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Development in applications of porous metals①

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[Abstract] Applications of porous metal materials are reviewed so far. These applications deal with filtration and separation, energy absorption, electrode matrix, fluid distribution and control, heat exchangers, reaction materials, constructional materials, electromagnetic shielding, biomaterials and so on. All these are expected to promote the improvement of the property and structure for porous metals.

[Key words] porous metal; porous material; metal foam
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1 INTRODUCTION

The notable feature of porous metals is the existence of a great deal of voids within the inner body metals compared with compact metals. This imparts the materials many excellent properties, such as small mass density, big specific surface area, high energy absorption, low heat conductivity (for close-cell bodies), high heat exchange and radiation ability (for open-cell bodies), excellent permeability (for open-cell bodies), good absorption of electromagnetic waves (for open-cell bodies), flame-stopping power, resistance to heat or heat shock, gas sensitivity (some of them are very sensitive to certain gases), possibility of regeneration, good workability and so on. Porous metallic materials can be used in many fields, such as aerospace technology, atomic energy, electrochemistry, petrochemistry, metallurgy, machinery, medicine, environmental protection, and building trade. Their applications cover separation, filtration, gas distribution, catalysis, electrochemical process, noise erasure, impact-energy absorption, electromagnetic-wave shield, heat exchange and some other technical processes. They have been used to produce filters, catalyst supporters, porous electrodes, energy absorbers, silencers, shock-absorbing buffers, electromagnetic shielding or compatible elements, heat exchangers, flame arresters and so on[1~13]. Furthermore, they can be used to produce many composite materials or to serve as gaskets. In many cases, they are both functional and structural. In a general word, they are excellent and versatile engineering materials. This paper aims at introducing the different applications of these materials.

2 FILTRATION AND SEPARATION

Excellent permeability makes the porous metals the ideal materials for various filters. The pore canals within the porous metallic materials can stop and arrest solid particles in flowing media so that the gas or liquid can be filtered and separated. The most widely used metallic filter materials are porous bronze and porous stainless steel. Some porous metallic materials can serve as separation media, e. g. separating oil from water or water from refrigerants. Some of them can also be used as diffusion media for aerating liquids or distributing CO_2 in liquids. In the biochemical field, metal foam is used as a support for the osmotic membranes in kidney machines.

Some researchers[14] succeeded in producing a porous W-Ni-Fe alloy. They started with fine powder of W, into which 1% ~ 2% Ni-Fe (mass fraction) was added. After pressing, pre-sintering, grinding, classifying and intensified sintering, they got the prefabricated alloy powder. This alloy powder was then added with 2% stearic acid or 0.4% (mass fraction) poval. Through forming, pre-sintering and sintering, the porous W-Ni-Fe alloy was obtained. The influence of the sintering temperature and time on the properties of this porous alloy are listed in Table 1 and Table 2[14]. This product can be used to purify the combustion gas of which the temperature is as high as 1523 K and the pressure is as high as 11.8 MPa. Li et al[15] chose the water-atomized powder of 0Cr18Ni9 stainless steel as the raw material. Shaped by steel-mould pressing or isostatic pressing, then sequentially sintered in vacuum or pure hydrogen gas, a porous stainless filtration material was produced. This material possesses high strength, good thermal conductivity, excellent corrosion resistance, and has been applied to the production of polyester film in petrochemical industry.

Porous metals have many applications as filter materials. Those matters that can be filtered including steam or liquid nitrogen at high or very low

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Table 1 Influence of sintering temperature on properties of porous alloy (heat treated for 2 h)[14]

Temperature /K	Relative permeability coefficient /(L·min^{-1}·m^{-2}·Pa^{-1})	Maximum aperture /μm	Total porosity /%	Bending strength /MPa
1 723	12.3	152.25	30.88	53.2
1 873	1.44	140.40	31.52	114.0
2 023	1.48	146.60	28.48	114.3

Table 2 Influence of sintering time on properties of porous alloy[14]

Time /h	Relative permeability coefficient /(L·min^{-1}·m^{-2}·Pa^{-1})	Maximum aperture /μm	Total porosity /%	Bending strength /MPa
0.5	1.54	151.65	32.03	127.7
1	1.40	125.40	30.38	132.6
2	1.84	146.60	29.52	114.1

temperatures, organic solvent with strong dissolving power, melted polymer with high viscosity and pressure, fluid with notably variable pressure or flux, highly polluted fluid, the grains of catalyst to be recovered and so on[16].

