Manufacturing Routes for Metallic Foams

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Editor's Note: A hypertext-enhanced version of this article can be found at www.tms.org/pubs/journals/JOM/0012/Banhart-0012.html

The study of metallic foams has become attractive to researchers interested in both scientific and industrial applications. In this paper, various methods for making such foams are presented and discussed. Some techniques start from specially prepared molten metals with adjusted viscosities. Such melts can be foamed by injecting gases or by adding gas-releasing blowing agents which cause the formation of bubbles during their in-situ decomposition. Another method is to prepare supersaturated metal-gas systems under high pressure and initiate bubble formation by pressure and temperature control. Finally, metallic foams can be made by mixing metal powders with a blowing agent, compacting the mix, and then foaming the compact by melting. The various foaming processes, the foam-stabilizing mechanisms, and some known problems with the various methods are addressed in this article. In addition, some possible applications for metallic foams are presented.

INTRODUCTION

Solid metallic foams are known for their interesting combinations of physical and mechanical properties such as high stiffness in conjunction with very low specific weight or high compression strengths combined with good energy absorption characteristics. Although interest in these materials is increasing, some confusion exists concerning the term "metallic foam," which is often used in a general way to describe materials that are not foams in the strictest sense.

To properly identify a metallic foam, one has to distinguish between

- Cellular metals: the most general term, referring to a metallic body in which any kind of gaseous voids are dispersed. The metallic phase divides space into closed cells which contain the gaseous phase.

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- Porous metals: a special type of cellular metal restricted to a certain type of voids. Pores are usually round and isolated from each other.
- (Solid) metal foams: a special class of cellular metals that originate from liquid-metal foams and, therefore, have a restricted morphology. The cells are closed, round, or polyhedral and are separated from each other by thin films.
- Metal sponges: a morphology of a cellular metal, usually with interconnected voids.

This paper will focus on foams in the strictest sense—liquid-gas mixtures, in the first stage of their evolution, which are solidified to solid foam. As surface tension creates a morphology in the liquid state (isolated gas bubbles which are separated from each other by metal films) the corresponding solid-metal foams show a similar morphology.

The manufacture of cellular metals in the most general sense, as described in published works,[1] does not always involve foaming methods. Often, a polymer foam is first opened by a special treatment and then replicated to yield a metallic structure. Replication can be carried out by coating with metal vapor, electroplating, or investment casting. The result is a structure with open porosity—a sponge rather than a foam. The physics of foaming has nothing to do with the metallic state because only the polymer precursor was foamed. Other structures can be used as templates for creating cellular materials: loose or sintered bulks of inorganic or organic granular matter, hollow spheres, or even regular polymer structures which are converted to a metallic structure in a designated processing step. In contrast, true foaming methods do not use a template for obtaining the special morphology; the metal is self-forming during foaming.

Figure 1 provides an overview of the methods available for making metal foams.[1] One distinguishing factor is whether molten metal or metal powder is used (although the actual foaming always takes place in the liquid state). A second difference is the gas source used for creating porosity: an external source can be used, a blowing agent can be decomposed in-situ, or dissolved gas can be forced to precipitate. Third, foaming can be instantaneous (i.e., addition of gas leads to immediate foaming), or an intermediate product is created that can be foamed in a later stage (delayed foaming). Finally, the mechanism of foam stabilization is different for the various methods as will be explained later. Some methods have been given a name, others were given a commercial name by the manufacturer.

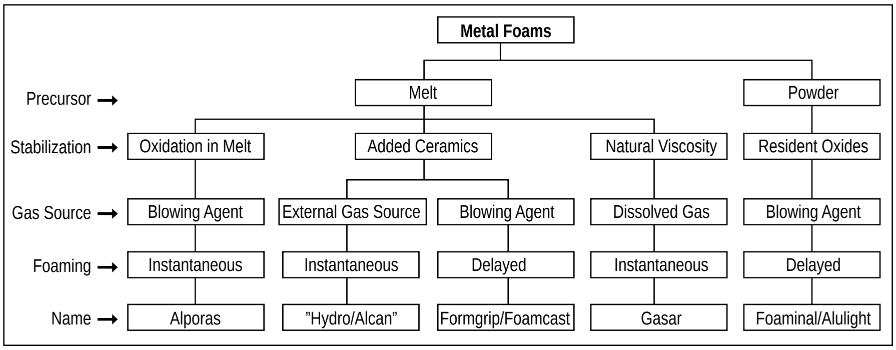


Figure 1. A family tree of metal foams.

