METALLIC FOAM EXPERIMENTS UNDER MICROGRAVITY

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ABSTRACT

X-ray analysis was found to be a very powerful method for the in-situ study of the metal foaming process on Earth. Under normal conditions, the inevitable presence of gravitationally-driven drainage makes investigation of coarsening very difficult, because of the rapid variations of foam properties induced by the gravitational flow. Under microgravity we can remove these limitations in order to generate improved models of the foaming metals. So it is possible to isolate some of the key effects which govern foam evolution, namely drainage, flow, coarsening, and coalescence. Experiments scheduled to fly on the XRMON and μg-FOAM MAP projects and using our ground equipment are presented. Microgravity experiments are prepared to fly on parabolic flights and Maser 11.

1. INTRODUCTION

Metal foams have become in recent years more and more industrially relevant [1]. Their multifunctional qualities make them very attractive, but suffer from high production costs and poor reproducibility. Gas nucleation and pore distributions at early stages are determining for later structural development, but metal foam structure formation is still not completely understood [2].

The μg-FOAM MAP project started in 2000 and focused until recently on development of an ambitious program of microgravity-related experiments [3]. Its third phase was recently approved. In parallel, XRMON MAP, started in 2007, is motivated by the possibility of in-situ X-ray investigation of fundamentals in solidification of metals and other important phenomena in the field of materials science. The ability to study under microgravity conditions will constitute a very important supplement to present material research.

In this framework, the Swedish Space Corporation (SSC) was commissioned to design and construct a metal foam experiment module for microgravity. The hardware is explained in more detail in their contribution to this symposium [4]. The metallic foam experiment was selected for the first flight, and is scheduled to fly on Maser 11 may 2008. Parabolic flights to test the equipment, define processing parameters, and select samples are planned for the end of 2007.

2. FOAMING STRATEGIES

There are many different trade names and ways of producing metallic foams [5]. The main foaming strategies, namely direct foaming of a prepared melt and indirect foaming of a solid precursor via a blowing agent, are shown in Fig. 1. In the case of direct foaming, addition of particles for stabilization is mandatory, similar to addition of surfactants in aqueous foams, although the two act in different ways [6].

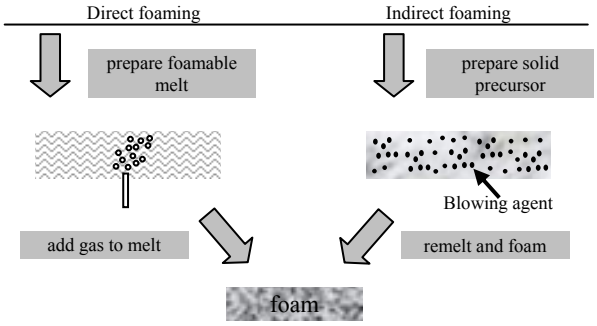

Figure 1. Main strategies for metal foaming.

For microgravity experiments, both so-called "foaming routes" were taken into account. Considering the difficulty of developing a suitable gas injector for microgravity, and the recent increase in metal foam applications made by indirect foaming, we decided to select a solid precursor for space research.

3. APPLICATIONS

The number of applications involving metal foams is increasing from year to year. The demand for a more reliable product with smaller tolerances is coming from the customers. Increasing quality is now an important step for serial productions. In parallel, prices are sinking, making metal foams more attractive for a wider range of applications.

The most successful products on the market are made by the indirect foaming route, e.g. flat Aluminium Foam Sandwich (AFS) where the core is an Al-alloy foam and the face sheets are dense steel or Al-alloy plates of ~ 1-5 mm. In Fig. 2 we can see some AFS from the company Alm, with a metallic bonding between core and face sheet [7]. Large serial productions of more than 100,000 pieces per year are also underway, like the bumper

support for the Audi Q7 “pikes peak”, produced by Alulight Austria [8].

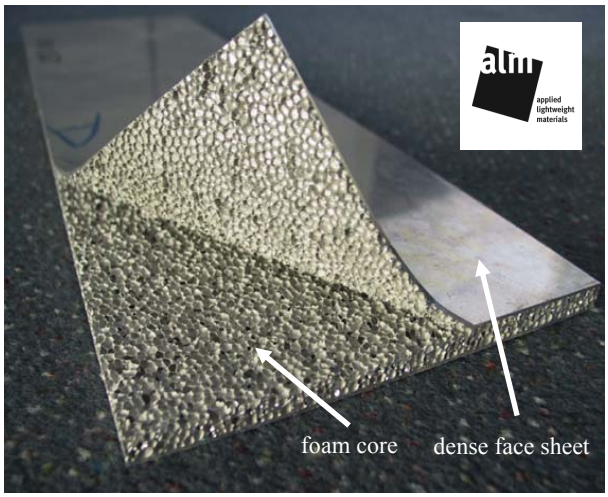

Figure 2. Aluminium Foam Sandwich panel showing the foam core. Courtesy of Alm Saarbrücken, Germany.

