Matrix Alloys for Production of Aluminium Foams

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**Abstract:** As matrix for these specimens, aluminium based alloys with low liquidus and solidus temperatures were selected. Alloy systems considered include established combinations of aluminium with Cu, Mg, Si and Zn as well as special quaternary mixtures of these elements. First examinations presented include thermal analysis of alloys as well studies on expansion vs. time and temperature relationships of precursor material based on new alloys and foaming agent variants.

**Keywords:** metal foams, matrix alloys, foaming agent, temperature, time.

1 INTRODUCTION

Selection of alternative matrix alloys has to consider technical and economical requirements. These include question like the compaction behaviour of selected powders and derived mixtures, the availability of ingredients as well as the achievable properties of the final foam. Table 1 presents a selection of technical Al alloys characterized by low liquidus/solidus temperatures.

<table>
<thead>
<tr>
<th>Content [wt.-%]</th>
<th>Alloy</th>
<th>Two-phase-reg. [°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Al</td>
<td>Cu</td>
</tr>
<tr>
<td>93</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>92.5</td>
<td>-</td>
<td>0.5</td>
</tr>
<tr>
<td>89.5</td>
<td>-</td>
<td>0.5</td>
</tr>
<tr>
<td>89</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>85.8</td>
<td>1.2</td>
<td>0.5</td>
</tr>
<tr>
<td>85.8</td>
<td>3.5</td>
<td>-</td>
</tr>
</tbody>
</table>

Powder compacts without foaming agent were prepared from powder mixtures yielding these compositions by uniaxial hot pressing at 450 °C. From these, specimens were taken for thermal analysis. Further samples destined for expander studies contained 0.5% of “as received” or annealed TiH₂. Samples were based on elementary Al, Si, Cu and Zn as well as pre-alloyed AlMg5 powder. Three A1Si9-Cu3 variants were produced based on elementary powders (alloy A), elementary powders and A1Si12 to provide Si (alloy B), and an Al-A1Si12-CuZn25Al1 mixture (alloy C). The choice of elementary is usually preferred, as the Al99.7 used to provide the Al content is characterised by high ductility and thus readily embeds other constituents.

2 MATRIX ALLOYS

Binary Al-Si alloys using elementary powders are unproblematic in terms of alloy formation, since direct contact between alloying elements is guaranteed. This is exemplified by a comparison of two alloys of composition A1Si7, one based on elementary, the other on Al and A1Si12 powder.

DSC studies of melting as depicted in Figure 1a show negligible differences. In contrast, the ternary and quaternary alloys given in Table 1 did not exhibit the characteristics expected — instead, melting was dominated by the Al-Si eutectic at 577 °C[1]. Explanations may be found in low contents of additional alloying elements, since A1Si9Cu3 proves to be an exception to this rule: as Figure 1b shows, all variants show a peak corresponding to the eutectic composition A1Si67.5-Si5.8-Cu26.7, which melts at 520.3 °C[1].

Lowest initiation of melting may be seen in Figure 1b for variant C. A further advantage of this combination is revealed in metallographic sections prepared from precursor material of all A1Si9Cu3 variants. On the surface of Cu powder particles in contact with the Al matrix, Al-Cu compounds form...
in alloy variants A and B already during hot pressing at 450 °C.

In the process, coherence of these particles with the matrix is lost (Fig.2).

![DSC curves for AlSi7(a) and AlSi9Cu3(b) alloy variants](image1)

Fig. 1. DSC curves for AlSi7(a) and AlSi9Cu3(b) alloy variants [1]

In contrast, while also reacting with the enclosing matrix, CuZn25Al1 particles do not suffer a comparable loss of coherence. Together with the joint presence of Al, Cu and Zn in addition to Si, this serves to explain earlier melting in alloy AlSi9Cu3-C and may prove beneficial for foaming.

Nevertheless, expansion vs. time and temperature measurements on AlSi9Cu3 samples show significant start of expansion only when temperature regions associated with the Al-Si eutectic are reached (Fig.3).

Expansion levels are good at (average of 3 samples) 492 % at 635 °C for “as-received” TiH2 and 447 % at 654 °C for TiH2 annealed 16 h in air at 400 °C, the effect of pre-treatment thus being discernible. Combination with TiH2 treted 4 h at 500 °C in air shifts maximum expansion further to 694 °C, while expansion levels drop to 286 %, which is in good agreement with a reduction in the amounts of hydrogen released by this TiH2 variant.[2]

Considering the composition of the Al67.5-Si5.6-Cu26.7 eutectic, means to provide greater amounts of liquid phase at low temperatures seem worth investigating.

