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Investigation of Lead Foams Under Microgravity

Thomas Wübben, Stefan Odenbach
ZARM, University of Bremen, Bremen, Germany
wuebben@zarm.uni-bremen.de
John Banhart
Fraunhofer-Institute for Advanced Materials, Bremen, Germany

Abstract

Metallic foams are a recently developed light weight material. They are porous structures consisting of metals like aluminium tin, zinc, lead etc. or their alloys. The pore sizes are in the range of millimetres and relative densities down to 10% of the original material can be achieved. Since metallic foams combine relative low weight with high stiffness, their applications are mainly light weight structures as used for example in cars. Other applications such as sandwich structures and metallic filters are of interest.

To make metallic foams applicable for an industrial use, some technical and principle problems still remain to be solved. These concern mostly the structure of the resulting foam, which is very inhomogeneous and not well understood. Our aim is to contribute to the understanding of the physical processes that take place during the foaming process. In this paper we will introduce the production method for metallic foams. Then we will describe the two main physical processes during the foam genesis and present our experimental idea and setup used to obtain information on these processes. Finally we will discuss the first results we obtained in parabolic flights and terrestrial experiments.

1. Production method for metallic foams

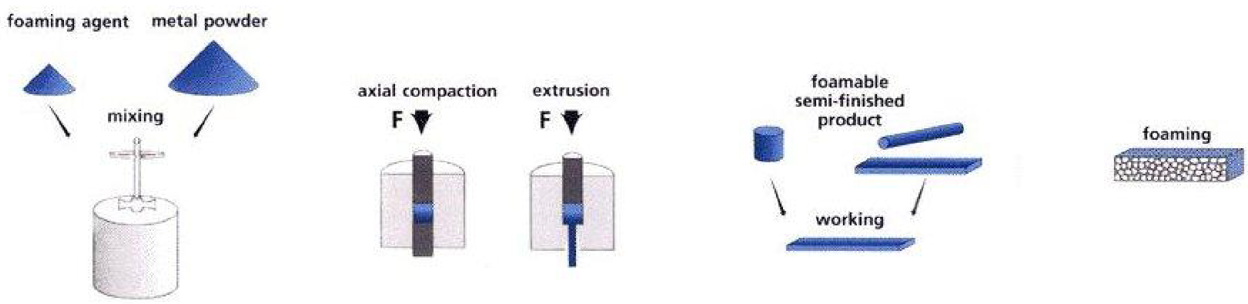


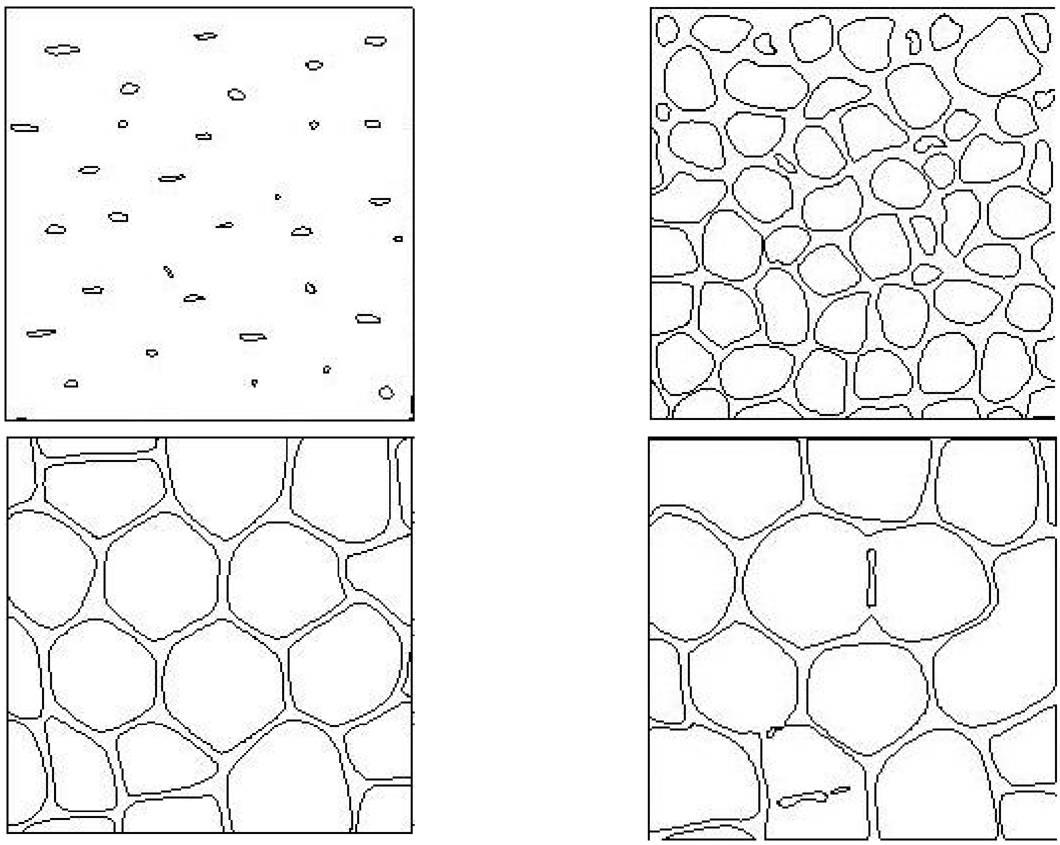
Figure 1: Production method for metallic foams [1]

