Industrialisation of P/M foaming process

F. Baumgärtner, H. Gers
Schunk-Honsel-Entwicklungsgemeinschaft, Heuchelheim-Meschede, Germany

Abstract

This review covers the main foaming process of aluminium foam and its alloys by P/M pre-material, the so-called IFAM-process. By mixing aluminium or aluminium alloy with a foaming agent and its compaction by various steps, a suitable pre-material is obtained. By heating the pre-material in foaming tools, pore formation commences and by further heating the foam growth will occur. Pure aluminium and some alloys are discussed by considering the temperature-expansion-behaviour. The foam stabilisation is also a serious process step to get a defined pore size. Both the foam growth and the foam stabilisation depend on the foam equipment such as the type of furnace, the shape and material of the foaming mould and the cooling rate during foam stabilisation.

The advantage of the IFAM-process is to produce various shapes of pre-material. The ram extruded raw material can be rolled to blanks or clad to sandwiches with defined thickness of all layers. It is advantageous to use a standard raw material to get several kinds of foam parts like volumetric elements, foam sheets or aluminium foam sandwiches (AFS), if needed in a 3-dimensional structure.

1 Introduction

Many technical systems became reality because of using a cellular material to get special properties. The systems profit from the widespread properties of such kinds of materials. In such situations, metal foams, newly developed at the beginning of the 90´s, can nowadays give new solutions to special technical problems. The particular properties of Al-foams, like high stiffness to weight ratio, high energy dissipation, low density, easy recycling, reduced acoustical, thermal and electrical conductance, chemical resistance etc open new possibilities for innovative constructions. Beside the pure weight reduction, Al-foams are able to give a solution as a complete system. Foamed metals are not only a material for simple substitution, but they will also find acceptance where an intelligent material will be needed to give solutions to several demands.

Beside Al-foam structures in furniture design, the material finds respect in technical systems. For example, structural lightweight solutions such as horns for pantographs will be realised. A big potential for metal foams will be due to the possibility of getting higher stiffness of existing systems by using a core of foam. For example the automotive industry reduces weight with decreasing steel sheet thickness. But with decreasing the thickness of several parts, buckling will increase, too. By using an Al-foam core it is possible to get a higher stiffness and rigidity. Additionally by the high energy dissipation capability of the foam, the passive crash safety will increase. A highlight in lightweight construction is the use of aluminium foam sandwiches (AFS) in space frame constructions. Karmann, for example, has shown an

J. Banhart, M.F. Ashby, N.A. Fleck: *Metal Foams and Porous Metal Structures.* © MIT Verlag (1999)

increasing structural rigidity for the whole car body by using AFS instead of conventional steel panels. Simultaneously a weight reduction is possible and the demand for a high recyclability of the whole system will be assured.

2 Production Process

2.1 Fundamentals of the production process

The IFAM-production process consists of various steps [1-3]. It begins with mixing aluminium powder with other typical alloying elements and a foaming agent, usually TiH_2. The selection of the raw powders depend on the purity, the particle size and distribution, the alloying elements and other parameters of the powder. This powder mixture should be homogeneous with respect to the material properties like homogeneous density or the distribution of the TiH_2 to get a high quality foam with controlled pore size distribution. The mixture is compacted to a highly dense pre-material which can be foamed. The pressing itself can be done by various techniques, but they have to guarantee an embedded foaming agent in the metal matrix without any open porosity.

The typical procedure to get a raw material about nearly 100% theoretical density is the use of cold isostatic pressing before ram extrusion. These steps ensure process parameters in a beneficial temperature interval below the decomposition temperature of the foaming agent. Cold isostatic pressing (CIP) is needed to present slugs for extrusion with a defined pre-density of about 70-80% TD and a guarantee of preventing pollution, de-mixing and to have better handling. The CIP-slugs are not foamable and by heating them up to the decomposition temperature of the foaming agent, the H_2-gas will get lost by diffusion through the open porosity of the slugs. To obtain foamable material, the slugs are extruded into rods or any other profile. The advantage of such kind of production of raw materials is the easy scaling up from laboratory state into mass production. The R&D-activities always take place on typical presses used for serial production with the guarantee to get a higher output if there is a demand for it.

