Foaming kinetics of aluminium alloys

I. Duarte, P. Weigand, J. Banhart
Fraunhofer-Institute, Bremen, Germany

Abstract

Metallic foams were produced applying the powder metallurgical method, i.e. mixing metal and foaming agent powders and subsequently pressing them to a foamable precursor material. This material was then foamed by heating it up to its melting point inside an "expandometer", which was constructed for foaming tests. The expansion and the temperature of the foamable precursor material were monitored by means of a laser sensor and thermocouple, respectively, during the foaming process. The present studies comprise the effects of the aluminium alloy composition (AlSi7 and 6061), the foaming temperature and some of the pressing parameters of the foamable precursor material.

1 Introduction

A manufacturing method for producing closed cell metal foams from metal powders was developed some years ago [1-3]. Basically, the process consists of mixing the metal and the foaming agent powders, and compacting them to a dense semi-finished product (called foamable precursor material). The powders are usually compacted by hot pressing or extrusion. In a final step, the foamable precursor material is foamed by heating it up to its melting point. This softens the metal and simultaneously makes the foaming agent decompose and release gas, thus forming bubbles in the semi-molten metal and creating a highly porous structure.

2 Materials

Cylindrical tablets of foamable aluminium alloy - 6061 or AlSi7 - each containing 0.6 wt.% titanium hydride were produced either by hot pressing (for AlSi7) or extrusion (for 6061). The tablets were 9 mm thick and 31 mm in diameter. Pre-alloyed 6061 powders (<160 μm) were used. AlSi7 alloys were obtained by blending elementary aluminium (99.74%, < 160 μm) and silicon powders (<100 μm).

3 Experimental Procedure

The tests were performed by foaming the tablets inside the expandometer. The apparatus uses a laser sensor to measure the expansion during the foaming process of the metal foam (see Figure 1). The foaming chamber is a quartz glass tube. The bottom end of the glass tube is connected to a vacuum pump and gas source, while the top end is attached to a laser single point sensor. The foaming tests were performed with the furnace at a pre-set temperature. The furnace was closed around the glass tube, causing an immediate rise of the temperature of the foamable precursor sample, which was previously placed inside a confining steel tube. The measurement of the volume of the expanding melt together with the sample and furnace temperature generates a pair of functions V(t) and T(t) which characterise the expansion

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

kinetics. The thermocouples and the laser sensor are connected to a computer via an A/D interface. The data is analysed with a standard acquisition programme.

