Foaming kinetics of Al-Si-Cu alloys

Hans-Martin Helwig, Francisco Garcia-Moreno, lohn Banhart

Hahn-Meitner Institut, Glienickerstr. 100, 14109 Bei-lin, Germany
Technische Universität Bel-/in, Hardenbergstr. 36, 10623 Berlin, Germany
E-mail: he/i.r+g@$n.ti.de

Abstract

The gap between the decomposition temperature of blowing agent and melting temperature of aluminium alloys is considered to play a key role for future structure of aluminiuin foams by the powder metallurgical route. One way to improve foaming is the usage of new alloys with lower melting temperatures. One promising alloy-system is Al-Si-Cu. The influence of the copper content on the expansion of powder metallurgical aluininium foams containing 6% Si is studied with two different inethods of expansion measurement, mechanical expandometry and in-situ x-ray expandoinetry. We characterize the foaming behavior of alloys quantitatively, in order to explain the effect of melting temperature on foaming kinetics.

1. Introduction

Metallic foams can be produced by the powder metallurgical (PM) route [1]. Metal powder is mixed with a blowing agent and compacted to a precursor material. This precursor material can either be further processed or directly foamed. Foaming means melting the material in a furnace, so that gas released by the blowing agent forms bubbles in the melt. Unfortunately, for aluminium alloys, the gas release start temperature (–400°C) of the coininon blowing agent TiH_2 is lower than the inelting temperature of most alloys. The result is gas being released in the solid or early seini-solid state, forming cracks instead of bubbles and leading to a very inhomogeneous pore structure and gas losses to the environment. The two principal ways to encounter this problein are either the pre-treatment of the blowing agent to delay gas release [2], which means pre-oxidizing the TiH_2 powder, or the application of an alloy that melts at lower temperatures.

One way to decrease the melting teinperature of the precursor material is using an aluminiuin-silicon alloy. The binary phase diagram shows an eutectic point at a silicon content of 12.6 % and 577 "C, which is much closer to the gas release temperature range of TiH_2 than pure aluminiuin (660°C). lmproved results in metal foaming were achieved with hypoeutectic alloys. The currently most common alloy in PM metal foarning is the AlSi7 casting alloy.
In some cases, however, there is a need for new alloys with an even lower melting temperature range, especially developed for metal foaming. One example are Aluminium Foam Sandwiches (AFS) [3], which are manufactured by roll-cladding of face sheets to foamable precursor, followed by foaming. An alternative alloy to AlSi7 used in the production of AFS is the AlSi6Cu6 alloy. The lower liquidus teinperature compared to AlSi7 makes it possible to use high-strength EN AW-60XX alloys as face sheets, which would melt if an AlSi7 core were heated up to a temperature high enough to provide a satisfactory expansion.

In this work, we compare the alloys AlSi6 and AlSi6Cu4 in order to separate the effects of silicon and copper. The copper content was limited to 4%, because the maximum copper content used in conventional alloys is also 4%, thus avoiding excessive corrosion and embrittlement. For the mechanical expandometry, the copper content was increased in 2% steps from 0% to 6%.

2. Mechanical expandometry

Foamable precursors were prepared by uniaxial hot-pressing of a mixture of elementary powders. The compaction force was 300KN for a cylindrical tablet of 36mm diameter, resulting in a pressure of 295MPa, the compaction temperature was 400°C and the compaction time 5 minutes.

