Metal foams near commercialization

Metal foams combining low weight with other mechanical properties, such as good energy absorption and thermal resistance, have long been sought for a variety of industrial applications. Now, a powder metallurgy (PM) process developed at the Fraunhofer Institute for Applied Materials Research (IFAM) in Bremen, German, looks set to meet this demand. IFAM scientists John Banhart, Joachim Baumeister and Markus Weber outline the process and the materials it can produce, as well as looking at the potential applications.

Cellular materials are widespread in everyday life finding uses in construction, impact cushioning, insulation, noise and vibration dampening, filtering and many other applications. Highly porous materials are known to have a high stiffness combined with a very low specific weight. For this reason, cellular materials frequently occur in nature as construction materials, with examples including wood and bone[1].

Considerable effort has been made in the past to foam metals to obtain a material which combines the properties typical for any highly porous structure with the unique properties of metals. Despite this activity, none of these efforts has succeeded in finding a practical and economical process, being unable to overcome problems with foam properties, reproducibility and costs.

Using a powder metallurgical (PM) production method[2] developed at Fraunhofer Institute for Applied Materials Research (IFAM) in Bremen, Germany, it is now possible to obtain metallic foams of various metals and alloys in a fairly simple way. These foams enlarge the application range of cellular materials because of their excellent mechanical, thermal, electrical and other physical properties, as well as the fact that they are easier to recycle in comparison to polymeric foams. Parts of an arbitrary shape can be made by this foaming technique. Sandwich structures composed of a porous metallic foam core and metallic face sheets can also be produced with several options concerning material combinations and shapes.

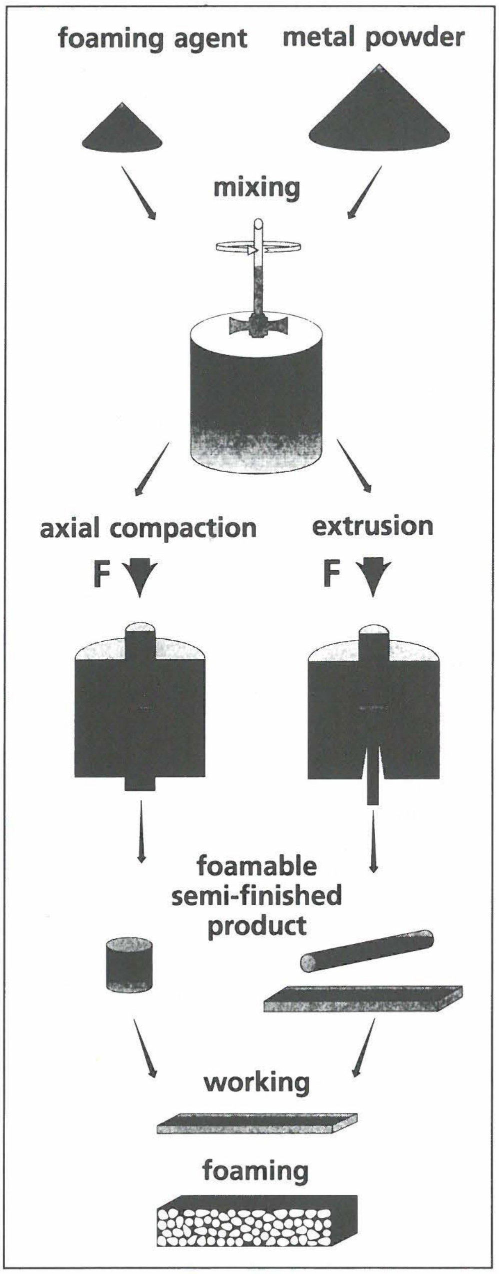

FIGURE 1: The process for making metal foam from metal powders.

The process

The production process begins with the mixing of metal powders — elementary metals, alloys or powder blends — with a foaming agent, after which the mix is compacted to yield a dense, semi-finished product (Figure 1). In principle, the compaction can be done by any technique that ensures the foaming agent is embedded into the metal matrix without any residual open

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porosity. Examples of such methods include uniaxial compression, extrusion and powder rolling.

Heat treatment at a temperatures near the melting point of the matrix material is the next step. During this process the foaming agent, which has been homogeneously distributed within the dense metallic matrix, decomposes. The released gas forces the compacted PM material to expand into its highly porous structure.

Prior to foaming the precursor material can be processed into sheets, rods, profiles and other shapes by conventional techniques like rolling, swaging or extrusion in order to improve the flow conditions during foaming inside moulds.

The density of the metal foams can be controlled by adjusting the content of foaming agent and several other foaming parameters, such as temperatures and heating rates. If metal hydrides are used as foaming agents, a content of less than 1% is sufficient in most cases.