A cheap and practical diesel particular filter (DPF) system, in which the material used is porous 3-D reticulated Ni-Cr-Al alloy with porosity of 85%, was developed in Japanese Sumitomo Electrical Industry Corporation for the first time. It was easy to purify the exhaust gas of diesel engines, and the purified gas reached the standard issued in 1997[17]. As for ceramic filters, if too much soot is arrested, local temperature-rise will happen at the combustion part, and excessive temperature-difference will occur because of the low heat-conductivity of ceramics. This will make the filter crack and melt. Ban et al[18] invented the porous bodies of Ni-20Cr and Ni-33Cr-1.8Al alloys, which had the high-temperature corrosion resistance to diesel exhaust-gas without the cracking problem of ceramics, and can be used as the filter material to reduce environmental pollution.

When porous stainless steel or porous titanium are used as the decarbonizing material in the major liquid transfusion, the filtration effect can be improved several-fold, and the cost of maintenance is reduced. In metallurgical industry, when tantalum powder is smelted by wet process, the porous nickel filter is used to filtrate melted sodium. Porous titanium is used for the filtration of zinc sulfate solution during zinc smelting. In steel works, porous stainless steel is used for the purification of coal gas of blast furnace.

In aerospace industry, porous stainless steel is applied to the purification of the hydraulic oil in aircraft or guided gyroscopes, the purification of gas in the automatic fuel pipelines and the recovery of catalyst used in hydrocarbon combination process.

In atomic energy industry, filters made of porous nickel, Monel metal and stainless steel are used for the abstraction of UF6 and the filtration of the tail gas released by the vulcanization bed, which is used for the denitration of oxygen-uranium base nitrate. Filters made of porous metals such as low carbon steel, chromized iron, stainless steel and molybdenum, are used for the filtration of the dioxide cooling-gas in atomic power station and for removal of the small pollutants with radioactive rays existing in the purification liquid of a reactor.

Since 1980s, with the development of industries for petrochemistry, textile and papermaking, the need for heat-resistant, pressure-resistant and corrosion-resistant porous materials have ceaselessly grown. In petrochemical industry, porous materials of low carbon or stainless steel are used for the removal of silt and sediment in oil drilling well. Porous iron filter is used for the separation between oil and wax in oil extraction and purification. In the textile industry, pipes of porous stainless steel produced by powder sintering are used for the pre-filtration and scatter of spinning jets and for the removal of colorant particles in hot washing water. In papermaking industry, porous metals of 316L, 317LN alloys and titanium are used for paper-pulp rinse and sewage treatment.

In chemical industry, many kinds of chemical matters including nitric acid, 96% sulfuric acid, ethylic acid, boric acid, nitrous acid, oxalic acid, alkali, hydrothion, ethyne, vapor, sea water, molten salt, sodium hydroxide, gaseous hydrogen fluoride and so on, can be filtered by the corrosion-resistant porous metals like stainless steel or titanium for the purpose of purification or recovery.

Generally, in any situation of solid-liquid, liquid-liquid and gas-liquid separation and filtration, porous metallic materials can be utilized. Porous titanium is a new filtration and purification material. It can serve the chemical reaction with high degree of dispersion[19]. The strong resistance to corrosion is its outstanding characteristic. It can be used to filtrate vari-

ous media, such as sea water, chloride, hypochlorite, wet chlorine, oxidative acids, oxidative alkalis, various organic acids, strong oxidative agent and various high-temperature or low-temperature media. When fine-filtering porous titanium is used to filtrate air, the bacteria like bacillus and bacteriophage can be reliably removed. The high strength and stiffness make it possible to self-support and can endure pressures from any direction.

3 ENERGY ABSORPTION

Energy absorption is an important application of porous metallic materials. For example, bumpers and bump levellers are the typical energy-absorbing apparatus. Their application fields cover automobiles, landing gears of spaceships, safety pads of lifters or conveyers and the energy-absorbing lining of the protective hood for high-speed grinding machines.