Even for space applications, the properties of metal foams are interesting. For instance, they are considered as a candidate for micrometeorite protection of satellites and space stations, as they can dissipate and absorb the energy of an impact. Their multifunctional properties combine lightweight structures with thermal insulation, damping, fire resistance, and crash absorption. Fig. 3 shows a prototype of a conical fitting for the Ariane rocket, made from welded curved AFS panels.

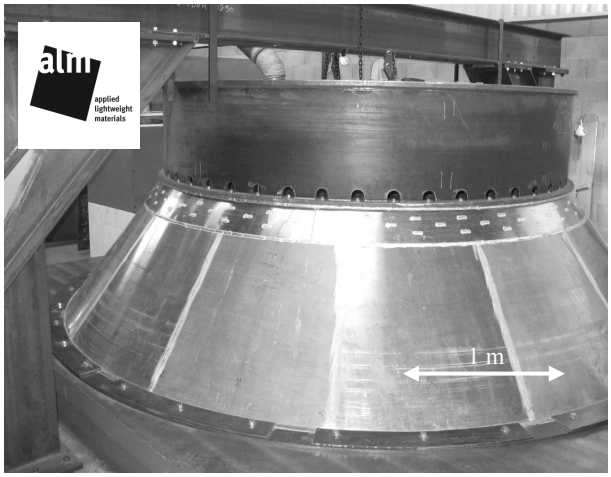

Figure 3. Prototype of conical fitting for the Ariane rocket. Courtesy of Alm Saarbrücken, Germany.

To improve the existing foaming processes and the foam quality, more fundamental research is needed, for example to fully understand the governing mechanisms. For such research, microgravity experiments are a unique tool.

4. NEED FOR MICROGRAVITY

There are problems in foam production that cause poor reproducibility in the final properties of the parts, leading to inferior products. Pore size distributions in general are very non-uniform. There are several reasons known for this: for instance, pressing of powders causes anisotropy in precursors, which leads later to flaws and large pores. It causes also poor foamability and low expansion factors. Also, a very precise temperature profile and a minimal heating rate for foaming are needed, as blowing agents are very temperate sensitive and start to release gas below the melting temperature of the metal [9]. In large-scale production it is very difficult to provide a homogeneous temperature distribution. This causes different local expansions and pore sizes in the samples.

4.1. Analysis Environment

In liquid foams, several overlapping effects can take place, each being interconnected with the others. Fig. 4 shows an overview of the most relevant effects in a standard analysis environment. To be able to study foams in detail, we have to isolate these effects from each other. In metallic foams there is little coarsening due to the inability of gas to diffuse through the relatively thick films and flow of bubbles can be avoided by choosing stationary conditions in which foam expansion has come to an end. This was proofed by in-situ X-ray radioscopy measurements.

Foaming under microgravity gives the unique chance of studying coalescence of bubbles without the influence of drainage. A sounding rocket experiment will give us enough time for foaming (~ 1 min.), keeping the foam in the liquid state to measure coalescence during further 5 min. Ground experiments will be used as reference for direct comparison of results. Expansion and drainage evolution will be also analysed.

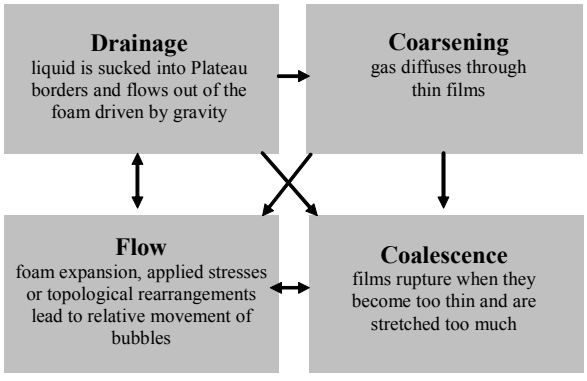

Figure 4. Scheme of analysis environment for liquid foams: dominating effects and their interconnections. Drainage can be avoided by microgravity experiments.