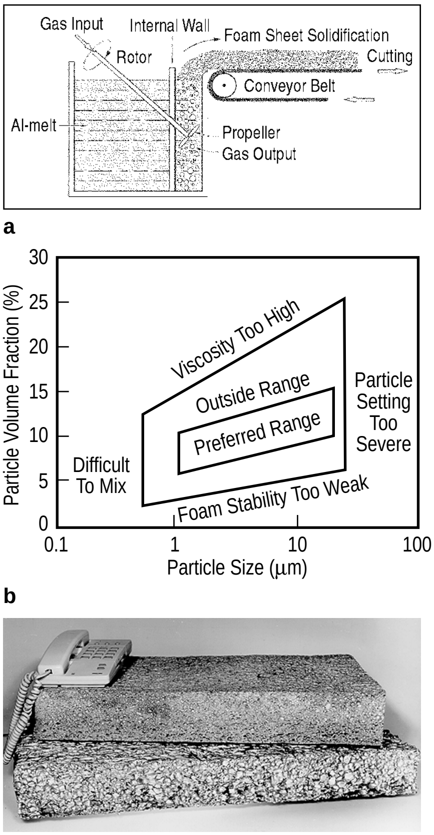


Figure 2. (a) Direct foaming of melts by gas injection;[2] (b) preferable range of stabilizing powders;[4] and (c) a sample made by Hydro-Aluminium.

PRODUCTION METHODS FOR METALLIC FOAMS

Under certain circumstances metallic melts can be foamed by creating gas bubbles in the liquid. Normally, gas bubbles formed in a metallic melt tend to quickly rise to its surface due to the high buoyancy forces in the high-density liquid. This rise can be hampered by increasing the viscosity of the molten metal, either by adding fine ceramic powders or alloying elements to form stabilizing particles in the melt or by other means. Metallic melts can be foamed in one of three ways: by injecting gas into the liquid metal from an external source, by causing an in-situ gas formation in the liquid by admixing gas-releasing blowing agents to the molten metal, or by causing the precipitation of gas which was previously dissolved in the liquid.

Foaming of Melts by Gas Injection (Hydro/Alcan)

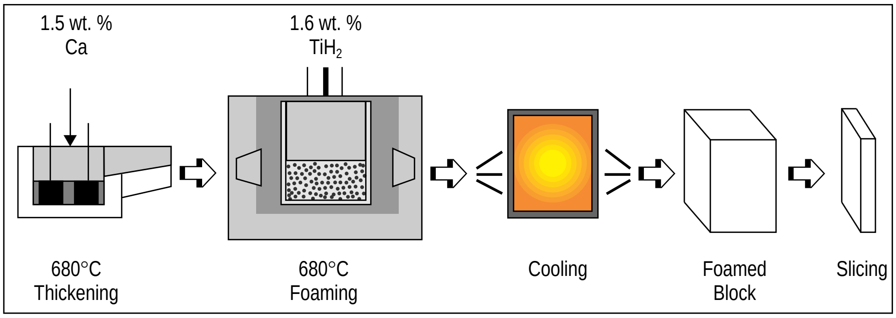
The first method of foaming aluminum and aluminum alloys is being exploited by Hydro Aluminium in Norway and by Cymat Aluminium Corporation in Canada.[2,3] According to this process, described schematically in Figure 2a, silicon-carbide, aluminum-oxide, or magnesium-oxide particles are used to enhance the viscosity of the melt. Therefore, the first step comprises the preparation of an aluminum melt containing one of these substances, making it a metal-matrix composite (MMC). This step reportedly requires sophisticated mixing techniques to ensure a uniform distribution of particles. A variety of aluminum alloys can be used.

The melt is foamed in a second step by injecting gases (air, nitrogen, argon) into it using specially designed rotating impellers or vibrating nozzles. These generate very fine gas bubbles in the melt and distribute them uniformly. The resultant viscous mixture of bubbles and metal melt floats up to the surface of the liquid where it turns into a fairly dry liquid foam as the liquid metal drains out. Because ceramic particles are in the melt, the foam is relatively stable. It can be pulled off the liquid surface (e.g. with a conveyor belt) and is then allowed to cool down and solidify. The resulting solid foam is, in principle, as long as desired, as wide as the vessel containing the liquid metal allows it, and typically 10 cm thick. The volume fraction of the reinforcing particles typically ranges from 10% to 20% with a mean particle size from 5 µm to 20 µm. The choice of particle size and content has been carried out empirically. If content or particle sizes are too high or too low problems can result, as shown in Figure 2b. The densities of aluminum foams produced this way range from 0.069 g/cm^3 to 0.54 g/cm^3, average pore sizes from 25 mm down to 3 mm, and wall thicknesses from 50 µm to 85 µm.[5] The average cell size is inversely related both to the average cell wall thickness and to the density and can be influenced by adjusting the gas flow, the impeller speed, nozzle vibration frequency, and other parameters.

