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Industrialisation of Aluminium Foam Technology

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Abstract

Aluminium foam can be manufactured applying a variety of methods including direct foaming of aluminium alloy melts and advanced metal powder processing. Complex-shaped foam components and 3D-shaped sandwich panels consisting of foam cores and aluminium face sheets can be produced. The application potential of these materials is discussed for various fields, namely light-weight construction, crash energy absorption and thermal or sound insulation. Four case studies are presented – a lifting arm for a lorry, a crash box for a car, an impact energy absorber for a tram and a motor bracket for a car. Such studies allow us to assess in which application fields aluminium forms perform well and in which direction future development should be directed.

1. Introduction

Solid metallic foams are known to have many interesting combinations of different properties such as high stiffness in conjunction with very low specific weight or high compression strengths combined with good energy absorption characteristics. For this reason, the interest in these materials is still increasing. The development of metal foams is described in review articles and conference proceedings [1-5]. A dedicated web-page offers up-to-date information [6]. The present paper will be restricted to closed-cell *aluminium foams* which have a good potential for market introduction. We shall first review different manufacturing routes and then discuss applications.

2. Manufacturing Methods

There are two main strategies for making aluminium foams (Table 1). The direct foaming methods start from a molten metal containing uniformly dispersed non-metallic particles into which gas is injected to create a foam. Alternatively, titanium hydride can be added to the melt which then decomposes leading to the same effect.

Indirect foaming methods start from a solid precursor which consists of an aluminium matrix containing uniformly dispersed blowing agent particles, mostly titanium hydride. Upon melting this precursor expands and forms a foam.

Table 1: strategies for making aluminium foams (search for manufacturers using Ref. [6])

direct foaming	melt aluminium alloy make alloy foamable create gas bubbles collect foam solidify foam ↓	indirect foaming	prepare foamable precursor remelt precursor create foam solidify foam ↓
manufacturers	Cymat, Canada Foamtech, Korea HKB-LKR, Austria Shinko-Wire, Japan (Distributor: Gleich, Germany)	manufacturers	alm, Germany Alulight, Austria Gleich-IWE, Germany Schunk, Germany

2.1 Direct Foaming of Melts by Gas Injection

Foaming aluminium or aluminium alloys by gas injection is already in the state of commercial exploitation [7]. Silicon carbide, aluminium oxide or magnesium oxide particles are used to enhance foam stability, thus making the alloy foamable. The volume fraction of the reinforcing particles typically ranges from 10 to 20%, the mean particle size from 5 to 20 μm. Gas injection (usually air) is done through specially designed rotating impellers or vibrating nozzles. The resultant foam accumulates on top of the liquid from where it can be pulled off, e.g. with a conveyor belt, and is then allowed to cool and solidify.

The foamed material is either used in the state it comes out of the casting machine, having a closed outer surface, or is cut into the required shape after foaming which is cumbersome due to the particles in the matrix. Advantages of this foaming process include the large volume of foam which can be produced and the low densities which can be achieved. Cymat, Canada, produces its foam – called *Smart Metal* – in this way.

Quite recently the melt foaming route has been revolutionised by scientists working at the Light-Metals Competence Centre (LKR) and the metallurgical plant in Kleinreichenbach (HKB), both in Austria [8]. The key point is a new concept of gas injection which leads to foams with an excellent uniformity of cell sizes. Moreover, by casting the foam into moulds, complex-shaped foamed parts with a closed outer skin can be generated. Commercial exploitation of this type of aluminium foam –called "*Metcomb*" – is on the way.

2.2 Foaming of Precursors

Foamable precursor materials can be produced in various ways:
1. by mixing aluminium powder and titanium hydride and compacting this mix e.g. by hot pressing, extrusion or powder rolling to a dense precursor [9]. If alloy foams are required, powdered metals have to be added to the mix accordingly ("*Foam-in-Al*" or "*Alulight" process),*
2. by pre-compacting powder mixtures to billets, heating these billets to the semi-solid state and thixocasting them to shaped precursor parts [10],
3. by adding blowing agent to an aluminium alloy melt after which the melt is solidified. This can be done in a die-casting machine [11] or in an ordinary crucible in which case, however, the blowing agent powders have to be pre-treated to prevent them from premature decomposition [12] ("*Formgrip*"-process).
4. by processing a liquid aluminium spray and allowing for deposition in the presence of a blowing agent.

