



## Regular Article

# Particle size and fraction required to stabilise aluminium alloy foams created by gas injection

K. Heim\*, F. García-Moreno, J. Banhart

Technische Universität Berlin, Hardenbergstraße 36, 10623 Berlin, Germany  
 Helmholtz-Zentrum Berlin, Hahn Meitner Platz 1, 14109 Berlin, Germany



## ARTICLE INFO

## Article history:

Received 22 March 2018

Accepted 23 April 2018

Available online xxxx

## Keywords:

Al-foams

Composites

Particle stabilised

X-ray imaging

## ABSTRACT

Liquid metal foam owes its stability to the presence of solid particles. To elucidate the conditions under which such particles stabilise foams, 15 different aluminium-alloy based metal matrix composites were melted, after which air was injected with the objective to create bubbles and eventually metal foam. Foam formation was monitored in-situ by X-ray radiography. All systems were classified foamable, partially foamable and unfoamable. Foamable composites form a preferred range in the stability diagram displaying particle fractions vs. particle size, thus experimentally confirming earlier claims. All investigated composites fall into the same range even though their alloy and particle types vary.

© 2018 Acta Materialia Inc. Published by Elsevier Ltd. All rights reserved.

The most direct way to create a metal foam is to inject gas into a molten alloy. While this idea occurs already in a very early patent [1] details on processing were disclosed and the importance of foam stabilisation discovered only many years later, as reviewed in Ref. [2]. It is now known that a dispersion of non-metallic particles in a liquid alloy is a pre-requisite for growing foam. Such particles decorate bubble/metal interfaces and prevent two bubbles that come into contact with each other from forming a bigger joint bubble. How exactly particles prevent coalescence is not known in detail and some controversy remains [3–5].

The conditions under which an alloy can be foamed by particles have been investigated for the important system Al-Si/SiC. Originally, this particle-reinforced metal matrix composite was developed as an alloy with improved mechanical properties, but during processing in the liquid state its foamability was discovered. The ability of SiC particles of various diameters and volume fractions to keep foam stable was investigated and a preferred range identified. However, the particle fraction vs. particle size stability diagram published in a patent [6] is only schematic and not based on documented experiments (although some might have been carried out). Aluminium alloy melts containing varying contents of stabilising SiC particles have been studied to determine the particle fraction required to create stable foams by gas injection [3]. Other studies concentrated on important parameters such as the particle size [7] immersion depth of the gas injector [8], type of blowing gas [9], or injection conditions [10].

The aim of this paper is to provide an experimental proof of the stability diagram suggested in Ref. [6]. As no series of composites with a wide range of different particle sizes is available, we chose different

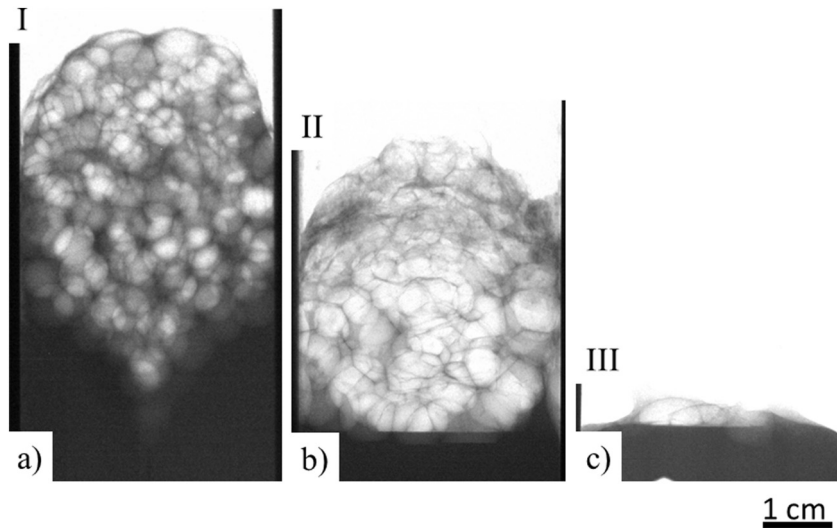
alloys stabilised with different particles, in total 15. They represent a wide range of particle size vs. particle fraction combinations. We monitor the formation of liquid metal foam in-situ by X-ray radiography and distinguish between various levels of foamability. The result of the study is the confirmation of the stability diagram and the finding that it does not sensitively depend on the type of metal matrix composite.