A natural consequence of gravitationally induced drainage[6] is evident in foamed slabs (Figure 2c), which usually have a gradient in density, pore size, and pore elongation. Moreover, the shearing forces of the conveyor belt lead to diagonally distorted cells in the final product, causing a pronounced effect on the mechanical properties, which become anisotropic.[7] To avoid such results, the foam can be pulled off vertically. The foamed material is either used with a closed outer surface (its state upon coming out of the casting machine) or is cut into the required shape after foaming. The high content of ceramic particles can make machining of MMC foams difficult.

Advantages of the direct-foaming process include the capability for continuous production of a large volume of foam and the low densities that can be achieved. MMC foams are, therefore, probably less expensive than other cellular metallic materials. A possible disadvantage of the direct-foaming process is the eventual necessity for cutting the foam, thereby opening the cells.

Foaming pure, additive-free metallic melts with inert gases may be a means to avoid some of the unwanted side effects of stabilizing additives in metallic melts (e.g., brittleness).[1] To keep viscosity low, the foaming process has to take place at temperatures very close to the melting point. This can be done by bubbling gas



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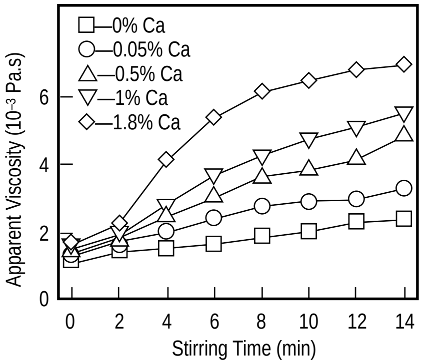

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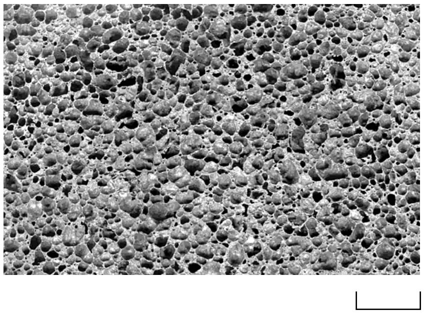

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Figure 3. (a) Direct foaming of melts by adding gas-releasing powders (Alporas-process);[8] (b) viscosity vs. stirring time;[9] and (c) the pore structure of foam (Southeast University, China).

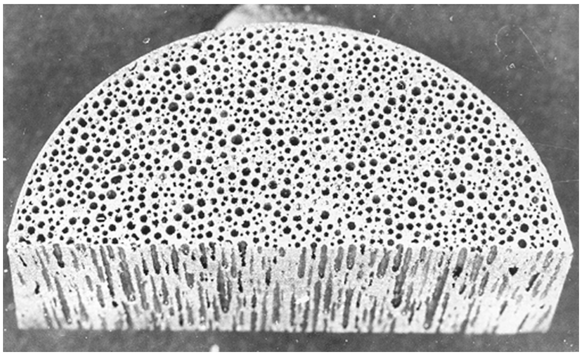

Figure 4. Gasar, showing largely elongated pores (V. Shapovalov).

through a melt which is constantly cooled down (e.g., in a continuous casting process). The bubbles are then caught in the solidifying liquid and form a foam-like structure. In the liquid state such systems are very unstable compared to particle-stabilized metals, which can be kept liquid for some time.

Foaming of Melts with Blowing Agents (Alporas)

A second way for foaming melts directly is to add a blowing agent to the melt instead of injecting gas into it. Heat causes the blowing agent to decompose and release gas, which then propels the foaming process (Figure 3a).[8] Shinko Wire Company, Amagasaki, Japan, has been producing foams in this way since 1986 with production volumes reportedly up to 1,000 kg per day. In a first step, about 1.5 wt.% calcium metal is added to an aluminum melt at 680°C. The melt is stirred for several minutes, during which its viscosity continuously increases by a factor of up to five because of the formation of calcium oxide (CaO), calcium-aluminum oxide ($CaAl_2O_4$), or perhaps even Al_4Ca intermetallics, which thicken the liquid metal. Figure 3b shows the effect of stirring on the viscosity of aluminum melts with various calcium additions.[9] After the viscosity has reached the desired value, titanium hydride (TiH_2) is added (typically 1.6 wt.%), serving as a blowing agent by releasing hydrogen gas in the hot viscous liquid. The melt soon starts to expand slowly and gradually fills the foaming vessel. The foaming takes place at constant pressure. After cooling the vessel below the melting point of the alloy, the liquid foam turns into solid aluminum foam and can be taken out of the mold for further processing. The entire foaming process can last 15 minutes for a typical batch (2,050mm × 650mm × 450 mm^3). A careful adjustment of process parameters has been shown to lead to homogeneous foams (Figure 3c). In fact, the foams produced in this way—trade name Alporas—seem to be the most homogeneous aluminum foams currently available. An empirical relationship exists not only between average cell diameter and the viscosity of the melt but also between the final foam density and viscosity.[9] Typical densities after cutting off the sides of the cast foam blocks are between 0.18 g/cm^3 and 0.24 g/cm^3, with the average pore size ranging from 2 mm to 10 mm. The viscosity of molten aluminum can also be enhanced by bubbling oxygen, air, or other gas mixtures through the melt, thus causing the formation of alumina; by adding powdered alumina, aluminum dross, or scrap foamed aluminum; or by using metallic viscosity-enhancing additives. However, the proper adjustment seems to be quite difficult and requires complicated temperature cycles and mechanical agitation.