4.2. Flight campaigns

During the parabolic flights, we plan to run different experiments to analyse the influence of the precursor, in terms of alloy composition (pure Al, AlSi7, AlSi6Cu4, AlSi8Mg4, etc.) and precursor production route (uni-axial, thixo-cast, extruded or rolled). A suitable precursor will be selected for the Maser 11 sounding rocket campaign. The influence of foaming parameters like heating profile, heating rate, temperature homogeneity, and influence of gas release on the system will be also studied.

During microgravity experiments in Maser 11, samples will be pre-heated in a small furnace/cartridge to ~ 350-400 °C and then foamed during microgravity at a temperature slightly above the melting temperature. Foam re-melting will be also considered. Foam evolution will be recorded in-situ by X-ray diagnostics (the hardware will be provided by SSC).

After the experiments, a broad sample and data analysis will be performed. It will consist mainly of quantitative X-ray image analysis of foam evolution, foam expansion, foam density, drainage, pore size distribution, solidification microstructure analysis, and minimum cell wall thickness measurements, with comparison of results on Earth and under microgravity.

5. X-RAY ANALYSIS

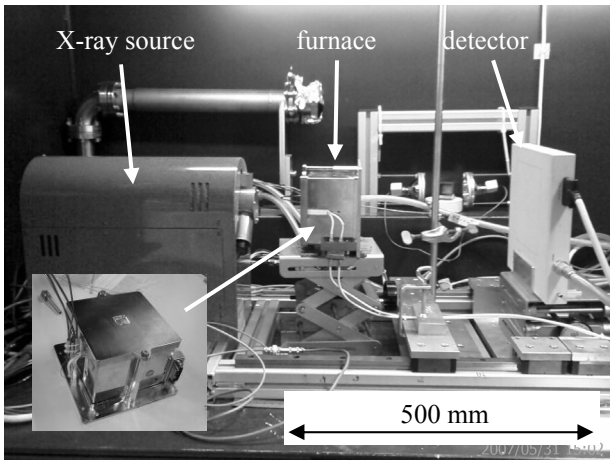

Figure 5. X-ray scanner available at the Technical University of Berlin during tests on the microgravity furnace provided by SSC.

X-ray diagnostics has been found in recent years to be a powerful tool for in-situ examination of liquid metal foams [10, 11]. Beyond synchrotron measurement campaigns, a lab scanner consisting of a microfocus source and flat panel detector, both from Hamamatsu, has been built at the Technical University of Berlin (see Fig. 5). The advantages of this facility are continuous accessibility, high energies, a large field of view due to the possibility of magnification, and acceptable spatial and time resolution for our purpose. The disadvantages compared to a synchrotron are lower flux and polychromatic light [12].

5.1. Scientific Requirements

A minimal foam dimension and X-ray field of view of 20 x 20 x 10 mm^3 is required in order to avoid edge effects and to have enough bubbles for reliable quantitative analysis. An adjustable foaming temperature in the range of 500 – 700°C is needed, with a heating rate of at least 100 K/min. The reason for this is to avoid cracks and gas losses before the samples are molten, as a product of overpressures inside the samples due to the blowing agent gas production [9]. Also, a temperature stability of around ± 5 K and a constant pressure of ~ 1 bar have to be provided.

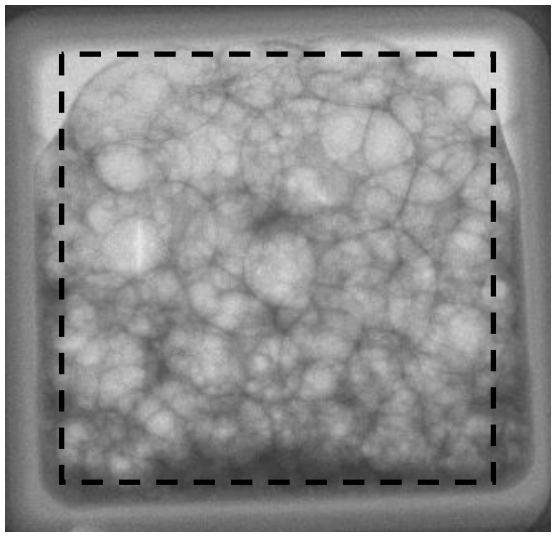

Figure 6. X-ray image showing an ALSi-alloy foamed on Earth in the microgravity furnace and kept in the liquid state for 60s. Drainage on the bottom part is clearly observed. Dashed lines marks the analysed area.

