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Behaviour of aluminum foam under fire conditions

J. Grabian[a], K. Gawdzińska[a,*], M. Szweycer[b]

[a] Institute of Basic Technical Sciences, Maritime University of Szczecin, ul. Podgórna 51/53, 70-205 Szczecin, Poland

[b] Institute of Materials Technology, Poznań University of Technology, ul. Piotrowo 3, 61-138 Poznań, Poland

* Corresponding author. E-mail address: kasiag@am.szczecin.pl

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Abstract

Taking into account fire-protection requirements it is advantageous for aluminum foam, after melting at a temperature considerably exceeding the melting point, to have a structure of discontinuous suspension of solid inclusions to liquid metal instead of liquid consistency. Continuity of the suspension depends on the solid phase content. The boundary value of the phase determined by J. Śleziona, above which the suspension becomes discontinuous, is provided by the formula (1). Figure 1 presents the relationship graphically. Boundary values of the v_s content resulting from the above relationship is too low, taking into account the data obtained from the technology of suspension composites [4]. Therefore, based on the structure assumed for the suspension shown in Figure 2 these authors proposed another way of determining the contents, the value of which is determined by the relationship (3) [5].

For purposes of the experimental study presented in the paper two foams have been molten: a commercially available one, made by aluminum foaming with titanium hydride, and a foam manufactured in the Marine Materials Plant of the Maritime University of Szczecin by blowing the AlSi7 +20% SiC composite with argon. Macrophotographs of foam cross-sections are shown in Figure 3. The foams have been molten in the atmosphere of air at a temperature of 750ºC. The products of melting are presented in Figure 4. It appears that molten aluminum foam may have no liquid consistency, being unable to flow, which is a desired property from the point of view of fire-protection. The above feature of the molten foam results from the fact that it may be a discontinuous suspension of solid particles in a liquid metal. The suspended particles may be solid particles of the composite that served for making the foam or oxide membranes formed on extended metal surface of the bubbles included in the foam. The desired foam ability to form a discontinuous suspension after melting may be intensified by insertion of solid particles into the metal serving for foam formation.

Keywords: Aluminum foam; Suspensions.

1. Introduction

One of the properties of construction materials is their behavior under fire conditions. Metals, particularly those with low melting point such as aluminum, at high temperature will melt and flow in the fire area, thus posing additional threat to its surroundings. Metallic foams are certainly materials whose behaviour in the surrounding fire has not been fully investigated.

This article aims at the determination of the structure of the material formed during the production of foam, composed mainly of aluminum, at temperatures ranging from the melting point to the boiling or flash points. This structure may have a critical influence on the use of metallic foam as a safe material for structural or lining elements having such desired properties as vibration damping, absorption of energy produced by thermal reaction explosions etc. Stable behaviour of aluminum foam at temperatures higher than the melting point - which means there is no flow of liquid metal – can be a feature of metallic i.e.

aluminum foam making it a competitive material to traditionally used polymer foams, which under fire conditions emit substantial amount of smoke and toxic compounds.

2. Theoretical considerations

Above the melting point of aluminum or its alloy, the metal making up the main component of metallic foam will melt. However, as the surface of contact between the metal and gaseous phase is well developed and the material used for making metallic foam may contain substantial amounts of ceramic grains which stabilize the liquid foam [2], the product of melting will not be a homogenous solution – it will be a suspension of solid particles in liquid metal. Such suspension may behave like a liquid if the structure maintains continuity, while in the case of liquid phase discontinuity it may even have powdery or non-liquid consistency.

The solid phase content above which the suspension continuity is lost may vary. An attempt to determine the conditions of suspension continuity has been made by J. Sleziona, who formulated the following relationship [3]:

$$v_s = \frac{\pi}{6}\left[\frac{1}{1+\sqrt{\varphi \cdot \sin^2\left(\frac{\theta}{2}\right)}}\right] \qquad (1)$$

where:

v_s – volumetric content of solid phase in a suspension, above which continuity is lost;
p – factor of solid particle shape in a suspension;
θ – angle of wetting of solid particles by liquid in the atmosphere of air.

