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## Light-metal foams: Some recent developments

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### Abstract

Metallic foams have now reached the maturity of development in terms of process stability, materials properties and costs required for industrial applications. The fine-tuning of the manufacturing process carried out in the past few years has been responsible for this success. Nowadays, Al foam panels as large as 2.5 m × 1.5 m in area and having a uniform pore structure are commercially available. In parallel to this development, new processing routes are being explored, including foaming with novel blowing agents, foaming by application of under-pressure, foaming of scrap and of other metals such as magnesium. Some of the steps of these developments are reviewed.

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### 1. Introduction

The first ideas to foam metals date back to the 1920s, but only since the 1950's and 1960's, actual production technologies have been developed [1]. In the 1970s, foamed aluminium materials of good quality became available. Commercial success, however, was restricted, probably due to cost issues. In the 1980s and 1990s, a second surge of process development enlarged the range of available materials and led to some small commercial applications [1]. This is the current status: metal foams can be made by processing aluminium powders or melts and are produced for a range of applications, mostly architecture.

There are a number of commercial aluminium foam manufacturers: the company Pohltec metalfoam in Cologne (Germany) is a producer of aluminium foam sandwich panels made by foaming densified mixtures of aluminium and TiH<sub>2</sub> powders. Cymat Corp.

(Canada) and Aluivent (Hungary) are suppliers for foams made by injecting gas into particle-metal suspensions. Foamtech (Korea), for example, produces foams by admixing TiH<sub>2</sub> blowing agent to aluminium melts.

A large part of aluminium foam application is currently in the architectural and design sectors. An example is shown in Fig. 1, featuring a foam-cladded building in the Swiss Alps. The panels were made from aluminium foam sandwich panels produced by Pohltec metalfoam, Cologne (Germany). The unique surface resembling natural stone was prepared by partially remelting one of the face sheets of the panels.

Other applications include automotive parts and components of tools and machines. The market for aluminium foams is currently quite small, which is why new developments and a reduction of materials' costs are necessary.

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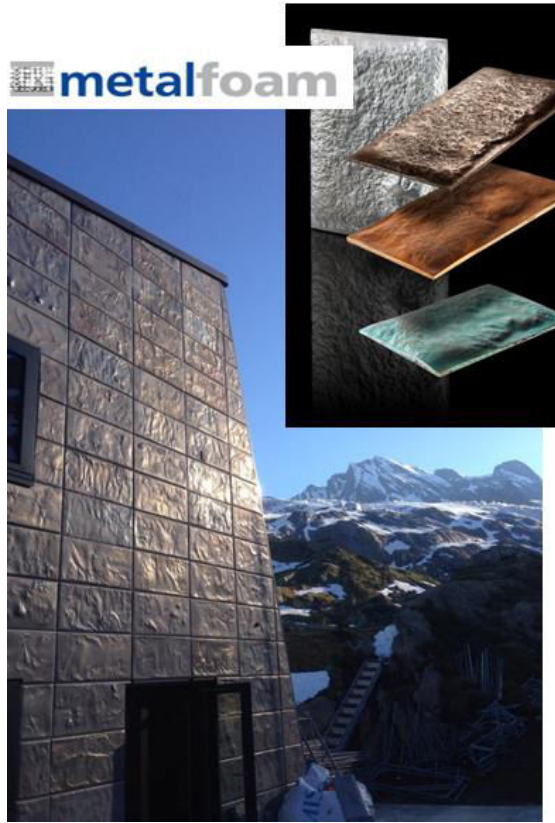


Fig. 1. Aluminium foam tiling of the Anenhütte in the Swiss Alps. Inset: different AFS surface treatments (Courtesy W. Seeliger).

This paper focusses on some recent suggestions on how to improve foaming of light metals. The aim is to make better and less expensive foams and to extend the range of foamable materials to magnesium alloys.

