METAL FOAMS

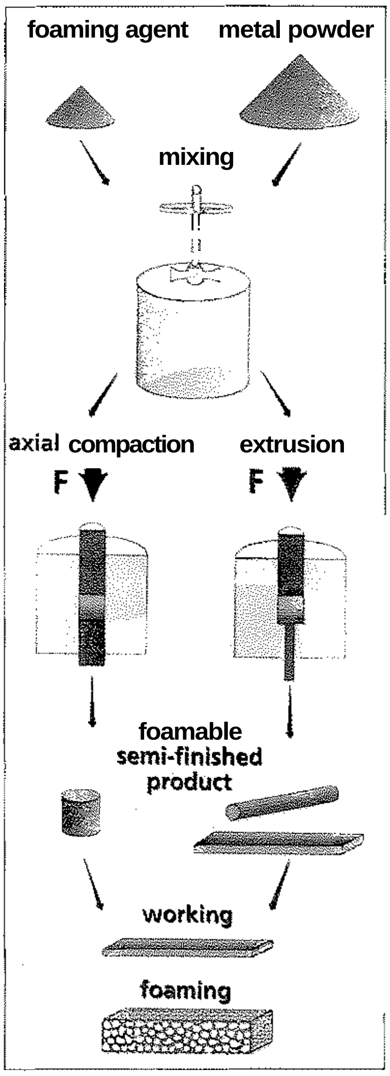

Fig. 1 — Production of metal foam.

Anew powder metallurgy process for production of metal fonms increases the application range of cellular materials. It was first developedfor aluminum foams nnd has recently been extended to other metals and nlloys.

Chin-Jye (Mike) Yu and Harald H. Eifert*
Fraunhofer Resource Center
Newark, Del

John Banhart and Joachim Baumeister
Fraunhofer Institute for Applied Materials Research
Bremen, Germany

Metal foams are metallic cellular materials that have a high porosity fraction, typically ranging from 40 to 90 vol%. Because of their high stiffness and low specific weight, cellular iiiaterials are applied in construction, packaging, insulation, noise and vibration damping, and filtering. They are considered by many tobe a new class of engineering materiai.

Typical foaming processes include casting, poivder pressing, metallic deposition, and sputter deposition. Metal foams can be fabricated in a variety of different ways, and many attemyts have been made in the past to develnp good foamstructure. However, the choice frequently seems to be between high cost and poor quality.

Recently, a powder method for fabricating metal foams was invented at the Fraunhofer Institute for Applied Materials Research (IFAM). This niethod allows for direct net-shape fabrication of foamed parts with a relatively homogeneous pore structure. Metallic foams fabricated by this approach exhibit a closed-cell microstructure with higher mechanical strength than open-cell foams. This type of microstructure is particularly appropriate for applications requiring reduced weight and energy-absorption capabilities.

Thr powder metallurgy production method makes it possible to build metallic foam parts that have complex geometry. Sandwich structures composed of a porous metallic foani core and metallic face sheets can also be produced, with options exploiting combined materials and shapes. These foams enlarge the application raiige of cellular materials because of their excellent physical and mechanical properties, as weil as their relative recyclability.

This article describes the process, microstructure, properties, and applicatioiis of metallic foams produced by the P/M niethod.

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Metal powder process

The process is begun by mixing metal powders (eitlier pre-alloyed metal powders or powdcr blends) with a small amount of foaming agrnt. When thc agent is a metal hydride, a content of less than 1% is generally sufficient. After the foaming agent is uniformlv distributed within the matrix powders, the mixture is compacted into a dense, semi-finished product with no residual open porosity (Fig. 1). Typical compaction methods include uniaxial pressing, extrusion, and powder rolling. The foamahle material may be further shaped through subsequent metalworking processes such as rolling, swaging, or extrusion.

Following the metalworking steps, the foamable material is heated to temperatures near the melting point of the matrix material. During heating, the foaming agent decomposes, and the released gas (hydrogen) forces the densified material to expand into a highly porous structure. The density of the metal foams can be controlled by adjusting the amount and type of the foaming agent and several other foaming parameters, such as temperature and heating rate.

The most common aluminum alloys for foaming are pure aluriiinum, 2xxx alloys, and 6xxx alloys. Aluminiim-silicon casting alloys are also recommended, because of their low melting points and good foaming properties. However, the Fraunhofer approach is also suitable for other metals such as tin, rinc, lead, bronze, and steel. Different alloys can be foamed by selecting appropriatc foaming agents and process Parameters.

