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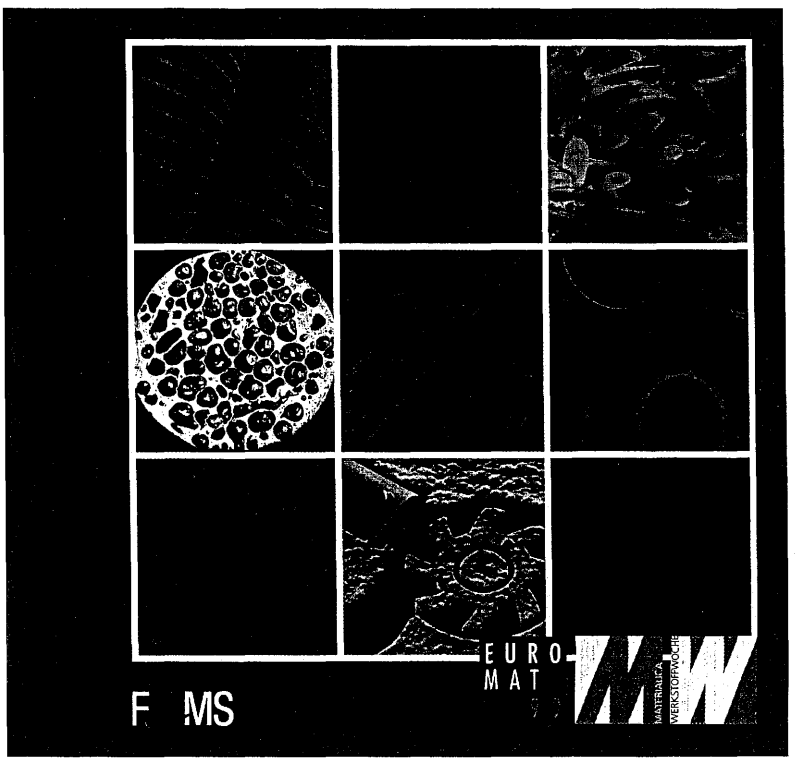

Influence of process parameters on the expansion behaviour of aluminium foams

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Abstract

Metallic foams were produced applying the powder compact method, i.e., by mixing powdered metals and a foaming agent and subsequently pressing the mixture to a foamable precursor material. This precursor material is then foamed by heating it up to its melting point. The expansion of the foamable precursor material and its temperature were monitored during the entire foaming process by means of a laser sensor and a thermocouple, respectively. The influence of some of the manufacturing parameters on the expansion behaviour of aluminium alloys was investigated. Besides the foaming kinetics the evolution of morphology (shape and size of the cellular pores) during the foaming process is discussed.

1 Introduction

While a lot is known about how to produce metal foams, little is known about how to explain the mechanisms governing the foaming process. This applies to most of the production processes [1]. Currently a number of research groups including our own one have launched investigations to clarify some of these mechanisms (see papers in Ref. [2]). While some groups have developed tools that allow for observing the foam during the foaming process, namely the shape of the foaming front or even the evolution of the gas bubbles, others have been trying to simulate the growth of the bubbles with computational methods [3-5].

We have developed an apparatus that allows for measuring the expansion of a foam inside a mould. With this device, called "laser expandometer", the rise of a metal foam in a cylindrical tube is observed by means of a laser sensor. Recent studies [5] have shown that this apparatus is a more sensitive tool than previous models in which the rise is monitored mechanically with a movable piston [6]. The laser sensor does not disturb the foam during its growth and collapse.

Effects of alloy composition, pressing parameters of the foamable precursor material and the foaming cycle (temperature and heating rate) on the expansion process are studied in the present paper. The objective is to gain insight into the foaming process of a metallic melt and to optimise process parameters with respect to foam quality and process stability.

2 Experimental Procedure

2.1 Sample preparation

Cylindrical samples (h=9 mm, ϕ=31 mm) of foamable aluminium alloys – 6061 and AlSi7 – each containing 0.6 wt.% TiH_2, were produced either by hot pressing (for AlSi7) or extrusion (for 6061) according to the patented Fraunhofer Process [7]. Pre-alloyed 6061 powders (<160 μm) were used. AlSi7 alloys were obtained by blending elementary aluminium (99.74%) and silicon powders. The particle sizes of the powders used are listed in Table 1.