Solid-Gas Eutectic Solidification (Gasar)

A method developed about a decade ago[10] exploits the fact that some liquid metals form a eutectic system with hydrogen gas. If one of these metals is melted in a hydrogen atmosphere under high pressure (up to 50 atms), the result is a homogeneous melt charged with hydrogen. If the temperature is lowered, the melt will eventually undergo a eutectic transition to a heterogeneous two-phase system (solid + gas). If the composition of the system is sufficiently close to the eutectic concentration, a segregation reaction will occur at one temperature. As the melt is solidified, gas pores precipitate and are entrapped in the metal. The resulting pore morphologies are largely determined by the hydrogen content, the pressure over the melt, by the direction and rate of heat removal, and by the chemical composition of the melt. Generally, largely elongated pores oriented in the direction of solidification are formed (Figure 4). Pore diameters range from 10 μm to 10 mm, pore lengths from 100 μm to 300 mm, and porosities from 5% to 75%. The pore size distribution is non-uniform because of concurrent growth of small and large pores and coalescence. Pores may be conical or even corrugated. The word "gasar" was coined to refer to the porous materials formed by solid-gas eutectic solidification. Gasar is a Russian acronym meaning "gas-reinforced."

Foaming of Powder Compacts (Foaminal/Alulight)

Foamed metals can be also be prepared from metal powders.[11,12] The production process begins with the mixing of metal powders—elementary metal powders, alloy powders, or metal powder blends—with a blowing agent, after which the mix is compacted to yield a dense, semi-finished product (Figure 5a). The compaction can be achieved using any technique in which the blowing agent is embedded into the metal matrix without any notable residual open porosity. Examples of such compaction methods are uniaxial or isostatic compression, rod extrusion, or powder rolling. The precursor has to be manufactured very carefully because residual porosity or other defects will lead to poor results in further processing. The next step is heat

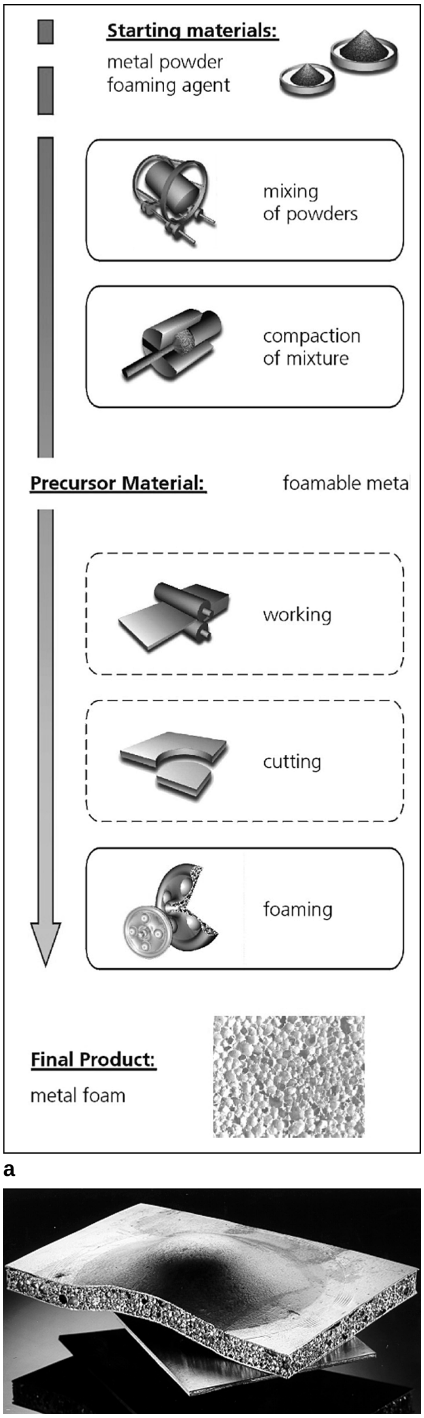

Figure 5. (a) The principle of powder-compact foaming method,[11] (b) steel/aluminum foam/steel sandwich (Fraunhofer, Bremen).