In all cases a foamable precursor is obtained which can be foamed by (re-)melting. Foam making based on one of the indirect foaming methods (first in the list) is now in the stage of a small-scale commercial exploitation by the companies Schunk (Gießen, Germany), Applied light-weight materials, alm (Saarbrücken, Germany), Innovativer Werkstoffeinsatz (Stralsund, Germany) and the Austrian company Alulight (Ranshofen) [6].

3. Applications

3.1 General Concepts

Metal foams have properties which make them suitable for automotive industry which has been extremely interested in them since they were first developed. Potential applications also exist in ship building, aerospace industry and civil engineering [1]. The principal functionalities can be distinguished as follows:

- *Light-weight construction*: aluminium foams can be used to optimise the weight-specific bending stiffness of engineering components. The bending stiffness of flat foam panels is approximately inversely related to foam density. Light-weight construction exploits the quasi-elastic and reversible part of the load-deformation curve.

- *Energy absorption*: owing to their high porosity aluminium foams can absorb a large quantity of mechanical energy when they are deformed, while stresses are limited to the compression strength of the material. Foams can therefore act as impact energy absorbers which limit accelerations in crash situations. This mode exploits the horizontal regime of irreversible deformation in the load-deformation diagram. As metal foams can have much higher collapse strengths than polymer-based foams – up to 20 MPa – they can find applications in areas not accessible to foams up to date.

- *Acoustic and thermal control*: Aluminium foams can damp vibrations and absorb sound under certain conditions. Moreover, their thermal conductivity is low while they can withstand elevated temperatures. These properties are not outstanding – polymer foams, e.g., can be much better sound absorbers – but they could be useful in combination with other features of the foam. This application makes use of the internal configuration of a foam, namely the labyrinth of struts and the associated air-filled voids.

A metal foam is more likely to be competitive if not just one, but two or even more properties are exploited. True *multi-functionality* would, e.g., imply that a light-weight construction reduces noise and absorbs energy in the case of a crash.

In most cases a bare foam is not the optimum solution for a given engineering problem. Stiffness optimisation calls for sandwich panels with dense face sheets rather than for simple foam panels and foam can act very efficiently if filled into dense metallic sections or hollow cast parts which are reinforced by the foam filling.

We shall discuss four different concepts of aluminium foam composites and corresponding applications.

3.2 Light-weight Construction with Aluminium Foam Sandwich (AFS) Panels

The AFS technology developed in 1994 by Fraunhofer-IFAM in Bremen and Karmann GmbH, a German car builder, is one example of the use of foams in conjunction with dense material [13]: Sandwich panels consisting of a foamed metal core and two metal face sheets can be obtained by roll-cladding conventional aluminium sheets to a sheet of foamable precursor material manufactured from powders. The resulting composite can be shaped in an optional step, e.g. by deep drawing. The final heat treatment, in which only the foamable core expands and the face sheets remain dense, then leads to sandwich structures. The ability to make 3D-shaped panels and the high stiffness-to-weight ratio are a clear advantage to competing technologies such as honeycomb tructures. In combination with new constructional principles AFS could replace conventional stamped steel parts in a car and lead to significant weight reductions. 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 because such sandwich panels act as vibration dampers beside being light. AFS sandwich parts can be joined with aluminium sections by various welding techniques which facilitates their integration into the car body [14].

