Heat distribution during metal foaming

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Aluminium foams are produced by melting powder compacts containing a blowing agent in a pre-heated furnace at various temperatures and subsequent cooling under various conditions. Free foaming of AFS sandwich materials and foaming of precursors inside a mould is considered. Time and spatially dependent temperature curves are recorded and used for discussing the foaming process.

1 Introduction

Aluminium foams can be produced by heat treatment of powder compacts [1,2], consisting of metal powders and a blowing agent, usually TiH_2. Unfortunately, the uniformity of the resulting foams is not as good as needed for industrial applications especially when more complex parts are made. Up to now the temperature course during foaming has only been measured for small samples, usually inside an "expandometer" [3]. We now measure temperatures under more realistic conditions in a part making process trying to clarify the influence of temperature gradients on the foaming process.

2 Experimental

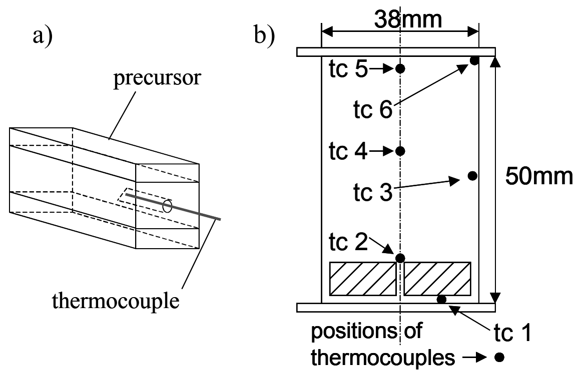

Fig. 1. Positioning of thermocouples in a) foaming sandwich b) mould

The experimental set-up consists of a chamber furnace, equipped with a multi-channel thermocouple data logger and a PC. The samples can be placed in the centre of the furnace suspended by wires, with no contact to the furnace walls. Fig. 1 shows the arrangement of the thermocouples for both sample types.

For the closed-mould-foaming experiments, up to 6 thermocouples are fixed to the mould in different positions. The numbering given in Fig. 1b is used in Figs. 2-4 to label each temperature curve. The precursor material consists of AlSi7 with TiH_2 as blowing agent. Samples are round, 10 mm thick and 36 mm in diameter and are placed at the bottom of the mould. A hole is drilled into the centre of each tablet to allow to position tc2 and tc4.

In the sandwich samples (Fig. 1a), a thermocouple is placed in a 10 mm deep hole, drilled into the core layer of the precursors. The thickness of the AA6060 face sheets is

0.8 mm, of the foamable core layer 1.4 mm. The core layer consists of AlSi6Cu6 with TiH_2 as blowing agent. The size of the precursor pieces is 20×50 mm.

3 Results

3.1 Foaming of foam cylinders in closed moulds

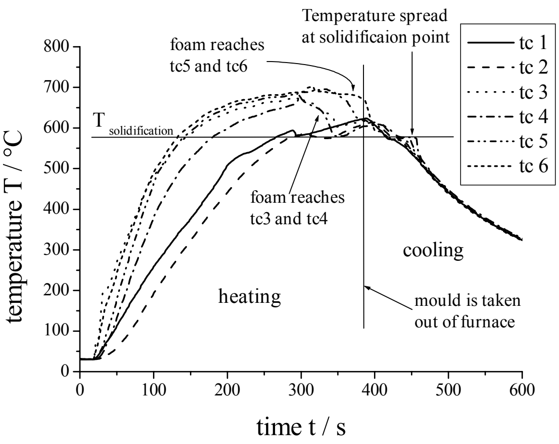

Fig. 2. Foaming Experiment in mould, furnace temperature 700 °C, slow cooling

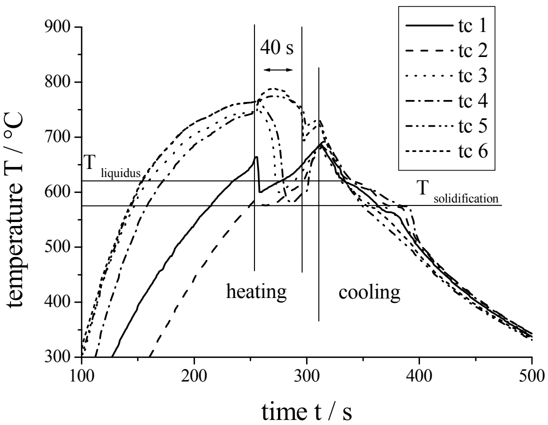

Fig. 3. Same as Fig.2,but furnace temperature 800 °C

As shown in Fig. 2, large temperature gradients appear after inserting the mould into the pre-heated furnace. Due to the large heat capacity of the precursor the temperatures at the top of the mould are up to 300°C higher than at the bottom. With progressing foam expansion the temperature curves tc 3-6 merge into the temperature course of tc 1 and 2 as the foam reaches the respective thermocouple. After the mould is completely filled, at approx. t=400 s, and is taken out of the furnace, the temperature is fairly uniform (±10°C). At the solidification temperature the curves spread slightly again due to the different distance to the mould wall and the different cooling conditions. At 800°C (Fig. 3) foam expansion is more rapid than at 700 °C and the melting process is accelerated from 100 s to 40 s until the mould is completely filled. At this moment, the largest measured temperature spread is more than 120 °C (between tc 4 and tc 6). Except for tc 4 all tcs indicate temperatures above T_{liq}. Overheating near the mould should be the reason for the foam collapse that can be observed in the resulting solid foams. Foams probably become instable at the moment the mould is completely filled. Using an air stream cooler, cooling time to total solidification is reduced from 80 s to 50 s compared to slow cooling. The curves in

Fig. 4 show a larger scatter during solidification (approx. 40°C compared to 20°C) and solid state cooling (approx. 80°C compared to 10°C in Fig. 2). In all air-cooled samples, the foam structure shows pronounced cracking of cell walls [4].

