7.2
Functional Applications

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Cellular metallic materials are finding an increasing range of applications. Whether a suitable porous metal or metal foam can be found to solve a given problem depends on many factors, summarized here by the following keywords.

- *Morphology:* type of porosity needed (open versus closed), amount of porosity needed, size of porosity desired, total internal surface area of cellular material required.
- *Metallurgy:* metal, alloy, or microstructural state required.
- *Processing:* possibilities for carrying out secondary operations on the foam or cellular solid, such as shaping, cutting, joining, coating.
- *Economy:* cost issues, suitability for large-volume production.

7.2.1
General Considerations

The first point is, in particular, crucial for any evaluation of applications for cellular metallic materials. Many applications require that a medium, either liquid or gaseous, be able to pass through the cellular material. There may be a need for various degrees of "openness", ranging from "very open" for high rate fluid flow to "completely closed" for load-bearing structural applications, and appropriate materials satisfying these conditions have to be found. Figure 7.2-1 shows which types of porosity the various application fields require. Normally, a difference is made between whether an application is "functional" or "structural", but there is considerable overlap between these two notions.

The question of from which metals or alloys a given type of cellular structure can be manufactured is also important. Structural load-bearing parts have to be light because otherwise they would be made from conventional massive metals or alloys. Therefore, aluminum, magnesium, or titanium cellular or porous metals are preferred for such applications. For medical applications, titanium may be preferred because of its compatibility with tissue. Stainless steel or titanium is required for applications in which aggressive media are involved or high temperatures occur.

Finally, processing and cost issues have to be considered. The technology must be available to bring the selected cellular metal into the required shape and to incorporate it into the machine or vehicle where it has its function. A technology for making cellular metal will be futile if the required component cannot be manufactured at a reasonable price.

In the following sections, applications for cellular metals are discussed that are predominantly "functional" in the sense discussed. Traditional powder metallurgy

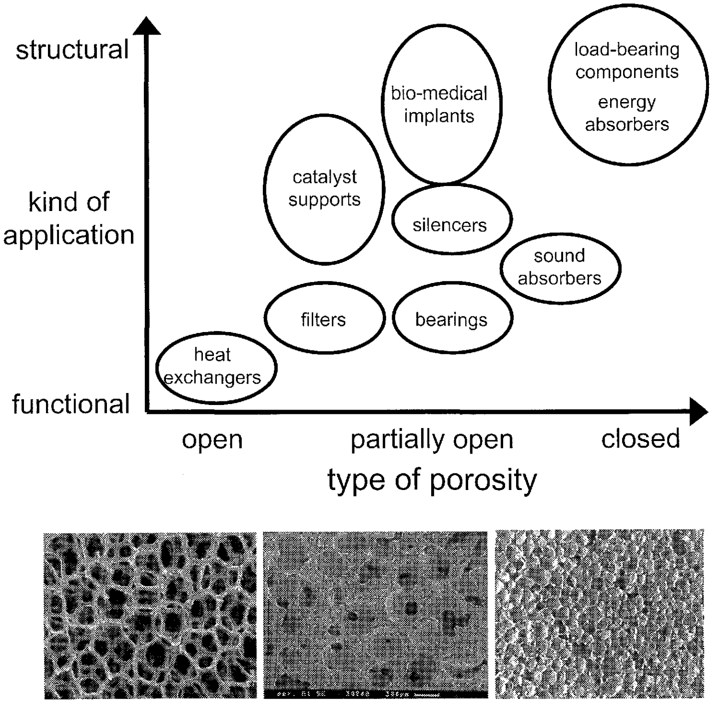


Figure 7.2-1. Applications of cellular metals grouped according to the degree of open porosity needed and whether the application is functional or structural.

(PM) has created porous sintered metals for a wide range of applications [1–3]. It is therefore not surprising to find very similar applications for the cellular metals described in the present text, provided they have a certain degree of open porosity.

