

Chapter 2

Various Fabrication Methods of Cellular Metals and Foamed Metals

Abstract This book concerns about porous metals with directional pores. In general, porous materials are defined as holey materials, which are mainly characterized by porosity. The porous materials with high porosity and low density are called as foamed materials, which resemble bubbling materials such as soap and beer. Cellular materials look like honeycomb, whose porosity is also high and the density is low. The holey materials, whose porosity is less than 70 %, are usually called porous materials. Depending upon the shape of pores, isotropic and anisotropic porous materials are classified. The former has rather isotropic spherical pores, while the latter has cylindrically elongated pores aligned in one direction. In this chapter, various fabrication techniques of foamed metals and cellular metals are presented.

Keywords Closed pores • Hollow spheres • Metal foams • Open pores • Porosity

2.1 Materials Definition

There are several nomenclatures to call metallic materials which possess high porosity. Usually, it is accustomed to classify these materials by their relative density, ρ^*/ρ_s , the density of the high-porosity metal ρ^* divided by that of the solid metal (nonporous metal) ρ_s . Special ultra-low-density foams can be made with a relative density as low as 0.001. Polymeric foams used for cushioning, packing, and insulation have relative densities which are usually between 0.05 and 0.2. As the relative density of the foamed metals increases, the cell walls thicken and the pore space shrinks; above about 0.3 there is a transition from a cellular structure to porous structure which is better thought of as a solid containing isolated pores. Thus, the porous materials are defined as the materials whose porosity ranges less than 70 %.

The shape of pores in most of foamed and sintered materials is nearly spherical and isotropic, while the shape in lotus and gasar-type porous materials is

anisotropic and long cylindrical, which is evolved unidirectionally during the solidification. Thus, the pore morphology is defined with the following parameters:

Pore diameter (or pore size)

Pore length

Pore aspect ratio: the ratio of pore length against the diameter

Pore orientation

Porosity: pore volume fraction

Regardless of porosity, pore size, and pore shape, two kinds of pores are existent depending upon the fabrication methods: closed pores and open pores. “Closed pores” are surrounded by material wall and each pore is isolated, which are usually filled with gas, while “open pores” are pores connected to each other in space; the pores are held by struts. The closed pores are not permeable to gas or fluid, but the open pores are usually permeable.

2.2 Various Fabrication Methods

A metallic foam was first tried to be produced by Sosnik in 1948 [1]. In order to create pores, he put mercury into molten aluminum. In 1956 Elliot replaced mercury with foaming agents generating gas by thermal decomposition [2], and until now, many researchers have developed metallic foam using this technique without the toxicity of mercury. Then in 1963, Allen invented a powder-compact foaming technique to manufacture metallic foams, and the basic processing techniques for such metallic foams were almost completed [3].

A variety of cellular and foamed metals have been fabricated by researchers and industries. Metal foams and porous metals are made by the following processes, which are summarized from the book [4].

2.2.1 Melt Gas Injection (Air Bubbling) [4]

Pure liquid metals cannot easily be caused to foam by bubbling a gas into them. Drainage of liquid down the walls of the bubbles usually occurs too quickly to create a foam that remains stable long enough to solidify. However, 10–30 % of small, insoluble, or slowly dissolving particles, such as aluminum oxide or silicon carbide, raise the viscosity of the aluminum melt and impede drainage in the bubble membrane, stabilizing the foam. Gas-injection processes are easiest to implement with aluminum alloys because they have a low density and do not excessively oxidize when the melt is exposed to air or other gases containing oxygen. A variety of gases can be used to create bubbles within liquid aluminum. Bubbles formed by this process float to the melt surface, drain, and then begin to solidify. Low relative density, closed-cell foams can be produced by carefully controlling the

gas-injection process and the cooling rate of the foam. Various techniques can be used to draw off the foam and create large (up to 1 m wide and 0.2 m thick) slabs containing closed cell pores with diameters between 5 and 20 mm. This technique is the least costly to implement and results in a foam with relative densities in the range 0.03–0.1.