The material may be foamed into complex

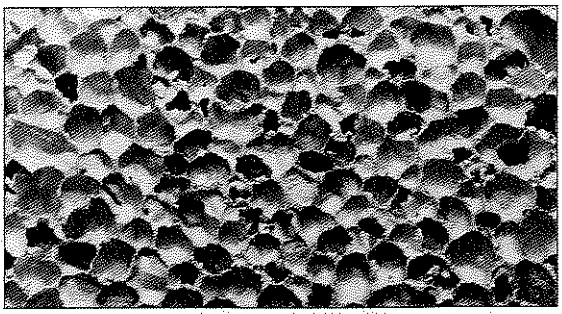

Fig 3 — Typical example of aluminum foam microstructure

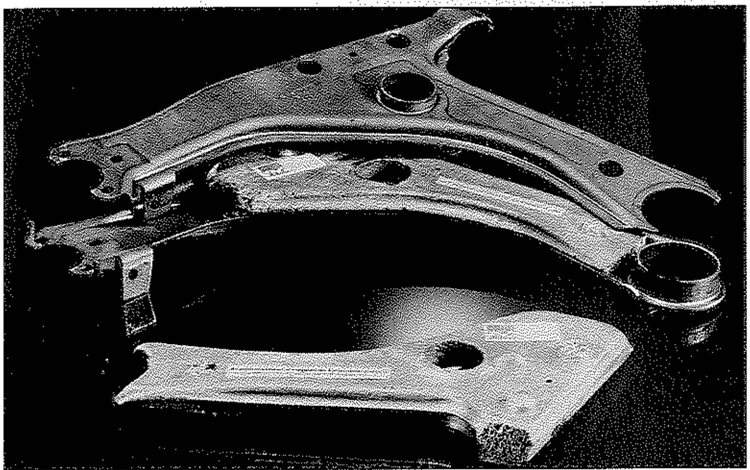

Fig. 2 — A shaped part made by filling a hollow steel mold with aluminum foam.

The materials may be foamed into complex shapes.

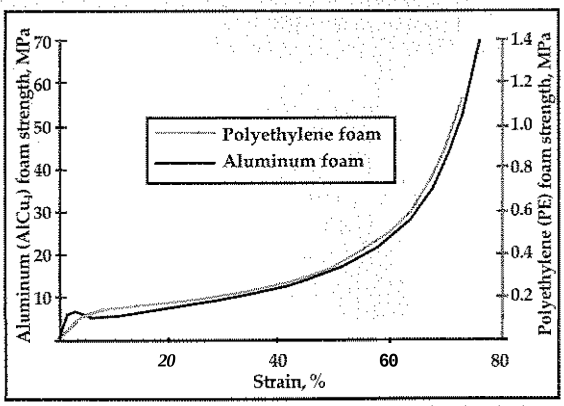

Fig. 4 — Loading curves of aluminum and polyethylene foams. Note that although the shapes are almost identical, the aluminum foam (red) is about 50 times stronger than the polyethylene foam (blue).

shapes by inserting the foamable material into a hollow mold and expanding it through heating. Figure 2 shows a near-net-shape part prepared in this way.

Sandwich panels consisting of a foamed metal core and solid face sheets may be fabricated by gluing the face sheets onto a foam core. If pure metallic bonding is required, face sheets and foamable material can be roll-clad to make a sandwich structure before foaming.

Microstructure and properties

The foamed aluminum parts produced by this powder method feature a relatively homogeneous closed-cell microstructure (Fig. **3**) with a fractional density as low as 20% of pure aluminum, whose density is 2.7 g/cm^3. The density values of aluminum foams usually range from 0.4 to 1.0 g/cm^3, although values down to 0.2 g/cm^3 can be achieved with some modifications to the materials and process parameters. This type of microstructure is responsible for the high specific stiffness-to-weight ratio (SWR) of the foam. Localized ceii coiiapse and rapid compaction energy dissipation provide the energy-absorption capability of the material.

A typical l o a d i i curve of metal foams indicates several stages, as shown in Fig. 4: initial, almost linear deformation; plastic collapse; and final densification. It can be seen from the comparison between the stress-strain curve of an aluminum ($AlCu_4$) foam (initial fractional porosity 83%) and the corresponding curve of a polyethylene (PE) foam (initial fractional porosity 87%), that the shapes of the two loading curves are similar. However, the stress level of the $AlCu_4$ foam is approximately 30 times higher than that of the I'E foam. 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.

Specific mechanical properties can be achieved by careful selection of the foamable matrix alloy. By foaming age-hardenable alloys, the strength of the foamed alloy can also be optimized during the subsequent heat treatment.

Potential applications

The following is a list of applications currently being investigated:

- *Automotive industry*: Light, stiff structures made of aluminum foam and foam sandwich panels could help to reduce weight and increase stiffness. Examples are hoods, trunk lids, and sliding roofs. The German automaker Karmann recently worked with Fraunhoferin developing three-dimensional aluminum foam sandwiches in the Ghia roadster (Fig. 5). The resultant foam sandwich panel is about eight times stiffer than the original steel panel, at a 25% lower weight.

