during the solidification process, which can be controlled by the solidification velocity[3,5,6]. Because the solidification velocity is almost same in present study, the average pore diameter is not varied so much and independent of the amount of magnesium hydroxide. In addition, the increased insoluble hydrogen caused by the increase in added magnesium hydroxide is easy to form the pores at magnesia, which may serves as nucleation sites for insoluble hydrogen. Hence, it is considered that the number of the pores increases with increasing amount of magnesium hydroxide.

4. Conclusions
The lotus-type porous aluminum with the longitudinal cylindrical pores aligned in one direction was fabricated by the unidirectional solidification through thermal decomposition of magnesium hydroxide in a vacuum.

The hydrogen dissolved in the aluminum melt through thermal decomposition of magnesium hydroxide evolves the pores at the magnesia formed by the thermal decomposition of magnesium hydroxide in the melt, which may serves as nucleation sites for insoluble hydrogen. Therefore, when the amount of magnesium hydroxide increases, the porosity and the number of the pores increase. The average pore diameter is not varied so much and almost independent of the amount of magnesium hydroxide.

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