Although most applications are based on aluminium foams, the Fraunhofer method is not restricted to this metal — tin, zinc, brass, bronze and lead can also be foamed by choosing appropriate foaming agents and process parameters. The most usual alloys for foaming, however, are pure aluminium, 2xxx alloys and 6xxx alloys. Casting alloys, such as AlSi12, are also frequently used because of their low melting point and good foaming properties, while in principle virtually any aluminium alloy can be foamed by properly adjusting the process parameters.

Foaming a piece of precursor material in a furnace will result in a lump of metal foam with an undefined shape unless the expansion is limited in certain directions. This is done by inserting the precursor material into a hollow mould and expanding it by heating. In this way near-net shaped parts, such as the component shown in Figure 3, can be prepared.

Sandwich panels consisting of a foamed metal core and face sheets can be obtained by gluing the face sheets to a sheet of foam. Alternatively, if a pure metallic bonding is required, conventional sheets of metal can be roll clad to a sheet of foamable precursor material. The resulting composite can be deformed in an optional step, e.g. by deep drawing. The final heat treatment then leads to a sandwich structure (Figure 4).

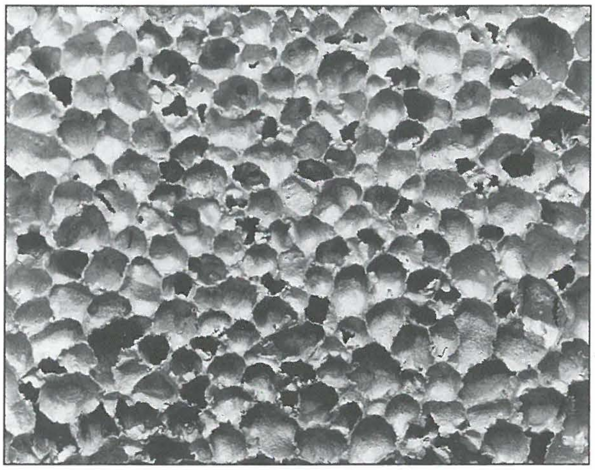

FIGURE 2: Optical micrograph of an aluminium foam (ratio 3:1).

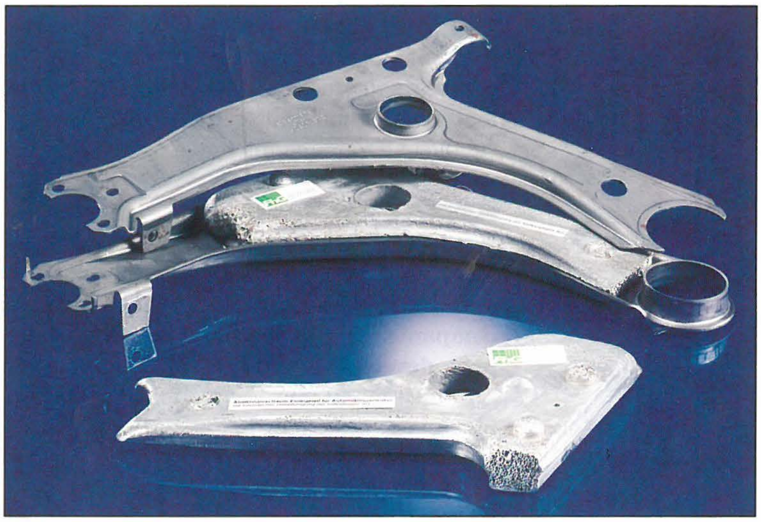

FIGURE 3: A shaped part made by filling a hollow steel mould with aluminium foam.

Properties of metal foams

The most prominent property of foamed metal is its low density. Density values of aluminium foams usually range from 0.4-1.0 g/cm^3, although values down to 0.2 g/cm^3 can be achieved. The porosity of metal foams is closed (Figure 2) and the materials usually develop a closed outer skin hiding their porous interior.

The mechanical properties strongly depend on the apparent density of the foamed metal. Compression strength, flexural strength and Young's modulus increase rapidly with increasing density. An example of this dependence is given in Figure 5, where the plastic deformation behaviour is shown for various foams of different densities. A behaviour typical of all kinds of foams is observed — a linear increase of stress at the beginning of the deformation giving way to a plateau of constant stress for deformations up to 60% followed by a recompaction at very high strains.

Mechanical properties are also influenced by the choice of the matrix alloy. By foaming age-hardenable alloys the strength properties can be optimized. Because of the special form of the compressive stress-strain curve, foamed materials are capable of absorbing large amounts of energy at a relatively low stress level. With aluminium foams an energy absorption of 90%, as compared to an ideal absorber, for compressions up to 70% can be achieved.