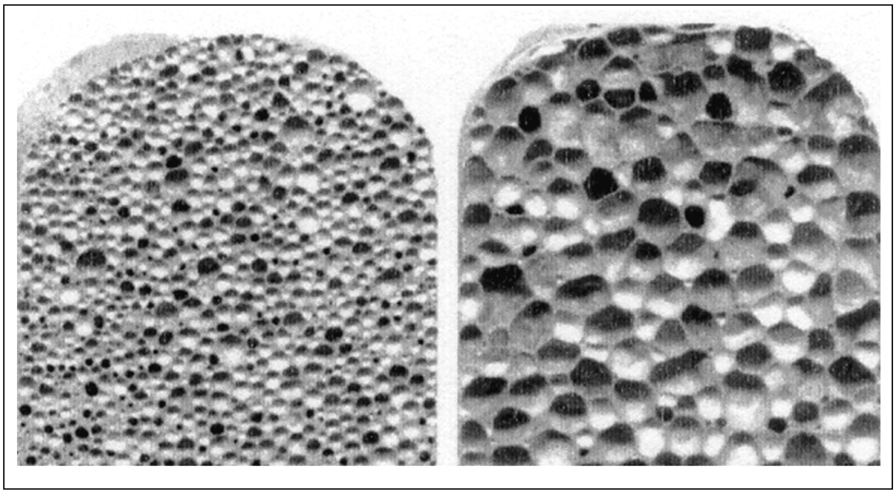

Figure 6. Two samples of aluminum/silicon-carbide foam.[19]

treatment at temperatures near the melting point of the matrix material. The blowing agent, which is homogeneously distributed within the dense metallic matrix, decomposes and the released gas forces the melting precursor material to expand, forming its highly porous structure. The time needed for full expansion depends on the temperature and size of the precursor and ranges from a few seconds to several minutes. The method is not restricted to aluminum and its alloys; tin, zinc, brass, lead, gold, and some other metals and alloys can also be foamed with appropriate blowing agents and process parameters.

If a piece of precursor material is foamed in a furnace, the result will be a lump of metal foam with an undefined shape unless the expansion is limited. This is done by inserting the precursor material into a hollow mold and expanding it by heating, creating near-net shaped parts with a closed outer skin and a highly porous cellular core.[13] Complicated parts can be manufactured by injecting the still-expanding foam from a reservoir into suitable molds.[14]

Sandwich panels consisting of a foamed metal core and two metal face sheets can be fairly easily obtained by bonding the face sheets to a piece of foam with adhesives. Alternatively, if pure metallic bonding is required, conventional sheets of metal—aluminum or steel—are roll-clad to a sheet of foamable precursor material.[15,16] The resulting composite can be deformed in an optional step, e.g., deep drawing. The final heat treatment, in which only the foamable core expands and the face sheets remain dense, then leads to sandwich structures such as the one shown in Figure 5b. Aluminum foam can be combined with steel or titanium face sheets as well as with aluminum face sheets. In the latter case, alloys with melting points that are different from the core material and the face sheets must be used to avoid melting the face sheets during foaming. A large aluminum/aluminum foam sandwich was developed in a joint effort by the German car maker Karmann in Osnabrück and Fraunhofer-Institute in Bremen for a concept car in which structural aluminum foam applications were demonstrated.[17] Such sandwiches are three-dimensional, up to two meters long and about one meter wide.

The powder-compact melting method is in small-scale commercial by the German companies Schunk (Giessen) and Honsel (Meschede) and the Austrian companies Alulight (Ranshofen) and Neuman Alufoam (Marktl). The names "Foam-in-Al" and "Alulight" have been coined for these foams.

Foaming of Ingots Containing Blowing Agents (Formgrip/Foamcast)

The powder-compact melting process was recently modified by incorporating titanium-hydride particles directly into an aluminum melt instead of using powders to prepare a foamable precursor material. To avoid premature hydrogen evolution the melt has to be either quickly cooled down below its melting point after mixing or the blowing agent has to be passivated to prevent it from releasing gas before solidification. The former technique, named "Foamcast," was carried out in a die-casting machine, when the powdered hydride was injected into the die simultaneously with the melt.[18] Normal casting alloys such as A356 without ceramic additives were used. The resulting cast part was virtually dense and could be foamed by re-melting in analogy to the powder-based method described previously. However, achieving a homogeneous distribution of TiH_2 powders in the die is challenging. The latter route requires that TiH_2 powders be subjected to a cycle of heat treatments that form an oxide barrier on each particle and delay decomposition. The powders are then added to a melt and can be cooled at comparatively slow rates after stirring.[19] Melts containing silicon carbide are used to obtain stable foams. The foaming process can be influenced by varying heating rates and final foaming temperatures, thus allowing for producing a variety of different pore structures (Figure 6). The process has been named "Formgrip," which is an acronym of foaming of reinforced metals by gas release in precursors.