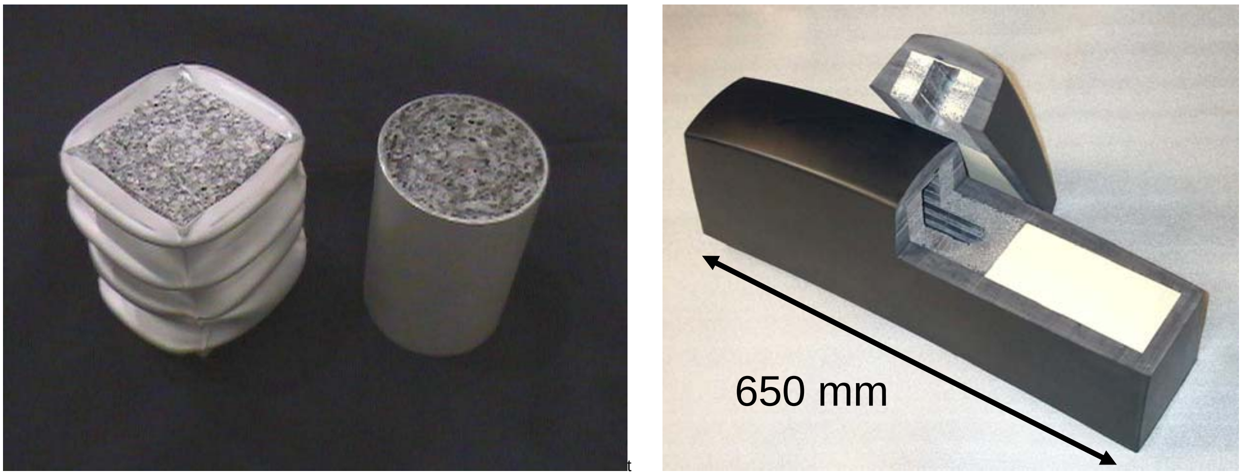
Recently Advanced Light-weight Materials (alm) – a spin-off company of Karmann's metal foam activities – has constructed a novel lifting arm supporting a repair platform mounted on a small lorry [15] (see Figure 1). The objective was to increase the vertical range of the platform from 20 m to 25 m while keeping the total weight of the vehicle below 3.5 tonnes. The aim was to keep operational costs low by preventing the lorry to fall into a different weight class above 3.5 tonnes implying higher insurance rates and requiring more skilled drivers. Finite-element calculations showed that a welded structure based on aluminium sections would not be able to support the weight of the platform, while a steel-based structure would be at least 80 kg to heavy. AFS panels could be successfully used to solve the problem. The solution consists of flat AFS panels which were MIG-welded together. The total weight is 105 kg which is acceptable. The vertical force at the turning point of the arm is 65 kN, the torque at the bottom part of the arm 85 kNm. The components were tested quasi-statically and in cyclic tests to up to 80000 cycles and showed no signs of damage. There is now a small-scale production of parts for the manufacturer of the lifting system, Teupen GmbH Gronau (Germany). AFS is successful in this case because it allows one to increase the lifting height of the system while keeping the weight below a certain threshold defined by legislation.

courtesy of alm

Figure 1: Base of a lifting arm made from AFS sandwich panels.

3.3 Foam-filled Tubes and Sections

Another example for aluminium foam applications are crash absorbers. As insurance companies are enforcing safety guidelines that protect the passengers in the event of a collision and also minimize damage done to the car and the ensuing repair costs, automakers have been using the idea of a crash box to meet these standards. Such crash boxes are placed between the impact beam and the front rail of the car. They deform to absorb all the energy of a 15 km/h crash, protecting more expensive front end components in addition to the car frame. One choice for the crash box is an empty tube that plastically collapses and in doing so absorbs energy. The failure mode of the tube is to create plastic folds along the length of the tube at regular intervals. By inserting an aluminium foam core made by direct foaming of a melt into the centre of the tube energy absorption could be increased. The outer tube still folds along its length but the number of folds increases; as a result the energy absorbed by the filled tube is greater than the empty tube. Energy is also absorbed by the foam core and the total energy absorbed by the foam filled tube is greater than the sum of the individual energies of the tube and the foam. Figure 2a shows a deformed foam-filled tube. Studies done by FIAT and the Norwegian University of Science and Technology show that, along with the improved axial energy absorption, there is also great improvement of energy absorption in off-axis collisions. Cymat had a joint development program with Valeo to design a crash box for implementation in Valeo's front-end module systems.



courtesy of Cymat

courtesy of Hübner, Schunk, Siemens

Figure 2: a) Prototypes of crash absorbers based on Al extrusions with a filling of Cymat aluminium foam
b) Crash energy absorber for a tram built for the COMBINO vehicle system.

