Fabrication of lotus-type porous magnesium through thermal decomposition of magnesium hydride

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Abstract. Lotus-type porous magnesium was fabricated through thermal decomposition of MgH₂ powders as a source of hydrogen. Liquid magnesium was cast into a mold in which MgH₂ powders were placed and solidified unidirectionally in the mold, which achieved the growth of unidirectional elongated pores in magnesium matrix. The fabrication method is safer than a conventional method using pressurized hydrogen atmosphere, because the risk of explosion can be avoidable. The effect of the amount of MgH₂ powders and the distance from the bottom of the ingot on the porous structure was investigated, which clarified that the two factors have the large influence on the pore growth.

1. Introduction
Lotus-type porous metals with cylindrical pores oriented in one direction [1,2], gather much interest because of their unique anisotropic pore structure. Since stress concentration hardly occurs for loadings along the longitudinal direction of the pores, the mechanical strength in the longitudinal direction is superior to that of conventional porous metals with isotropic pores[3,4]. Furthermore, the unique structure provides various functions such as energy absorption and sound absorption[1]. Therefore, lotus metals are expected to be used as light-weight structural materials with various functions.

A lotus metal can be fabricated through unidirectional solidification of a metal in pressurized hydrogen atmosphere, when hydrogen solubility gap between the liquid and solid exists in equilibrium state [1,2]. When the liquid metal is solidified unidirectionally, a part of the hydrogen dissolved in the liquid is rejected at the solid-liquid interface owing to the hydrogen solubility gap. Then, the rejected hydrogen forms pores, and the pores grow unidirectionally along the solidification direction. In this method, pressurized hydrogen gas is indispensable for hydrogen to be dissolved in liquid metal. Thus, the method is called as “pressurized gas method”.

Recently, Nakajima and Ide developed a new method for fabricating lotus metals without using pressurized hydrogen gas[5]. The fabrication method, so-called “thermal decomposition method”, uses hydrogen thermally decomposed from compounds in place of pressurized hydrogen gas for hydrogen to be dissolved in liquid metal. Since pressurized inflammable hydrogen gas is not used in the thermal decomposition method, the fabrication process is safe and the production cost is much lower than that of the conventional method. Therefore, the thermal decomposition method is expected to promote practical applications of lotus metals.
In the present study, lotus magnesium was fabricated with the thermal decomposition method using MgH₂ powders as the hydrogen source, and the effects of the amount of the MgH₂ powders and the distance from the bottom of the ingot on the porous structure were investigated.

2. Experimental procedure

The apparatus for fabricating lotus magnesium consists of a crucible surrounded by a high-frequency induction coil and a cylindrical mold, which are installed in a chamber. The side wall of the mold is made of a stainless steel sheet of 0.10 mm in thickness, and the bottom of the mold is made of a water-cooled copper. The MgH₂ powders (98 mass%) of 0.2, 0.4, or 0.6 g were placed on the bottom of the mold; the diameter of the powders is about 10 - 100 µm. The MgH₂ powders whose onset temperature for decomposition is lower than that of TiH₂ powders were used, because pores were not formed owing to the insufficient decomposition when TiH₂ powders were used. The chamber was filled with argon gas of 0.10 MPa. Pure magnesium (99.9 mass%) of 50 g was melted by induction heating inside the crucible. Then, the melt was poured into the mold. The melt was solidified unidirectionally because only the bottom of the mold was cooled and the lateral side of the mold was made of thin stainless steel sheet which has a small cooling capacity.

The solidified ingots were cut out by a spark erosion cutting machine, and the cross sections parallel and perpendicular to the solidification direction were observed. The porosity, average pore diameter and number density of pores on cross sections perpendicular to the solidification direction was measured by an image analyzer (WinRoof, Mitani Corp.)

3. Results and discussion

Figure 1 shows the pore structures of cross sections of prepared ingots for \( M = 0.6 \) g, where \( M \) is the mass of used MgH₂ powders. The cross sections are (a) parallel and (b) perpendicular to the solidification direction. Cylindrical pores oriented along the solidification direction were formed in the ingots, which was similar among the ingots prepared for \( M = 0.2, 0.4, \) and \( 0.6 \) g. It is confirmed from this result that lotus-type porous magnesium can be fabricated with the thermal decomposition method using MgH₂ powders.