The production method as shown in figure 1 is based on a powder metallurgical concept: a metallic powder is homogeneously mixed with an amount of about 2 wt.% of a blowing agent such as TiH_2. The resulting mixture is then compacted to obtain a foamable material. The mechanical properties of this intermediate product allow the same customised shaping procedures known for usual metals. After shaping the precursor material is heated up to the melting temperature of the metallic material. The heating causes a decomposition of the blowing agent and a production of gas. As the metal melts, the gas expands and bubbles are generated inside the melt. The resulting porous structure is finally conserved by cooling the material to below the melting point.

2. Physics of the foaming process

During the production of a metallic foam by the method described above, various steps of foam genesis have to be considered. The complete process can be divided into four major stages as shown schematically in figure 2 [2].

a) Start of foam genesis b) Early foam



c) Completed foam d) Bubble coalescence

Figure 2: Steps of formation of the metallic foam [2]

As soon as the metal softens, the blowing agent starts to expand. Small bubbles arise in the liquid metal (a). During the following growth of the spherical cells interaction between the individual cells becomes important effecting a change of shape from spherical to polygonal (b). The final foam consists of polygonal cells surrounded by liquid lamellae (c).

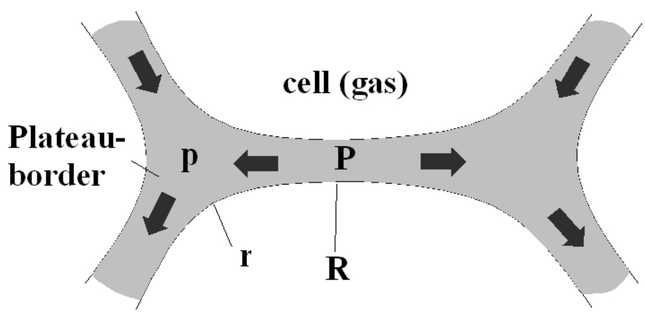


Figure 3: Lamellae between bubbles in the foam

Since the pressure inside the Plateau-borders is lower than inside the lamellae:

$$\boldsymbol{p} - \boldsymbol{P} \propto \gamma\left(\frac{1}{\boldsymbol{r}} - \frac{1}{\boldsymbol{R}}\right)$$

where γ is the surface tension, the liquid tends to flow in towards the Plateau-borders, see figure 3. These will thus thicken at the cost of the thickness of the lamellae, which will finally break leading to a coarsening of the foam (d).

Under terrestrial conditions gravitational acceleration will enhance this effect, since the liquid contained inside the Plateau-borders drains out of the structure. Therefore two main physical effects influence the stability of the foam: on the one hand the surface tension γ which mainly depends on the consistence of the metal and the presence of surfactants. The thinning of the lamellae caused by this is on the other hand enhanced by the gravity driven drainage, which will depend on the density and the viscosity of the liquid metal.