Figure 1 illustrates this relationship in a graphic form:

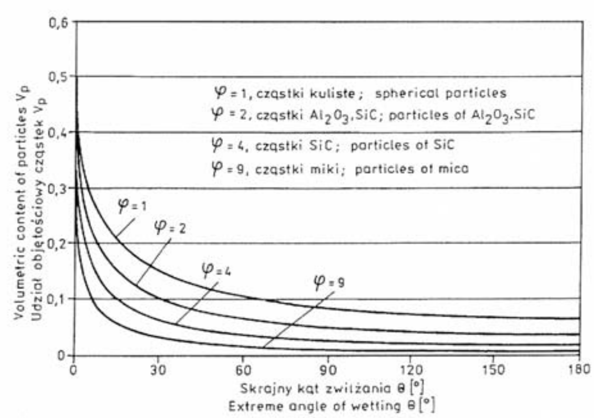

Fig. 1. Boundary volumetric content of solid particles in a continuous suspension in relation to the angle of wetting and shape coefficient [3]

If we take into account data from suspension composite technologies, the values v_s resulting from the relation (1) are too low. Taking this into account, D. Witczak [5] has assumed that:

- continuity of a suspension occurs when the liquid fills in spaces between reinforcement particles, as shown in figure 2a;
- continuity of the liquid phase begins to be lost when spaces between the solid phase particles are not completely filled in with a liquid which allows these particles to be in direct contact with one another, as shown in Figures 2b and 2c. Therefore, it can be written that:

$$\frac{v_{rz}}{v_p} = \frac{\rho_p}{\rho_{rz}} \qquad (2)$$

where:

v_{rz} – actual volume of solid phase,
w_p – apparent volume of solid phase particles,
ρ_{rz} – actual density of solid phase,
ρ_p – apparent density of solid phase particles.

Therefore:

$$v_s = \frac{\rho_p}{\rho_{rz}} \qquad (3)$$

The rightness of such approach has been verified by an application of a physical model of the suspension and that of Al_2O_3 particles suspension in liquid slag composed of salts.

a) b) c)

Fig. 2. Suspension structure: a – with continuous liquid phase, b – with discontinuous liquid phase which poorly wetting the solid phase, c – with discontinuous liquid phase well wetting the solid phase [5]

The above considerations referring to slag suspensions may be practically applied in the case of suspensions of solid particles in a liquid material used for the production of foam. By analogy, it can be stated that:

- on account of fire protection, it is important that as a result of melting of aluminum foam or aluminum alloy foams the resultant material is a discontinuous suspension of solid particles in liquid metal;
- whether such mixture will have the above property depends on:
  - volumetric content of solid particles,
  - shape of these particles.

3. Experimental research

As it is difficult to determine the density values needed for an estimation of continuity in metallic foam or in a suspension formed after foam melting, the suspension structure was examined experimentally.

Two types of foam were used for the exploratory research:

- commercially available aluminum foam produced with TiH_2;
- foam made at the Marine Materials Department, Maritime University of Szczecin, by blowing the composite AlSi + 20% SiC with argon.

Macrophotographs of the foam cross-sections are presented in Figure 3.

a)

b)

Fig. 3. Foam cross-sections: commercial foam (a) made at the Maritime University (b)

Foam samples were melted in a furnace with the air atmosphere at a temperature of 750°C. The products of melting are displayed in Figure 4.

a)

b)

Fig. 4. Products of molten foam: commercial (a) and foam made at the Maritime University (b)

Products of the melting of commercial foam, which did not contain artificially added ceramic particles, have a non-homogenous structure. The structure has areas of discontinuous suspension (of non-liquid consistency) and areas of suspension at the border of continuity and discontinuity (semi-liquid consistency). The products of foam made at the Maritime University have homogenous discontinuous structure that showed no symptoms of flowing.

4. Conclusions

1. When molten, aluminum foam may have neither liquid consistency nor ability to flow, a property desired in terms of fire protection.
2. The above property of molten foam results from the fact that, if properly composed, it becomes a discontinuous suspension of solid particles in liquid metal.
3. The particles forming the suspension can be:
   - solid particles of a composite used in foam production;
   - oxide membranes that form on the extensive metal surface, being the surface of bubbles contained in the foam.

4. The desired ability of molten foam to form a discontinuous suspension can be intensified by adding solid particles to the metal used for foam production.

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