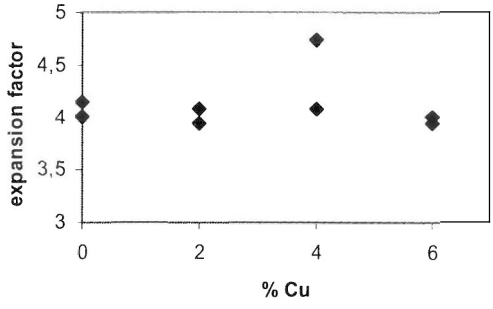

Figure 1. Maximum expansion factors reached with different copper contents

For mechanical expandometry [4,5] the sample is heated up with an infra-red radiation heater in a cylindrical glass tube. A thermocouple is placed directly in the sample, which allows for a direct measurement of the sample temperature. The samples are heated up at a constant heating power, resulting in a heat transfer of about 10W (calculated at 500°C) into the sample and a resulting heating gradient of 0.5K/s, up to a temperature of 630°C, after which the temperature is kept constant for 300s. After this period, the glass tube is cooled with pressurized air. This teinperature evolution allows for expansion measureinents without overheating of the foam thus avoiding an excessive foam collapse. This temperature evolution resembles the conditions during industrial production.

Fig. 1 shows the maxima of expansion achieved with different copper contents. Except one sample containing 4% copper, all samples reach nearly the same expansion height. Obviously, copper seems to have only a small influence on the maximum expansion during the entire foaming cycle.

If the expansion is plotted versus temperature (Fig 2), one can see the effect of copper on the foaming kinetics. A higher copper content decreases the start temperature for the foaming process, but does not lead to a higher expansion in our case. Expansion curves of 2 identical alloys show significant similarity in their dependence on the sample temperature. It seems that different alloy compositions change the foaming kinetics in the period when the foam temperature passes the melting temperature range of the alloy. Although the solidus teinperature for the copper containing alloys is about 525°C in all of our cases, the initial temperature for the foaming process decreases with the copper content. The fact that a higher copper content provides a larger amount of melt at the same temperature leads to the conclusion that a minimum amount of liquid is necessary for the initiation of the foaming process. In the case of AlSi6, 100% expansion are reached in an isothermal step where eutectic AI-Si melt is produced, while in the case of the copper containing alloys this initial expansion in a smooth increase with the temperature.

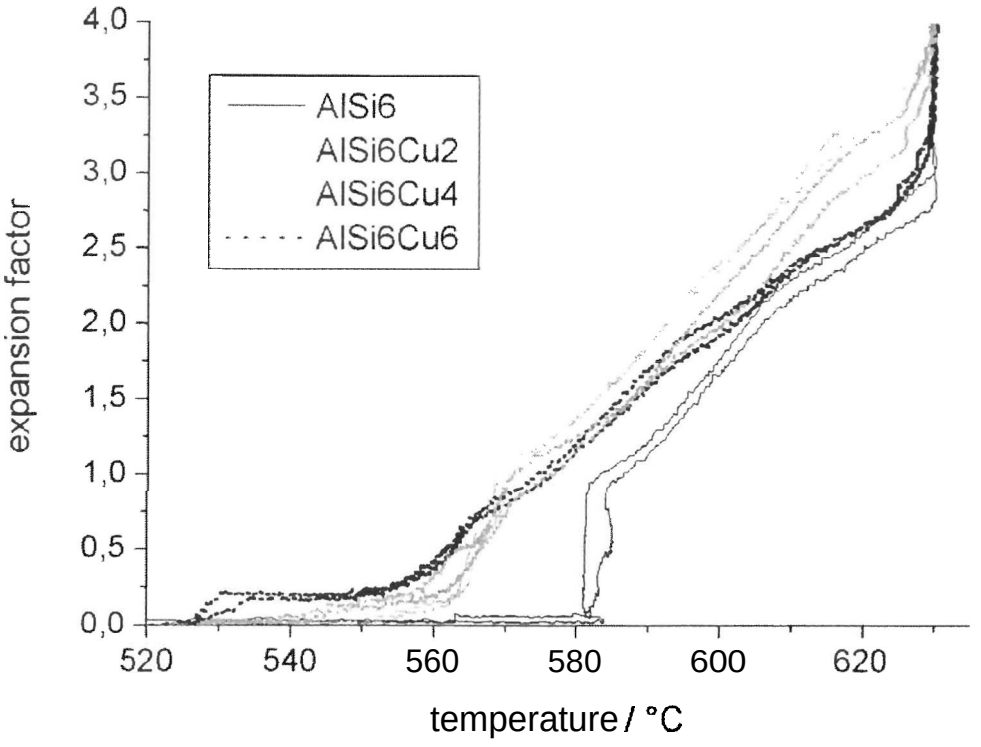

Figure 2. Expansion curves plotted versus the temperature for different copper contents

3. X-ray investigations

For the x-ray experiments the resulting tablets were cut into pieces of 7.6mm height, 5mm thickness and 20mm width. The position of the samples in the beam was chosen in a way that the pressing axis was always in vertical direction.