5.2. Density and Drainage Measurements

The line integration over the sample width, as a function of the sample height of an X-ray image (see Fig. 6) gives us a quantitative value for the foam density ρ, where I is the absorbed intensity:

$$\rho(h, t) \sim \ln I(h, t) \qquad (1)$$

We can adjust 100% of density by the initial bulk precursor and 0% by the air. That way a density calculation for all the images of a radioscopy gives us the foam density as a function of sample height and time (Fig. 7).

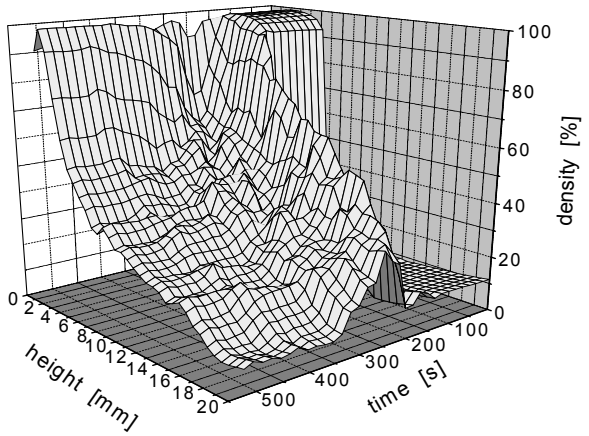

Figure 7. Quantitative analysis of foam density as a function of sample height and time, corresponding to the dashed lines in Fig. 6.

5.3. Cell Wall Rupture and Coalescence Analysis

From the recorded X-ray sequence we can also perform cell wall rupture event detection, supported by software [11]. Any single rupture event is detected by comparing 2 subsequent images. The software is able to recognize the rupture and build the gravity centre of each event. In this way a spatial dependence analysis of the number of events can be performed (Fig. 8).

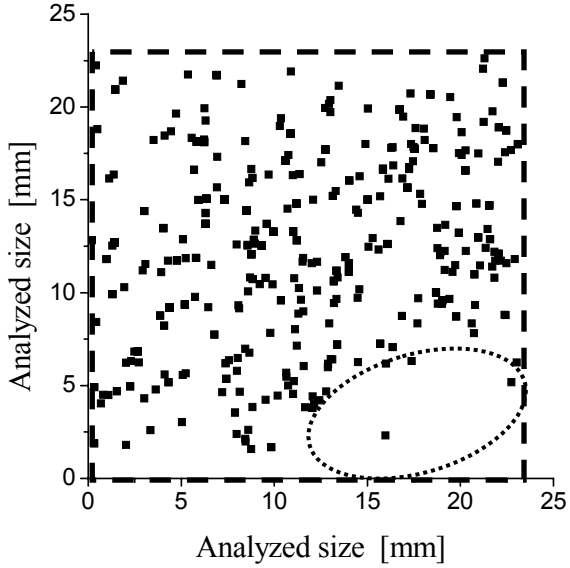

Figure 8. Example of spatial distribution of cell wall rupture events. Some areas have a reduced number of ruptures due to drainage (dashed ellipse). Dashed lines show the analysed area.

Also the time dependence of ruptures can be studied (Fig. 9). The histogram shows that after the foam is stabilised, rupture rate increases, probably due to drainage. After more than 1000s the rupture rate decreases extremely, as only a few big bubbles are left.

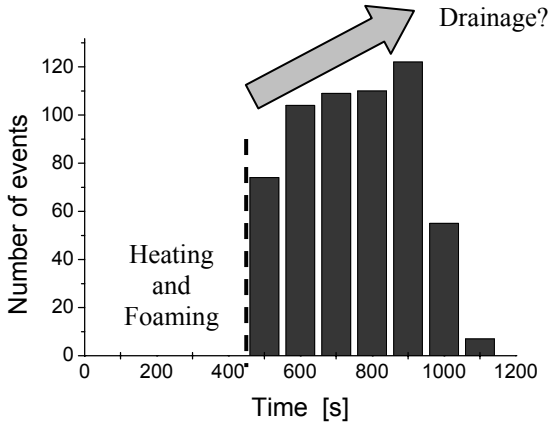

Figure 9. Example of cell wall rupture distribution in time. Increase in coalescence could be drainage driven.

6. CONCLUSIONS

Metal foams are attractive for industry and science. Foam expansion, density and cell wall rupture can be measured quantitatively with X-ray diagnostics. There is a need for microgravity to avoid drainage-driven effects. Microgravity analysis, in terms of a parabolic flight (end of 2007) and a sounding rocket (Maser 11, March 2008) will be performed.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

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