STABILITY OF METALLIC FOAMS

Foams are unstable systems because their large surface area causes energy to be far from a minimum value. Foams can therefore be, at the most, metastable, constantly decaying at a certain rate. With foams, then, stability is the equivalent of slow decay. Aqueous and non-aqueous foams are stabilized by surfactants which form a dense mono-layer on a foam film. Such layers reduce surface tension, increase surface viscosity, and create electrostatic forces (the so-called disjoining forces) to prevent a foam film from collapsing.[20] Metallic foams must be stabilized by different means because there are no surfactants and electrostatic forces are screened in metals. Like water, pure metallic melts cannot be foamed, but additives are required to act as stabilizers to create a foam.

Silicon-carbide particles, for example, were added to the melt in the Hydro/Alcan foaming process. These particles, typically about 10 µm in diameter, were proven necessary by measuring foaminess as a function of particle content. It was found that 8–20 vol.% silicon carbide in aluminum was needed depending on how the gas is injected into the liquid.[21] A micrograph of a foam of this type is shown in Figure 7. The original

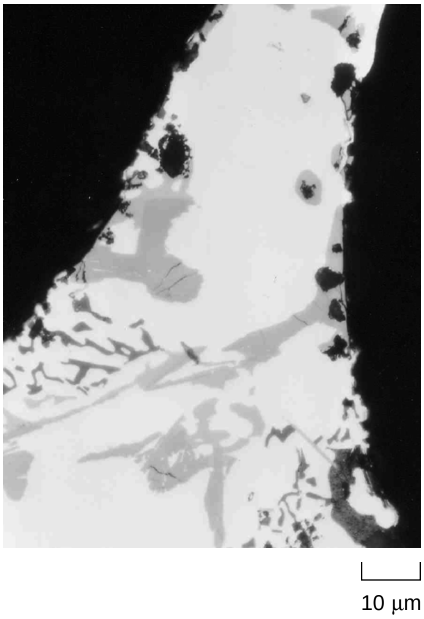

Figure 7. Microstructure of foam made by injecting gas into silicon-carbide-reinforced melt (Alcan foam).

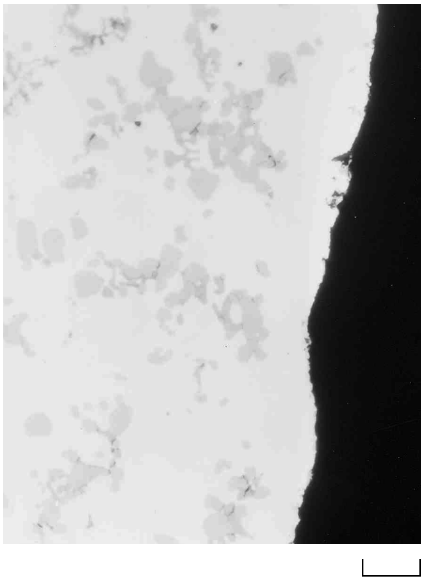

Figure 8. Microstructure of the cell wall material of an Alporas foam.

composition of the material was not communicated, but presumably it contained about 7 wt.% silicon, some magnesium, and about 15 wt.% silicon carbide. Inclusions are evident, all with angular contours but with varying shapes and colors. Although an analysis by energy-dispersive x-ray analysis (EDX) yielded a variety of different compositions, very small particles are difficult to analyze because EDX recorded an average over a circular area of 8 µm diameter and 3 µm depth. However, one can find regions which contain MgO (fairly large with $d \approx 20$ µm), fine Al-Si near-eutectic regions, iron-rich phases, and, finally, silicon-carbide particles with a dispersion of size. The inclusions can be found all over the cross section of the foam films with a slight tendency for an accumulation at the film surfaces.