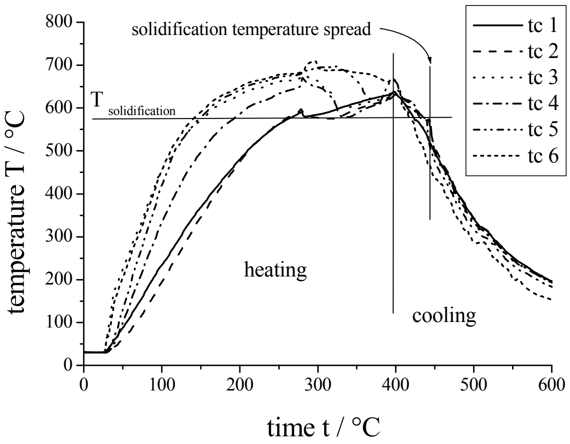

Fig. 4. Same as Fig. 2, but faster cooling

A possibility to avoid these cracks is water quenching. Compared to air-cooled samples the foam structure shows no cracks, although large temperature gradients appear during quenching. By quenching the samples directly after the mould is taken out of the furnace immediately stops the foam expansion, while slower air-cooling implies some after-expansion until all metal has solidified. Due to this, it was not possible to fill the mould completely and water quench when using the same heating conditions suitable for air cooling. Unfortunately, when using a pre-heated furnace, compensating this with longer heating time means an increase of the maximum foam temperature and the onset of foam collapse.

3.2 Free foaming of aluminium sandwiches

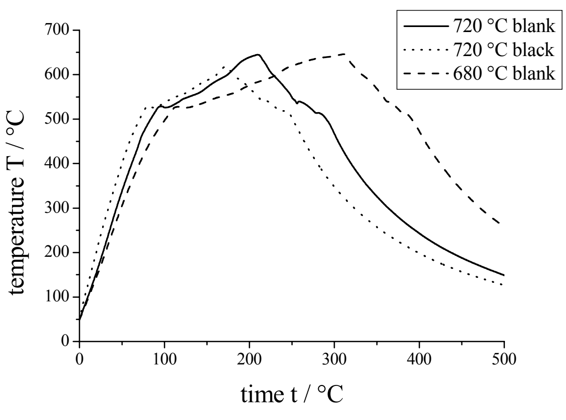

Fig. 5. Effect of furnace temperature on heating rate

Fig. 5 shows heating curves of sandwich materials obtained under 3 different conditions. Heating was interrupted after T= 620°C (610°C for black samples) had been reached to avoid foam collapse at higher temperatures. Two effects can be seen: higher furnace temperatures increase the heating rate and shorten foaming time. Painting samples black has the same effect due to increased radiation heat transfer. In comparison to the variation of the furnace temperature, painting the samples influences the heating rate more strongly at lower temperatures than at higher ones.

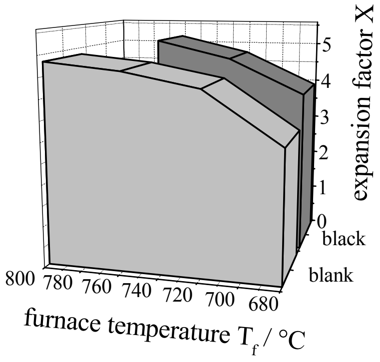

Fig. 6. Influence of heating rate on expansion factor

The expansion factor is defined as the thickness of the foam-layer over the thickness of the precursor layer. In Fig. 6 the results for black and blank samples are compared. We find that the expansion factor increases with heating rate although total foaming time decreases. It is considered to be the effect of hydrogen effusion during heating in the solid state that determines the maximum expansion An analogous effect has been observed for free foam expansion of AlSi6Cu4 [5].

As already remarked in Sec. 3.1 a main problem is that varying end temperature, foaming time and heating rate independently is not possible using a pre-heated furnace but would require a more flexible heating concept.

4 Conclusions

Measuring spatially resolved temperatures during manufacture of metal foam parts is a practical method for analysing and controlling the foaming process. The rapidly varying conditions during mould filling could be monitored and show an interplay between temperature equalisation and material flow in the mould. Too high temperatures cause gradients, but going to lower temperatures reduced maximum foam expansion. Using the usual pre-heated furnace, the problem became obvious that heating rate, foaming temperature and time cannot be varied independently. We could observe a significant influence of the heating rate on the expansion of AFS sandwiches, which is technologically important, but the possible parameter variation is also limited as it is not possible to vary the heating rate while keeping the total foaming time constant. Our next step in the future will be improving the furnace concept based on the experiences we made with the actual equipment. We hope to be able to combine high heating rates with independent selectable constant holding temperatures soon.

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