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A method for manufacturing cellular metals with open- and close-type porosities

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ABSTRACT

New approach for manufacturing metallic cellular materials with controlled open pore geometry and cells arrangement is presented. The method is based on the combination of rapid prototyping of a template with powder metallurgy. Modification of the procedure allows for additional introduction of closed-type porosity with pores smaller than those defined by the rapid prototyped template. The accuracy of the method for controlling the size, shape and arrangement of open-type pores is presented on the example of zinc with an inorganic template ($CuSO_4$). The same materials are used to produce a structure with two types of porosities combined in one structure, regular opened and irregular closed. The control of pore geometry allows for optimization of metallic cellular materials for their mechanical, chemical and biological applications.

1. Introduction

Metallic foams and cellular metallic materials present a relatively new type of engineering materials, being of high interest due to their particular properties that allow a wide range of applications. Whereas manufacturing cellular metals does not require melting, metallic foams are a dispersion of gas bubbles obtained in a liquid metal followed by solidification [1].

Depending on the type of porosity, which can be opened, partially opened or closed, the applications are more functional, taking advantage from the increased surface area, or more structural, taking advantage from the metallic matrix. The most common application fields include heat exchangers, filters, catalysts supports, bearings, silencers, sound absorbers, biomedical implants, load-bearing components and energy absorbers. The type and volume of porosity are typically determined by the fabrication and/or processing method [1,2], which motivates the search for better process control.

The currently available production methods are classified according to the state in which the metal is processed (solid, liquid or vapor) [1], most of them, still being under development with efforts focused on better understanding and control of the production parameters as well as the resulting material properties [3–5]. Despite of the intense research, none of the currently available production methods allows an accurate control of pore geometry and arrangement [6]. For instance, in foaming through the powder metallurgical route (PM) the obtained pore size is a result of a metastable equilibrium between the pressure of gas evolution and surface tension of the liquefied metal [7–11], which makes it practically impossible to obtain two identical pieces. Another example is the sintering and dissolution method where the porosity is determined by the shape and size of the leached template. Due to the random distribution of the template the obtained pore geometries cannot be fully controlled [12–15].

In this paper we present a new method for manufacturing metallic cellular structures with controlled pore geometry and cell arrangement that is obtained by combining rapid prototyping with powder metallurgy. Unlike the direct laser rapid prototyping of metal alloys [16] the method does not require a dedicated equipment and the desired structure is obtained by removal of a rapid prototyped template, which in principle, can be any material.

2. Experimental procedure

The fabrication starts with the computational design of the desired porosity using 3D Studio Max(Autodesk) software. In our example, cylindrical tubes of 18 mm diameter and 28 mm height are produced. The desired porosity is formed by perfectly arranged spheres of 3 mm, 3.5 mm and 4 mm diameter, respectively as shown in Fig. 1A. The template structures are then printed in calcium sulfate ($CaSO_4$, average particle size 34 μm, Z Corp, ZP131) using a Z Corporation Spectrum 510 3DP unit with interlayer thickness of 0.089 mm and a 600×540 dpi in plane resolution. The resulting 3D replica of the aimed pore structure is subsequently filled with a suspension of zinc powder with particle sizes 1–4 μm, irregular shape (Fig. 1B). The liquid phase of the suspension is a volatile solvent (xylene) of low surface tension (~30 mN/m at 20 °C) which facilitates the infiltration of the complex void of the template. The degree of compaction of the metal particles in the $CaSO_4$ cast determines whether the produced matrix is fully compact or it develops its own porosity resulting in a two-level structure (hierarchical porosity).

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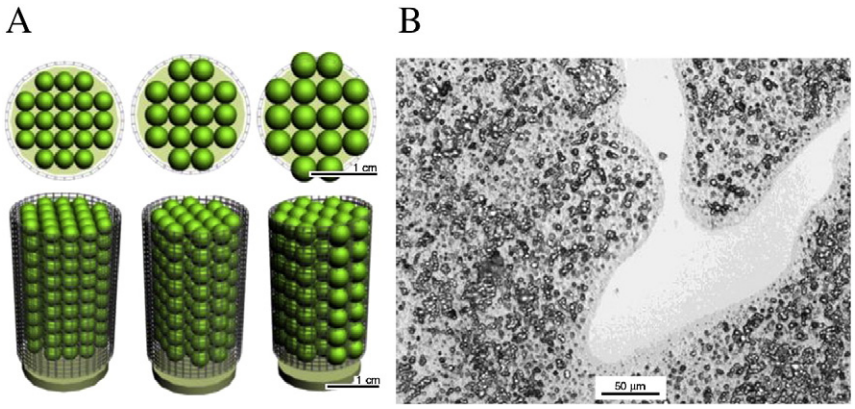

Fig. 1. A) Replica of spherical open pore geometry designed for rapid prototyping; B) zinc particle suspension seen in optical microscope.