2.2.2 Gas-Releasing Particle Decomposition in the Melt [4]

Metal alloys can be foamed by mixing into them a foaming agent that releases gas when heated. The widely used foaming agent titanium hydride (TiH_2) begins to decompose into Ti and gaseous H_2 when heated above about 738 K. By adding titanium hydride particles to aluminum melt, large volumes of hydrogen gas are rapidly produced, creating bubbles that can lead to a closed-cell foam, provided foam drainage is sufficiently slow, which requires a high-melt viscosity. The Shinko Wire Company has developed an aluminum foam trade named Alporas using this technique. The process begins by melting aluminum and stabilizing the melt temperature between 943 and 963 K. Its viscosity is then raised by adding 1–2 % of calcium which rapidly oxidized and forms finely dispersed CaO and CaAl_2O_4 particles. The melt is then aggressively stirred and 1–2 % of TiH_2 is added in the form of 5–20 μm diameter particles. As soon as these are dispersed in the melt, the stirring system is withdrawn, and a foam is allowed to form above the melt. Control of the process is achieved by adjusting the overpressure, temperature, and time. When foaming is complete, the melt is cooled to solidify the foam before the hydrogen escapes and the bubbles coalesce or collapse. The cell size can be varied from 0.5 to 5 mm by changing the TiH_2 content, and the foaming and cooling conditions. Relative densities from 0.2 to as low as 0.07 can be obtained. As produced, the Alporas foam has predominantly closed cells, though a subsequent rolling treatment can be used to fracture many of the cell walls in order to increase their acoustic damping.

2.2.3 Gas-Releasing Particle Decomposition in Semisolids [4]

Foaming agents can be introduced into metals in the solid state by mixing and consolidating powders. Titanium hydride, a widely used foaming agent, begins to decompose at about 738 K, which is well below the melting point of pure aluminum and of its alloys. This raises the possibility of creating a foam by dispersing the foaming agent in solid aluminum using powder metallurgy processes and then raising the temperature sufficiently to cause gas release and partial or full melting of the metal, allowing bubble growth. Cooling then stabilizes the foam. It begins by

combining particles of a foaming agent with an aluminum alloy powder. After the ingredients are thoroughly mixed, the powder is cold compacted and then extruded into a bar or plate of near theoretical density. This precursor material is chopped into small pieces, placed inside a sealed split mold, and heated to a little above the solidus temperature of the alloy. The titanium hydride then decomposes, creating voids with a high internal pressure. These expand by semisolid flow and the aluminum swells, creating foam that fills the mold. The process results in components with the same shape as the container and relative densities as low as 0.08. The foam has closed cells with diameters that range from 1 to 5 mm in diameter.

2.2.4 Casting Using a Polymer or Wax Precursor as Template [4]

An open-cell polymer foam mold template with the desired cell size and relative density is first selected. This can be coated with a mold casting slurry which is then dried and embedded in casting sand. The mold is then baked both to harden the casting material and to decompose the polymer template, leaving behind a negative image of the foam. This mold is subsequently filled with a metal alloy and allowed to cool. The use of a moderate pressure during melt infiltration can overcome the resistance to flow of some liquid alloys. After directional solidification and cooling, the mold materials are removed, leaving behind the metal equivalent of the original polymer foam. Metal powder slurries can also be used instead of liquid metals. These are subsequently sintered. The method gives open-cell foams with pore sizes of 1–5 mm and relative densities as low as 0.05. The process can be used to manufacture foams from almost any metal that can be investment cast.

2.2.5 Metal Deposition on Cellular Preforms [4]

Open-cell polymer foams can serve as templates upon which metals are deposited by chemical vapor decomposition (CVD), by evaporation, or by electrodeposition. Nickel is deposited by the decomposition of nickel carbonyl, $\text{Ni}(\text{CO})_4$. An open-cell polymer is placed in a CVD reactor and nickel carbonyl is introduced. This gas decomposes to nickel and carbon monoxide at a temperature of about 373 K and coats all the exposed heated surfaces within the reactor. Infrared or RF heating can be used to heat only the polymer foam. After several tens of micrometers of the metal have been deposited, the metal-coated polymer foam is removed from the CVD reactor and the polymer is burnt out by heating in air. This results in a cellular metal structure with hollow ligaments. A subsequent sintering step is used to densify the ligaments. The foam with open sizes in the 100–300 μm diameter range is available. It gives the lowest relative density (0.02–0.05) foams available today.