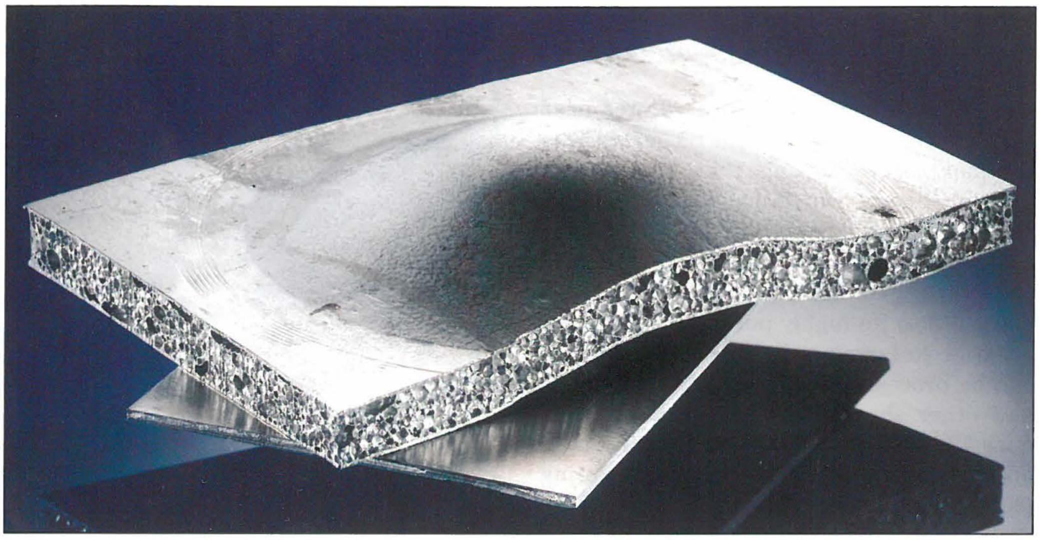

FIGURE 4: A 3-D shaped sandwich panel featuring steel face sheets and a core of foamed aluminium. The roll clad precursor can be seen beneath the sandwich.

The electrical and thermal conductivities of foamed metals are reduced in comparison to the corresponding solid materials, whereas the thermal expansion coefficient remains unchanged.

Applications

Until now aluminium foams have only been applied on a small scale as demonstration and testing items. There are two companies in Europe, however, which are now developing production facilities for aluminium foams. Various application ideas, as outlined below, are currently under investigation.

Automotive industry: Increasing safety demands in cars is leading to a higher vehicle weight in many cases. This is in conflict with further demands for low fuel consumption. Light, stiff structures made of aluminium foam, preferably in the form of sandwich panels, could help to reduce weight. Examples are bonnets, boot lids and sliding roofs, where a high stiffness is needed in order to prevent these parts from vibrating or to avoid torsional deformation. The German company Karmann (Osnabrück) is currently testing three-dimensionally shaped sandwich panels in cabriolets, where stiffness problems frequently occur.

Obviously, an important application field for metallic foams is energy absorption. Using suitable elements of aluminium foam it is possible to induce a controlled, programmed deformation in the crash zone of cars and trains with maximum energy consumption[3]. In comparison with existing energy absorbers the isotropy of the foamed metal is an important advantage. Possible applications are elements for side and front impact protection.

An interesting property of foams is their influence on the deformation behaviour and failure mode of aluminium and steel profiles and other hollow parts when they are filled with foam. Foam filling generally leads to higher deformation forces when profiles are bent, to higher energy absorption, when profiles are axially crushed. This property can be used in bumpers, underside protections of lorries, A- and B-pillars or other elements which are in danger of buckling or being compressed or have to absorb a large amount of energy.

Sound absorption and insulation is a very important topic in car manufacturing. A problem often encountered is that sound absorbing elements also have to be heat resistant which rules out polymer foams or leads to combination of materials, such as polymer foams and aluminium sheets, which are not desirable[4]. Aluminium foams at the current state-of-the-art do not exhibit excellent sound absorption properties because of their predominantly closed porosity, but they are heat resistant. Efforts are under way, however, to improve its suitability for these applications.

