

Determination of metal foam flow conditions at a temperature higher than the liquidus temperature

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Abstract

As it is known a foam made of composite with aluminium alloy matrix and SiC particles reinforcement does not reach the liquid state even at a temperature over 1000°C. The causes of such behaviour of foam have been examined. It has been found that it is due to two phenomena. One is connected with the creation of continuous layer of oxides at the boundary of gaseous pores and liquid metallic phase. The other is an increase of the apparent viscosity of solids suspended in liquid metal along with an increased content of these inclusions to the point where the suspension loses its continuity.

Keywords: Aluminium; Aluminium alloys; Metal-ceramic composites; Foaming; Metal foams

1. Introduction

Initial tests of melting aluminium-based foams and composites with Al-alloy matrix have shown that heating foam samples to a temperature higher than the liquidus temperature of the alloy or composite (even to 1000°C) does not result in obtaining a liquid suspension of ceramic particles in a metal. The effects of annealing at a temperature of 1000 °C were as follows:

- for a foam made of aluminium using titanium hydride a semi-fluid suspension was obtained in some places changing into a solid phase with powder consistency (Fig. 1a),
- for a foam made by blowing gas into liquid composite with Al-alloy matrix reinforced with SiC grains (20% of metal mass) a sample of foam was obtained that did not change its form (Fig. 1b).

Figure 1 shows samples of the above mentioned foams after annealing them at a temperature of 1000°C. This is an important observation indicating fire resistance of the examined material making it useful in aircraft, passenger ship and other constructions [1–3].

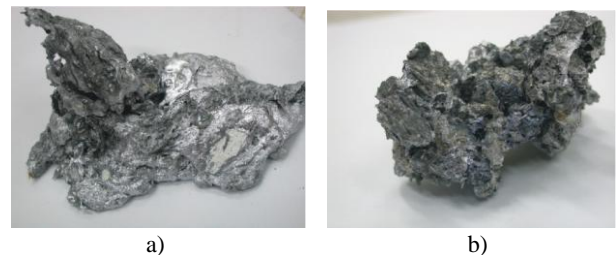


Fig. 1. Samples obtained from foams: aluminium (a) and AlSi7Mg composite + 20% SiC (b), after annealing at a temperature of 1000°C

Three phenomena should be considered in order to explain the described behaviour of foam:

- change in the viscosity of liquid metal caused by suspended solids,
- loss of continuity by the suspension,
- formation of solid oxide layers on the surface boundary between metal (alloy matrix) and pore and between composite suspension and pore.

2. Change in the suspension viscosity depending on the content of solid particles in liquid metal

Apparent viscosity of the suspension can be calculated using Eilers equation [4]:

$$\eta = \eta_0 \left[1 + \frac{2,5\Phi_r}{2(1-1,35\Phi_r)} \right] \quad (1)$$

where:

- η_0 – dynamic viscosity of the liquid,
- Φ_r – volumetric fraction of the dispersed phase particles.

This equation is applicable to the volumetric concentration of the dispersed phase $\Phi_r < 0.5$.

At a certain content of solid particles the suspension loses its continuity, which is revealed by a change of its consistency from liquid to powder. The condition of suspension continuity has following form [5]:

$$v_s = \frac{\rho_p}{\rho_{rz}} \quad (2)$$

where:

- v_s – maximum fraction of solid particles in a continuous suspension,
- ρ_p – bulk density of solid phase particles,
- ρ_{rz} – actual density of the solid phase.

The mechanism showing how the suspension loses its continuity is illustrated in Fig. 2.

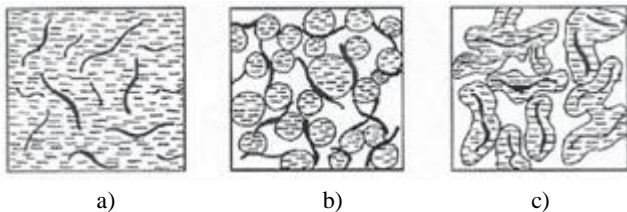


Fig. 2. Suspension structure: a – with continuous liquid phase, b – with discontinuous liquid phase poorly wetting the solid phase, c – with discontinuous liquid phase well wetting the solid phase [6]

In the case of metal foam, suspended particles are poorly wetted by liquid metal, which creates conditions for changing the

discontinuous mixture into powdery consistency. The formation of such mixture is conditioned by:

- volumetric fraction of solid particles,
- shape of these particles.

