Available online at www.sciencedirect.com

ScienceDirect

Journal of Magnesium and Alloys 4 (2016) 1–7
www.elsevier.com/journals/journal-of-magnesium-and-alloys/2213-9567

Full Length Article

# Effect of fluidity on the manufacturing of open cell magnesium alloy foams

Xue-Zheng Yue [a,*], Koichi Kitazono [a], Xue-Jie Yue [b], Bo-Young Hur [c]

[a] Graduate School of System Design, Tokyo Metropolitan University, Tokyo 191-0065, Japan
[b] Department of Architectural Engineering, Xinxiang University, Xinxiang 453000, China
[c] Gyeongsang National University, 501, Jinju-daero, Jinju, Gyeongnam, Republic of Korea

Received 11 July 2015; revised 24 November 2015; accepted 25 November 2015

Available online 28 December 2015

**Abstract**

The effect of fluidity on open cell AZ31 metal foam samples fabricated using a solid state space holder method was investigated. Granule was fabricated by plaster powder and perlite powder. Granules were sieved which compacted layer by layer in casting mold. Preforms which made by granules were then heated to 200 °C, 300 °C, 400 °C, 500 °C under a rough (mechanical) vacuum before pressure infiltration with AZ31 Mg alloy. Samples were infiltrated using vacuum pressure values range of 8–14 KPa. The conditions of pressure and temperature were performed in order to get different fluidity on manufacturer of open cell AZ31 metal foam specimen quantity. It is found that the fluidity plays significant role to determine the open cell AZ31 alloy foam. The fluidity is affected by preheat temperature and infiltration vacuum pressure. The macrostructure, the distribution of the pores, microstructure, infiltration length, and porosity were investigated.


*Keywords:* Magnesium alloy; Fluidity; Open cell; Vacuum

## 1. Introduction

Recently, metallic foams (especially for Mg/Mg alloy foams) have attracted more and more attention, as they can be used as structural and functional materials due to their unique properties [1]. The casting of metals and alloys around a filler material has recently attracted a lot of interest, because it is potentially a very economical way to create cellular structures of a wide range of metals and porosities. The filler material can either consist of low-density materials that remain in the material (foamed glass, hollow ceramic or metallic microspheres) or it can consist of compact materials that are removed after the casting process. Metal sponges formed in this latter way are of open porosity and can be functionally used as catalysts, heat exchangers or coolers [2–5].

Jinnapat and Kennedy studied on open cell Al foams made by infiltration molten Al into porous salt [6]. Grohn and Hintz investigated the determination of parameters of infiltrated metallic foam composites. The open cell structure reticulated polyurethane foams were used [7]. Osorio-Hernández et al. researched for manufacturing of open-cell pure Mg foams by replication process and mechanical properties [8]. Fluidity is an important factor for the successful and steady production of castings, and yet the study on the fluidity of open cell AZ31 Mg alloy foam is rarely reported in the world [9].

In the present work, infiltration processing offers a versatile and economical route to the production of open cell AZ31 Mg foams, where simple equipment is used and net shape can be obtained. Granule was fabricated by plaster powder and perlite powder. Granules were sieved which compacted layer by layer in casting mold. The size of granule determines pore sizes of metal foam and relative density. These foams have homogeneous open-porosity, and cell sizes were equivalent to the granule size of the precursor (1.70 mm Ø). Replication processing applied to the production of Magnesium foams consists in infiltrating an open pore bed of bonded granule particles with molten metal and then leaching the granules in water after solidification of the matrix. The inertia gas was adopted to prevent explosion and combustion in pouring. Molten

* Corresponding author. Graduate School of System Design, Tokyo Metropolitan University, Tokyo 191-0065, Japan. Tel.: +8107015818880; fax: +8107015818880.

*E-mail address:* yzyz87222@gmail.com (X.-Z. Yue).

http://dx.doi.org/10.1016/j.jma.2015.11.007

Fig. 1. The open cell AZ31 Mg alloy foam specimen with 1.70 mm Ø (30 mm*30 mm*30 mm).