## 2. Improving the powder route of foam manufacture

### 2.1. Novel blowing agents

When manufacturing Al alloy foams from metal powders, usually the blowing agent  $\text{TiH}_2$  is used. Other possible blowing agents have not been systematically investigated. Especially mixed hydrides based on alkaline elements contain a high amount of hydrogen. Use of them might lead to a cost advantage compared to  $\text{TiH}_2$  and possibly to other improvements. To evaluate such hydrides,  $\text{LiBH}_4$ ,  $\text{NaBH}_4$ ,  $\text{KBH}_4$  and  $\text{LiAlH}_4$  powders were acquired and applied in the usual way to promote foaming, i.e. 0.5 wt.% of each hydride was admixed to a blend of Al, Si and Mg powders, the mixture was hot compacted and foamed at 700 °C. The foaming process was followed in-situ by X-ray

radiography. The corresponding foams are shown in Fig. 2 for five stages of the foaming process. The traditional blowing agent  $\text{TiH}_2$  was included for matters of comparison.

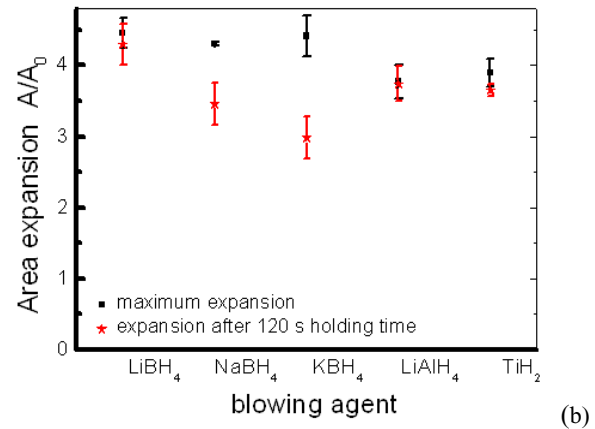
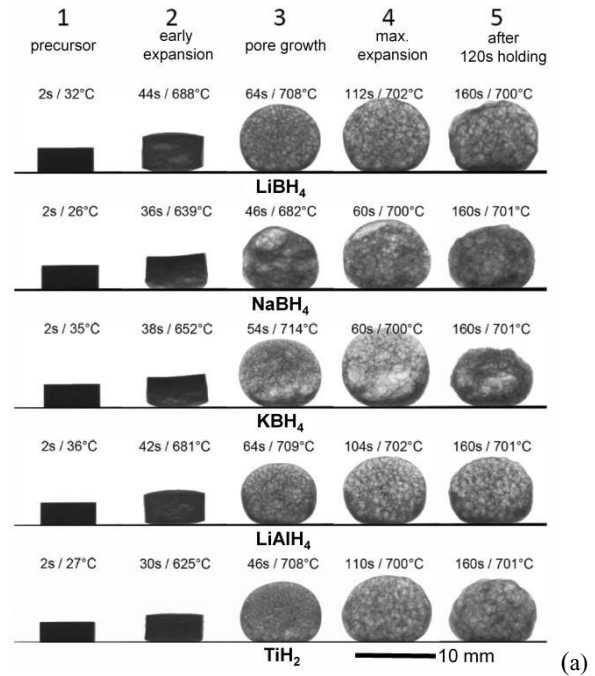


Fig. 2. a) Radioscopic images in various stages of expansion of alloy AlSi8Mg4 containing 0.5 wt.% blowing agent. The foaming temperature was 700 °C. b) Increase of projected foam area  $A$  compared to initial area  $A_0$  given as 'area expansion'  $A/A_0$  achieved at maximum expansion and after 120 s of holding at 700 °C [2].

The radiographs demonstrate the ability of all the hydrides to promote foaming. In terms of foam quality, however, the Na and K-based compounds yield an inferior result.  $\text{LiAlH}_4$  is comparable to  $\text{TiH}_2$ , while  $\text{LiBH}_4$  is the best blowing agent in this series, but more expensive than  $\text{LiAlH}_4$ .

These experiments refer to the powder manufacturing route for foams. Whether such hydrides are useful for the melt route remains to be shown.