It has been found that the maximum volumetric fraction of spherical particles in the continuous suspension is 74.4% [6], while particles shaped like flakes, e.g. Al_2O_3 make up 15–20% [5, 7].

3. Possible increase of oxide film content in the foam-creating suspension

When the suspension is produced the metal is strongly stirred. This creates conditions for pore surface oxidizing, particularly when the gaseous phase during the blowing is not perfectly inert. Such possibility also exists after foam is created, as the appearing pores are not always ideally closed. Therefore, authors decided to estimate the fraction of surface oxides in the volume of metal the foam is made of. The estimation consisted in:

- taking a macroscopic photo of the foam sample microsection (Fig. 3);

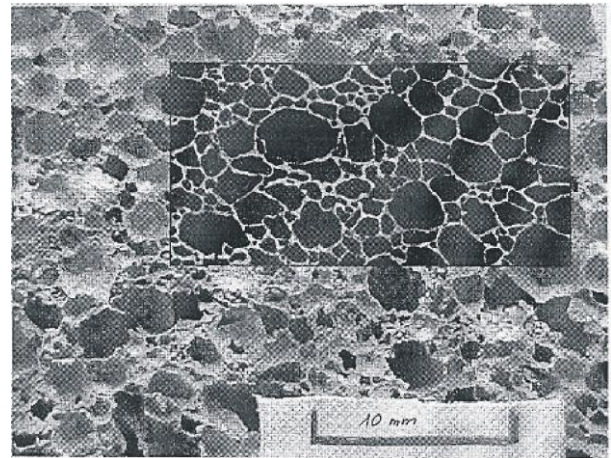


Fig. 3. Macrostructure of the foam sample microsection, magnified 5.5 times

- determining the foam porosity by the gravimetric method: 87.7%;
- determining mean pore diameter in the darkened area of Fig. 1: 1.15 mm;
- calculating the number of pores in 1 cm^3 of foam: 635;
- calculating the specific area of pores: 26.37 $[\text{l}/\text{cm}^3]$;
- calculating the volume of oxides in 1 cm^3 of foam, assuming that the oxide film thickness is $1 \mu\text{m}$; the result was $2.64 \text{ mm}^3/\text{cm}^3$, which corresponds to the oxide volumetric fraction of $2.15\%/1 \mu\text{m}$ of oxide layer in the foam metal volume. The obtained value allows to estimate the fraction of oxide inclusions in the foam metal volume for the known thickness of layer from which these inclusions are created.

4. Examination of the oxide layer on the surface of cells

Foam made of a composite with AlSi9Mg alloy matrix reinforced with SiC particles was microscopically examined. The examination consisted of two steps:

- identification of phases on the microsection of a wall between foam pores,
- determination of oxygen content on the microsection of this wall.

The wall structure is shown in Figure 4a, while Figures 4 b-f present the results of a microanalysis of the phases in the wall. At point 2 a layer of oxides can be seen on pore surface running at an angle to the microsection. The phase at point 3 is an Al-Si eutectic, point 4 indicates iron-rich AlSiFe (Mn) phase. Points 5 and 6 are silicon carbide (other elements may come from the substrate – steel melting pot).

The oxygen content distribution on the microsection of a wall between pores was tested for three foam samples:

- sample not annealed at a high temperature after it was made, denoted by N,
- sample annealed at a temperature of 750°C for 30 min. in the air atmosphere, denoted by Z,
- sample annealed at a temperature of 750°C for 30 min. in the argon atmosphere, denoted by A.

Both annealed samples (Z and A) did not change their form or size. Due to the amount of tested material compression tests could not be carried out at this stage. The results of microscopic observations of the samples and oxygen distribution on their microsection are given in Figures 4 and 5. It can be seen that oxygen distribution on the microsections of walls between pores in samples non-annealed (N) and those annealed in argon (A) does not differ significantly. Signals from oxygen are much larger in samples annealed in the air atmosphere. Although this indicates a higher content of oxygen in these places, it did not affect the sample behaviour during annealing.

