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Analysis of Metal Foaming Behaviour and Development of Foaming Processes

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Abstract

The present paper highlights results from the priority program "Cellular Metals" of the Deutsche Forschungsgemeinschaft (DFG SPP 1075). Metal foams were made by foaming precursors containing a blowing agent. Two different manufacturing routes for precursors were analyzed and compared: hot-pressing of powders and thixocasting of cold-isostatically pressed powders. The foaming process was observed in-situ by X-ray imaging. Expansion kinetics, average pore sizes, drainage effects and pore morphologies were determined. The influence of gas atmosphere and overpressure on expansion and pore size was studied. Thixocasting parameters such as the pre-heating conditions of the slug, the cold-isostatic compaction pressure and TiH_2 content were optimized. Foam expansion and drainage of the optimized precursor were studied.

Introduction

Due to its flexibility with respect to the choice of alloys and the possibility to produce complex-shaped metal foam and foam sandwich components powder-based foaming technologies have found much scientific and industrial interest [1,2]. One of these techniques is based on three process steps, namely mixing of metal with blowing agent powders, compaction to a precursor material and foaming by heating the precursor to above its melting temperature. Nevertheless, wide scale industrial production has not yet been implemented as securing a homogeneous and reproducible quality of both precursor and foam and reduction of the process costs have not yet been achieved. Especially the problem of inhomogeneous and sometimes badly reproducible pore structure of metal foams has led to the development of an alternative approach for the production of precursor material [3,4].

We investigate and compare two foaming routes (fig. 1): The well known *route I*, where the precursor material is hot-pressed after which it is foamed and *route II*, a new approach [3] based on thixocasting [5] of compacted powder slugs. This latter process labelled route II comprises the following steps:

- mixing of metal and blowing agent powders (e.g. aluminium, silicon, copper and TiH_2),
- cold-isostatic compaction to cylindrical slugs,
- heating of the slugs to the semi-solid state,
- thixocasting in a vertical or horizontal cold-chamber high-pressure die casting machine,
- removing of the casting and the overflows, and
- foaming.

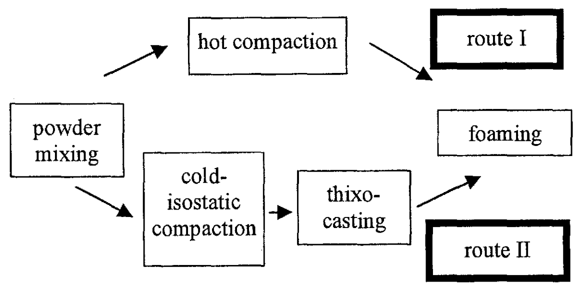

Figure 1: *Steps of foam production routes.*

Specific differences in the foaming behaviour of precursor material obtained by route I and II could be observed as well ex-situ by standard metallographic analysis as in in-situ radioscopy experiments [6]. The main differences were ascribed to a more isotropic structure of the thixo-cast precursor and to better co-ordinated decomposition temperatures of the blowing agent and the melting point of the matrix alloys.

To understand the processes determining foam quality and the differences between the technological approaches in a better way a new radioscopy unit [7] was developed which is especially adapted to in-situ investigations of metal foams. Foaming can be carried out and observed in different atmospheres, pressures and different controlled temperature regimes. In the experiments the dependence of the foaming behaviour on these parameters and for different production technologies for the precursor material was investigated. Expansion, foam density and drainage were characterised in-situ during the foaming process. Furthermore, ex-situ foam expansion measurements were performed in order to find the optimal TiH_2 content for the thixocasting process.

Experimental

For an in-situ analysis of the process a radioscopic unit was used. The foaming process can be recorded in-situ and in real-time with frequencies up to 9 Hz and resolutions down to 5 μm. It consists of a Hamamatsu 150 kV microfocus X-ray source, a heating unit transparent to X-rays and a 2240 × 2368 pixels panel detector also from Hamamatsu (Fig. 2). Magnifications up to 10 times are obtained by changing the distances between source, sample and detector. The pressure heater used allows for a defined gas atmosphere and pressures in the range of 0.01 to 10 bar.