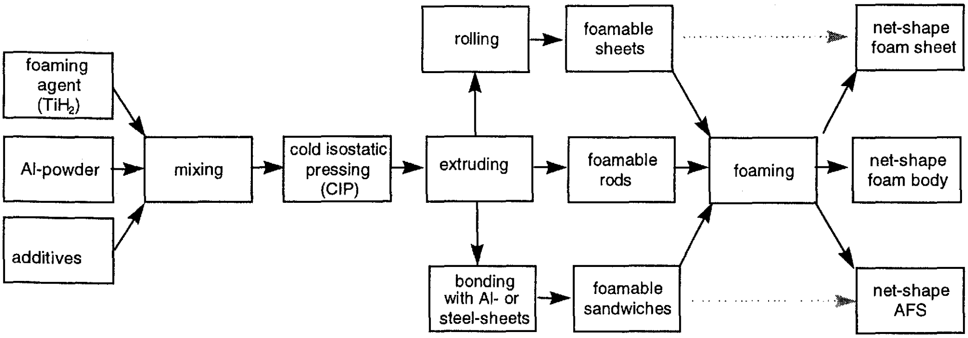

Fig. 1: P/M production process of Al-foams (IFAM-process)

Beside this technique to get foamable raw material, the material may also be transformed in another way. By conventional rolling foamable sheets will be produced up to a minimum thickness. Another possibility is to clad the foamable raw material with conventional sheets of metal, for example steel or Al-layers have been clad until now. The aim is to produce a sandwich structure only consisting of metal. By deep drawing, the sheets and the sandwiches may be transformed to 3-D-shaped sheets for special applications; the aim is to get near net shape precursors [4].

Heat treatment at temperatures near the melting point of the foamable matrix is necessary to produce the desired foam structure. During the foaming process the foaming agent decomposes. The released gas forms bubbles and the matrix expands up to a maximum volume, this means to a minimum density. The density of the growing foam can be controlled by several parameters. For example the foaming agent content, heating rates and others will be mentioned and also the influence of the equipment such as the mould material, the mould shape and the type of furnace. The typical attained density of such kind of foams is between 0,4 and 0,8 g/cm^3 including the complete closed skin around the foam body.

2.2 Fundamental aspects of foam kinetics

Above all, based on pre-material produced on conventional production lines, the foaming step is the main critical step to receive a high quality foam body. Provided that the raw material is of a sufficient homogeneity (quality criteria are discussed later), the material is inserted in special foaming moulds. By heating up to temperatures near the melting point of the Al or Al-alloy the raw material expands and fills up the hollow foaming mould. If the mould is filled up, the foam has to be cooled to set the foam structure. The difficulty is the thermodynamically unstable process with various intermediate stages such as heating the mould, heating the material, decomposition of the foaming agent, reduced thermal conductivity caused by growing pores near the surface and so on.

To solve some of these critical aspects, an optimised foaming agent is needed. At the moment TiH_2 seems to be the best material to foam Al and its alloys. The hydrogen release of TiH_2 starts above 450°C (atmospheric pressure 1 bar) and ends at the melting point of Ti (1668°C). For the typical foaming temperatures only 50 – 70 % of hydrogen content will be needed. Typical thermo-gravimetric curves of three different TiH_2-batches are shown in Fig. 2.

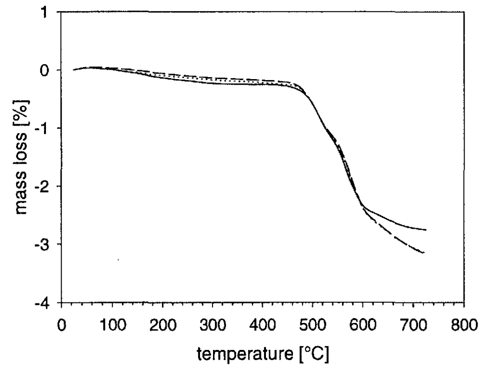

Fig. 2: Thermo-gravimetric curves for TiH_2-powder in Argon, heating rate 15 K/min

The release of hydrogen in the heated foam-material occurs at higher temperatures because of the strength of the Al-matrix around the TiH_2-particle. That is why the expansion of raw material starts at higher temperatures. Generally, the foam growth consists of several steps:

pore initiation, pore growth (by further heating), pore coalescence and foam collapse. This means that there has to be a discussion on the three steps pore initiation, pore growth (up to maximum) and foam stabilisation.