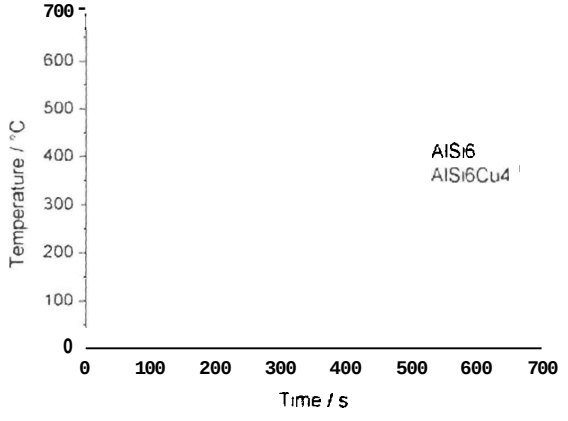

Figure 3. Temperature evolution in the x-ray furnace during the experiments

To characterize the influence of the 4% copper added to the "conventional" AlSi6-alloy, a sample of both alloys was foamed during in-situ x-ray observation.

The x-ray radioscopy device used was developed at TU Berlin especially for the observation of metal foams and is described in detail in the literature [6]. The x-ray tube was operated at 100kV and 100 μA. The resolution was limited by the 120 x 120inm^2 flat panel detector to 12.5 μm, the distortion resulting from the cone beam geometry is 0.1mm (less than 2% of the sample height), which is acceptable for our purpose. Images were acquired every 2 seconds with an exposition time of 500ms.