## 2.2. Foaming of magnesium alloys

Mg alloy foam could further reduce weight in light-weight components and also provide some additional functionality, e.g. biodegradability. By simply replacing Al powder by Mg and using the usual processing conditions, no good foam is obtained as previous studies by the first author have shown, see also Ref. 3. Problems encountered include obtaining an airtight precursor and oxidation during pressing and foaming. We therefore modified the conditions and produced a variety of Mg and Mg-Al powder compacts containing 0.5 wt.% TiH<sub>2</sub>. They were either uniaxially hot pressed or extruded, and foamed either under ambient pressure or at 10 bar overpressure with subsequent pressure release, both in Ar atmosphere. The latter condition did yield good results, see Fig. 3.

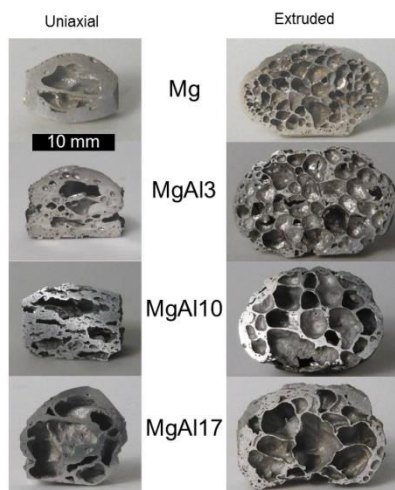


Fig. 3. Foaming trials carried out with various Mg alloys and precursors densified in two different ways. Foaming was carried out at 10 bar overpressure in argon atmosphere [4].

Uniaxially hot-compacted precursors did not expand properly and showed pronounced bubble coalescence. In contrast, extruded materials foamed well, especially pure Mg.

## 3. Improving the melt routes of foam manufacture

### 3.1. Foaming of scrap

One strategy to reduce the cost of foams is to use scrap as a starting material. For the powder route this appears

difficult, but for the melt route it is feasible. To verify this, aluminium alloy LM29 (AlSi10Cu3Mg1) machining swarfs were degassed, dried and briquetted. The oxide content of the alloys increased to  $\geq 0.5$  wt.% in the course of this treatment. Induction melting for 50 min to 70 min at 800 °C to 950 °C and subsequent casting into a permanent mould provided the starting material for the foaming experiments. In a series of experiments, between 1 wt.% to 4 wt.% of Mg were added to the melt to aid dispersion and wetting of oxide filaments in the metal matrix.

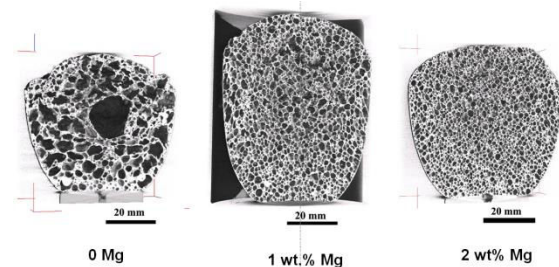


Fig. 4. X-ray tomography cross-sections of foams produced by foaming aluminium swarf containing various levels of Mg [5].

Foams were generated by adding 1.5 wt.% of TiH<sub>2</sub> to the remelted alloy by stirring and allowing the melt to foam for 100 s at 700°C. Fig. 4 displays three tomographic images of foams generated in this way. The level of Mg has a visible impact on the foams generated. Without Mg addition, the cell structure appears heterogeneous and drainage has given rise to an extended melt sump. Addition of Mg however, has stabilised the foam which now appears uniform and shows little drainage. The stability-increasing action of Mg is related to the generation of a stable network of oxide particles in the melt [5].

### 3.2. The search for more effective stabilizing particles

All metallic foams contain stabilising, nonmetallic particles, which are either oxides formed during processing or added ceramic particles, e.g. SiC. The latter are very effective stabilisers but as only large particles ( $>10$   $\mu\text{m}$ ) can be added to aluminium melts in a reliable fashion, usually  $\geq 15\%$  volume fraction is needed, which drives costs and makes the metal brittle. One solution to reduce particle size is to produce particles in-situ in a melt via a chemical reaction, thus avoiding mixing and wetting problems [6]. We produced spinel particles by reacting 5 wt.% microsilica (SiO<sub>2</sub>) particles (44  $\mu\text{m}$  mean diameter) with an AlMg2.5 melt for 5 h at 750 °C. After this, 1.5

wt.% of  $\text{TiH}_2$  were added to the melt, which was then solidified. This material was reheated to  $T = 740^\circ\text{C}$  and allowed to foam in a cylindrical mould for 100 s or 150 s. Fig. 5 shows the quality of the resulting metal foams. Especially for 100 s foaming time, a regular cell morphology and high volume expansion were achieved. The necessary particle content is just a few percent in these cases.