With foamed aluminum, the deformation due to the highest energy-consumption will be controlled at the impact zone of car bodies. The situation is the same for the protection against the side impact[20]. For example, to fill hollow steel or aluminum shells with foamed aluminum are enable these parts to behave well in deformation when they are loaded. Car bodies and other parts of engines can be manufactured or reinforced by foamed metals to obtain a high stiffness and a light mass.

Since the safety standard of vehicles is elevated (especially in automobile industry), the mass of vehicles ceaselessly increases. Nevertheless, this contradicts the further requirement such as lowering the fuel consumption. Thus, materials with small mass density and high energy-absorbing ability are favored a great deal. As for organic foams, although the mass density is low, the energy that can turn into the deformation energy is also small, and the strength is very low. But when metallic foams are adopted, a huge amount of energy can be absorbed. Baumeister et al[21] made use of powder metallurgy to produce a foamed aluminum with uniform structure and high porosity of 90% (as shown in Fig. 1). In their way, parts with complicated shapes can be made to meet the above demands.

Using foamed metals as the impact-energy absorbing structure for the shock-resistant part, the shock resistance is increased, and the safety insurance against collision is improved for automobiles[22, 23].

Noise silencing is another important application of porous metals in respect of energy absorption. Foamed metals possess excellent acoustic properties that can match those of polymer foams, and can preserve these properties at high temperatures. As a sound-absorbing material, it should have series of good properties of sound absorption efficiency, gas permeability, fire resistance and structure

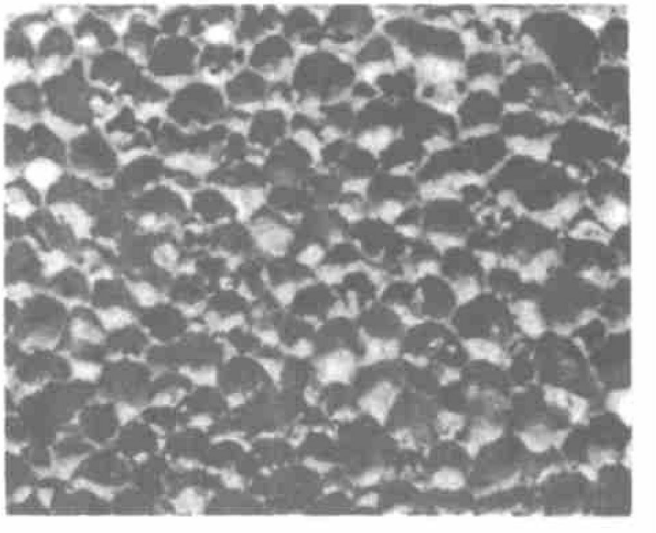

Fig. 1 Foamed aluminum used to absorb energy[21]

strength[24]. Nonmetal fiber materials like glass wool have bad deformability, and their sound absorption efficiency will be spoiled under the condition of rainwater. The sintered materials like ceramics have low impact strength. Therefore, porous metals are widely used in buildings, automatic office equipment and radio recording rooms. They act as not only outside decorations but also sound-absorbing materials.

Sound absorption means an incident sound wave is neither reflected nor transmitted. Sound energy is absorbed absolutely in material. Foams having low initial densities are found to be better sound absorbers than those with high relative densities[25]. On the other hand, at the same initial relative density, sound absorption is maximized by a foam with an optimal thickness. Fig. 2 shows sound absorption property of a commercially available aluminum-foam named Alporas foam[25]. The sound-eliminating materials used under special conditions like the exhaust system of gas turbines must meet the composite demand of high efficiency, long lifetime and light mass. Since the light porous titanium is resistant to corrosion and scour of high-speed airflow at high temperatures, it is satisfied to be used for the noise control of exhaust systems of turbine[26].

The technology of speed increase and mass reduction for trains has been studied for more than ten years in Japan. However, this brings rail-vehicles the more serious vibration and noise. Thus, the demand to control the noise caused by automobiles and trains become an important subject for this technology. A foamed aluminum alloy developed by Naoe[27] possesses very good sound-elimination and vibration-absorption efficiency, and can be used as the damping materials for automobiles and trains.