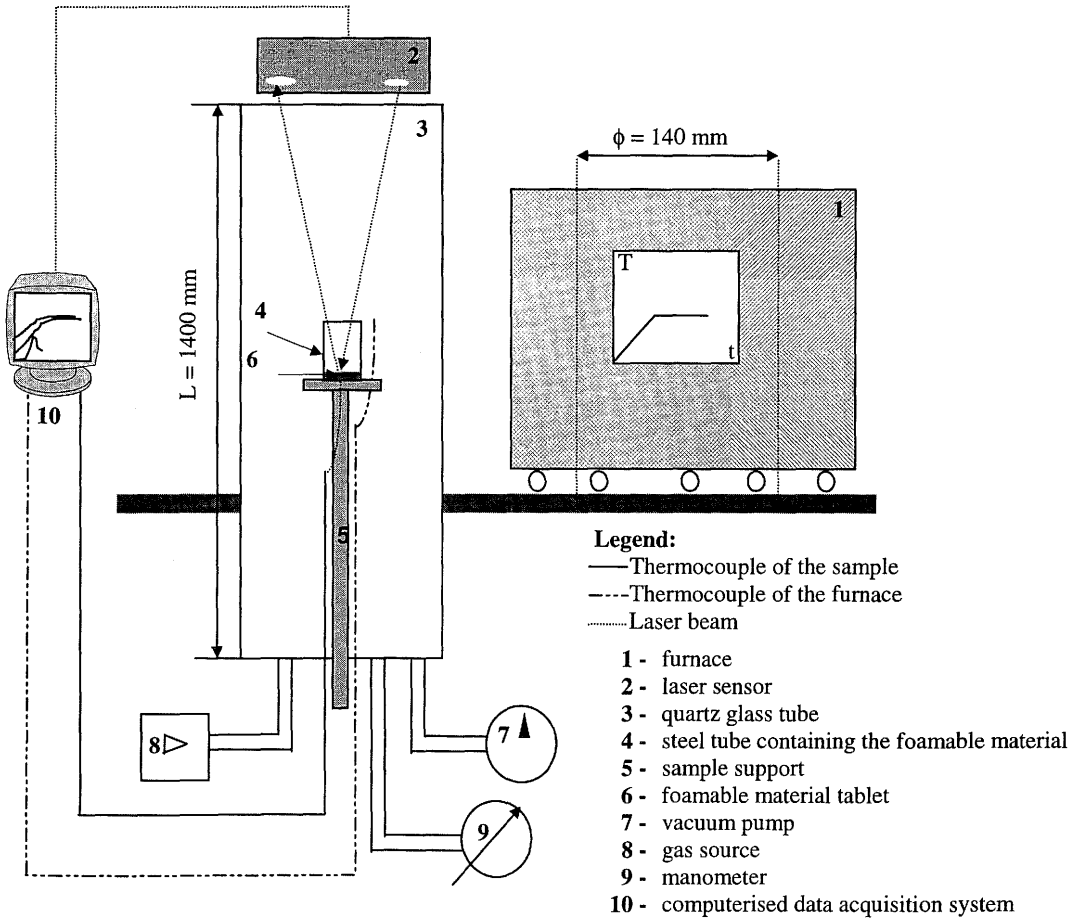


Figure 1. Schematic drawing of the apparatus used for the foaming tests.

4 Results

4.1 Comparison with previous results

In an earlier study, the foaming kinetics of aluminium foams were measured by means of an apparatus, which uses a ceramic movable piston instead of a laser [4]. The expanding melt displaces the piston and generates the volume expansion function - V(t). The aim of one test was to compare expansion curves given by this old expandometer – called "mechanical expandometer" and the new one using the laser sensor – called "laser expandometer". For this extruded foamable precursor samples made of 6061 alloy and containing 0.6 wt. % of titanium hydride were used. The foaming tests were conducted at 800°C (pre-heated furnace) for both expandometers. Figure 2 shows an example for expansion and temperature curves measured by the two measurement systems.

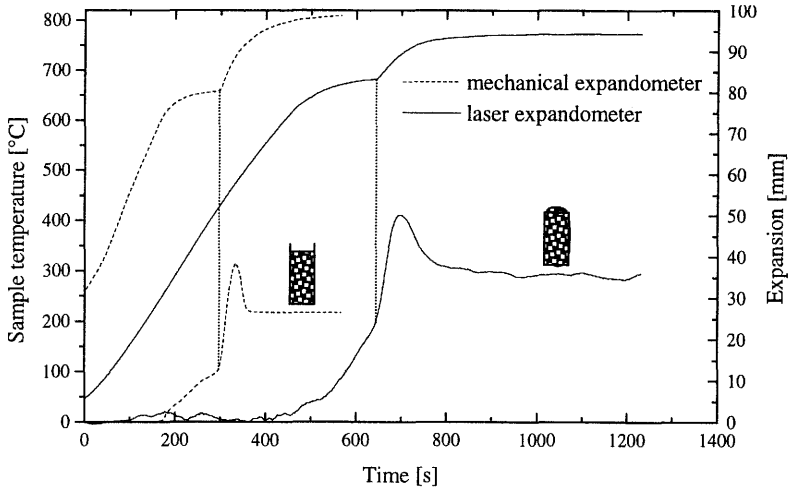


Figure 2. Expansion and temperature curves of aluminium alloy 6061 foamed, in a pre-heated furnace at 800°C. Vertical dotted lines show the liquidus temperature of the alloy.

Both data sets show the same stages of the foaming process, namely:

1. below the solidus temperature of the aluminium alloy, the expansion is small;
2. as the solidus temperature of the aluminium alloy is reached, it starts to soften and expands as a consequence of the decomposition of TiH_2 to H_2 gas and Ti;
3. at the liquidus temperature of the aluminium alloy the expansion rate increases rapidly until the maximum expansion is reached;
4. finally, after the maximum expansion, the foaming agent is exhausted and no longer releases hydrogen. At this point the foam starts to collapse towards some "equilibrium" stage.