With regard to energy absorption, it is possible to engineer controlled deformation into the crash zone of cars and trains with maximum impact-energy dissipation. Possible applications include elements for side and front impact protection. In general, foam filling leads to higher deformation forces when profiles are bent and to higher energy absorption when profiles are axially crushed. Potential applications include bumpers, underside protection of trucks, A- and B-pillars, and other elements subjected to large deformation.

Sound absorption and heat insulation are also important properties in the automotive industry. In many cases, sound-absorbing elements must also be heat resistant. Existing polymer foams or a combination of materials, such as polymer foams and aluminum sheets, may not be acceptable because of their poor heat resistance and poor recyclability. However, aluminum foam may improve these properties to meet the design criteria.

- *Aerospace industry*: Metai foam sandwich panels offer good potential to replace expensive honeycomb structures in the aerospace industry. The attributes of metal foams include the isotropy of the foam material and fire retardation to maintain the integrity of the structure. Roll cladding for direct metallic bonding caii eliininate the need for adhesive bonding in the sandwich panels.

- *Building industry*: Many construction applications require light, stiff, and fire-resistant elements, or supports for such elements.

Foamed sandwich panels could help to reduce the energy consumption for elevators by trimming the deck weight. Combining energy absorption and high specific stiffness, the foamed sandwich panels may be a good candidate for these applications.

Another application of the metal foams is to fasten plugs into concrete walls. To fill the gap between the plugs and the wall, the foamable materials can be inserted into the gap and locally heated. The foamable material will expand and fill the space between the plugs and the concrete wall, provided the resultant foam density is high enough.

- *Further applications*: Additional applications can capitalize on the properties of foams made from other metals. For example, lead and nickel foams may be suitable for batteries, and gold or silver foams may be applicable in art and jewelry.

Furthermore, open-cell foams can be fabncated by modifying the process scheme. This material would be excellent for several applications, such as heat exchangers, filters and catalyst carriers. Foaming of high-temperature alloys such as nickel and titanium will also help expand the application range, especially for aerospace and bio-medical components. ■

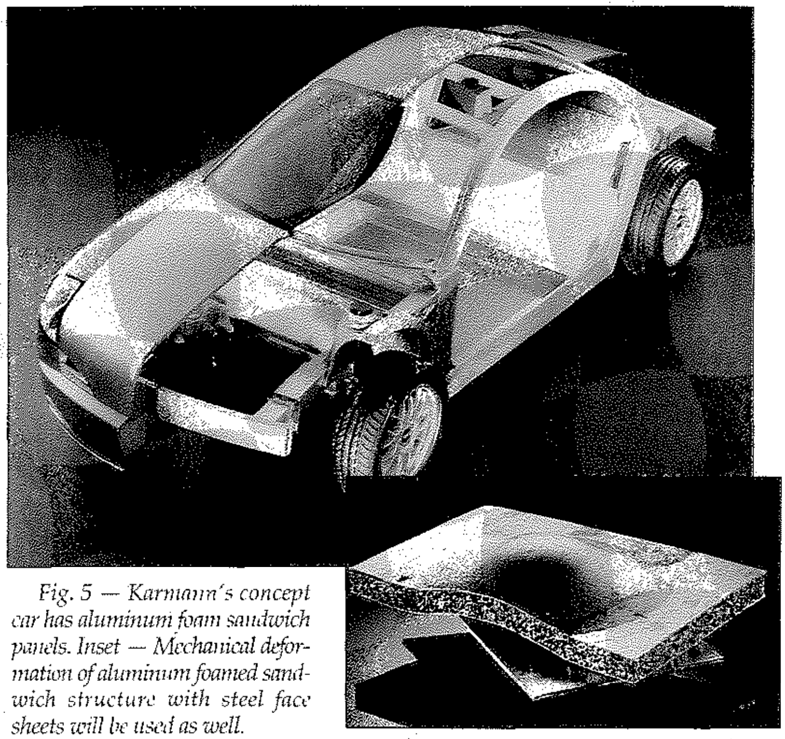

Fig. 5 — Karmann's concept car has aluminum foam sandwich panels. Inset — Mechanical deformation of aluminum foamed sandwich structure with steel face sheets will be used as well.

For more **information:** Dr. Chin-Jye (Mike) Yu is program mnnager, metal foaming, Fraunhofer Resource Center, 501 Wyoming Rd., Newark, DE 19716; tel: 2021 269-6761; fax: 302/369-6752; Web site: www.frc-de.fraunhofer.com; e-mail: yu@frc-de.fraunhofer.com.