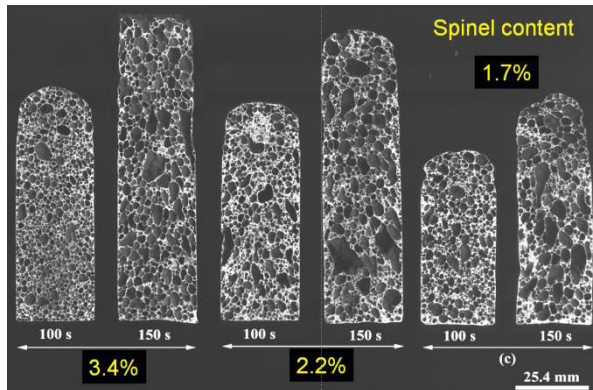


Fig. 5. Foams manufactured by creating spinel particles (content given in wt.%) in a melt by in-situ reaction and foaming the composite by  $\text{TiH}_2$  addition.

### 3.3. Foaming without any blowing agent

Eliminating the necessity for using a chemical blowing agent would be a great advantage for foaming metals. The gas needed for the expansion of bubbles has to be extracted from the melt or injected from outside. The former option involves dissolving enough gas in the melt prior to foaming. However, the solubility of gases in Al-based melts is in general low. Hydrogen is the most suitable gas but the solubility drop during solidification has to be amplified by pressure manipulation. It was shown that reasonable foams can be obtained by charging various Al alloy melts at ambient pressure and let the melt be sucked into an evacuated mould. If one ensures that the inlet of the mould is sealed fast enough by solidifying metal, the pressure within drops to  $2 \times 10^{-2}$  mbar in 10 s, while cooling is fast, on average 35 K/s. The metal starts to expand under these conditions, see Fig. 6. The resulting foam structures exhibit different levels of uniformity. Remarkably, even pure Al without any particles forms a foam, however, with quite a non-uniform pore structure. AlMg5 alloy with and without particles performs much better. The best results are obtained from AlSi9Mg5 alloy containing 5 wt.%  $\text{SiO}_2$  particles. The method resembles the experiments reported for

molten Mg scrap alloys, where the gas came from adsorbates on the scrap material used [8], or the pressure-induced foaming of pressed powder compacts [9] where the gas resides on the powder particles. In the present case, however, no such impurities were present.

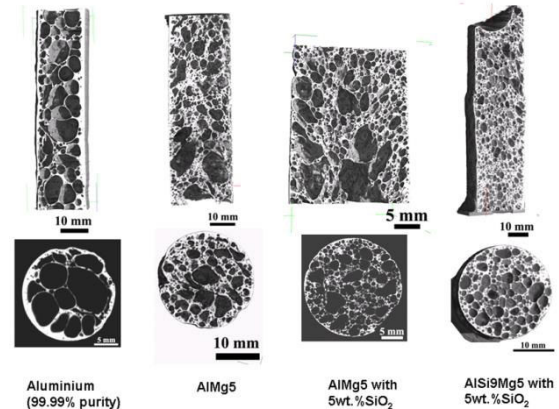


Fig. 6. X-ray tomographies of four different alloys foamed by rapid drop of pressure. Top: longitudinal sections of cylinders, bottom: cross sections [7].

## 4. Conclusions

Traditional foaming routes for metal foams have been modified or extended, including the use of new blowing agents, foaming Mg alloys or scrap, foaming melts with in-situ generated particles, without particles or without blowing agents. Encouraging results were obtained. Future innovations in metal foaming techniques could lead to better and cheaper metal foams and an increased market acceptance.

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