Besides, the gas transported over long distances through high-pressure pipeline can produce high-intensity noise. Using foamed metals to transport gas in the gas-diffusion way, the noise can be almost

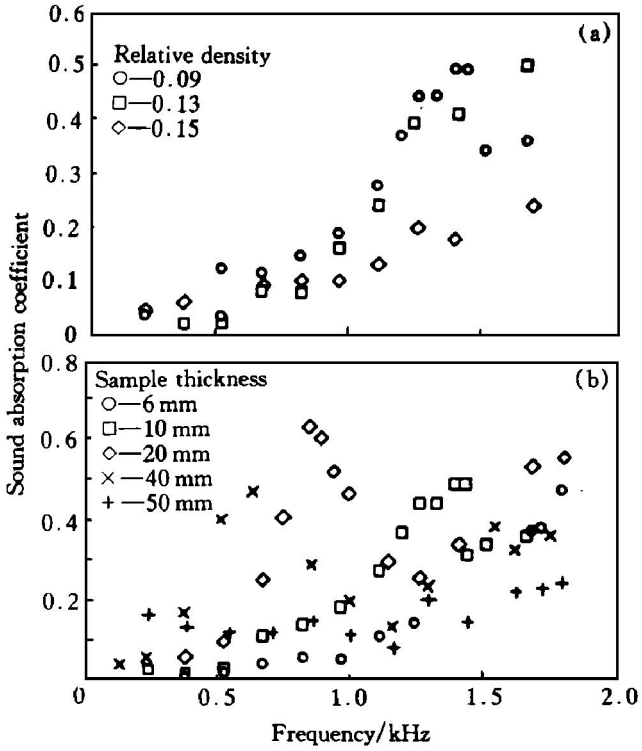

Fig. 2 Sound absorption coefficient of commercially available aluminum foam (Alpora foam) plotted as function of frequency[25]
(a) —Samples with foam thickness of 10 mm;
(b) —Samples with relative density of 0.09

completely eliminated. Foamed metals can also be used in other cases of pressure reduction, for example, mufflers for air tools can be made from foamed copper with the density of 5%.

In the ultrasonic inspection and measurement, foamed metals have been used as the receptor materials[20] because their ultrasonic resistance locates in the suitable range.

4 ELECTRODE MATERIALS

In the fields of high technology, continuous requirements are put forward on high energy-density, long lifetime and low production-cost for the secondary alkaline batteries, such as nickel-hydrogen and nickel-cadmium types, and the traditionally sintered nickel plates are challenged. Nowadays, in various storage batteries, fuel cells and air cells, porous nickel is used as the electrode with the porosity as high as possible. To adopt the plates made of foamed metals or metallic fibers instead of the traditional sintering materials, the consumption of nickel decreases by half while the mass of plate reduces about 12%, yet the energy density is greatly increased[28]. In Yuasa Company, Japan, the porous metallic plate was used for the cadmium electrode. Compared with the sintering plate, the specific energy increases by 33%[29].

The foamed copper produced by electrodeposition can be used as the cathode for electrolyzed copper reduction and the electrode for organic electrosynthesis. Foamed nickel[30~33] (as shown in Fig. 3) is used as the flow-through and flow-by porous electrodes in chemical reaction engineering. This kind of electrode possesses excellent properties for electrolyte diffusion, migration and matter exchange. Langlois et al[34, 35] further studied the potential distribution of the flow-through electrode made of foamed nickel. The result showed that the potential distribution in the porous electrode depended on the electircal resistance of the porous material to a great extent on condition that the thickness of the electrode was small.

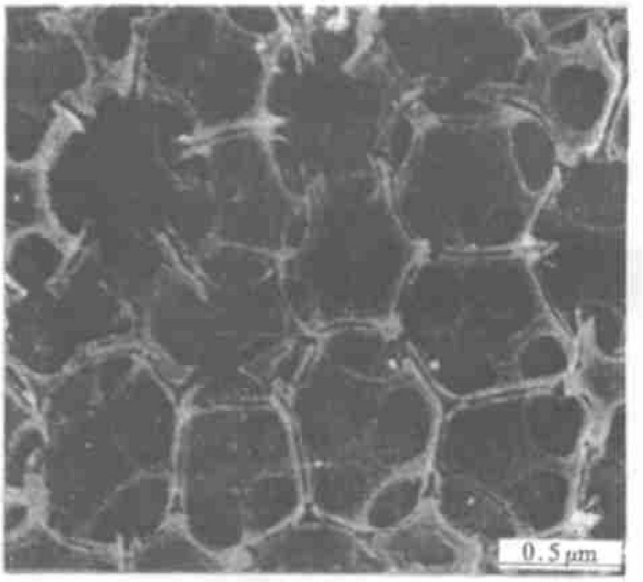

Fig. 3 Photograph of nickel foam[32]