Table 1. Size range of the powders used.

Powders	D10, μm	D50, μm	D90, μm
Aluminium	128.20	56.78	17.44
Silicon	91.31	29.61	4.409
Titanium hydride	41.12	15.28	2.865

2.2 Foaming tests

The cylindrical foamable precursor material was foamed by heating it up to its melting point inside the laser expandometer, which is described in detail in Refs. 5, 8 and 9. During the foaming process the height of the foaming front and the temperature of the expanding sample were continuously monitored. One obtains a volume function V(t) and a temperature function T(t) for each sample.

3 Results and discussion

3.1 Effects of manufacturing process parameters

3.1.1. Compaction

For studying the influence of the hot pressing temperature on foaming kinetics, various foamable AlSi7 samples were produced by axial compaction at various compaction conditions. In order to avoid an uncontrolled oxidation of powders during heating, hot pressing was carried out in two steps: pre-pressing and the actual hot pressing. Figures 1 shows the expansion curves of samples which were pressed at different temperatures between 200°C and 550°C. All other process parameters including the heating conditions during foaming (pre-heated furnace at 750°C) were the same for all samples.

It is evident that the hot pressing temperature is a critical parameter for foaming. As one can see in Figure 1, the maximum expansion is achieved for compaction temperatures around 450°C. For higher and lower temperatures the maximum expansion is lower and in the extreme case, for 200°C and 550°C, there is virtually no expansion any more. Low compaction temperatures lead to insufficient densification with a lot of residual porosity corresponding to a low green density (see Table 2). The hydrogen gas can escape from the melting precursor instead of creating pores. Too high compaction temperatures, i.e. well above 500°C, lead to lower maximum expansions because much of the hydrogen is already lost during compaction.

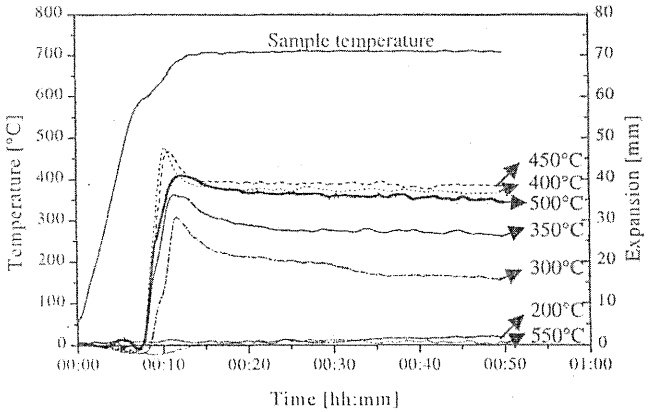


Figure 1: Expansion of AlSi7 with 0.6% wt. TiH_2 prepared at different hot pressing temperatures.

Table 2. Density of foamable precursor material.

Thot pressing [°C]	200	300	350	400	450	500	550
paverage [g/cm3]	2.46	2.58	2.61	2.65	2.66	2.66	2.68

3.1.2 Foaming cycle

3.1.2.1 Foaming temperature

The effects of the foaming temperature on foaming kinetics were studied on 6061 and AlSi7 alloys samples. These samples were compacted at 450°C and foamed in a pre-set furnace between 600°C and 800°C. Figure 2 shows that the maximum expansion is reached at different furnace temperatures for the two alloys reflecting the different melting points alloys. In addition, figure 3 shows how the foamed samples appear after the complete foaming test which took 50 minutes (after which they are partially collapsed).

As one can see, the maximum expansion depends very much on the furnace temperature chosen. Temperatures around or just above the melting point of the respective alloy lead to rather low volume expansions. Clearly, a certain excess temperature above the melting point is needed to obtain full expansion. AlSi7 requires at least 750°C, the 6061 alloy 800°C furnace temperature leading to final temperatures in the sample of 725°C or 770°C, respectively. This corresponds to 150°C above the solidus temperature of the respective 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 quick rise of the temperature to a value well above the melting point leads to effective pore formation and growth.