![Figure 1](image_url)

**Figure 1.** Porous structures of lotus magnesium prepared by thermal decomposition method using MgH₂ powders of 0.6 g. (a) Cross section parallel to the solidification direction. (b) Cross section perpendicular to the solidification direction, where the distance between the cross section and the bottom of the ingot is 25 mm.

In the present thermal decomposition method, a way for supplying melt with hydrogen is different from that in a conventional pressurized gas method. In the present thermal decomposition method, MgH₂ powders are heated by melt poured into the mold. Then, hydrogen is thermally decomposed from the MgH₂ powders. The decomposed hydrogen is dissolved in the melt, while pressurized
hydrogen gas in a chamber is dissolved in the melt in the pressurized gas method. The formation of pores from the melt containing hydrogen is similar between the two methods; in the thermal decomposition method, pores elongated along the solidification directions forms during unidirectional solidification owing to the hydrogen solubility gap between the liquid and solid.

![Figure 2](image1)

**Figure 2.** (a) Porosity $p$ and (b) average pore diameter $d_{\text{Ave}}$ of lotus magnesium as a function of a distance from the bottom of the ingot, $L$.

![Figure 3](image2)

**Figure 3.** Number density of pores $N_{\text{pore}}$ of lotus magnesium as a function of a distance from the bottom of the ingot, $L$.

Figure 2 (a) shows the porosity $p$ of lotus magnesium as a function of a distance from the bottom of the ingot, $L$. The porosity increases with increasing $L$ for $M = 0.2$ and $0.4$ g, while the porosity for $M = 0.6$ g hardly increases with increasing $L$. This is because the hydrogen dissolved in liquid, which determines the porosity, is almost saturated at the beginning of the solidification for $M = 0.6$ g. Figure 2 (b) shows the average pore diameter $d_{\text{Ave}}$ of lotus magnesium as a function of a distance from the
bottom of the ingot, $L$. Average pore diameter $d_{\text{Ave}}$ increases with increasing $L$. The rate of the increase in $d_{\text{Ave}}$ with regard to $L$ decreases with increasing $M$. Therefore, $d_{\text{Ave}}$ for $M = 0.6$ g is the smallest when $L = 15 - 25$ mm, while $d_{\text{Ave}}$ is almost independent of $M$ when $L = 5$ and 10 mm.

The number density of pores $N_{\text{pore}}$ increases with increasing $M$ as shown in Fig. 3. Since the hydrogen rejected at the solid-liquid interface increases with increasing $M$, the nucleation site of pores (number density of pores) increases with increasing $M$. The number density of pores $N_{\text{pore}}$ decreases with increasing $L$ for all $M$ values. This is probably caused by the coalescence of small pores formed near the bottom of the ingots into a large pore with advancing pore growth, which occurs to decrease the interface energy between pores and liquid metal. When $M$ is small ($M = 0.2$ g), it is probable that pores cannot easily coalesce, i.e., the single pore growth is dominant. In this case, an increase in porosity causes an increase in average pore diameter. Therefore, an increase in porosity with increasing $L$ provides an steep increase in $d_{\text{Ave}}$ with increasing $L$. On the other hand, when $M$ is large ($M = 0.6$ g), it is probable that the coalescence of pores is dominant when the distance $L$ is small (near the bottom of the ingot). When the distance $L$ is large, a steady state condition for pore growth is probably achieved. Therefore, the rate of the increase in $d_{\text{Ave}}$ with increasing $L$ is almost saturated for large $L$; the porosity and number density of pores are also saturated for large $L$.

4. Conclusions
Lotus-type porous magnesium with cylindrical pores oriented in one direction was fabricated with a thermal decomposition method using MgH$_2$ powders as a compound which provides hydrogen. Liquid magnesium was cast into a mold in which MgH$_2$ powders were placed and unidirectionally solidified, which achieved the growth of pores elongated along the solidification direction.

The effect of the mass of MgH$_2$ and distance from the bottom of the ingot on the porous structure was investigated, which clarified that the two factors have the large influence on the porosity, average pore diameter, and number density of pores. The coalescence of pores during pore growth probably affects the change in the porous structure during unidirectional solidification.

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