Applying foamed nickel to electrochemical reactors, the function of electrochemical unit is improved due to the increase of the surface area of electrode. Foamed nickel can also be used without membranes in some industrial applications[36]. Moreover, foamed nickel is apt to serve as the three-dimensional porous anodes for the electro-oxidation of organic compounds. For example, the multiphase electro-catalytic oxidation of benzyl alcohol promotes the generation of acetaldehyde, and the foamed-nickel electrode makes the current strength of electrolysis and the conversion rate of alcohol increase nearly 30%[37].

In addition, foamed nickel is also applied to the electrode of high-pressure Ni-H_2 battery[38] and the diffusion electrode of fuel cells[39], which serve in spaceships. As the support of the active substance in lead-acid batteries, porous lead can greatly lighten the electrode[40].

The electrical resistivity of the electrode matrix is a basic property, sometimes of key importance. Study on the relationship between this property and porosity[41~43], it is found that the resistivity increases faster and faster when the porosity increases (as

shown in Fig. 4).

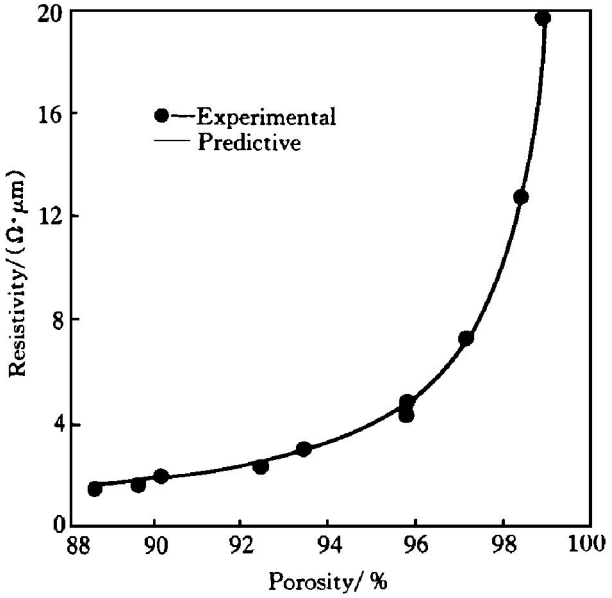

Fig. 4 Plot of electrical resistivity as function of porosity on nickel foam[43]

5 DISTRIBUTION AND CONTROL OF FLUID

Porous metallic materials are also widely used in the field of fluid distribution. For example, porous stainless steel is used to control the cooling gas or liquid for the shell of the nose-cone yaw-meter of rockets. Porous powder-metallurgy materials are massively used for the air-float roller of the plastic float membrane in tape processing equipment. Other distribution elements are used to aerate liquids. For example, the porous nickel pipe is used to aerate beer, and the porous plate of stainless steel or titanium is used to uniformly oxygenate blood by medical oxygenators, and so on.

As for the technology of fluidized bed in petrochemical and metallurgy industries, the commonly used plates for fluid distribution are porous metallic types made by the sintering of powders of various metals including bronze, nickel, Monel alloy, stainless steel and so on.

Porous metals are also used for fluid control. For example, they are used to produce meters of gas or liquid and delay timers for signal control in an automatic system.

6 HEAT EXCHANGER

Porous metals possess a large specific surface area, and are the efficient materials for heat exchange and radiation. Cell-opened porous metals are suitable for heat exchangers, heaters and radiators. Among them, both circulatory air heater and electric-resistance water heater display very high efficiency and excellent employability. They can be combined with tubulous or flat metallic products to form assemblies, which are advantageous for 3-D complicated flow to overcome the harmful influence of boundary layer on the condition of forced convection. Cell-closed porous metals can be used as heat-insulating materials, whose strength and heat resistance are better than those of traditionally used materials.