The first step is pore initiation by heating the raw material. Between surface contacts of former powder particles and at surface contacts to the TiH_2-particle, hydrogen gas will build first pore nuclei. By further heating the Al-matrix will become plastic and more and more hydrogen gas will release, so the pores are able to grow. By filling up the foaming mould the foam has to be cooled down under solidus temperature to set the foam structure. The cooling rate is, similar to the heating rate, very important to the foam quality.

To achieve an optimised temperature control during foaming, temperature-expansion curves were measured in co-operation with the IFAM. Fig. 3 shows some curves for various Al-materials. They clearly show the starting point of pore initiation, pore growth and the temperature of maximum expansion. Beside these typical discussed parameters, the possible foam stabilisation may be determined. It is not only a question of minimising density, but the foaming process also needs acceptable time-temperature control capabilities. This means foam stabilisation must be possible.

Fig. 3 shows the typical expansion behaviour of the cast alloy AlSi12 in comparison to the wrought AlMgSi (AA 6061). The eutectic temperature of the AlSi12-alloy at 577°C leads to maximum expansion rates, caused by a very low viscosity of the melt. Film drainage, pore coalescence and foam collapse will however occur at low temperatures. In contrast, the AlMgSi alloy shows a lower expansion rate but the temperature range between pore initiation and foam collapse is even higher. This means the time-temperature control is not as critical for wrought alloys. The cooling rate depends as well on the foam alloy. By using a low cooling rate the danger of foam collapse will occur because of film drainage in the cell walls.

Beside the foam process control, the properties of the raw material influence the expansion behaviour. The influences, for example, could be powder size, powder quality, particle size, particle size distribution, particle shape, homogeneity of mixture, compaction pressure and time, temperature control during transformation and much more.

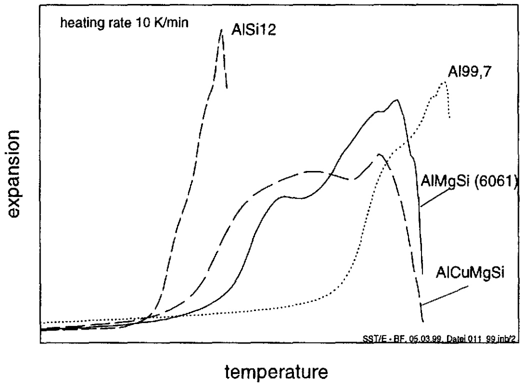

Fig. 3: Analysis of foam growth of Aluminium and its typical used alloys.

2.3 Examples of foam growth

Generally, a high heating rate leads to a minimum density, small pore sizes and homogeneous pore size distributions. The problem is that the temperature control is not easy with regard to foam collapse. On the other hand a low heating rate enables a high quality process control and a good foam stabilisation (viscosity control), but long batch times occur and the pore size distribution will be not as good.

Loading the mould with raw material, the desired density is defined by a simple calculation of the volume of the hollow mould and the mass of the raw material. The foaming mould may be loaded with several small pieces or one single precursor. The user has to pay attention to the foam body shape and, if necessary, to the filling of the mould with small pieces. The expanding material is surrounded by an aluminium skin, caused by the surface tension of the liquid or semi-liquid expanding material. It forms the so-called foam skin. This skin should fill up the whole mould and isolates the pores inside the foam body from the atmosphere. It should be avoided that several foam skins come together, otherwise a defect in the foam body will be ensure. In addition it must be arranged that the shear rate between the skins is high enough and that they fuse by breaking up the oxide surface layer (Fig 4).

Design guidelines are necessary to avoid such kinds of mistakes. The foam body needs similar design guidelines as they are known from the cast technology. Wall thickness transition, the adequacy of radii etc. should be noted.