Beside qualitative also quantitative analysis of the recorded images can be performed using a self-developed software [7]. The apparent cross section of the samples is calculated from individual images as a function of time. As the samples were not cylindrical the expansion in the direction of the beam could not be taken into account. We therefore show the apparent change of cross section (e.g. in fig. 6). Clearly the course of F/F_0 displayed in fig. 6 falls short of the true volume expansions given, e.g., in fig 5. However, for obtaining expansion profiles and for comparison this is acceptable.

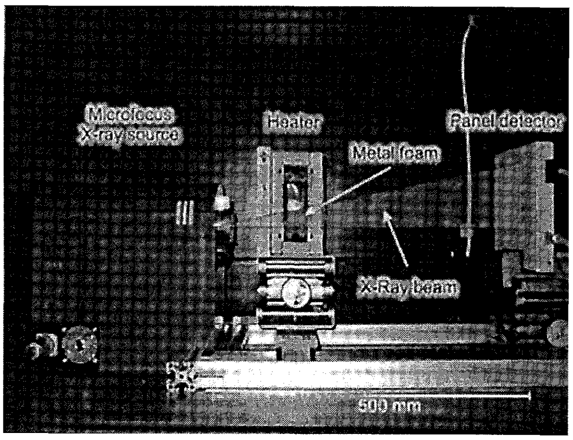

Figure 2: *X-ray foam scanner.*

Investigation of the Influence of Atmospheric Pressure on Foaming Behaviour

In early stages of the foaming process differences between both foaming routes were found, e.g. the expansion is anisotropic in route I due to the uni-axial compaction step in making precursors, leading to cracks perpendicular to the compression axis and a coarser final pore size distribution. That is not the case for route II. On the other hand the volume expansion factors $\eta=V_{final}/V_0$ found for route I range up to 7, but only up to 4 for route II.

To investigate the influence of the atmospheric gas composition and pressure on foaming, a pressure heater was used [8]. Expansion using the same precursor material could be reduced to $\eta \sim 4$ applying pressures up to 10 bar during the foaming phase. Fig. 3 shows that foam expansion for an AlSi6Cu4 alloy can be controlled from $\eta{\sim}2$ at 8 bar to $\eta{\sim}4$ at 1 bar, just by adjusting the furnace pressure. Not only expansion can be controlled this way, but also the technologically very important average pore size, in this case from ~ 0.1 mm at 8 bar to ~ 1mm at 1 bar.

Different gas atmospheres (oxygen, argon) could influence stability of a foam e.g. due to the formation of oxide skins. However, for AlSiCu alloys no significant influence of the gas atmosphere was found. The reason can be that the formation of oxide skins even under argon cannot be avoided due to residual oxygen impurities or to oxides contained in the samples.

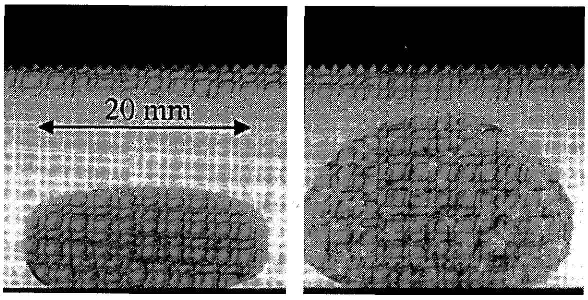

Figure 3: *Radioscopic pictures of a route I precursor foamed in air under 8 bar (left) and under 1 bar (right), T = 600°C.*

Investigation and Optimization of Foaming Behaviour and Parameters of Thixo-cast Precursor Material

In-situ radioscopy was used together with conventional methods to optimize the blowing agent content, the compaction pressure and the heating parameters and of thixo-cast slugs made of AlSi6Cu4 and AlSi11. For the casting experiments a component with a complex geometry was used, see fig. 4. The casting parameters, e.g. casting velocity, were optimized to ensure a complete mould filling. The castings were controlled visually and by means of conventional X-ray radioscopy using a YXLON MU2000 160kV unit. For the optimization experiments the adapted casting parameters were kept constant for all specimens to ensure reproducibility.