Aerospace: In aerospace applications the replacement of expensive honeycomb structures by foamed aluminium sheets or aluminium foam sandwich panels could lead to reduced costs. Also, an important advantage can be the isotropy of the

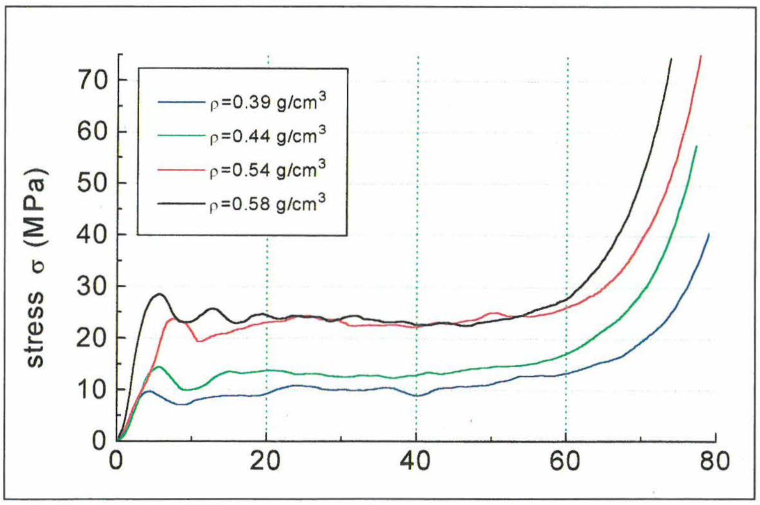

FIGURE 5: Stress-strain diagrams of aluminium foams of various densities.

Other methods for foaming metals

There are other routes than PM to produce a metal foam. They can be prepared by adding a foaming agent to a bath of molten metal after properly adjusting the viscosity of the melt. The foaming agent is usually a powdered metal hydride which releases hydrogen when it comes into contact with the molten aluminium. If a sufficient amount of hydride is added, the entire metal bath starts to foam. The result is a block of foam which can be cut into sheets for further processing.

An alternative way to foam aluminium is to add 10-15% silicon carbide particles to a melt. Provided the powder and the mixing procedure are appropriate, the manipulated melt has an enhanced viscosity and can be foamed by introducing gas by an impeller.

The resulting foam will accumulate on top of the liquid and can be drawn off by a belt. Foam slabs of considerable size (e.g. 0.1 x 1 x 10 metres) can be produced this way.

This method, however, encounters problems with drainage effects and with the homogeneity of the resulting foams. ■

properties of such panels and the absence of any kind of adhesive bonding giving rise to a more benign behaviour in the case of fires where it is essential that the structure maintains its integrity.

Building industry: There is a broad spectrum of potential applications for metal foams in the building industry which has a need for light, stiff and fire resistant facade elements, balustrades or for supports for such elements. Honeycombs or other materials are often ruled out because of high prices, high weights or a lack of temperature resistance.

Aluminium foams or foam panels could be very helpful in reducing the energy consumption of elevators. Because of the high frequency and high speed of accelerations and decelerations in modern elevators, lightweight construction is an important issue. Safety regulations, however, often prevent the application of conventional lightweight construction techniques. Because aluminium foams can act as energy absorbers and as a stiff structural material at the same time, these applications seem very promising.

The properties of the foamable precursors of metal foams could also be utilised by the building industry. In order to fasten plugs in concrete walls, for example, a piece of foamable aluminium could be inserted into the borehole before the plugs are inserted. The foamable precursor material would then be locally heated to enable it to expand. provided the density of the foam is high enough. Provided its density is high enough, the foam generated in this way will fill the gap between the concrete and the plugs leading to a very strong connection.

Special applications: There are plans to use aluminium foams as impedance adapters for acoustic applications. Other applications need a very light and stiff buoyant filling material for devices used for measuring the filling level of hot or corrosive media. As already mentioned, metals other than aluminium can also be foamed. Lead foams could serve as supports for the active material in lead acid batteries thus making the construction of very light electrodes possible.

Foams based on gold or silver have aesthetic appeal and are thought to be a potential new material for jewellery.

The future

By modifying the preparation technology it could be possible to obtain open pored aluminium foams opening up several additional applications, such as heat exchangers, filters and catalyst carriers. Consequently, investigations of foamed metals are being extended in this direction.

An extension of technology to the foaming of metals such as steel or titanium will introduce a wide scope of applications which make use of the high temperature resistance, extreme strength and various other properties of these materials. Due to their excellent bio-compatibility, for example, titanium foams could be used in prosthetic applications.

While these applications still lie in the future it appears that closed cell aluminium foams are ready to open up an important new niche for the PM industry. ■

References

(1) L.J. Gibson, M.F. Ashby, *Cellular Solids*, Pergamon Press, Oxford, (1988).

(2) J. Baumeister et al, Patents: German Patent (DE) 4018360 (1990); DE 4101630 (1991); DE 4124591 (1993); DE 4401740 and US patent US 5151246 (1992); European Patent EP 0460392A1 (1996).

(3) J. Banhart et al., *Proc. 29th Int. Symp. on Automotive Technology & Automation: Materials for Energy-Efficient Vehicles*, ed: D. Roller, Croydon, (1996), p. 611 (see also p. 645).

(4) J. Banhart (ed.), 'Metallschäume' (Metal foams), *Proc. Symp. Metallschäume, March 1997, Bremen (partially in English)*.