3. Experimental idea and setup

The physical circumstances during foam genesis can be summarised in the scheme shown in figure 4: our idea for getting a better knowledge about the influences and interactions of both effects is to

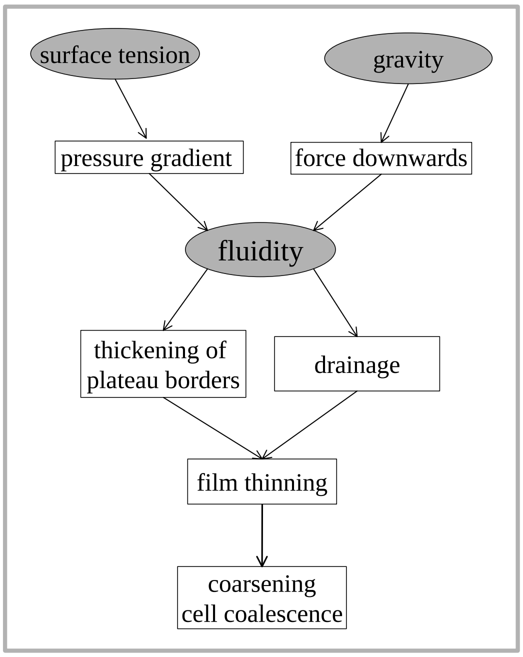


Figure 4: Major influences during the formation of metallic foams

investigate each branch of the diagram separately by varying the determining parameters. While the surface tension is affected by the properties of the used material, major control of drainage can only

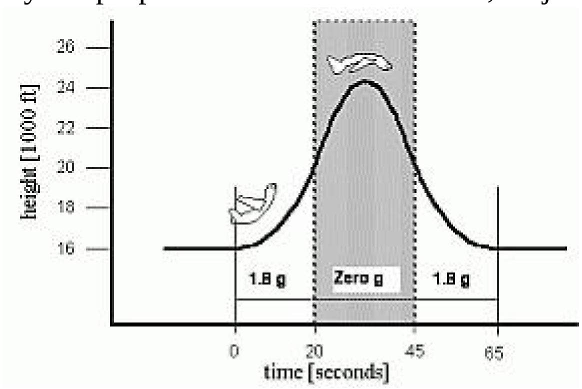


Figure 5: Flight profile of parabolic flights

be obtained by variation of gravitational acceleration. This paper focuses on the first results we obtained in experiments under microgravity, that is with only surface tension influencing the foaming process. The reduced gravity conditions were generated in parabolic flights (see figure 5): an aircraft containing experiments and experimenting staff is accelerated in an upward direction and is brought to a parabolic trajectory providing free fall conditions. During this period of about 22s the experiments are weightless and investigations under low gravity conditions can be performed.