2.2.6 Entrapped Gas Expansion [4]

In the process Ti-6Al-4V powder is sealed in a canister of the same alloy. The canister is evacuated to remove any oxygen and then backfilled with between 0.3 and 0.5 MPa of argon. The canister is then sealed and consolidated to a high relative density (0.9–0.98) by HIPing causing an eightfold increase in void pressure. This is too low to cause expansion of Ti-6Al-4V at room temperature. The number of pores present in the consolidated sample is relatively low, so a rolling step is introduced to refine the structure and create a more uniform distribution of small pores. In titanium alloys, rolling at 1,173–1,213 K results in void flattening and elongation in the rolling direction. As the voids flatten, void faces come into contact and diffusion bond, creating strings of smaller gas-filled pores. Cross rolling improves the uniformity of their distribution. Various cold sheet forming processes can then be used to shape the as-rolled plates. The final step in the process sequence is expansion by heating at 1,173 K for 20–30 h. The high temperature raises the internal pore pressure by the ratio of the absolute temperature of the furnace to that of the ambient, i.e., to between 10 and 16 MPa, causing creep dilation and a reduction in the overall density of the sample. This process results in shaped Ti alloy sandwich construction components with a core containing a closed-cell void fraction of up to 0.5 and a void size of 10–300 μm .

2.2.7 Hollow Sphere Structures [4]

Several approaches have recently emerged for synthesizing hollow metal spheres. For one example, hollow spheres are formed from a slurry composed of a decomposable precursor such as TiH_2 , together with organic binders and solvents. The spheres are hardened by evaporation during their flight in a tall drop tower, heated to drive off the solvents and to volatilize the binder. A final heat treatment decomposes the metal hydride, leaving hollow metal spheres. The approach can be applied to many materials and is not limited to hydrides. As an example, an oxide mixture such as Fe_2O_3 plus Cr_2O_3 can be reduced to create stainless steel.

In another method developed at IFAM, Bremen, polystyrene spheres are coated with a metal slurry and sintered, giving hollow metal spheres of high uniformity. The consolidation of hollow spheres gives a structure with a mixture of open and closed porosity. The ratio of the two types of porosity and overall relative density can be tailored by varying the starting relative density of the hollow spheres and the extent of densification during consolidation. Overall relative densities as low as 0.05 are feasible with a pore size in the range 100 μm to several millimeters.

2.2.8 Co-compaction or Casting of Two Materials, One Leachable [4]

Two powders, neither with a volume fraction below 25 %, are mixed and compacted, forming double-connected structures of both phases. After consolidation one powder (e.g., salt) is leached out in a suitable solvent. Foams based on powder mixes of aluminum alloys with sodium chloride have successfully been made in large sections with uniform structures. The resulting cell shapes differ markedly from those of foams made by other methods. In practice the method is limited to producing materials with relative densities between 0.3 and 0.5. The cell size is determined by the powder particle size and lies in the range 10 μm –10 mm.

References

1. Sosnik B (1948) US Patent No. 2,434,775
2. Elliot JC (1956) US Patent No. 2,751,289
3. Allen BC (1963) US Patent No. 3,087,807
4. Ashby MF, Evans A, Fleck NA, Gibson LJ, Hutchinson JW, Wadley HNG (2000) Metal foams: a design guide. Butterworth-Heinemann, Boston

<http://www.springer.com/978-4-431-54016-8>

Porous Metals with Directional Pores

Nakajima, H.

2013, XII, 284 p. 244 illus., 43 illus. in color., Hardcover

ISBN: 978-4-431-54016-8