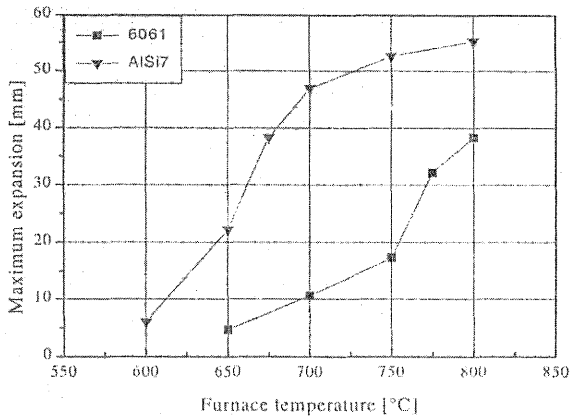


Figure 2: Maximum expansion at different furnace temperatures for 6061 and AlSi7 alloys.

Figure 3 shows the samples after the foaming tests that in total lasted 50 minutes. As one can see, the 6061 alloy is more prone to collapse of the foam structure after maximum expansion.

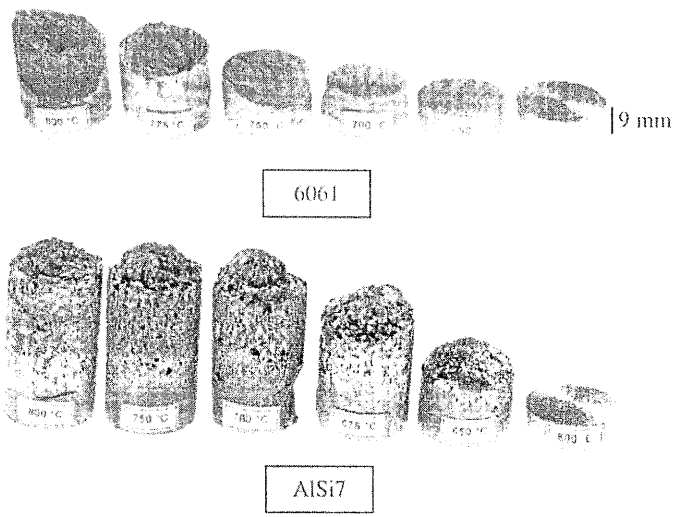


Figure 3: Samples after the foaming tests (50 minutes) at different furnace temperatures (600°C-800°C).

3.1.2.2 Heating rate

Different furnace temperatures lead to different heating rates and influence the foaming process this way. In order to evaluate the influence of the heating rate independently, a series of foaming experiments was carried out at 800°C with variable heating rates. For this 6061 alloy samples were placed into the cold furnace which was then heated up at a given rate.

Figure 4 shows four expansion curves obtained this way, the highest heating rate corresponding to using a pre-heated furnace as described in previous sections.

Clearly, higher heating rates lead to an earlier expansion of the foamable precursor material because the melting temperature is reached at an earlier time. Beside this difference, the three expansion curves for the highest heating rates are very similar. Only significantly lower heating rates lead to a change of the expansion characteristics, namely a lower maximum expansion. The reason for this are gas losses due to diffusion of hydrogen and perhaps the strong oxidation of the sample which might hinder expansion.

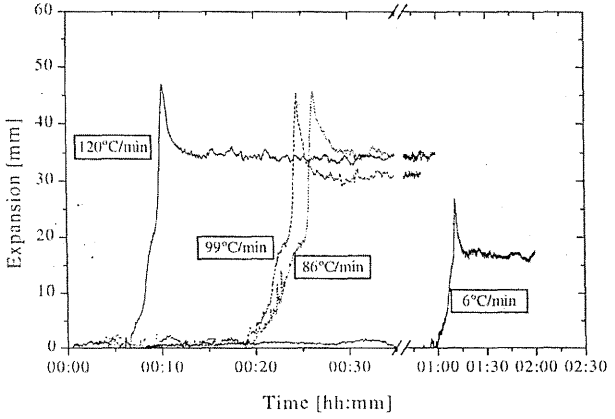


Figure 4: Expansion curves of 6061 samples containing 0.6 wt. % TiH_2 for different heating rate.