Magnesium does not spontaneously penetrate open pores in granule, such that only coarse foams can be produced with conventional vacuum-assisted gravity casting [10–12].

Effect of preheat temperature of preforms and seepage pressures were theoretically analyzed and determined on the casting process. Open cell AZ31 Mg alloy was investigated for compression deformation behavior and energy absorption property. The good fluidity and castability were investigated for the longest infiltration length, less defects and uniform pore structure. The results showed that as increased of the preheat temperature and the seepage pressures, the fluidity was increased in a certain extent; however, there were some defects on the foam structure at the high seepage pressure [13,14].

Representative samples of the open-cell AZ31 Mg foams with 30 mm*30 mm*30 mm size are shown in Fig. 1. In this image, it can be observed that the sample has a homogeneous distribution of the spherical pores with equivalent cell size to granule. The corresponding stereo micrographs of open-cell Mg foams are shown in Fig. 5, which demonstrates that all samples show open cell structures with interconnected pores.

## 2. Experience

AZ31 Mg alloy ingot was used as a basic metal. The chemical compositions of the AZ31 alloy are listed in Table 1.

Table 1
Chemical compositions of AZ31 Mg alloy ingot (%).

| Element | Al | Zn | Mn | Si | Cu | Fe | Mg |
|---|---|---|---|---|---|---|---|
| AZ31 | 3.49 | 0.82 | 0.41 | 0.07 | 0.08 | 0.06 | Bal |

### 2.1. Manufacturing process

1. Preparation of the porous leachable bead preforms: Some same sizes of granules were arranged in the granule mold by sieving process. The pore's shapes were predominantly controlled by the initial shape of the space-holder granules that were used to produce the preforms. Pores of the resulting foam "replicate" the initial shape of these space-holder granules.
2. Melting: A definite quantity of AZ31 Mg alloy was melted in a steel crucible in the upper furnace. The melting temperature was set at 750 °C. The melting time is 2 hours.
3. Infiltration of molten metal into the porous preforms: A range of pressures impact on the infiltration length for the open cell foam Mg alloy. In casting process, the low infiltration pressure is not enough to fill the porous preforms, the high infiltration pressures will crush the granules or can be not formed integrally and uniform, impacting on the quality of the open cell foam magnesium, with increase the difficulty level of the operating process. The whole fabrication process is operated under the mixed gas atmosphere of $CO_2$ and $SF_6$ (volume ratio: 6:1) to prevent the melt from ignition.
4. Solidification of the molten metal: At room temperature 24 °C, the cooling water was used into copper tube. The copper tube was rolled in part of the mold tube for cooling. After 30 mins, the casting was took out from the mold. Finally, metal/granules composite can be obtained.
5. Dissolution of the preforms in a hot water: The ultrasonic machine was used with 100 °C water for 6 hours. The open-cell Mg alloy foam has been fabricated successfully by removing the preform granules. The set of fabrication apparatus for making AZ31 open cell Mg alloy foam mainly consists of two resistance furnaces – one furnace is melting the magnesium alloy, another furnace is preheating the granule mold, a steel crucible and a stopper in the upper furnace which is the switch for the molten Mg alloy into the bottom furnace. A gas system supplies the inert gas to the upper furnace and the lower furnace as shown in Fig. 2.

### 2.2. Infiltration pressure analysis

It may be stated in several different forms depending on the flow conditions. The more widely used macroscopically approach relies on the work [15], who described the permeability of sand columns to a water flow. This first gradient law writes:

$$Q = \kappa \frac{A}{\eta} \frac{\Delta \hat{P}}{\Delta L} \quad (1)$$

where $Q$ is the fluid flux ($m^3\ s^{-1}$), $\Delta \hat{P}$ is the pressure (hydraulic head) differential in the flow (Pa), $\Delta L$ is the flow length (m), $\eta$ is the fluid dynamical viscosity (Pa·s), $A$ is the area normal to the flow ($m^2$), and $k$ is the porous medium permeability ($m^2$). It shows that the volumetric flow rate is a function of the flow area, elevation, fluid pressure and proportionality constant.