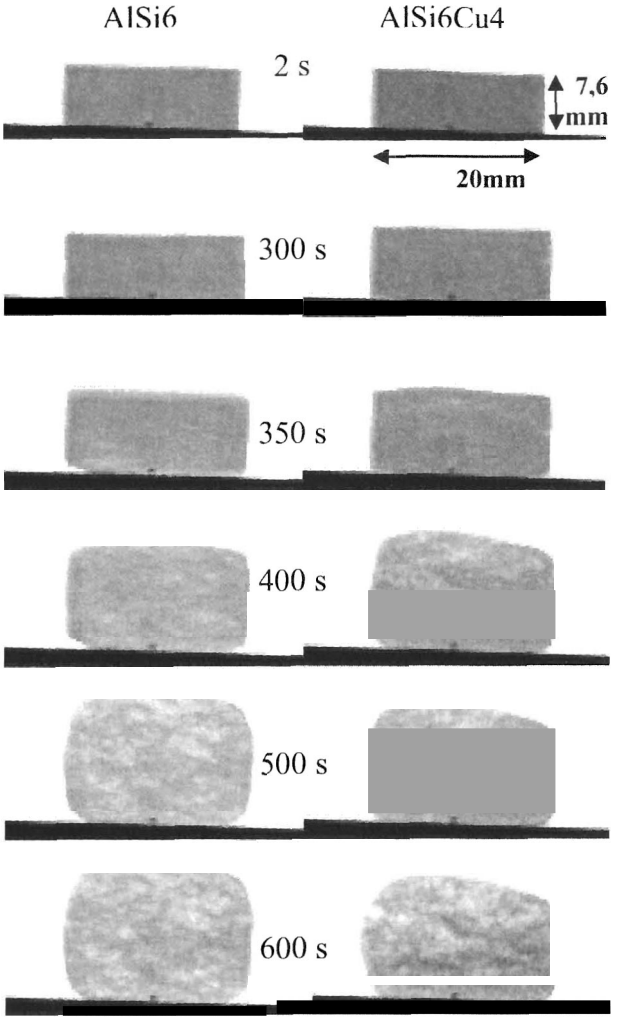

Figure 4. X-ray radioscopy images of the foaming process of AlSi6 and AlSi6Cu4

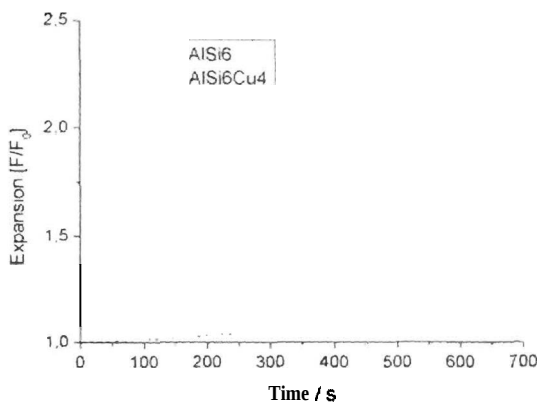

Figure 5. Increase of projection area, calculated from x-ray images

The sample is heated up by a resistive heater with a heating power of about 2kW to a final temperature of 610°C. Due to the slow heat transfer between thermocouple and heating element the temperature first increases up to a maximum of over 650°C, before decreasing to 610°C. Fig. 3 shows the temperature evolution and allows to assess the reproducibility of heating conditions in the furnace. The temperature evolution is nearly the same.

Like all foams produced from uniaxially compacted powders, the main expansion direction is parallel to the coinpaction axis.

It is obvious that due to the lower solidus temperature the copper containing alloy begins to expand earlier, but the AlSi6 sample reaches a higher expansion. The x-ray iinages (Fig 4) also show this significant difference in the kinetics of expansion. The shape of the sample differs. The copper-rich alloy forms a rounder shape than the copper free alloy and the copper-rich sample expands more in lateral direction, while the copper-free shows a nearly uniaxial behavior.

As the samples do not expand in one direction only, a inere specification of expansion height does not give full inforrnation. To gain inforrnation about voluine expansion the projection area of the foam is calculated by image processing, and given in Fig 5 as a function of time. The reason for the usage of the projection area instead of the height becomes clear, when the ratio of height and width expansion is calculated, as given in Fig 6. It indicates that the expansion of the alloy with the lower melting point (AlSi6Cu4) takes place in a more isotropic way than the one of the alloy with the higher melting point (AlSi6).

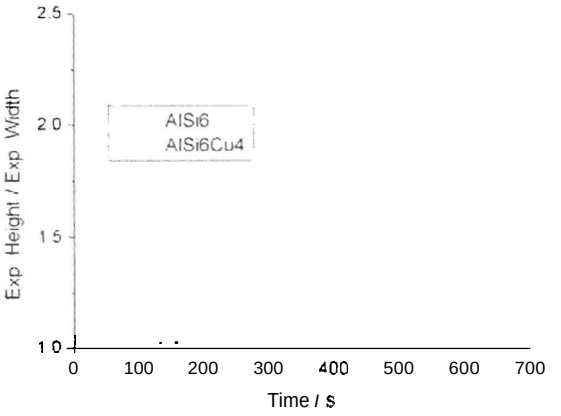

Figure 6. Ratio between expansion directions, calculated froin area and height expansion

4. Conclusions

It could be shown that the expansion kinetics of aluminium foams produced by the powder metallurgical route are influenced by the composition of the alloy. Mechanical expansion measureinents showed no increase of the achievable expansion height for samples heated up with the same teinperature profile, but showed significant differences in the teinperature dependence of the foaining kinetics for the different alloys. X-ray measurements with 2 exemplary alloys suggest that there is an influence on the structure development, in the way that copper seems to lead to a more isotropic. More experiinents with different copper content are necessary to quantify the copper influence in detail.

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