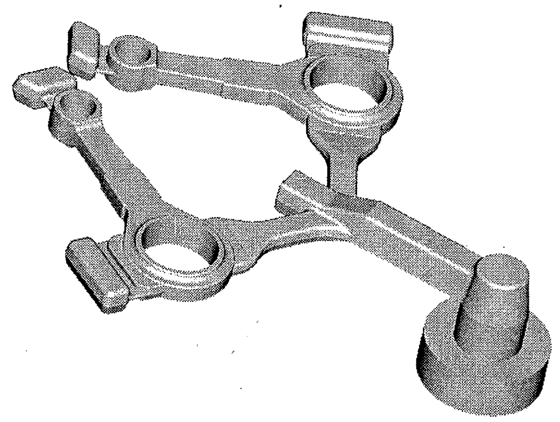

Figure 4: *Component geometry used for the thixocasting experiments.*

In first experiments in which slugs were heated prior to casting formation of dense surface skins was observed. Metallographic investigations showed that these skins are form by oxidation which hinders the dissolution of certain alloying elements such as copper and therefore increases the melting point of the affected regions of the slug. To prevent this oxidation the slugs were wrapped into anodized Al-foils. Slow and fast heating regimes were tested varying time and furnace temperature (e.g. 2h at 570°C or 1h at 610°C) in order to optimize slug temperature and to evaluate the influence of temperature homogeneity and premature loss of hydrogen on casting and foaming of the precursor material. As the latter effect was clearly more pronounced all following experiments were carried out using the fast heating regime. The optimal slug temperatures for casting were 567°C for AlSi6Cu4 and 585°C for AlSi11. However, as the temperature changes in the slugs are very slow above the solidus temperature heating time was used as control parameter rather than slug temperature.

As casting temperatures for the slugs are clearly inside the decomposition temperature range of titanium hydride, premature hydrogen loss occurs during heating up of the material leading to a certain expansion of the slugs. Only some extent of expansion can be accepted from a technological point of view due to the given diameter of the sleeve of the casting mould. As the observed expansion depended also on the slug composition especially the blowing agent content and the heating time had to be optimized for all different compositions. The dependence of the maximal expansion of the foams on the blowing agent content as shown in fig. 5 represents, therefore, not a direct comparison of identical treated slugs with only changing TiH_2-amounts but the comparison of slugs with different TiH_2 contents and heating parameters technologically optimized for each single composition. For most alloys cold-isostatic pressures of 1000 or 1500 bar, TiH_2-contents of 0.5 - 0.8 wt% and casting velocities of 0.3 m/s were found to produce satisfactory results.

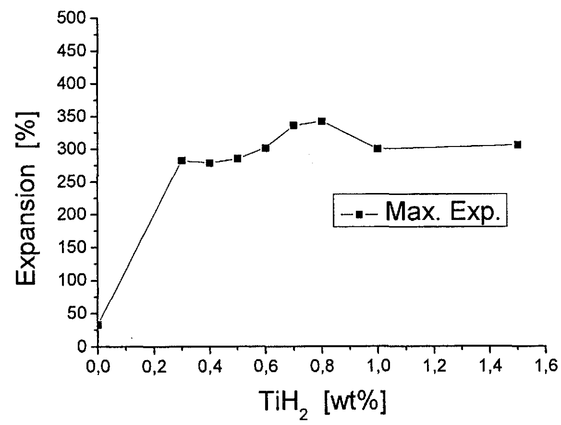

Figure 5: *Expansion of route II AlSi6Cu4 foams as function of TiH_2-contents, optimum at 0.8 wt%.*

Investigation of Foam Expansion and Drainage

Quantitative analysis of radioscopic pictures allows us to measure expansion and drainage during foaming. Fig. 6 shows the expansion curve of 2 thixo-cast foams. We can see that an increase in TiH_2 content and a reduction of the slug heating time leads to higher expansions. But as most of the production parameters such as TiH_2 content, isostatic compaction pressure, slug pre-heating time, etc. are correlated to each other, the optimal foaming conditions for each alloy have to be found. For route I optimal parameters are well known and were previously investigated [1,6-8].