Foamed steel is adaptable to a very wide range of temperature, and can be used to manufacture exhaust manifolds of automobile engines. Since the heat conductivity of the manifold is reduced a great deal, the time required for the temperature to rise to the level of normal operation of exhaust catalysis is shortened.

Besides, porous metals are fireproof and possess high permeability consistent with flame-stopping ability. So they can be utilized to prevent flame propagation along pipelines, and can also be used to manufacture fire extinguishers.

7 REACTION MATERIALS

Porous metals can be used to manufacture efficient catalyst or catalyst supporter because of the high specific surface area and the self-support strength in chemical industry. Sometimes, porous metals themselves, such as porous Raney copper[44] and porous nickel[45], are catalysts. The porous Cr-Ni stainless steel[46] is an example of catalyst supporter. The catalyst based on porous metals can be used in many reaction engineerings, such as the deep oxidation of hydrocarbon, selective oxidation of alcohol[47], hexane recombination[48] in petrochemical process. Making use of foamed metals to manufacture catalytic averagers of the toxic exhaust of automobiles, the discharged CO decreases by 2~ 3 times, and the toxicity lowers 90%[49]. In the field of environmental protection, foamed nickel is used in the oxidation-reduction of the six-valence Cr ion (highly toxic) in water solution[50], and porous titanium (whose properties are listed in Table 3) with uniform structure is used in the apparatus of industrial waste-water treatment[51].

Table 3 Properties of porous titanium[51]

Position	Relative permeability coefficient /(L·min^{-1}·cm^{-2}·Pa^{-1})	Maximum aperture /μm
Center	0.848	13.2
Brim	0.850	13.8

New Corporation of Iron and Steel cooperating with Panisonic Electrical Corporation developed a new deodorant material with good performance and long lifetime. It is a composite using porous iron-base body with three-dimensional network structure as matrix, which is combined with fine powder of iron and complex compound of organic acid. This material can be

applied to many cases like multi-functional deodorization, automatic air-purifiers and deodorant building-materials[52]. The process to produce this material starts with the slurry of fine iron-powder with size below 10 μm. In this slurry, the polyurethane foam is soaked and then sintered to form a porous iron-base body with three-dimensional reticulated structure. Sequentially, organic acid (of ascorbic acid series) is used to treat the surface to form the metallic complex compound, which can adsorb and store stinks by the further special chemical-treatment (generally by alkali). The metal iron provides the metallic complex compound with electrons to maintain its activity so that the deodorizing effect can last for a very long time. Compared with active carbon, it can deodorize more quickly, so can be used in families, great buildings and shops as air purifiers, and in automobiles as deodorizers.

8 CONSTRUCTIONAL MATERIALS

Porous metals can serve as light mass constructional materials especially at temperatures over 200 ℃. Foamed aluminum has been used early as core material for sandwich elements in aircraft[53]. When porous metal components are connected with compact matrix, the practicality of porous metals as constructional materials will be improved.

In aircraft and missile industries, porous reticulated metals are used for light mass and heat-conductive support structures[54]. Since they can be combined with the structural body by welding, sticking or electroplating, they can be used to produce sandwich parts. Such products can serve as the supports of the metallic shells of airfoils or the nose-cones of missiles in preventing high-temperature collapse. They can be also used as the reflection materials of radar mirrors.

In 1980s, Central Electrical Corporation, Japan, tried to pour the melted aluminum into the sponge-like polyester shape-material, which is removed with the special agent to obtain foamed aluminum with three-dimensional network structure that can be used as constructional materials in aeronautical industry[55]. Generally, because of its low mass density, foamed aluminum can be used in various light mass structures with reducing cost, and its incombustibility, weldability and isotropism make it especially important in aeronautical applications[20].

Also, with their advantages of incombustibility, non-poison, sound-adsorption, low moisture-absorption and light mass, the porous alloy materials like Al-Mo, Al-Si and Al-Cu are applied to various structures of aircraft, automobiles and ships[56].

In the area of transportation, the mass reduction of transportation tools can greatly save energy and reduce environmental pollution. The reduction of mass is a new development trend of the automobile industry. It is estimated that 7.5×10^5 barrels of petrol, which is 13% of the total consumption, can be saved everyday only in the United States if the mass of transportation tools is reduced 25%. The decrease of the consumption of mineral oil can lead to the reduction of the amount of the discharged CO_2[13].