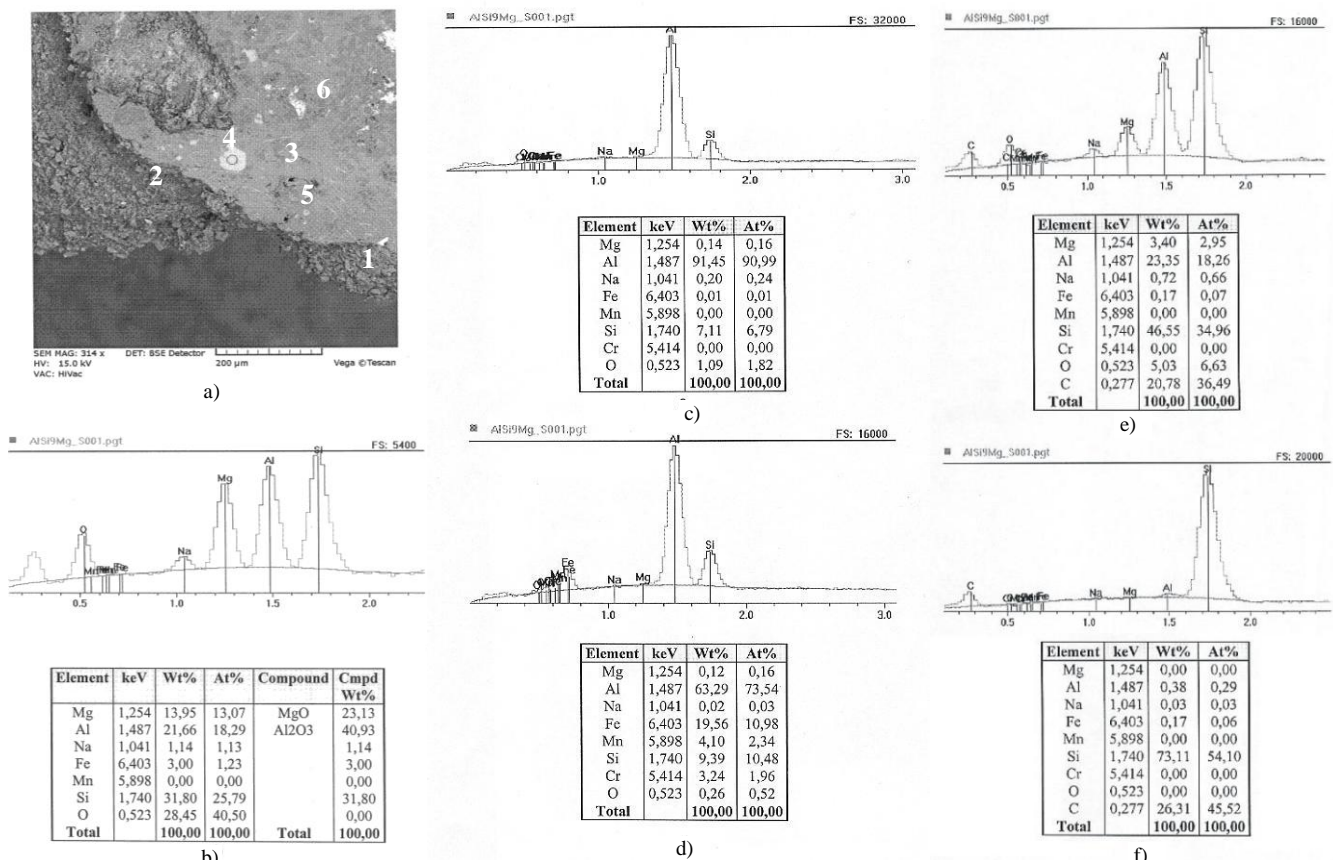


Fig. 4. Microstructure of a wall between foam pores (a) and phase microanalysis results: point 2 – (b), point 3 – (c), point 4 (d), point 5 – (e), point 6 (f)