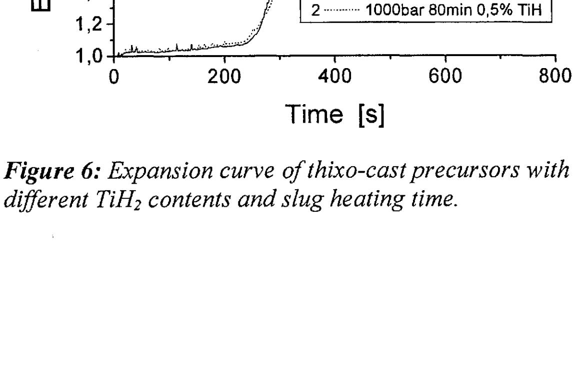

Figure 6: *Expansion curve of thixo-cast precursors with different TiH_2 contents and slug heating time.*

For AlSi6Cu4 alloy precursors produced by route II and foamed at a temperature of 625°C it was found that the samples still continue expanding slowly for several minutes after the main expansion. This phenomenon was not found for route I foams under same foaming conditions. There after the main expansion the foam volume keeps constant, even if internal coalescence is given. The absolute volume expansion is less for the route II material. These differences may be explained by the different compaction process, so that the released hydrogen can only be slowly delivered by the thixo-cast precursors.

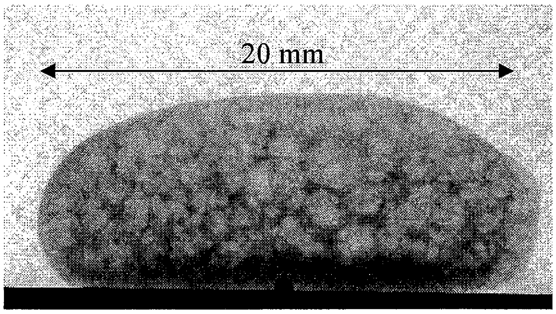

Figure 7: *Radioscopic picture of a route II foam with strong drainage (sample 2 of fig. 6).*

Expansion is not the only quality criterion to follow for parameter optimization. Other characteristics like pore size, coarsening or drainage have also to be considered. Fig. 7 shows strong drainage in sample 2 from fig 6, whereas sample 1 (not shown) is drainage free. The difference is the TiH_2 content and a 4 minutes longer heating time. Possibly the reduction of blowing agent can influence the pressure in the pores and cell wall stability and lead to drainage. Viscosity should not play a role in this case, because both samples have the same alloy composition and are foamed under the same conditions.

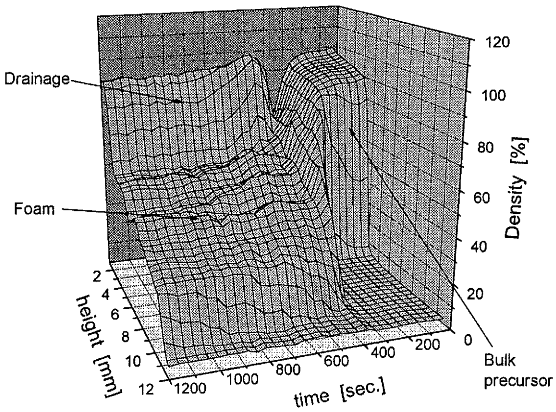

Figure 8: *Foam density over time corresponding to sample 2 in fig. 6.*

The density profile (fig. 8) corresponding to sample 2 in fig. 6 clearly shows the liquid metal draining to the bottom of the sample 400 s after the beginning of heating. This wet foam part occupies 1/5 of the total foam height and has a maximal density of ~ 100% of the bulk alloy, while the density of the rest of the foam is much lower.

Summary

Metal foam manufacture from hot-pressed powders and thixo-cast slugs was investigated. Foam volume expansion rates and pore sizes were adjusted in a certain range by foaming under different gas pressures. Maximal volume expansion factors of 7 for route I and 4 for route II were reached. Foam density profiles showed us foam homogeneity and drainage kinetics quantitatively. Optimal parameters for the thixocasting process were found, avoiding drainage and reaching acceptable expansions and pore sizes. From the view point of foam quality thixocasting is therefore an interesting alternative.

Acknowledgements

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