In the field of building, porous metals are needed to make light, hard and fireproof components, banisters or their supports. The frequent and quick variation of velocity of modern elevators brings an urgent demand for light mass structures (e. g. foamed aluminum or foamed panels) to lower the energy consumption, but safety rules usually exclude the traditional light mass structure technologies. Thus, foamed aluminum that possesses the characteristics both of energy absorption and mechanical strength presents a broad application prospect in this field[40].

A sandwich panel using porous metal as core is better than a traditional panel with honeycomb core. There is no need for sticking by resin, no danger caused by stratification and no worry about water seeping at joints. Besides, it is easy to make products into complicated shapes[57].

Cylindrical shells widely exist in engineering structures, e. g. oil well platforms far away from bank and aircraft bodies. Thin-wall cylindrical shells are easy to buckle and break when they are compressed along axes or bent. However, if they are supported by continuous low-density porous metallic cores, which serve as the elastic linings, their resistance to elastic bending will be greatly enhanced[58, 59].

Foamed copper is easy to produce, and is facile to deform, so it is apt to make fasteners[60]. Foamed metals can also be used as the reinforcing materials for many kinds of organic or inorganic materials. For example, to pour the melted aluminum into foamed nickel, a composite material of aluminum-alloy reinforced by foamed nickel (NFRA) can be obtained[61]. It is an aluminum-alloy base composite material. This kind of material with porosity of 6% ~ 30% (e. g. those reinforced by Fe or Ni foam) can be used in internal combustion engines[62].

The development trend of internal combustion engines will result in the high-load and high-power output. This trend is especially apparent for diesel engines. The hot compression from top part and the mechanical pressure make the piston of diesel engines crack or break down. Porous metals can be used as reinforcing material to promote the thermal and mechanical strengths. This material can be made by pressure casting, whose main step is to pour the piston material into voids of the reinforcing porous metals to form a composite structure. For example, the

melted aluminum or aluminum alloy at 680~ 820 ℃ can be poured into the porous Fe-base alloy containing chromium, nickel, molybdenum, carbon, copper, silicon, manganese and so on[63]. Further more, foamed nickel can be also used to replace the porous Fe-base alloy. Since the inter-diffusion between nickel and aluminum occurs during T6 solid solution treatment, an intermetallic compound, which is advantageous to the abradability of the circular groove, will form[64]. The tensile strength of the aluminum alloy reinforced by foamed nickel is improved. This material is easy to be prepared because the sides of voids of the foamed nickel is so large as 0.4~ 2 mm that the melted aluminum is easy to pour in it[65].

Furthermore, porous metals can be used as the light cores of panels, shells and pipes to produce various laminated composite materials[66] (as shown in Fig. 5).

9 ELECTROMAGNETIC SHIELDING

Porous metals are good materials for electromagnetic shielding or compatible components. With the high-speed development of modern electronic industry, electronic appliances are widely used, and the problem of electromagnetic radiation gets more and more serious. It not only interferes with other electronic equipment, but also results in information leakage, so the methods of electromagnetic shielding are very significant. Porous metals available in this field are mainly the three-dimensional reticulated copper or nickel with the internal cells all interconnected with each another. This structure is of good permeability, high dissipating capability and small mass density. Its shielding power is much bigger than that of metallic networks, and can match that of wave-guide windows. Compared with wave-guide windows, porous copper or nickel has the smaller volume and is more portable, so it is more suitable to be used in moving instruments or equipment[67].

10 BIOLOGICAL MATERIALS

Some porous materials like porous titanium, which are harmless to human body and possess good compatibility, have been used a great deal in medical and health area. For instance, porous-titanium hip-joints are used in orthopaedy; porous-titanium planted tooth roots are used for the renovation of teeth; porous W-Cr-Ni alloy composites are used in compound heart valvulae.