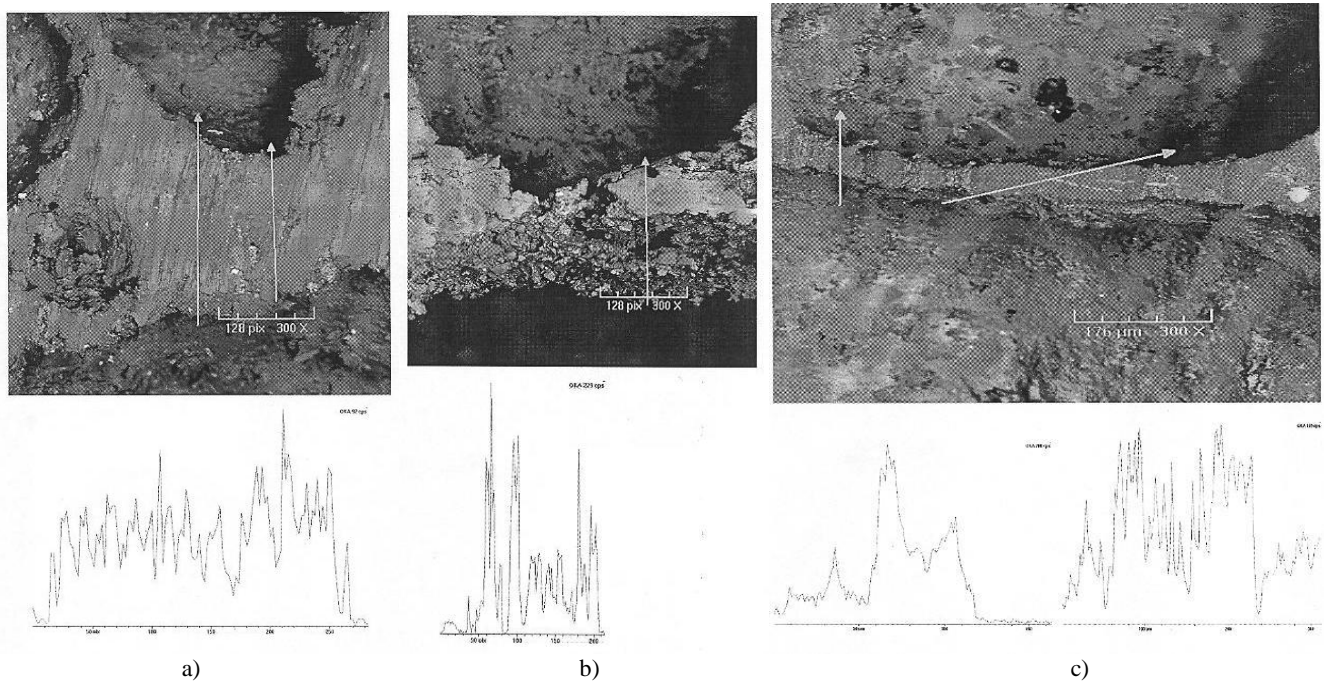


Fig. 5. Oxygen content on a microsection of a wall dividing foam pores: a – non-annealed sample (N), b – sample annealed in air (Z), c – sample annealed in argon (A)

5. Summary of the results

Metal foams made of pure aluminium alloy and of particle-reinforced composite material vary in behaviour when they are annealed at a temperature higher than the metal melting temperature. This indicates that various mechanisms take place.

In foams made of pure metal which, when molten, has low viscosity, oxide films created on metal-pore wall surfaces are not strong enough to maintain the molten metal in the form of foam. These films mix with liquid metal and together with oxides produced during the melting process change the viscosity of the suspension that forms until it loses its continuity. Tests of foam structure and calculations of oxide film volume to metal volume ratio show that the described mechanism of changes in the annealed foam to the thick liquid consistency or even powder is possible.

Foams made of composites are characterized by the higher viscosity which hampers the destruction of oxide film by metal. The film has sufficient strength to maintain the foam structure unchanged, even when annealed in argon. It has been observed that annealing in the argon atmosphere does not change the amount of oxygen on the pore-composite wall surface, which proves that oxygen film created during the foam production process is strong enough. Although annealing in the air atmosphere leads to a greater amount of oxygen on the tested surface, it has no significant influence on foam behaviour during annealing.

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