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Research Paper

A replication-casting device for manufacturing open-cell Mg foams

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ABSTRACT

The development of a replication casting device with the capability of manufacturing open-cell pure Mg and Mg alloys foams, with melting points lower than 950 °C is described. The device consists of three basic parts: a cylindrical reaction chamber, a valve system for controlling the vacuum and the gas injection, and a heating system. The purpose of the present design was to improve the existing laboratory-scale devices, making them simpler than those reported in the literature, as well as to optimize the parameters (atmosphere, temperature, injection pressure, etc.) of the replication casting process. The proposed device has shown significant improvement over other devices reported, especially in terms of easiness of operation, adjustability and low cost of maintenance. The design of the device provides the ability to produce large foams free from defects such as large volumetric shrinkage and large concavities. The latter is minimized by the implementation of a perforated nozzle for gas impulsion. Examples of manufactured open-cell pure Mg and Mg–10 wt.% Al alloy foams are also presented. The design is shown in a conceptual format; however it could be modified to produce larger or smaller samples.

1. Introduction

Porous metal structures, also known as metallic foams, have shown a combination of physical and mechanical properties such as high strength-to-weight ratio, high energy absorption capacity, large specific surface, high gas and liquid permeability and low thermal conductivity as has been reported by Baumgartner and Gers, 1999. As mentioned Banhart (2001), metallic foams with open-cells are mainly used in functional applications (heat exchangers, filters, catalysis supports), while the metallic foams with partially open and closed cells are used in structural applications (bio-medical implants, silencers, bearings, sound, energy absorbers, etc.).

As pointed by Ashby et al. (2000), pure aluminum (Al) and Al based alloys foams have been widely manufactured by several techniques. In contrast, little attention has been paid to developing pure Mg and Mg alloys foams, due to the high production costs and the difficulty of processing them. Mg foams have been mainly studied for their functional properties such sound and energy absorption capacity, excellent vibration reduction capacity. Wen et al. (2001) found that Mg foams were promising biomaterial for bone implants due to its open-cellular structure promote the in-growths of the new-bone tissues and the transport of the body fluids.

Some methods have been used to manufacture closed-cellular pure Mg and Mg alloys foams. Körner et al. (2004) proposed a method where combined high pressure casting using a thixomoulding machine in a cavity to add and disperse MgH_2 particles as foaming agent. Renger and Kaufmann (2005) obtained Mg foams using a technique called vacuum foaming method. Later, Yang et al. (2008) obtained a Mg foam by melt-foaming method, also known as blowing agent method, using $CaCO_2$ powders as foaming agent and a mixed of CO_2 and SF_6 atmosphere to protect Mg alloy from being ignited or oxidized during the process. On the other hand, the manufacture of the open-cell pure Mg and Mg alloys foams has been limited to the powder metallurgical method and replication casting process. Hao et al. (2009) obtained pure Mg foams by four stages powder metallurgy manufacturing process including mixing, compacting, dissolution and sintering. The space holding filler used was commercially carbamide particles with a rounded shape. Later, Aghion and Perez (2014) produced MRI 201S Mg alloy foams using Ammonium Hydrogen Carbonate salt particles as a space holding filler. Both works used high purity argon atmosphere as

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a protective gas. In contrast, as (San Marchi and Mortensen, 2002) mentioned, the replication casting process offers the possibility to produce open-cell foams with high control of the topology. However, the manufacture of open-cell pure Mg foams by the replication casting method is still limited.

The replication casting process was first proposed by Polonsky et al. (1961). According to Polonsky this method is able to produce an interconnected open-cell structure by infiltrating the molten metal under pressure through an open pore preform (or negative of the foam) made from granular particles. This step is followed by the dissolution of the particles using an adequate solvent. However, it was until 2001 when (San Marchi and Mortensen, 2001) retook this method to produce open-cell aluminum foam. The main parameters for the replication casting process are: 1) the infiltration pressure, 2) the melting temperature of the metal charge and 3) the design of the preform (material, size, solubility, etc.). The possibility of controlling these parameters with different mechanisms, the physic-chemical properties of the metal foams and the design of the preforms are factors that have led to develop a variety of devices.

The infiltration can be made by a mechanical mechanism or using gas pressure. Fabrizio et al. (2011) obtained an Al-Si-Mg foam using a hydraulic cylinder to generate the infiltration pressure. On the other hand, San Marchi and Mortensen (2001) used a hot-wall gas-pressure infiltration apparatus to produce the same type of foams.

In relation to the preforms, these are commonly manufactured with sodium chloride (NaCl) due to their heat resistance and water solubility. As Gaillard et al. (2004) mentioned, in the foams that are produced by the replication process, the initial shape of the leachable powder that was used to produce the infiltrated preform, predominantly controls the pore shape. As a consequence, the powder shape influences significantly the strain at which the foam stress–strain curve deviates from power-law behaviour. However, most of the devices used for replication casting process are limited to produce small foams constituted by not-reactive metals such as Al and Al alloys, Zn and Zn alloys, among others. The replication casting technique has not been extensively used for manufacturing pure Mg foams, due its reactivity with oxygen in liquid state and with the material of the preforms (NaCl) during leaching stage.

The above mentioned limitations open up the possibility of designing new practical devices for the replication casting process with optimal control of the parameters (atmosphere, injection pressure, temperature, etc.) that allow the manufacture of pure Mg and Mg alloys foams and other metallic foams. Therefore, the objective of this project is to manufacture a practical replication casting device for obtaining pure Mg foams, Mg alloys foams and other metallic foams with melting points lower than 950 °C, with optimum control of the process parameters. The design of the device allows producing samples with sizes up to 8.8 cm in diameter and 14 cm height, with the possibility of increasing or decreasing this geometry. With this replication-casting device, pure Mg foams and Mg alloys foams free from cavities and volumetric shrinkage defects can be obtained.

Fig. 1. Replication casting device: (a) steel reaction chamber sealed with two covers, (b) valve system and (c) heating system (furnace).

2. Description of the infiltration device

Fig. 1 shows the complete replication-casting device. The replication-casting device is conformed by three basic parts: First, a *reaction chamber* (a), followed by a *valve system* (b) for controlling the chamber pressure (i.e. vacuum or partial pressure) and gas injection for infiltration, and finally, a *heating system* (c). The heating chamber consists in an electrical resistance furnace with vertical chamber; this could be part of the device or could be external. In the following sections the design of the parts and operation of the replication-casting device will be described in detail.

2.1. Reaction chamber

In the reaction chamber the casting and infiltration process takes place. As can be observed in Fig. 2a, the chamber is composed by a hollow cylinder (1) and two covers (2–3). These parts are made of stainless steel 316. The stainless steel 316 is considered as the