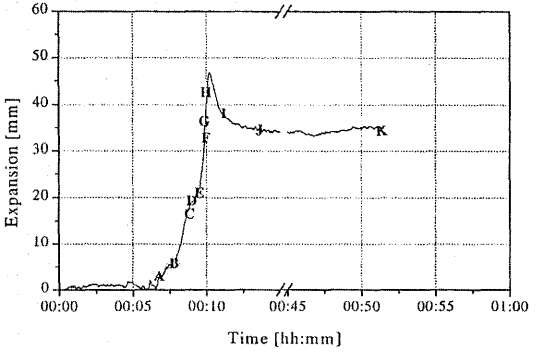
3.2 Evolution of foam morphology

Foaming tests were carried out in order to observe the evolution of the morphology of the cellular pores during foaming. For this experiments were carried out in a pre-heated furnace at 800°C (6061 alloy) and 750°C (for AlSi7 alloy), respectively. This choice of furnace temperatures ensures good conditions for each alloy (see section 3.1.2.1) with respect to foamability. The foaming process was stopped in different foaming stages by simply removing the furnace from the sample. In the following figures the global expansion curve for each alloy is shown. The points marked "**A**" to "**K**" (for 6061 alloy) and "**A'**" to "**K'**" (for AlSi7 alloys) indicate the different foaming stages which were prepared and for which micrographs are shown.

Both the aluminium alloys show the same foaming stages, namely pores initiation, pore growth and collapse. It is interesting to see that foam growth is neither isotropic nor uniform in both alloys. An anisotropy occurs when the pores are formed. One observes pores with an elongation perpendicular to the direction in which the powder was consolidated. The directionality of pressing creates an anisotropic texture in the foamable precursor material and initial pores which more resemble cracks than bubbles. As the expansion advances, the pores begin to become rounded and the anisotropy almost vanishes until only a slight asphericity remains. The pores which are formed are rarely uniform in size. The reason for this can be local agglomerates of the foaming agent or structural defects which facilitate pore formation. As the decomposition of TiH_2 already commences at about 380°C, tiny voids in the precursor material already form in the solid state preferably near such structural defects.

Increasing the temperature further increases the internal gas pressure of each pore and pore growth accelerates especially after the solidus temperature has been reached. After maximum expansion no more hydrogen gas is released and the foam begins to collapse. One collapse mechanism, *drainage*, is the flow of molten metal from the cell walls into the cell-edges and through the cell edges downwards driven by gravity. A result of drainage is a thick layer of metal at the bottom of the samples, as one can see in alloy 6061 (points I, J and K in Figure 6). Another mechanism, *coarsening*, is the growth of pores at the expense of others. One reason for this is diffusion of hydrogen from one cell to the other driven by the difference in internal pressure. These processes lead to a structure with very large and irregular pores (see Fig's. 5 and 6).

The collapse behaviour of the two aluminium alloys studied is quite different, the aluminium alloy AlSi7 being more stable than the 6061 alloy. The collapse of AlSi7 is slower than that of 6061, as it can be seen by comparing point K of Figure 5 with K' of Figure 6. Alloy 6061 is more prone to drainage showing a thick layer of metal at the bottom which builds up with time, as one can see comparing points I, J and K in Figure 5. The reason could be that alloy 6061 has a lower viscosity at the final sample temperature (770°C) than AlSi7 (725°C).