Composite F3S20S produced by Alcan, Montréal, Canada, containing 20 vol% SiC particles of 10  $\mu\text{m}$  mean diameter embedded in an alloy AlSi9Mg0.6 (in wt%) was considered a reference material in this work due to its known foamability, see Fig. 1 and Table 1, #2. All the composites prepared in the present study are based on alloy AlSi9Mg0.6. The foamable materials prepared can be divided into three categories depending on how they are manufactured: (i) Composites are called *extrinsic* ('Ex') when they contain particles that were added to a melt from the outside. Beside SiC particles, Al<sub>2</sub>O<sub>3</sub> or SiO<sub>2</sub> have been used as extrinsic particles [8,11–14]. Composites are manufactured by adding powders to the vortex in the melt while stirring at 1000 rpm. (ii) Composites are called *intrinsic* ('In') whenever particles are formed by reactions inside the liquid alloys. Such particles are produced by adding oxidants such as SiO<sub>2</sub> and CuO to create Al-based oxides (Al<sub>2</sub>O<sub>3</sub>, Al<sub>2</sub>MgO<sub>4</sub> (spinel) or Al-Mg-O transition phases) and by a flux-assisted synthesis route leading to the formation of TiB<sub>2</sub> particles [15]. (iii) Some composites contain *primary* crystals that are formed in the first stage of solidification of eutectic alloys. Primary Fe and Si-rich crystals were obtained after modifying the basic alloy AlSi9Mg0.6 by addition of 3 wt% Fe or 11 wt% Si, respectively ('Pr'). Further details of these composites and composites used by other researchers can be found in Table 1.

For the foaming experiments, all composites were melted in a chamber and foamed by air injection through a stainless steel cannula of 500

\* Corresponding author.

E-mail address: [mail@korbinianheim.de](mailto:mail@korbinianheim.de) (K. Heim).



**Fig. 1.** X-ray radioscopies of structures obtained by foaming (or attempting to foam) a) foamable composite AlSi9Mg0.6 + 20 vol% SiC ( $DP \sim 10 \mu\text{m}$ ), b) partially foamable composite AlSi9Mg0.6 + 2.5 vol% Al<sub>2</sub>O<sub>3</sub> + spinel (intrinsic composite created by oxidation using CuO), c) unfoamable composite AlSi9Mg0.6 + 10 vol% Al<sub>2</sub>O<sub>3</sub> ( $DP = 0.1\text{--}0.3 \mu\text{m}$ ). All composites were blown with air for 15 s injection, after which the melt was held for 60 s at 680 °C.

$\mu\text{m}$  outer and 200  $\mu\text{m}$  inner diameter. A detailed description of the setup and procedure can be found elsewhere [16]. The temperature of the melt (680 °C) and the air overpressure in the injection line (300 mbar) were kept constant. The foaming process was observed by in-line radioscopy employing a microfocus X-ray source with 5  $\mu\text{m}$  spot size operated at 100 kV and 100  $\mu\text{A}$  and capturing the radiographs on a panel detector with  $2240 \times 2368$  pixels of each  $50 \times 50 \mu\text{m}^2$  pixel size [17]. Images were taken every 500 ms. Program “ImageJ” was used to process images, to analyse the foam structure and to determine bubble size and the height of the foam column.

To discuss the ability of a material to be processed to a foam, the term *foamability* is coined. Alloys and composites in which upon gas injection stable are created and the bubble size distribution is narrow, no notable events of bubble merger are observed and the bubbles pile up continuously to form a foam layer of growing thickness are called *foamable* (I). If, however, bubbles merge with others during foaming (a.k.a.

coalescence), giving rise to a coarser and less uniform bubble size distribution than in the case of foamable alloys and a foam column is formed, however of a limited height, a composite is called only *partially foamable* (II). If bubbles lose gas or collapse immediately after reaching the melt surface and disappear or form a characteristic onion-shaped structure of bubble remnants a composite is deemed *unfoamable* (III). In Fig. 1, the different levels of foamability (I, II, III) are exemplarily shown for foams blown by injecting air into a melt held at 680 °C. The state shown was obtained by injecting for 15 s and holding for 60 s after.

The experiments in this work were performed under the same conditions for all the composites, see Table 1. The levels of foamability obtained are given in the 7th column of the table. The materials investigated by other researchers (see references) might have been manufactured using different equipment and parameters such as injector diameter, gas type, pressures, etc., but the process is fundamentally

**Table 1**

Composites used for gas injection experiments in this work (entries in bold letters) and some data found in the literature.