Experimental setup

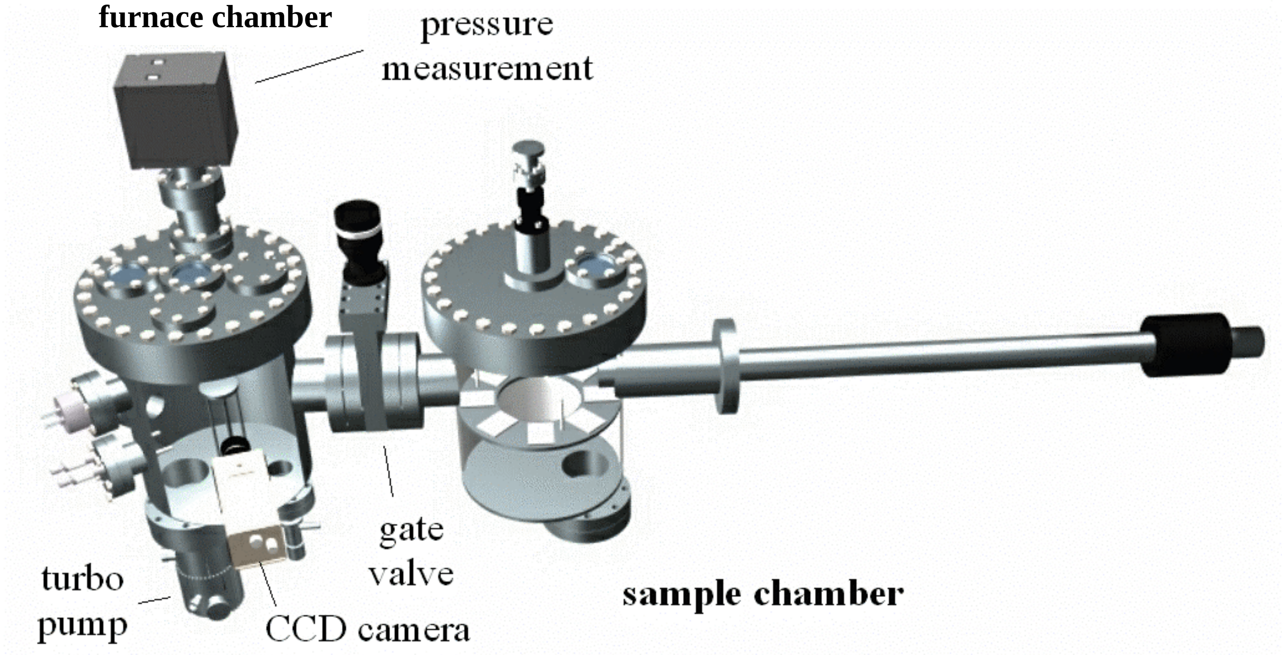


Figure 6: Schematical sketch of the experimental setup

For our investigations we use the experimental setup shown in figure 6. The main part is the furnace chamber (left side), which can be heated to 250°C and contains a temperature controlled heated plate to foam one sample of 20x20x2mm^3 in size before foaming. The chamber is equipped with measurement devices for pressure and temperature as well as a CCD camera for optical observation. A turbo pump provides the possibility to perform experiments under low pressure conditions down to 10^{-9} mbar. The sample chamber (right side in the figure) allows storage of up to 12 samples, which are transferred by a transfer bar into the furnace. A gate valve between furnace and sample chamber separates the experimental environment from the samples before and after foaming. Both chambers can easily be separated at this point to use the furnace chamber as a stand alone device.

4. Results

During the recent ESA- and DLR-parabolic flight campaigns we foamed several samples of three different alloys under low gravity conditions. We used lead alloys because of their high density and low melting point. In this article we focus on the comparison of samples foamed under low gravity to terrestrial conditions.

4.1 Analysing method

To analyse the pore structure of the samples, they first have to be cut. This is done by electrical discharge machining to avoid deformation of the lamellae. At this stage we cut the samples only once perpendicular to the heating direction. After cutting the pores are filled with white creme or gypsum to enhance the contrast for the digital image processing. The analysis is mainly focussed on the size (measured by the equivalent diameter) and on the circularity of the pores, which is defined as the square of the perimeter divided by the area of the pore.

4.2 Comparison of μg and terrestrial samples

Figure 7 shows pore structures of samples foamed for 30 s.

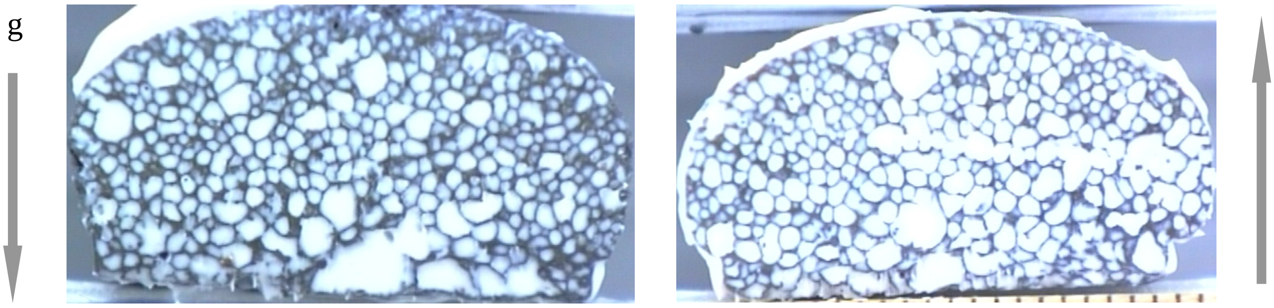


Figure 7: Structures after 30s of foaming. Left: foamed under terrestrial conditions; right: foamed under low gravity conditions (alloy: PbSb10Sn10); the arrows indicate the direction of gravity and foaming, respectively.

For these two samples the experimental parameters like pressure, surrounding temperature and heating scenario were the same. Therefore the only difference during the foaming process was the gravitational acceleration. The histograms show the results of the digital image processing for structures obtained under terrestrial conditions (5 samples) and under low gravity conditions (1 sample), where ρ describes the width of the distribution.