However, there are some differences between the two expansion curves, namely its maximum and the time of initiation of the foaming process. The mechanical expandometer shows:

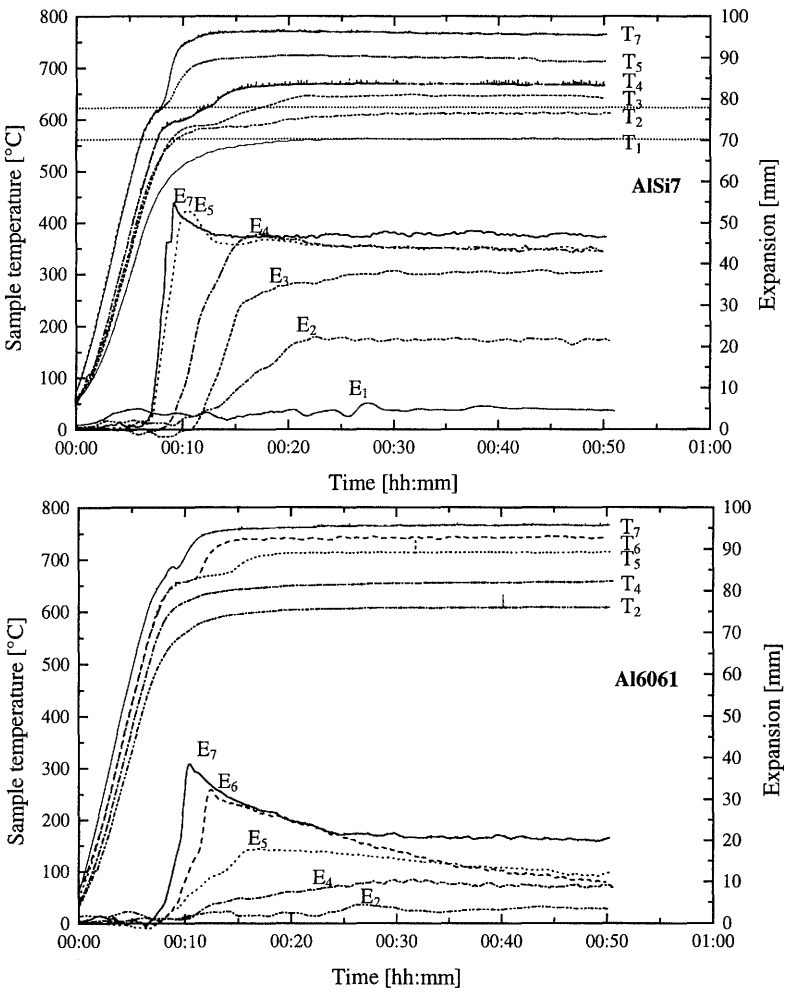
1. an earlier starting of the foaming process: this is due to a higher heating rate of the foamable precursor material as a consequence of the absence of an insulating glass tube and a small furnace;
2. a lower maximum expansion: This is due to the weight of the piston (8.7 g) and some friction between the piston and the confining steel tube which hinder expansion. Moreover, the laser measures the position of the centre of the expanding foam. As the foam expands without any restriction in the vertical direction the surface of the foam is vaulted. The reading of the laser expandometer therefore tends to be a bit too high (approximately 2 mm);
3. the collapse regime can not be resolved properly: The piston sticks fast after some initial collapse.

In contrast, the laser expandometer allows for monitoring all phases of the expansion. The laser expandometer shows some fluctuations in the heating phase before foaming: This is not real expansion effect but a consequence of strong turbulence in the furnace when it is heated up. In later stages of the experiment the turbulence diminishes because the temperature becomes more uniform.

The main conclusion of this first study is that the laser sensor is a more sensitive tool to measure the expansion during the foaming process than the mechanical expandometer, because it does not disturb the foam during its growth and collapse.

4.2 Effect of foaming temperature

The influence of foaming temperature on the foaming kinetics was investigated. For this study cylindrical foamable precursor samples of AlSi7 and 6061 alloys containing 0.6 wt. % TiH_2 were used. The pre-set furnace temperature was varied between 600°C and 800°C.