In the Alporas process, additives are aluminum-, calcium-, or mixed oxides, which are formed in the melt by internal oxidation after adding calcium metal and stirring. The source of oxygen could be alumina or other oxides that are in the melt before adding calcium, or air that is dragged into the melt during agitation. A micrograph of an Alporas foam (Figure 8) shows two different types of precipitates: light gray precipitates, the majority of which are about 10 µm in diameter, and a small fraction of smaller, dark gray inclusions, about 3 µm in diameter, that are connected to the light gray particles. An EDX analysis finds the light gray areas contain roughly 5 at.% calcium, 12.5 at.% titanium, and 5 at.% oxygen, the dark areas 12 at.% calcium, 2 at.% titanium, and 6 at.% oxygen. The dark areas, because of their small size, could not be measured precisely, however. The values obtained are in a reasonable agreement with values found in published reports.[6] The precipitates likely contain various mixed oxides of aluminum, calcium, and titanium such as Al_2CaO_4 or $Al_2Ca_3O_6$, or oxide mixes Al_2O_3+TiO_2,[22] or intermetallic compounds such as Al_4Ca, Al_2Ca, or Al_3Ti.[23,24] There is no evidence that the precipitates are concentrated on or near the bubble/air interface but they seem to be fairly evenly distributed over the cross section of the cell walls. One can easily find parts of the bubble surface which do not contain any precipitates. This casts doubts on the hypothesis that solid particles floating on the walls of films are responsible for their stabilization in analogy to the action of surfactants in aqueous foam.[21,25]

In the Foaminal/Alulight process, the stabilization can be ascribed to metal-oxide filaments which reside in the powder compacts used, because oxides cover the surface of each powder particle prior to solidification and remain in the compact after pressing. These filaments are very thin, especially for aluminium where their thickness is believed to be well below 100 nm. The important role of these oxides in foam stabilization is shown in Figure 9. Lead foams were manufactured by mixing lead powders with different degrees of oxidation with a blowing agent, compacting the mix, and foaming it. Powders with very low oxide contents lead to unstable foams; as the foam rises liquid drains from it and limits its expansion. More stable foams result when powders with higher oxide contents are used and a large part of the liquid lead is kept in the foam structure at least until maximum expansion has been reached. There is also some evidence that the same mechanisms are effective for aluminum.[27]

Metallic foams, therefore, appear to be stabilized by solid particles. The action of foam stabilization is not entirely clear yet, but some current ideas on metal foams have been published[19,21,25] as well as general information on foams.[20] There are two questions to be discussed in this context. First, where are the solid particles located in the foam? Second, are they incorporated into the metal or do they segregate? Their behavior is governed by the wettability of the particles by the melt, commonly described by the contact angle between the two. This angle is determined primarily by the chemical composition of the particle but probably also by its size, shape, surface roughness, and concentration in the liquid. The particles in the silicon-carbide stabilized aluminum foams of the Hydro/Alcan- and Formgrip-type have been said to be partially wetted as they accumulate on the inner walls of bubbles.[19,21] This view, however, is supported neither by the work of the author (Figure 7) nor the micrographs shown in Figure 6. Surface oxides have not yet been directly observed in the foams made by powder-compact melting. All that is known is that aluminum-powder compacts have oxide contents up to 1 wt.% and that the foams show oxide layers on their surfaces that are 30 nm thick after foaming under argon.[27] However, part of this oxide might have formed by reactions with residual oxygen in the foaming chamber. Recent real-time x-ray observations of the aluminum-foaming process have revealed that oxidation of evolving foams increases the apparent viscosity of films that are near the surface and, therefore, exposed to oxygen.[28] However, this effect should not be confused with the postulated effect of particles accumulating on the film surface.

Second, how does a given configuration of ceramic particles and metal films influence foam stability? Various mechanisms have been proposed:

- Uniformly dispersed solid particles increase the bulk viscosity of melts. This slows down the vertical motion of liquid metal and contributes to kinetic foam stability. Especially in thin films there could be a progressive effect when the solid particles touch and form barriers. As the films get thinner, these barriers build up and become less penetrable to the melt, thus creating a self-stabilizing mechanism by a kind of

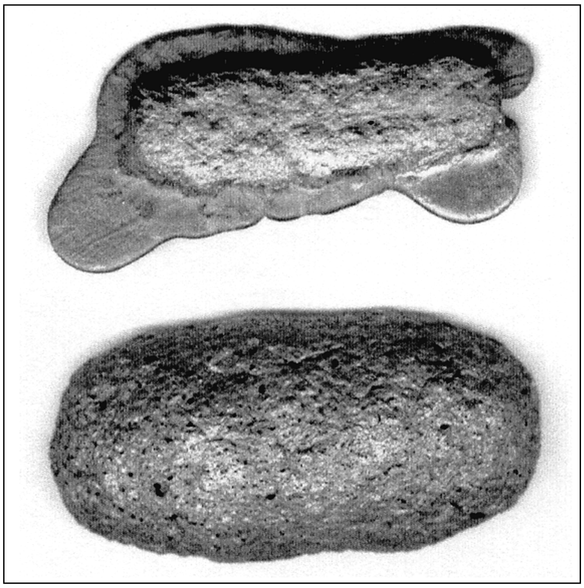

Figure 9. Lead foams made from two different lead powders. (a) Low-oxygen powder (0.06 wt.%) and (b) higher oxidized powder containing 0.46 wt.% O.[26]

additional structural viscosity. Moreover, as viscosity drops with rising temperatures, liquid metallic foams are more stable if they are kept at temperatures close to the melting point.