As figure 3 implies, further addition of copper is the course to follow, since this constituent controls the percentage of the ternary eutectic in Al-Si dominated alloys.

![Microstructure of AlSi9Cu3 precursor variants A(a) and C(b)](image2)

Fig. 2. Microstructure of AlSi9Cu3 precursor variants A(a) and C(b)[1]

For this reason, three additional alloys were defined which complement elements providing increasing amounts of Al-Si-Cu eutectic with the Al-Si eutectic and are thus configured for two-phase areas between 520 and 580 °C.

Based on the experience with AlSi9Cu3, Cu was provided as CuZn25Al1-powder. Tab.2 summarizes the compositions and gives density values measured on powder compacts containing 0.5 % TiH2.

![Volume expansion vs. time](image3)

Volume expansion vs. time (a) and vs. temperature (b) for alloys given in Table 2 (broad lines indicating mean, thin lines individual expansion curves).

Figure 4 depicts the expansion curves measured. In all cases, “as-received” TiH2 was chosen as foaming agent. Production of the
precursor material relied on the process described above for AlSi7 and AlSi9Cu3.

Fig. 3. Volume expansion vs. time (a) and vs. temperature (b) of AlSi9Cu3 alloy foam with different foaming agent variants, with broad lines indicating mean, thin lines individual expansion curves[2]

Fig. 4. Volume expansion vs. time (a) and vs. temperature (b) for alloys[4,5]

In all alloys, heating curves as shown in Figure 4a are characterised by a marked arrest point both near the ternary Al-Si-Cu and the binary Al-Si eutectic temperature.

Expansion is initiated at the former temperature, though its character is different in the AlSi8-Cu13Zn5 alloy: Whereas in the other two cases, the melting of the Al-Si eutectic separates two markedly different expansion phases, little distinction is visible for AlSi8Cu13Zn5 in that respect.

In contrast, the expansion vs. time curve can well be likened to an exponential growth function between the beginning of extensive melting at 520 °C and the point of inflection in the expansion peak’s rising flank.

The same has been seen for AlSi9Cu3 when using TiH2 in a severely annealed state as foaming agent, though only at the cost of higher expansion levels (Fig.3). Maximum expansion of AlSi8Cu13Zn5 reaches 420 % at 651 °C, compared to 475 % at 650 °C for AlSi10-Cu9Zn3 and 440 % at 647 °C for AlSi11Cu4Zn2.

3. CONCLUSION

AlSi9Cu3 alloys using CuZn-type powders for adding Cu content show prospects for realising lower melting temperatures and thus also potential
for advantageous characteristics in terms of pore initiation[6].

Based on this result, matrix alloys with even higher fractions of the ternary Al-Si-Cu eutectic were defined and evaluated in terms of expansion behaviour. The characteristics of the expansion curves obtained indicate that in two combinations of foaming agent and matrix alloy, namely AlSi9Cu3 using TiH₂ annealed 4 h at 500 °C in air and AlSi8Cu13Zn5 with “as received” TiH₂, the expansion could be shifted to the semi-solid-liquid phase entirely.

For the Fraunhofer process based on TiH₂ as foaming agent, such conditions had so far only been realised for Zn foams, which are known to yield expansion levels in a range of 800 – 1000 % using considerably higher levels of foaming agents in terms of the volume of gas available per unit volume of the matrix[2].

Future studies will have to look at comparable adaptations for the alloys compositions suggested have not seen much technical use yet, properties of the foams based on them need to be determined.

Considering the low meting point of aluminium, low firing temperature is requested. In this situation the adhesion between substrate and coating could be affected. For this reason, enamels developed for aluminium and its alloys should have a low melting temperature (since the substrate cannot exceed 600 °C in the firing step)[7].

In the case of closed-cell aluminium foams, the entrapped gas inside the cells also plays an important role in the dynamic compression, which extends their application in impact and explosion-proof domains [8,9]. Good energy absorption properties of closed-cell aluminum foams make them have wide applications in automotive, aerospace and military industries [10-12].

Table 2. Alloy compositions with increasing fractions of Al67.5-Si5.8-Cu26.7 ternary eutectic[4].

<table>
<thead>
<tr>
<th>Content [wt.-%]</th>
<th>Alloy designation</th>
<th>Powder compact density [g/cm³]</th>
<th>Percentage of Al-Si-Cu eutectic [wt.-%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al</td>
<td>Cu</td>
<td>Si</td>
<td>Zn</td>
</tr>
<tr>
<td>83.3</td>
<td>4.45</td>
<td>10.79</td>
<td>1.50</td>
</tr>
<tr>
<td>78.5</td>
<td>8.90</td>
<td>9.57</td>
<td>3.01</td>
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REFERENCES


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