Legend:

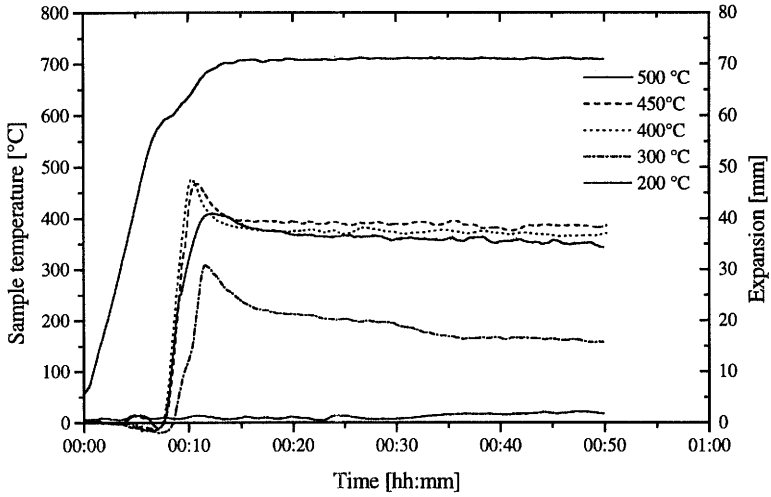
$T_{furnace}$ [°C]	600	650	675	700	750	775	800
E curve	E_1	E_2	E_3	E_4	E_5	E_6	E_7
T curve	T_1	T_2	T_3	T_4	T_5	T_6	T_7

Figure 3. Expansion (E) and temperature (T) curves of aluminium alloy samples containing 0.6 wt % TiH_2 foamed at different furnace temperatures (600°C-800°C).

Figure 3 shows the influence of the temperature on the foaming behaviour of the two aluminium alloys. As one can see, the foaming characteristics depend sensitively on the furnace temperature chosen. Temperatures around or just above the melting temperature of the respective alloy lead to rather low volume expansions. Apparently a certain excess temperature above the melting point is needed to obtain full expansion. AlSi7 requires 750°C, alloy 6061 even 800°C furnace temperature leading to final temperatures in the sample of 725°C or 770°C. This corresponds to 150°C above the solidus temperature of the alloy. The reason for this behaviour are hydrogen losses when the sample is heated to slowly at too low temperatures. As the decomposition of TiH_2 already starts at 380 °C, only a fairly quick rise of the temperature to a value well above the melting point leads to effective pore formation and growth. What also becomes apparent in Figure 3 is that higher temperatures lead to a more pronounced collapse after maximum expansion. The reason for this is the decrease in viscosity when the temperature is increased thus exacerbating deleterious drainage effects. After maximum expansion the foam usually collapses only partially and reaches some "equilibrium" height where it remains. The remaining foam is very coarse (see Figure 7) and is stabilised by its oxides so that no further collapse takes place.

4.3 Effect of the compaction conditions

All samples were pre-pressed before the actual hot pressing step to prevent the powders from uncontrolled oxidation during heating to the pressing temperature. The effect of the processing parameters (time of pre-compaction, time and temperature of the actual hot pressing) on the kinetics of the foaming process were investigated. For this study, cylindrical foamable precursor samples of the aluminium alloy AlSi7 were used. The powder mixtures were axially compacted at various compaction conditions. Figures 4 and 5 show the expansion curves of some samples subjected to the same heating conditions during foaming, but which were prepared under different hot pressing conditions. In Figure 4 the hot pressing temperature was varied at constant pressing times. In Figure 5 the compaction temperature was constant but the pre-pressing time t_1 and the hot pressing time t_2 were varied.



$T_{hot\ pressing}$ [°C]	200	300	400	450	500
$\rho_{average}$ [g/cm^3]	2.46	2.58	2.65	2.66	2.66

Figure 4. Expansion curves of AlSi7 samples containing 0.6 wt % of TiH_2, prepared at different hot pressing temperatures (t_1 = 60 min, t_2 = 20 minutes).