#	Alloy [wt%]	Particle type extrinsic (Ex) intrinsic (In) primary crystals (Pr)	Particle fraction [vol%]	Particle size [ $\mu\text{m}$ ]	Wetting angle [ $^\circ$ ]	Stability foamable (I) partially foamable (II) unfoamable (III)	Source	Figure
1	<b>AlSi9Mg0.6</b>	<b>SiC (Ex)</b>	<b>8</b>	<b>10</b>	<b>27</b>	<b>I</b>	<b>this work</b>	<b>2a</b>
2	<b>AlSi9Mg0.6</b>	<b>SiC (Ex)</b>	<b>20</b>	<b>10</b>	<b>27</b>	<b>I</b>	<b>this work [3,6,7]</b>	<b>1a</b>
3	Al	SiC (Ex)	10–20	10–15	27	I	[1]	
4	AlSi10Cu3Ni1.5	SiC (Ex)	20	13	27	I	[5]	
5	Al-Si + rare earth	SiC (Ex)	8–15	1/7/14/20	27	I	[12]	
6	<b>AlSi9Mg0.6</b>	<b>Al<sub>2</sub>O<sub>3</sub> (Ex)</b>	<b>10</b>	<b>0.6</b>	<b>60</b>	<b>I</b>	<b>this work</b>	<b>2b</b>
7	<b>AlSi9Mg0.6</b>	<b>Al<sub>2</sub>O<sub>3</sub> (Ex)</b>	<b>10</b>	<b>0.1–0.3</b>	<b>60</b>	<b>III</b>	<b>this work</b>	<b>1c</b>
8	AlSi9MgMn (A365)	Al <sub>2</sub> O <sub>3</sub> (Ex)	3–8	9/15/23	60	I	[13]	
9	AlSi10Mg	Al <sub>2</sub> O <sub>3</sub> (Ex)	12.5	23	60	I	[5]	
10	AlMg1SiCu	Al <sub>2</sub> O <sub>3</sub> (Ex)	10	11	60	I	[5–7]	
11	AlSi10Cu3Ni1.5	Al <sub>2</sub> O <sub>3</sub> (Ex)	10	11	60	I	[5–7]	
12	AlSi10Cu3Ni1.5 Mg3	Al <sub>2</sub> O <sub>3</sub> (Ex)	10	11	60	I	[5–7]	
13	Al-Si + rare earth	Al <sub>2</sub> O <sub>3</sub> (Ex)	11–20	3.5/5/10	60	I	[12]	
14	<b>AlSi9Mg0.6</b>	<b>TiB<sub>2</sub> (In)</b>	<b>6</b>	<b>1–3</b>	<b>0</b>	<b>I</b>	<b>this work</b>	<b>2c</b>
15	Al 99.98	TiC (Ex)	4	0.2	10	III	[3]	
16	<b>AlSi9Mg0.6</b>	<b>spinel, Al<sub>2</sub>O<sub>3</sub> (In) &amp; CuO (Ex)</b>	<b>2.5</b>	<b>1–10</b>	<b>60</b>	<b>II</b>	<b>this work</b>	<b>1b, 2d</b>
17	<b>AlSi9Mg0.6</b>	<b>spinel, Al<sub>2</sub>O<sub>3</sub> (In) &amp; SiO<sub>2</sub> (Ex)</b>	<b>0.2</b>	<b>0.01</b>	<b>70</b>	<b>III</b>	<b>this work</b>	
18	<b>AlSi9Mg0.6</b>	<b>spinel, Al<sub>2</sub>O<sub>3</sub> (In) &amp; SiO<sub>2</sub> (Ex)</b>	<b>5</b>	<b>1–10</b>	<b>70</b>	<b>II</b>	<b>this work</b>	<b>2e</b>
19	<b>AlSi9Mg0.6</b>	<b>SiO<sub>2</sub> (Ex)</b>	<b>20</b>	<b>100–400</b>	<b>70</b>	<b>III</b>	<b>this work</b>	<b>2f</b>
20	<b>AlSi9Mg0.6</b>	<b>CaO (In)</b>	<b>1.5</b>	–	n.a.	<b>II</b>	<b>this work</b>	
21	<b>AlSi9Fe3Mg0.6</b>	<b>Fe (Pr)</b>	<b>1</b>	<b>100–2000</b>	<b>0</b>	<b>III</b>	<b>this work</b>	
22	<b>AlSi9Fe3Mg0.6Cr0.5</b>	<b>Fe (Pr)</b>	<b>1</b>	<b>100–500</b>	<b>0</b>	<b>III</b>	<b>this work</b>	<b>2g</b>
23	<b>AlSi9Fe3Cr2Mg0.6</b>	<b>Fe (Pr)</b>	<b>1</b>	<b>50–300</b>	<b>0</b>	<b>II</b>	<b>this work</b>	
24	<b>AlSi20Mg0.6</b>	<b>Si (Pr)</b>	<b>19</b>	<b>200</b>	<b>0</b>	<b>II</b>	<b>this work</b>	
25	<b>AlSi20Mg0.6Ca0.2</b>	<b>Si (Pr)</b>	<b>19</b>	<b>500</b>	<b>0</b>	<b>III</b>	<b>this work</b>	<b>2h</b>

Download English Version:

<https://daneshyari.com/en/article/7910514>

Download Persian Version:

<https://daneshyari.com/article/7910514>

[Daneshyari.com](https://daneshyari.com)