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Scripta Materialia 54 (2006) 527–532
www.actamat-journals.com

Fabrication of aligned pores in aluminum by electrochemical dissolution of monotectic alloys solidified under a magnetic field

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Received 7 May 2005; received in revised form 3 October 2005; accepted 24 October 2005
Available online 21 November 2005

Abstract

Porous Al with regularly aligned deep pores was fabricated by producing Al–In monotectic alloys with a rod-aligned structure by solidification under a magnetic field and electrochemical dissolution of the rod phase. Pore diameter was also controlled from 1 to 20 μm by wire drawing.

Keywords: Solidification; X-ray computer tomography; Porous materials; Monotectic reaction; Magnetic field; Selective dissolution

1. Introduction

Porous media are classified into two types, isotropic and anisotropic porous media, in terms of pore shape. Powder metallurgy techniques [1–3] and a casting technique [4] have been developed to produce isotropic porous media. Meanwhile, for anisotropic porous media, the metal–gas reaction during solidification has been extensively studied for the fabrication of lotus-type porous media [5–12]. Coupled growth between the solid phase and gas phase occurs, and consequently, the gas phase is aligned like a minor phase during eutectic solidification [13]. The typical pore diameter for porous copper produced by the gas–metal reaction ranges from 50 to 100 μm [8]. From the viewpoint of various applications, the desired pore size ranges widely from nanometer size to millimeter size.

Fabrication of anisotropic porous media, with pore sizes of 5–20 μm, has been examined using monotectic solidification [14,15]. Recently, a static magnetic field was used to control the monotectic solidification of the Al–In system, and as a result, an aligned-rod structure was achieved even with monotectic compositions [15]. The In rods were removed by electrochemical dissolution and porous media were produced. It was also suggested that reduction of the solidified structure by plastic deformation could control pore diameter. Thus, pore size controlled by plastic deformation is also of interest. This paper describes the recent development of a process for the fabrication of porous media.

2. Production of porous media by monotectic solidification

It is known that regular structures can be produced by unidirectional solidification of monotectic alloys [16–18]. In monotectic systems, this regular structure possesses

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doi:10.1016/j.scriptamat.2005.10.059

some special features [15]. One is that with monotectic alloys the shape of the minor phase becomes cylindrical because it is liquid when the major phase solidifies. The other is that some monotectic alloys such as Al–In, Al–Bi and Cu–Pb are ductile.

The proposed fabrication process can be divided into three steps. The first involves formation of a regular structure by monotectic solidification. The second step is reduction of the regular structure by plastic deformation, the degree of which controls pore diameter. The third step is selective dissolution of the rod phase from the matrix by electrochemical etching.

In Al–In alloys, a regular structure is obtained only around a monotectic composition (Al–4.7at.%In) by conventional solidification [17]. The volume of the minor phase is only 5% with a monotectic composition (Al–4.7at.%In) [19]. Previously, a regular structure was obtained at Al–10at.%In by imposing a static magnetic field during unidirectional solidification. Thus, imposition of a magnetic field is a powerful tool, and extension of the composition range is also of interest. From the viewpoint of applications, it is also important to control the diameter of the pores.

3. Experiments

Mother alloys were made using 99.999% Al and 99.999% In. The specimens (4 mm in diameter and 100 mm in length) were unidirectionally solidified under a magnetic field of 0 or 10 T with the solidifying front maintained at the center of the magnetic field. The temperature gradient was approximately 2–3 × 10^4 K/m [20]. Details of the apparatus were reported previously [21].

The solidified structure was reduced by a wire drawing technique and subsequent drawings were performed using diamond dies. The specimens were not annealed in wire drawing procedures. The polarization curves of the Al–In alloys were measured in a standard three-electrode electrochemical cell. A 10% HNO_3 aqua solution was used for electrochemical dissolution [15]. The auxiliary electrode was a Pt plate, and the reference electrode was a saturated Ag/AgCl electrode. The In phase in the Al–In alloys was removed at a given constant potential.

Micro X-ray computerized tomography (μ-CT) in the beam line BL47XU of SPring8 [22] was used to confirm continuity of the rods and pores. The format of the transmitted images was 1000 × 1018 pixels and the effective pixel size was 0.5 μm × 0.5 μm.

4. Results and discussion

4.1. Unidirectional solidification of Al–In alloys

A previous study [15] showed that there was an optimum growth rate for production of a regular structure. Fig. 1 shows the solidified structure of the Al–10at.%In hypermonotectic alloys obtained. At a growth rate of

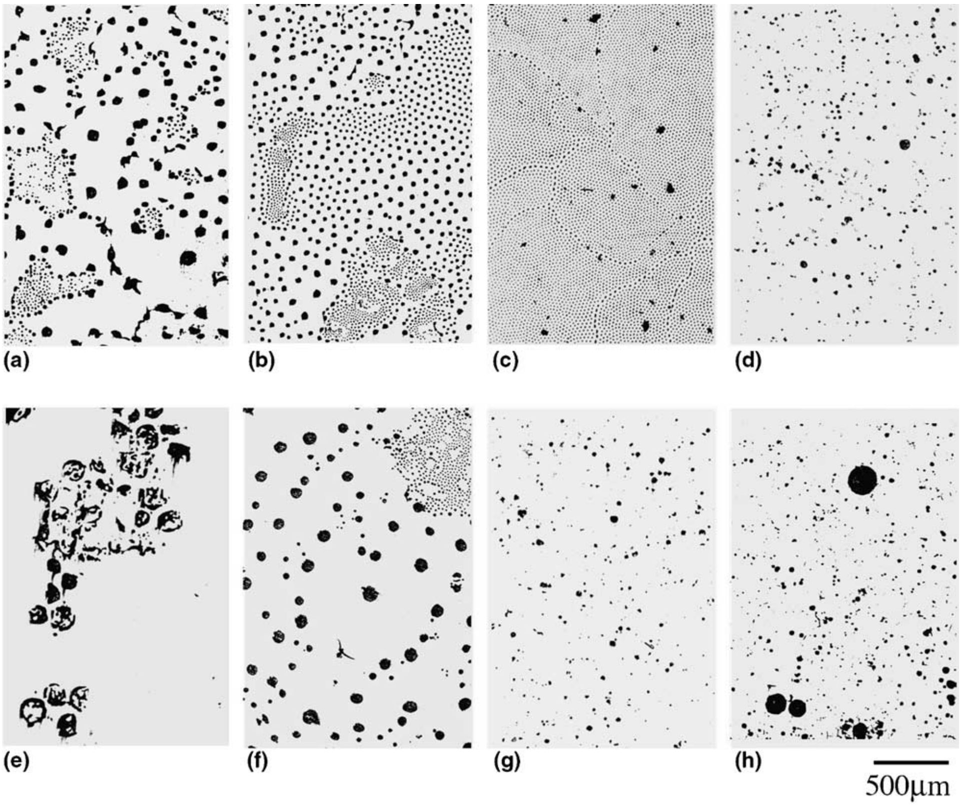

Fig. 1. Transverse sections of the unidirectionally solidified Al–In alloys. Growth rate and imposed magnetic field: (a) 0.56 μm/s, 10 T, (b) 1.36 μm/s, 10 T, (c) 2.7 μm/s, 10 T, (d) 6.0 μm/s, 10 T, (e) 0.56 μm/s, 0 T, (f) 1.36 μm/s, 0 T, (g) 2.7 μm/s, 0 T, (h) 6.0 μm/s, 0 T.