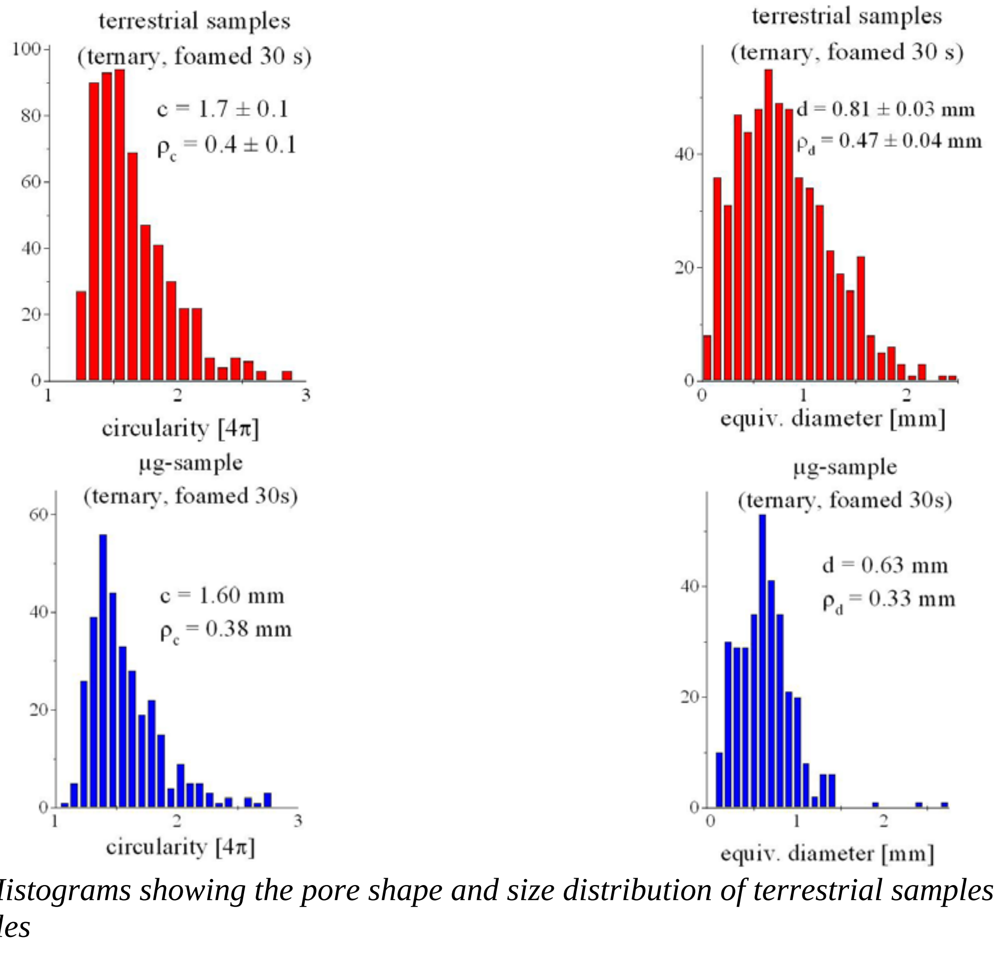


Figure 8: Histograms showing the pore shape and size distribution of terrestrial samples compared to μg samples

The comparison shows a slight difference in the shape of the pores, described by the circularity: for samples, which were subjected to gravity during foaming the circularity is higher than for µg samples. The statistics of about 5 samples shows a circularity for terrestrial structures of about c = 1.7 ± 0.1 and a width of $\rho_c = 0.4 \pm 0.1$ compared to c = 1.6 for µg-samples. Thus the pore shape seems to be influenced by gravitational forces.
This is supported by the analysis of the pore sizes: for terrestrial samples the pores are significantly larger (0.81 ± 0.03 mm) than for µg samples (0.6 mm). This result can be explained, since the gravity driven drainage enhances the film thinning due to surface tensional effects. Even though the material (PbSb10Sn10) shows only small visible drainage effects, the difference amounts to a factor of 1.3 in diameter.

5. Conclusion and outlook

The analysis of the pore structures of samples foamed under terrestrial and low gravity conditions shows a significant difference concerning pore shape and size: structures foamed under low gravity show smaller pores with shapes more spherical than terrestrial structures. Nevertheless one has to take into account that the statistics for reduced gravity samples has to be improved.

That the alloy used shows very little drainage is a pleasant feature for the ones who want to process the material but obscures the microgravity effects we are studying Therefore, a lead alloy which is more prone to drainage will be used in the next experiments. This material will then be investigated also with applied high gravity accelerations in a centrifuge.

6. References

[1] F. Baumgärtner, I. Duarte, J. Banhart, Adv. Eng. Materials **2**, 168 (2000)

[2] M. Weber, Thesis (MIT-Verlag, Bremen, 1997)

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