7.2.2 Biomedical Implants

Biomedical applications often have both a structural and a functional aspect, and are therefore very challenging. Titanium or cobalt–chromium alloys are used for prostheses or dental implants because of their biocompatibility. To ensure ingrowth of tissue, one usually produces a porous layer of the same or another biocompatible material on the prosthesis by thermal spraying or other methods [4]. Alternatively, one could use porous titanium or titanium foam for such applications and tailor the density distribution to meet the required strength and moduli of such components. There is no unanimity about how implants should be designed to ensure maximum durability and functionality. According to one opinion, the modulus of, say, dental implants should match the modulus of the jaw bone. Knowing the relationship between modulus and density of metallic foams, one could easily manufacture implants with an appropriately adapted modulus, ensure biocompatibility, and stimulate bone ingrowth into the (open) porosity [5]. Strength and design criteria have to be met as well. Magnesium foams could be used as biodegradable implants that serve as a load-bearing structure as long as the bone still grows but are gradually absorbed by the body in a later stage of recoalescence [4].

7.2.3
Filtration and Separation

There are two types of filters: filters holding back and separating solid particles or fibers dispersed in a liquid (suspensions) or filters holding back solid or liquid particles dispersed in a gas (smoke or fog). Examples of the first type are filters for cleaning recycled polymer melts, for removing yeast from beer, or for contaminated oil. The second type includes filtration of diesel fumes or water removal in air lines. Important filter properties are fine filtration capacity, good particle retention, cleanability, mechanical properties, corrosion resistance, and cost. Some of the cellular metals described in this text possess a combination of properties not covered by the traditional PM materials and might therefore be considered as complementary to these, such as the materials described in Sections 2.1.2, 2.3 and 2.4.

7.2.4
Heat Exchangers and Cooling Machines

Highly conductive foams based on copper or aluminum can be used as heat exchangers [6]. In this case open-cell structures are needed such as those described in Sections 2.3 and 2.4. Heat can be removed from or added to gases or liquids by letting them flow through the foam and cooling or heating the foam at the same time. Owing to the open porosity, pressure drops can be minimized (see Fig. 7.2-2). An example of such an application is a compact heat sink for cooling, for example, in microelectronic devices with a high power dissipation density such as computer chips or power electronic components. Nowadays, fin-pin arrays are the standard solution in such cases. Metal foams or ordered cellular metals of the type shown Fig. 7.2-3 can perform better if they are selected so that thermal conductivity is kept as high as possible with their flow resistance maintained low. These two requirements are contradictory. Therefore, an optimization problem has to be solved [7,9,10]. The variables are the dimensions of the individual struts and their spacing in the example given. A denser arrangement of metal naturally gives rise to a better heat conduction but also increases pressure drop. The optimum determined is represented by a certain area in the plane of the diagram spanned by the heat dissipation and the pressure drop, both expressed as dimensionless quantities, in Fig. 7.2-3.

Another application field for open-cellular materials is transpiration cooling. The high surface area, low flow resistivity, and good thermal conductivity of some of the materials used make them promising candidates for such purposes.

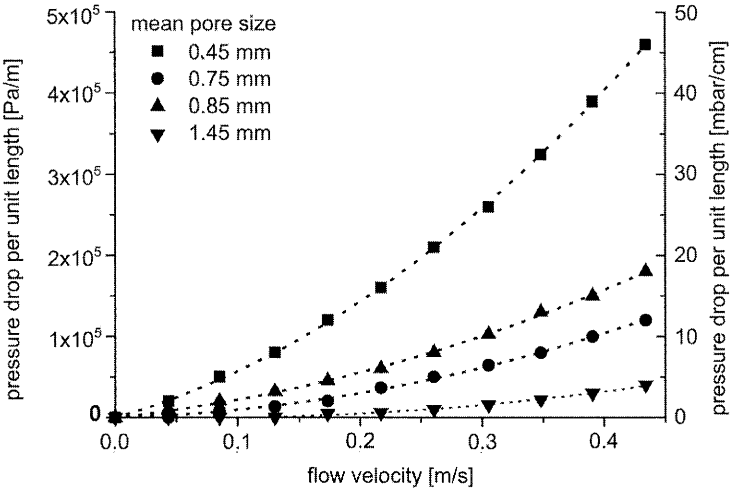
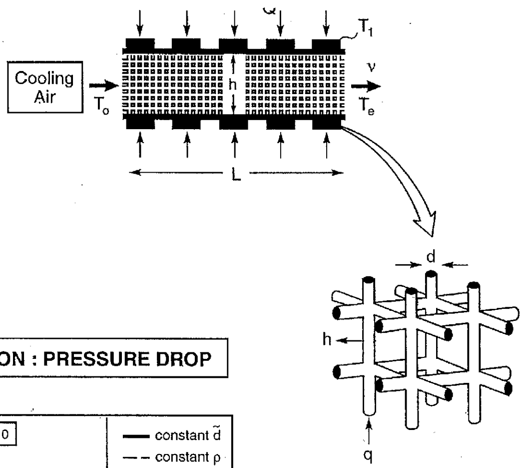


