Contemporary Engineering Sciences, Vol. 8, 2015, no. 16, 723-727
HIKARI Ltd, www.m-hikari.com
http://dx.doi.org/10.12988/ces.2015.54137

Technological Processes of Obtaining of Replicated Aluminium Foam

S. P. Kazantsev and D. V. Husnullin

Ural Federal University, Mira Str. 19, 620002 Ekaterinburg, Russia

Abstract

A comparison of technological processes of replicated aluminium foam obtaining by two impregnation techniques (impregnation under high gas pressure of sintered NaCl powder and vacuum impregnation of loose NaCl powder) is performed. The typical ranges of porosity, minimum and maximum pore size, permeability characteristics obtained by alternative technologies are shown.

Keywords: replicated aluminium foam, impregnation, porosity, pore size, permeability

Introduction

The technological process of impregnation of the water-soluble filler (NaCl) with melt has been offered in Ref. [1], and the following parameters have been validated: use of aluminium casting alloys, preheating of the filler in the impregnation mold to the temperature close to the melt solidification one. The fact that structure of obtained product is largely a «reverse imprint» of filler carcass structure has determined the name of material.

Due to a poor wettability of NaCl with molten aluminum and its alloys, an additional pressure needs to be applied for impregnation, as a hydrostatic pressure of melt and large filler granule size (8-12 mesh, which corresponds to 1.5-2.5 mm fraction) in Ref. [1]. The obtained material was proposed to use as a construction material or to fill with fusible salts in order to apply in chemical apparatus. The expansion of application field of porous castings, particularly for gases and liquids

filtering, has required the use of smaller fractions of filler and its melt-impregnation under pressure in the mold, respectively [2].

The impregnation technology is universal and can be used to obtain porous castings of various alloys, which requires only appropriate filler selection [3]. But experience has shown that the only competitive metal to manufacture the porous castings according to this technology is aluminium because of its low cost and ease of filler (NaCl) dissolution.

Technological process

The main requirement to porous metals is a predictability of pore size. The porous metal obtained by impregnation technique has two distinct pore sizes: the size of cavities formed by filler granules with radius R, and the size of bottleneck of radius r between these cavities (see Figure 1). Only bottleneck between filler grains are possible to be controlled by the technological parameters of the process. There are several approaches to solve this problem.

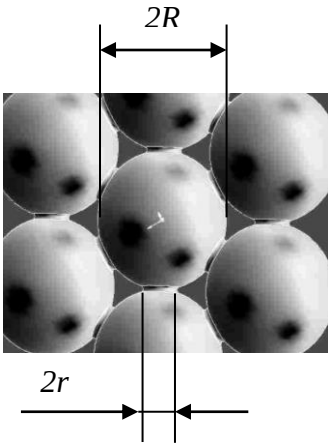

Fig.1. Porous structure

Scientific group of Professor Mortensen from Swiss Institute of Technology (Lausanne) has proposed to control the pore size by varying sintering time in the metallic mold or by cold isostatic pressing in elastic mold [4]. A high-pressure impregnation (up to 155 atmospheres) is used to exact match of pore space shape to filler carcass imprint.

Scientific group of Professor Furman from Ural Polytechnical Institute (Yekaterinburg) has suggested the initiating the impregnation process with vacuum suction of dispersed filler and separate furnace heating of the filler [5]. Unlike the technological process [4], the pores are not a mirror reflection of the filler carcass. Moreover, the very carcass does not exist, because there is no interconnection between the filler particles. The pores shape and size are determined by the physical-chemical interaction at the interface of two filler grains. The equation for determination of pore size in dependence of impregnation pressure has been derived in Reference [6], and is used for evaluation the finished product size (by calculation the permeability coefficient) on the manufacturer web-site [7].

The present work is devoted to investigation of differences in operational properties of porous casting aluminium obtained by techniques [4] and [5] on the base of Ph.D. theses of Jean-François Despois [8] (Professor Mortensen group) and Arcady Finkelstein [9] (Professor Furman group).

Porosity

Porosity is an essential characteristic of filters as it determines the service life. In case of sintering or cold isostatic pressing on the technology used by Swiss researchers, the filling porosity decreases with respective increase in the finished product porosity, which makes up 68-88%. However, the minimal pore size also

increases, which directly depends on porosity and is a function of process duration.

In the technology used by Russian researches, the porosity is not a function of pore size and is determined only by loose powder in the metallic mold. It makes up 47% and can be increased to 62% with the use of vibration and pressing, and 68% with the use of double-fraction powder.

Maximum pore size

The maximum pore size is limited by the filler fraction. The wetting angle of NaCl with aluminium casting alloys is 140º [9], and the impregnation initiation requires an additional pressure the value of which can be calculated with Laplace's Equation. The calculations with using the sphere model gives the maximum available filler fraction of 0,072 mm (for free filling) under filler evacuating [9], that corresponds to minimal fraction of 0.1-0.2 mm using in the manufacturing process. The high-pressure impregnation technique removes this limitation. However, the technical feasibility of reduction of filler grain size is small. As stated in Reference [8], in case of using filler of less than 50 microns fraction, a problem of casting corrosion during filler dissolution arises.