3.4 Metal Foams as Reinforcement of Polymer Structures

Crash absorbers are also required for rail-based vehicles. One example are railcars [16]. Again, the driver for technological innovation are safety issues. Trams must have an underride protection which prevents pedestrians hit by the tram to be dragged under the vehicle. This and other consideration sets certain design rules which have to be obeyed. At the same time, effective crash protection for collisions with heavier objects such as, e.g., cars is required. As mounting space is very limited the use of aluminium foam can be useful. A collaboration of three companies (the tram manufacturer Siemens, the manufacturer of the crash absorber Hübner, and the metal foam producer Schunk Sintermetalltechnik, all Germany) developed the crash system shown in Figure 2b for the modular tram concept COMBINO® which allows to realise customer-given design requirements with components based on the same chassis. The Al foam core was made by indirect foaming using precursors obtained by extruding powder mixtures and embedded into a rubber shell. The crash absorbers are now being produced in quantities of hundreds and are also sold to other tram manufacturers and tram operators for refurbishment.

3.5 Aluminium Foams as Cores for Castings

Yet another application makes use of the beneficial properties of Al foam inside a dense aluminium shell both during manufacture and in use after. One starts from a shaped part of aluminium *Metcomb* or *Alulight* foam (indirect or direct foaming). The parts have dense outer skins and can therefore be used as cores in low-pressure die-casting during which composites consisting of a cast outer surface and a light-weight inner core are formed [8,17,18]. Such composites have advantageous service properties such as higher stiffness and improved damping compared to the empty hollow parts while their weights are only marginally higher. LKR (Austria) and the German car maker BMW have jointly designed an engine mounting bracket based on such composites (see Figure 3). The produced parts show no noticeable infiltration of the directly foamed Metcomb core itself by the melt during casting. It can be loaded with the high weight of a car engine and absorbs mechanical vibrations by internal dissipation into thermal energy. Stiffness is enhanced and, as fracture toughness of such composites is high, these parts also increase safety in crash situations.

courtesy of LKR

Figure 3: Prototype of a BMW engine mounting bracket manufactured by LKR Ranshofen. From left: empty casting, composite part consisting of foam core and cast shell, section through composite part.

Summary

A number of new metal foaming technologies have been developed in the past decade which now offer a wide range of different forms of this exciting material. Compared to early developments in the 1960s and 70s the quality of metal foam has been improved and the possibilities for making composites widened. With some first applications already on the road it seems quite realistic that aluminium foams will find an even wider use very soon in cars, ships, aircrafts or even spacecrafts.

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References

[1] J. Banhart, Prog. Mater. Sci. 46 (2001) p. 559.
[2] J. Banhart, M.F. Ashby, N.A. Fleck, eds., *Metal Foams and Porous Metal Structures* (MIT-Verlag,

Bremen, 1999).
[3] J. Banhart, M.F. Ashby, N.A. Fleck, eds., *Cellular Metals and Metal Foaming Technology* (MIT-Verlag, Bremen, 2001).
[4] J. Banhart, N.A. Fleck, A. Mortensen, eds., *Cellular Metals: Manufacture, Properties, Applications* (MIT-Verlag, Berlin, 2003).
[5] H.P. Degischer and B. Kriszt, eds., *Handbook of Cellular Metals* (Wiley-VCH, Weinheim, 2002).
[6] www.metalfoam.net.
[7] A.-M. Harte, S. Nichol, in Ref. [3], p. 49
[8] D. Leitlmeier, H.P. Degischer, H.J. Flankl, Advanced Engineering Materials, 4, 735 (2000).
[9] F. Baumgärtner, I. Duarte, J. Banhart, Advanced Engineering Materials 2 (2000) 168.
[10] H. Stanzick, M. Wichmann, J. Weise, J. Banhart, L. Helfen, T. Baumbach, Advanced Engineering Materials, 4, 814 (2000).
[11] A. Melzer, J. Banhart, J. Baumeister, M. Weber, German Patent 19813176.
[12] V. Gergely, T.W. Clyne, Advanced Engineering Materials 2 (2000) p.175.
[13] J. Baumeister, J. Banhart, M. Weber, German Patent 44 26 627.
[14] J. Banhart, W. Seeliger, C. Beichelt, in Ref. [5], p. 113.
[15] W. Seeliger, in Ref. [4], p.5.
[16] K.E. Geyer in Ref. [3], p. 31 and Ref. [4], p. 25.
[17] F. Heinrich, C. Körner, M. Blenk, R.F. Singer, in Ref [3], p. 147.
[18] M. Brunnbauer, C. Körner, R.F. Singer, in Ref [4], p. 187.