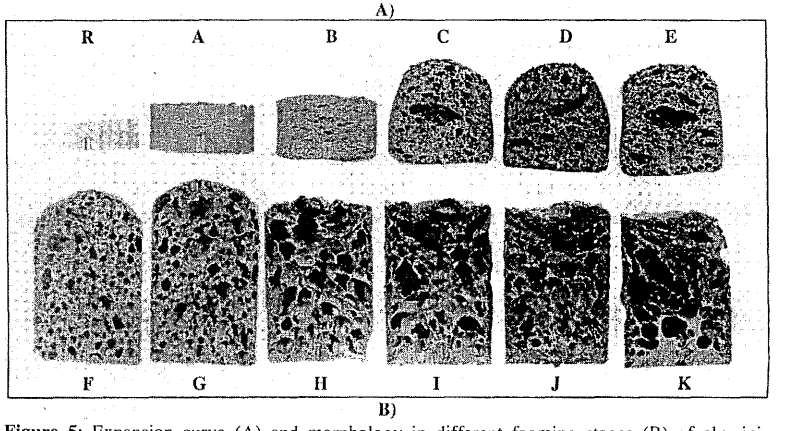


Figure 5: Expansion curve (A) and morphology in different foaming stages (B) of aluminium alloy 6061 samples (0.6 wt. % TiH_2) foamed in a pre-heated furnace at 800°C.

4. Summary

The studies presented showed that a good choice of compaction parameters and here especially the pressing temperature are essential for obtaining good foaming results. The foaming temperature has to be sufficiently high, typically 150°C above the liquidus temperature of the alloy, to avoid hydrogen losses and unwanted ageing effects during foaming. High heating rates are desirable. Slow heating leads to a reduced expansion. The foam growth of aluminium alloys is neither uniform nor isotropic. The morphology of the foam (shape and size of the cellular pores) also changes during the foaming stages. During the growth, the elongated initial pores, which are perpendicular to the pressing direction, grow and become more spherical and only a slight asphericity remains. After the maximum expansion has been reached no more gas is released and the foams begins to collapse due the drainage and coarsening effects.

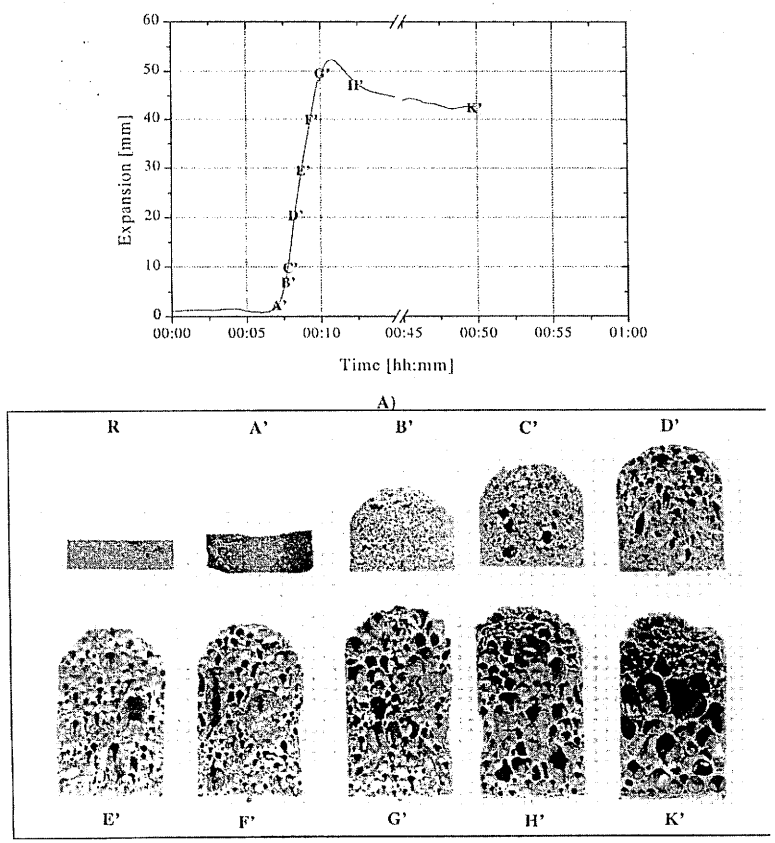


Figure 6: Expansion curve (A) and morphology in different foaming stages (B) of aluminium alloy AlSi7 samples (0.6 wt. % TiH_2) foamed in a pre-heated furnace at 750°C.

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