Figure 4 shows that the hot-pressing temperature is a very important parameter. To low compaction temperatures lead to insufficient compaction with some residual porosity (see density values given). The hydrogen gas can escape from the melting alloy without creating pores in this case. The same phenomenon is observed when the powders are extruded instead of hot pressed [5]. Too high compaction temperatures in turn lead to lower maximum expansions because some of the hydrogen is lost during compaction. Even higher compaction temperatures lead to a rapid loss of foamability [6]. The optimum compaction temperature therefore lies at 450°C for the case investigated, well above the initial decomposition temperature of TiH_2 (380°C). Figure 5 demonstrates that the compaction time is an uncritical parameter for the compaction temperature chosen. The variations observed are not systematic and within the range of normal statistical fluctuations.

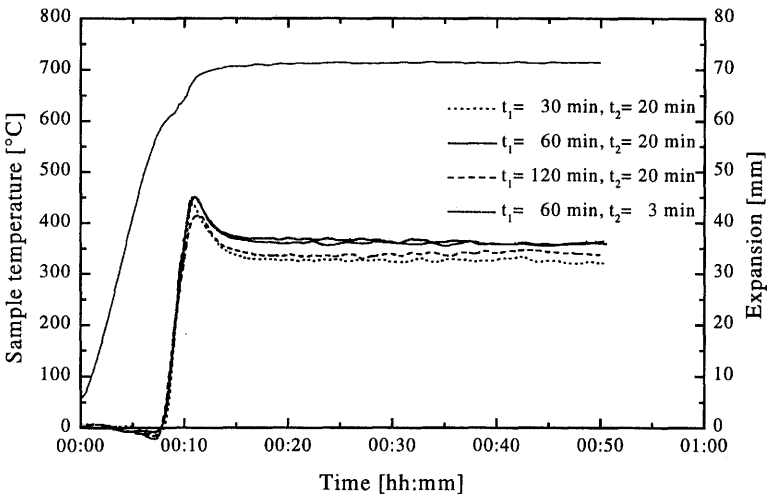


Figure 5. Expansion curves of AlSi7 samples containing 0.6 wt. % TiH_2, prepared with different pre-heating (t_1) and hot pressing times (t_2). $T_{hot\ pressing}$ = 450°C.

4.4 Evolution of the morphology of aluminium alloy during the foaming process

In order to visualise the evolution of the metal foam during the foaming process, foaming tests were performed at a pre-heated furnace at 800°C with the same procedure as described above. The foaming process was stopped in different stages by simply removing the furnace from the quartz tube. The expansion was monitored so that one can ascribe a position in the global expansion diagram to each sample: in Figure 6 the points A to K indicate the different foaming stages that were prepared.

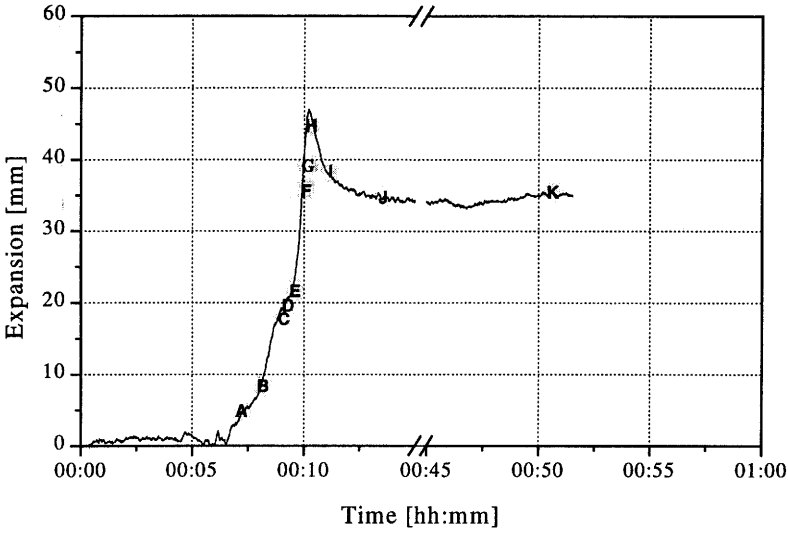


Figure 6. Expansion curve of aluminium alloy 6061 samples (0.6 wt. % TiH_2) in a pre-heated furnace at 800°C.