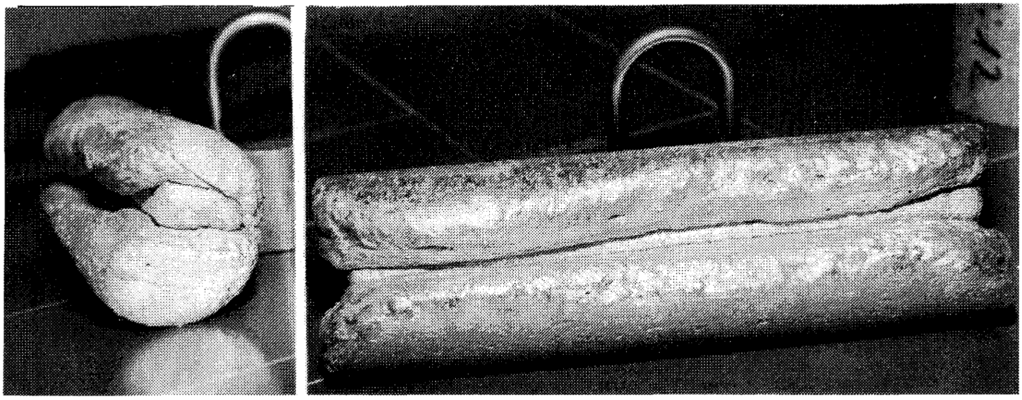

Fig. 4: Example for poor foam quality

Beside simple foam bodies, the aluminium foam sandwich (AFS) needs other typical basic guidelines and another heat treatment. The advantage of AFS is that it can be produced as flat panels or, after a deep-drawing stage, as 3-dimensional sandwich structures. The aim is to get a construction element with a high stiffness to weight ratio in comparison to the honeycomb. With the core layer of aluminium foam, the AFS offers a high rigidity. And by foaming this core layer after the deep-drawing process, the foam will get its typical structure. This means that the foam is not damaged as it would be if the foaming is followed by the deep-drawing step. The heat treatment to foam the panel has to be sensitive if Al-cladded sandwiches have to be foamed. The melting point of a typical Al-core layer is a maximum 100°C lower than that of the upper layers.

The advantage of such kind of foam materials is the upper layer with a defined thickness after foaming. This defined layer ensures the typical rigidity and gas density of the whole part. In comparison to this, the typical volumetric elements only have an aluminium skin around the whole body. This skin should be completely closed, but it is not in a defined thickness over the complete surface (Fig. 5).

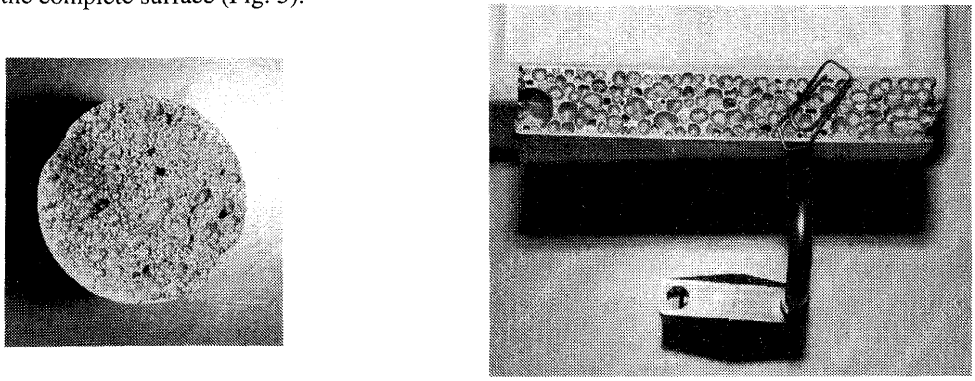

Fig. 5: Comparison of surface skin between volumetric foams ∅ 50 mm(left) and AFS (right)

3 Summary

It has been shown that complex net shaped foam parts can be made by foaming a P/M-based raw material. By applying the IFAM-process suitable precursors can be made by mixing, compacting, working. The foaming step itself depends on various factors with regard to technical equipment and to the quality of raw material and its transformation conditions.

Next to these conditions the foaming kinetics depend on the alloy (viscosity and surface tension) and on thermodynamic parameters during the foam process.

4 Acknowledgement

The work was supported by the MaTech-Program of the Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie (BMBF) under the No. 03 N 3039 2.

5 Literature

[1] Baumeister, J.: *Verfahren zur Herstellung poröser Metallkörper.* Patent IFAM: DE 40 18 360 C1.

[2] Weber, M.: *Herstellung von Metallschäumen und Beschreibung der Werkstoffeigenschaften.* Dissertation TU Clausthal, 1995.

[3] Kunze, H.-D., Baumeister, J., Banhart, J., Weber, M.: *Möglichkeiten zur Herstellung von Bauteilen aus geschäumten Metallen.* In: Innovative und wirtschaftliche Bauteile durch Pulvermetallurgie. VDI-Verlag GmbH Düsseldorf, 1993, 330-348.

[4] Baumgärtner, F. et al.: *Bauteile aus Aluminiumschäumen.* Ingenieur Werkstoffe Nr.3 (1998), 42-45