- It was suggested[21] that solid particles lead to flatter curvatures around the plateau borders and therefore, to a reduced suction of metal from the films into the borders. However, no experimental verification or theoretical explanation for this effect was given.
- The wetting angle has to be in a certain range to ensure that the bubble/particle interfaces are stable when the bubbles rises through the melt (i.e., the particles are not stripped off the bubbles), and that the particles on the interface lower the total energy of a pair of bubbles with particles in between (i.e., stabilize bubble/particle/bubble interfaces). There is no stabilization effect for insufficient wetting (high contact angle) as well as for over-wetting (low contact angle). In principle, from the known wetting angles of ceramic particles with a given melt, particles can be selected that have an optimum stabilization effect.[25]

In conclusion, although the stabilization mechanism is still not well understood, I believe the use of solid particles to enhance the viscosity of a metallic melt is the main means to stabilize the structure. A surface effect by partially wetted particles in analogy to the action of surfactants in aqueous foams seems rather implausible. The opposite could be true: it is apparent that metal films cannot be stretched as far as aqueous films, which can be made as thin as 10 nm, whereas metal films usually rupture at 20–80 μm depending on the type of foam, which is about the diameter of the solid particles. It can, therefore, be suspected that solid particles destabilize films when they become too thin rather than stabilize them.

CHALLENGES

The development of metallic foams looks back on a long history. The first serious attempts to make such foams date back into the 1950s. However, none of the processes available today and in the past have been brought to a level of sophistication comparable with that of polymeric foams. Deficiencies of the various metal-foaming techniques can be found on many levels, namely:

- A lack of understanding of the basic mechanisms of metal foaming. Knowledge is still speculative and some points remain unclear. For instance, why does one need 10–20 vol.% stabilizing particles for the Hydro/Cymat process while very small amounts of oxide filaments (≈1%) are sufficient in the powder-compact technique?
- Insufficient ability to make foams of a constant quality with pre-defined parameters. Much of the research and development work in the past seems to have been carried out on a mainly empirical basis without a detailed knowledge of the underlying mechanisms of the foaming process. One reason for this is that much of the work was carried out by companies or commercially oriented research institutes which have to earn money with a new technology very quickly. A solution would be an increase in fundamental research work. Only a detailed understanding of all process parameters would allow designed materials to be made with a pre-defined profile of mechanical and physical properties.
- Difficulties in finding applications for metallic foams. Beside some niche-market applications there is no real industrial application of metallic foams at the moment. The reasons for this are varied: Physical properties of foams are inadequate (solution: improvement of properties by optimizing the foaming process and materials selection); knowledge of foam properties is insufficient (solution: further characterization of properties. Scientific programs in Germany, the United Kingdom, and the United States are seeking a systematic evaluation of metal-foam properties); transmission of research results to construction engineers is not sufficient (solution: databases and design guidelines for metallic foams have to be created and disseminated. There has been some movement on this field recently[29]); foams are too expensive (solution: the selection of applications where the specific properties of foams are fully exploited is indispensable. This search cannot be done without a detailed knowledge of the properties of foams and of the limits of foaming processes however, so design engineers will not start such a search).

OPPORTUNITIES

Metal foams have predominantly closed cells which makes them useful for structural, load-bearing applications, whereas functional applications (filtration, damping, etc.) require open structures. There are three types of applications for metal foams.[1] In light-weight construction foams can take a large volume while maintaining a low weight; their weight-specific mechanical stiffness is relatively high. The specific stiffness of flat panels, for instance, is approximately proportional to their thickness. In energy absorption, their structure allows foams to absorb a large quantity of mechanical energy when they are deformed, while stresses are limited to the compression strength of the material. Metal foams with their high strengths can therefore act as high-capacity impact-energy absorbers. For acoustic and thermal control, foams can dampen vibrations and absorb sound under certain conditions. Moreover, their thermal conductivity is low. These properties are not outstanding—polymer foams are much better sound absorbers—but they could be useful in combination with other metal-foam features.

The automotive industry is considering applications based on one or more properties of metal foams. The aluminum-foam-steel sandwich of Karmann[17] is one example. Because these sandwich panels are three-dimensional and very stiff at a relatively low weight, they could replace conventional stamped steel parts in a car when combined with new constructional principles. At the same time they could also reduce the number of parts in the car frame, facilitate assembly, and, therefore, reduce costs while improving performance.

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