Figure 7 shows the corresponding micrographs of the foam being in various stages of evolution. Note that due to a certain after-expansion following the removal of the furnace the samples in Figure 7 correspond to slightly later stages as marked in Figure 6. One sees that initial pore formation leads to "cracks" perpendicular to the pressing direction rather than to round pores. As the foam evolves the cracks are transformed to fairly round pores. The effect of collapse also became visible. Coarsening and drainage can be seen especially for sample K.

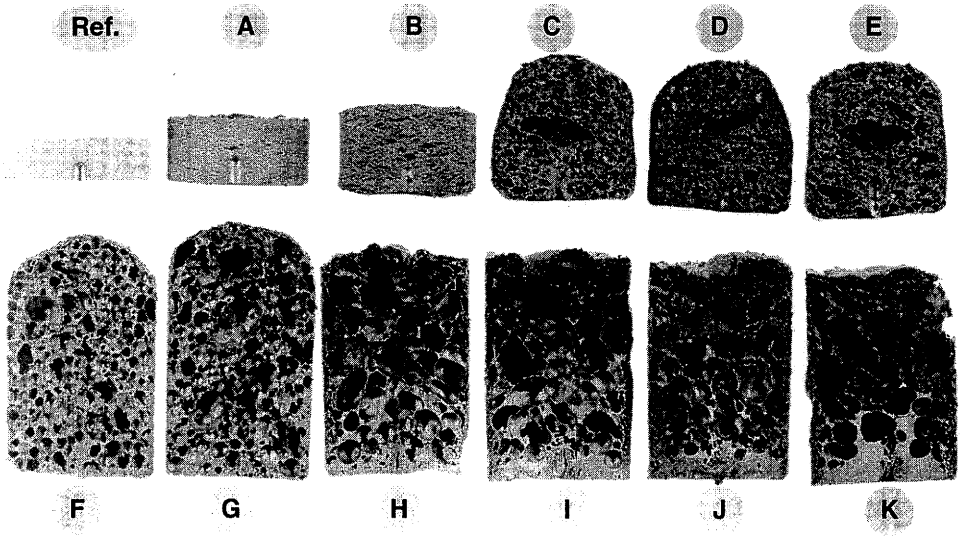


Figure 7. Morphology of the aluminium alloy 6061 in different stages of foaming (diameter of foams ≈ 30 mm). Letters show at which stage of expansion the furnace was removed from the expandometer (see Figure 6).

5 Conclusions

The foaming kinetics of aluminium alloys foams produced by applying the powder metallurgical route are determined by a complex interplay of several mechanisms which occur during the process. The foaming process is strongly governed by temperature effects. The main conclusion of this study is that the expansion curve is strongly dependent on the processing conditions, mainly on the hot pressing temperature to obtain the foamable precursor material, and the heating parameters during foaming.

6 Future work

More research work will be carried out in future to achieve a good knowledge of the foaming kinetics of the aluminium alloys and to obtain correlations between the final properties of the foams and the parameters of the each step of the manufacturing process. Future work includes: i) Study of the influence of more process parameters on the foaming kinetics of aluminium alloys, namely the type of foaming agent and its content, and atmosphere conditions (type of atmosphere and pressure); ii) Evolution of morphology (shape and size of cellular pores) and microstructure during the foaming process of aluminium alloys.

Acknowledgement: The work is being supported by EU (Marie Curie Training Programme ERB-BRMA-CT98-5103) and DFG (Programme SPP-1075).

References

[1] J. Baumeister, "Methods for manufacturing foamable metal bodies", German Patent 40 18 360 (1990), US Patent 5,151,246 (1992)

[2] J. Banhart, J. Baumeister, M. Weber, " Powder Metallurgical Technology for the Production of Metal Foam", Proceedings of Euro PM 95Euro, Birmingham, p. 201, (1995)

[3] J. Banhart, J. Baumeister, M. Weber, "Metal foams near commercialisation", Metal Powder Report, 53, 38, (1997)

[4] J. Banhart, P. Weigand, "Powder metallurgical process for the production of metallic foams", in Proc. Fraunhofer USA Symposium Metallic Foams, Ed. J. Banhart and H. Eifert, MIT-Verlag Bremen, p. 13, (1998)

[5] J. Banhart, unpublished work

[6] P. Weigand, Thesis, MIT-Verlag, Bremen (1999)