Figure 7.2-2. Pressure drop in partially open-porous cellular solids of the type shown in the middle of Fig. 7.2-1 [8].



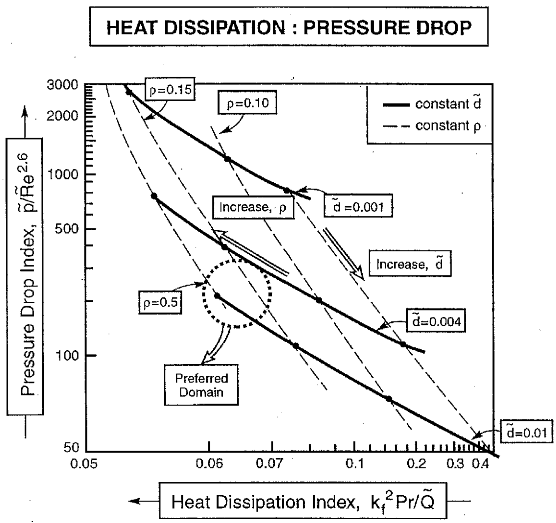


Figure 7.2-3. A diagram of an open-cell metal used as a heat dissipation medium for cooling high-power electronic components. Also shown is the trade-off between pressure drop and heat flux, with the preferred material domain indicated [7].

7.2.5
Supports for Catalysts

The effectiveness of catalysis critically depends on a high interfacial surface area between the catalyst and the gases or liquids to be reacted. Therefore, the catalyst is either processed into a highly porous structure or, if this is not possible, applied to another porous system such as a porous ceramic material. Cellular metals could replace such ceramics even if they cannot compete with them on surface area because they exhibit other useful properties such as high ductility and thermal conductivity. One application concept includes the preparation of a thin sheet of corrosion-resistant metal foam, filling this foam with a slurry containing the catalytic substance, by rolling for example, and finally curing at elevated temperatures [11]. The resulting catalyst has good mechanical integrity: even after many temperature cycles the catalyst is not separated from the metal foam support. One application for such catalysts is for removing nitrogen oxides NO_x from the exhaust fumes of power plants.

7.2.6
Storage and Transfer of Liquids

One of the oldest applications of porous PM materials is as self-lubricating bearings in which oil is stored in the interstices between particles and is allowed to flow slowly out, thus replacing the used oil. Of course, some of the cellular materials described in this book could fulfil the same function but with the advantage of having a higher storage volume than traditional PM parts. The application is not limited to oil: water can be kept and slowly released for automatic humidity control. Perfume can be stored and allowed to evaporate slowly. Porous rolls can hold and distribute water or adhesives to surfaces. Transport of the liquid can be driven by capillary action alone or by excess pressure in the roll. Finally, very open metallic structures can be used to store fluids at a constant and uniform temperature, for example, in cryogenic conditions. Moreover, the foam can reduce undesired movements of the liquid in partially filled tanks ("anti-sloshing") [10,12].

7.2.7
Fluid Flow Control

Porous materials can be used for controlling the flow of liquids and gases [1]. It is known that PM flow restrictors are more reliable and accurate than conventional micrometering valves. Because so many degrees of "openness" of cellular metals are available, one could find tailored solutions for even more applications by appropriately selecting a cellular metal. Metal foams have already been used as flow straighteners in wind tunnels [12] or flow distributors in valves [13].