Minimum pore size

The minimum pore size determines the nominal degree of filtration and permeability coefficient.

The minimum size of pores during sintering process is a function of porosity. In Reference [8] the minimum pore size has not been evaluated or calculated, most probably due to laboriousness. However, its value can be calculated either from known dependencies for particles sintering using them as sphere model, or from dependencies proposed in Reference [5]. The minimum pore size makes up 30-45% of filler fraction size (with porosity of finished goods of 75-88%, respectively), and it can reach 20% with 68% porosity of finished goods. However, at this level of porosity the filler carcass strength becomes small that leads to defective goods in the production of castings.

In case of dispersed filler impregnation technique, the minimum pore size is a function of residual pressure in the air collar formed during impregnation at the interface of two filler grains [6]. The minimum pore size value in the finished product varies in the range of 12-35%. In contrast to filler sintering technique, the dispersed filler impregnation technique allows obtaining maximum ratio of pore size of 12% only by reducing the pressure in the vacuum-receiver. It should be noted, that effect of impregnation pressure on the minimum pore size was also observed for filler sintering technique. The formation of «metal fingers» under high impregnation pressure (up to 155 atmospheres) investigated in Reference [10] has been explained with capillary force overcoming at melt penetration into thin gaps between filler grains. However, the «metal fingers» are observed not only at the interface of filler grains that proves their formation due to mechanical fracture of filler carcass.

Permeability

The permeability used in the technique under consideration is an empirical coefficient in Darcy's equation which characterizes the rate of filtration. Prediction of permeability coefficient is required for calculation of filtration rate and size of filter elements. The permeability coefficient is a function of resistance of the limited section (the minimum pore size in porous metal casting) and it amount in the porous body [8, 9]

The permeability can be governed by technological parameters of the process: by sintering time in case of filler sintering technique or by evacuating pressure in case of dispersed filler impregnation technique. The calculated permeability for both abovementioned techniques are in a good agreement with the experimental data.

The calculation formula of permeability K through minimum pore radius r for vacuum impregnation technique is [9]:

$$K = \frac{(1-\Delta_0)N \cdot r^3}{6\pi R},$$

where N is the coordination number (number of filler grain contacts with other grains);

Δ_0 is the initial porosity of filler.

The calculation formula of permeability K through porosity for sintered filler impregnation technique is [8]:

$$K = \frac{\Delta R^2}{\pi}\left(\frac{\Delta-\Delta_0}{3(1-\Delta_0)}\right)^{3/2},$$

where Δ is the porosity of filler carcass after sintering.

Conclusions

The water-soluble filler impregnation technology of porous aluminium manufacture competes with powder metallurgy and foaming technologies. A sintered filler high-pressure impregnation technique allows obtaining goods with structure close to metallic foams, which defines a perspective field of application and main directions of research [8] (first of all the mechanical behavior), respectively.

A dispersed filler vacuum impregnation technique successfully competes with powder metallurgy primarily in field of filtration, providing not only a greater efficiency due to a significant ratio of minimum and maximum pore size, but a longer service life before cleaning due to a higher porosity.

References

[1] H.A. Kuchek, *Method of Producing Clad Porous Metal Articles*, Patent US 3138856, 1964

[2] Takashi Ichikawa, Kazuhide Kanaiwa and Sumio Nagata, *Method for the Preparation of a Spongy Metallic Body*, Patent US 4556096 A, 1985.

[3] Michiru Sakamoto, Akira Kitahara, Hidetoshi Ueno and Sumio Nagata, *Process for Producing Porous Materials of Iron, Nickel, Titanium and/or other Metals,* Patent DE 3910282 A1, 1989.

[4] C. San Marchi and A. Mortensen, Deformation of open-cell aluminum foam, *Acta Materialia*, **49** (2001), 3959 - 3969.
http://dx.doi.org/10.1016/s1359-6454(01)00294-4

[5] B.A. Pastuhov et al., *Method of Porous Castings Producing*, Author's Certificate № 094152 (in Russian), 1988.

[6] E. Furman, A. Finkelstein and M. Cherny, Permeability of Aluminium Foams Produced by Replication Casting, *Metals*, **3** (2013), 49 - 57.
http://dx.doi.org/10.3390/met3010049

[7] http://www.compmat.ru/produktsiya/raschet-ploshchadi-filtratsii/ (in Russian)

[8] J.-F. Despois, *Replicated Aluminium Foam, Processing and Properties: Doctoral Thesis,* Ecole Politechnique Federale de Lausanne, 2005.

[9] A. Finkelstein, *Replicated Aluminium Foam, Theory and Practice: Doctoral Thesis*, Ural State Technical University, (in Russian), 2010.

[10] J.F. Despois, A. Marmottant, L. Salvo and A. Mortensen, Influence of the infiltration pressure on the structure and properties of replicated aluminium foams, *Materials Science and Engineering: A*, **462** (2007), 68 - 75.
http://dx.doi.org/10.1016/j.msea.2006.03.157

Received: April 16, 2015; Published: July 17, 2015