2.1. Structure with regular single opened porosity

The zinc suspension is cast into the $CaSO_4$ template and left to dry for 12 h. The sample is then placed in a furnace chamber and once a pressure of 10^{-1} Torr is reached, nitrogen gas is introduced at the pressure of 1.5 atm and heat treatment realized at 380 °C (48 °C below the melting point) for 2 h (heating rate of 22 °C/min). After cooling, the inorganic template is removed from the composite using a directed air blow (erosion by compressed air blown through a nozzle). This process is realized at room temperature and is possible because cohesion of the template weakens significantly during the heat treatment as the organic additives are pyrolized.

2.2. Structure with combined porosities (opened and closed)

In order to introduce the second porosity, the metal/inorganic composite, instead of drying in air, is heat treated at 100 °C (heating rate of 65 °C/min) for 5 min. In this process, evaporation of the solvent creates internal pressure, forcing re-arrangement of the metallic particles and producing internal porosity. Since the individual gas bubbles do not share a common space, the resulting porosity is of a closed type. The composite is then heat treated and the template removed as describe in Section 2.1.

2.3. Characterization

The obtained samples were characterized with respect to their pore structure and density. The structure is analyzed in transversal and longitudinal sections, whereas the density is determined using the mass–volume formula. Analysis of the closed irregular porosity is conducted by means of image analysis (ImageJ) using photographs of sections. The pores are quantified according to their apparent area on brightness filtered gray-scale data.

3. Results and discussion

The densities obtained for all samples are presented in Fig. 2A. The density decreases as a function of increasing sphere sizes for both

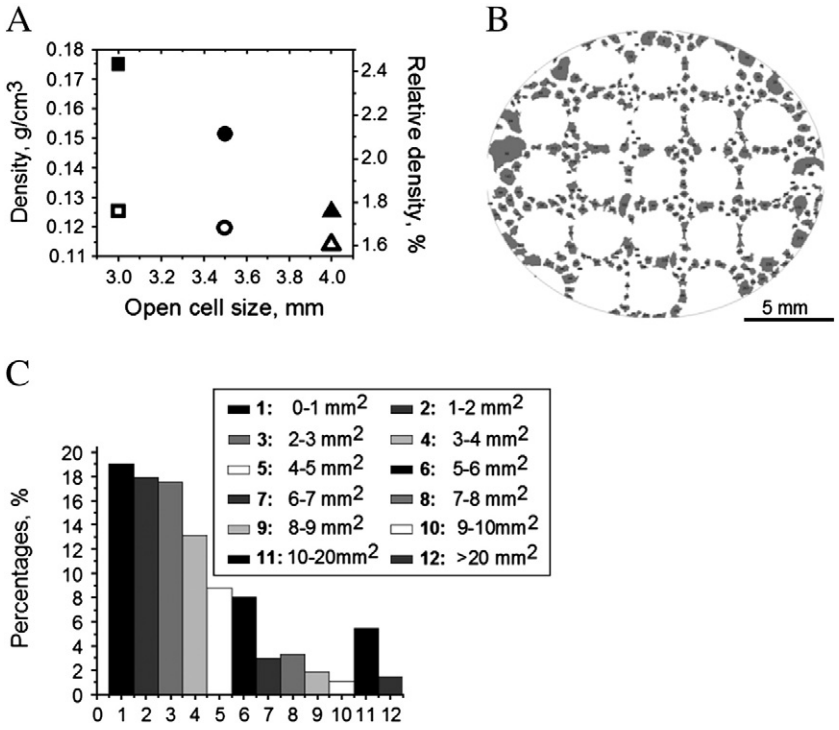

Fig. 2. A) Density as function of the template's cell size (open symbols—structures with opened porosities, closed symbols—structures with combined opened and closed porosities); B) Closed porosity discriminated by image analysis and C) the obtained pore size distribution for sample with open cell size of 3 mm.