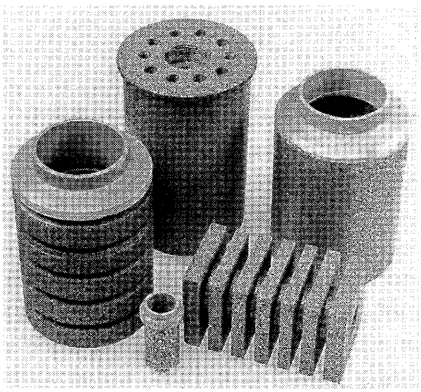


Figure 7.2-4. Different types of silencers (approximate diameter of components is 10 cm).

7.2.8
Silencers

Components for damping sound, pressure pulses, or mechanical vibrations are also common in industrial PM applications [1]. Materials with a certain degree of open porosity can be tailored to damp some frequencies selectively while they pass others. Sudden pressure changes occurring in compressors or pneumatic devices, for example, can be damped with porous sintered elements. Materials such as the investment cast foams described in Section 2.3 or the foams made by deposition (Section 2.4) could replace such traditional elements for reasons of cost and effectivity [13]. Figure 7.2-4 shows some silencers. The maximum diameter of the components shown is about 10 cm.

7.2.9
Spargers

Some applications require that a gas be introduced into a liquid homogeneously and at a constant rate. An example of such an application is the carbonation of beverages. This operation requires a porous part that creates sufficiently small gas bubbles and satisfies criteria such as corrosion, heat, or shock resistance. Porous metals can be a superior solution compared to other materials such as porous ceramics.

7.2.10
Battery Electrodes

Lead foams could serve as supports for the active material in lead–acid batteries in replacement of conventional lead gratings, thus allowing for constructing very light electrodes [14]. The electrochemically active mass, a paste containing very fine lead oxide powders, could be filled into the open voids of a lead foam where it would contact the electrolyte (sulfuric acid). The lead foam acts as a highly conductive lattice leading to a low internal resistance of the battery. The nickel foams described in Section 2.4 are already used as electrodes in pasted rechargeable NiCd or NiMeH batteries where weight savings and a higher energy density can be achieved [15–17]. Porous PM materials with their extremely high surface area are being used in fuel cells [1,15].

7.2.11 Electrochemical Applications

Nickel foams can be used as electrode material in electrochemical reactors. In filter-press electrodes, for example, a stack of isolated metal plates is used. The plates are separated by a turbulence-promoting plastic mesh and insulating membranes. If these meshes are replaced by sheets of cellular nickel with open channels (with each sheet attached to one of these plates), one increases the electrode surface while maintaining the turbulence promotion [18]. The reactors can be built more compactly this way. Nickel foams can also be used to improve electrocatalytic processes such as the electrooxidation of benzyl alcohol assisted by NiOOH, which is electrogenerated on nickel anodes. Packed beds of nickel foams were shown to improve the performance of such reactors [19].

7.2.12 Flame Arresters

Cellular metals with high thermal conductivities of the cell-wall material can be used to stop flame propagation in combustible gases. Open-cell foams of the type described in Section 2.4 have been shown to be capable of arresting flames even when they were travelling at velocities up to 550 m/s. In practice, long runs of pipes transporting combustible gases are protected close to possible sources of ignition so that, if ignition does occur, the flame cannot accelerate to high velocities [13].

7.2.13 Water Purification

Cellular metallic materials could be used to reduce the concentration of undesired ions dissolved in water. In this application the contaminated water flows through a highly porous cellular metal with an open structure. The ions react with the matrix metal of the cellular structure in a redox reaction. An electroless reduction of Cr(VI) ions by cast aluminum foams has been investigated [20]

7.2.14 Acoustic Control

A sound-wave control device can be obtained if one creates a lens- or prism-shaped part from a rigid open-cell material, such as a metal foam. The sound waves will then be guided and redirected by this acoustic device [21]. Moreover, closed-cell foams have been studied for their suitability as impedance adapters for ultrasound sources. Noise reduction functions are described in Section 5.3.

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7.3 Machinery Applications

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Cellular metals have existed as particularly innovative new materials for several years [1–3]. Since the development of foaming technology, a number of prototypes for use in the car and machine tool industries have been demonstrated [4–6].

This Section describes possible applications of foamed metals in mechanical engineering.