Other new applications have been developed since 1990s. Here are some examples: porous wolfram is applied to hot evaporation of silver or gadolinium (by means of injecting powder into porous body)[68], foamed copper is used as the matrix of viscoelastic body and low-temperature welding material[69], porous copper or nickel to measure the melting point of lead or Sn-Pb alloy[70], porous metals as

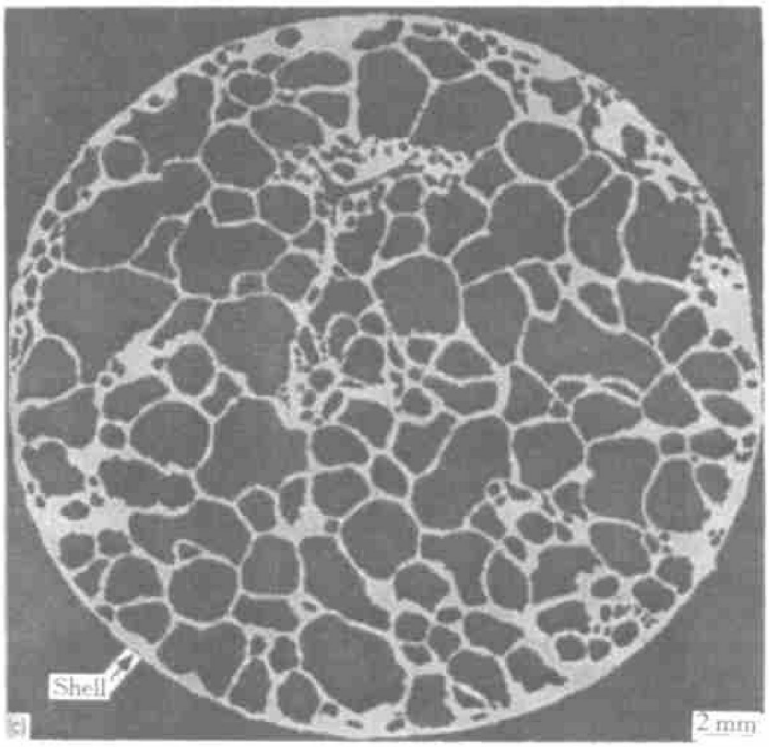

Fig. 5 Optical cross-sectional morphology of laminated composite material with light core of porous metal[66]

lamp-wick materials or the support materials of rockets or jet engines, porous bronze to serve as the exhaust plug in casting moulds. Some applications are still in the period of research and development. These applications include the absorbing agent of electromagnetic waves and neutrons electrization for solar and nuclear energies, the inner walls of nuclear reactors, the filling materials of the laminated panels used in shipping and aerospace industries, the sealing materials used in turbine jet engines, the hydrogen storage apparatus of hydrogen energy technology and so on. In the United States, the Sandia National Laboratory cooperated with the Special Metal Processing Corporation (SMPC) to study porous light metals that may become the materials with high strength and excellent properties. It is disclosed that they have been the foundation of rocket making plan[71].

A new porous metallic composite material introduced in UK Patent[72] can be used in the field of electrochemistry to produce the sensors of gas and the electrode of fuel cells. It can also be used for common purposes, such as the catalyst of chemical reactions, the catalytic active surface of high specific surface area, chromatographic-analysis separators and so on. The method for producing this material can be described as "metallization of porous matrix → oxidation in gaseous oxidative plasma zone → reduction in gaseous reductive plasma zone". The matrix can be ceramics or polymer, and the metal can be lead, palladium, nickel, silver, gold-palladium alloy, copper, etc.

11 SUMMARY

In most applications except like heat insulation, porous materials are developed in pursuit of not only high porosity, but also high through-hole ratio and high specific surface area, on the premise of sufficient mechanical strength. This not only results in the large scale production for the porous metallic materials with three-dimensional reticulated structure, but also makes its application rapidly popularize to relative field or somewhat widen the application of traditional porous materials. For instance, these high porosity metals can serve in various filters, liquid mixers, catalysts or their supporters, electrodes of fuel cells and batteries of nickel-cadmium, nickel-hydrogen and lithium, cathodes of electrochemical process for electrosynthesis and heavy-metal recovery, heat exchangers, sound-damping materials, electromagnetic shielding materials, composite metallic materials, some structural materials available in aerospace industry and so on[73~81]. Thus, in order to enhance and promote the application superiority that porous metals have won, the improvement of the preparation technology and the research of the property are very significant on high porosity metals.

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