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FORMING THE STRUCTURE OF COMPOSITE METALLIC FOAMS

WYTWARZANIE STRUKTURY METALOWYCH PIAN KOMPOZYTOWYCH

The Department of Marine Materials Engineering, Maritime University of Szczecin, has conducted research on the technology of metallic composites, focusing on composite aluminium foams stabilized with ceramic particles. One technology which enables efficient, inexpensive and diversified – in terms of foam structure – control of foam properties is the foundry technology consisting in gas injection into liquid metal. This method requires precise control of the process parameters, especially regarding temperature stabilization, as well as precise injection of the gas into the metal. The process of foaming of liquid aluminium or its silicon alloys can also be conducted using ceramic particles. This is a metallic-ceramic composite foaming process (patent PL 211439 B1). The paper presents the process of structure forming of metallic-ceramic foams.
Keywords: quality features, casting, metal matrix composites

W Zakładzie Inżynierii Materiałów Okrętowych Akademii Morskiej w Szczecinie prowadzono badania nad technologią kompozytów metalowych, a w szczególności kompozytowych pian aluminiowych stabilizowanych cząstkami ceramicznymi. Technologią pian pozwalającą na wydajne, tanie a także elastyczne, w zakresie zróżnicowania budowy pian, sterowanie ich właściwościami, jest technologia odlewnicza polegająca na wdmuchiwaniu gazu do ciekłego metalu. Metoda ta wymaga precyzyjnego sterowania parametrami procesu, zwłaszcza w zakresie utrzymania i stabilizacji temperatury, a także precyzyjnego wprowadzania gazu do metalu. Proces spieniania ciekłego aluminium lub jego stopów z krzemem można przeprowadzać także z użyciem cząstek ceramicznych, czyli stosować proces spieniania kompozytu metalowo-ceramicznego (opatentowany PL 211439 B1). W pracy tej opisano proces tworzenia struktury pian metalowo-ceramicznych.

1. Introduction

The essential feature of such specific material as metal foam is its spatial structure, whose geometric parameters strongly affect its performance characteristics. Metal foam can be characterized by these basic properties: porosity, shape and size of pores, ratio of actual to maximum porosity, specific surface area of bubbles, foam homogeneity: homogeneity of pore size and shape, homogeneity of pore distribution.

Therefore, for the material chosen to produce a foam: metal, metal alloy or composite, we can obtain various values of parameters describing performance characteristics, of which the most important are resistance to static and dynamic loads (the process and type of destruction are important). Other vital performance properties include, *inter alia*, vibration damping, electric, electromagnetic, thermal and other properties [1-3, 4]. It is essential that foam spatial structure can be precisely described. As the internal structure of foams strongly determines their strength properties in the first place, the geometry of elements making up foam should be precisely described [5-7]. By foam geometry is meant spatial interrelation between the material of pore films and voids filled with gas, i.e. pores formed in the process of foaming.

2. Formation of a foam layer

A foam layer is created as a result of gas bubbles flowing up and stopping under the surface of liquid metal. If all bubbles were round, then neglecting the thickness of films between the pores, foam porosity could not exceed 74.4%. To obtain a greater value, instead of round, bubbles should be deformed to polyhedral shapes, as presented in Figure 1.

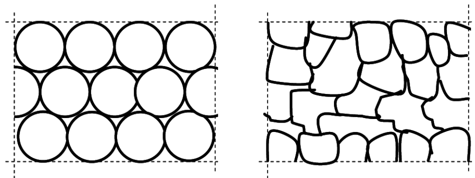

Fig. 1. Relation between porosity and bubble shape [4]

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Deformation takes place due to the high buoyancy forces causing the bubbles to rise, whose movement is counteracted by bubbles previously formed. The distribution of forces occurring between the bubbles is shown in Fig. 2.

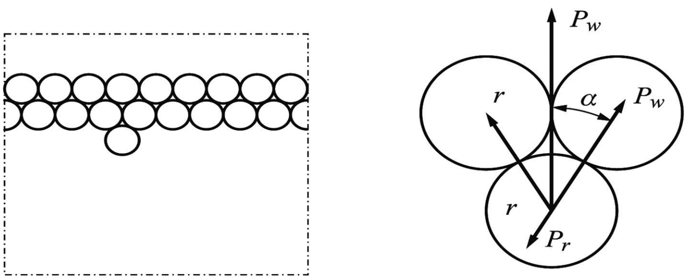

Fig. 2. Distribution of forces between foam bubbles [4]

The buoyancy force, as indicated in Fig. 2, is written in this form [2]:

$$P_W = \frac{4}{3}\pi r^3 \cdot \Delta\gamma \tag{1}$$

where:

r– bubble radius,

$\Delta\gamma$ – difference between specific weights of the liquid and of the gas.

The force P_N acting between bubbles due to buoyancy can be calculated from this formula:

$$P_N = P_w \cos\alpha \tag{2}$$

The reaction force P_γ due to bubble air elasticity, resulting from the bubble gas pressure, is equal to:

$$P_r = \pi r^2 \cdot p_k \tag{3}$$

p_k – capillary pressure inside a bubble is equal to:

$$p_k = \frac{2\sigma}{r} \tag{4}$$

where:

σ– surface tension of liquid metal.

For bubbles to deform under the buoyancy force, this condition has to be satisfied:

$$p_r < p_N \tag{5}$$

Therefore, taking into consideration the relations (2-4), we can write

$$r > \sqrt{\frac{3\sigma}{2\Delta\gamma\cos\alpha}} \tag{6}$$

because

$$r > \frac{2\sigma}{p_k} \tag{7}$$

Similarly, the capillary pressure can be calculated, while its value cannot exceed:

$$p_k < \sqrt{\frac{2}{3}\sigma\Delta\gamma\cos\alpha} \tag{8}$$

The calculations of the above values may be a basis for estimating the pressure of gas forming bubbles and the diameters of holes used to generate bubbles via the described mechanism. Therefore, the size (diameter) of a bubble depends on the force of displacement causing its breaking off from the substrate, while the diameter of a hole on which a bubble is formed or the pressure of gas flowing through do not affect bubble volume. These factors, however, affect the rate of bubble growth, which translates into the frequency of bubbles breaking off from the bubbles in the area of their formation, which, in turn, affects the rate of foam layer formation.

Foam stability depends on surface properties of the phases making up the foam, as these properties allow bubbles to join and be released into the atmosphere. Replacing a one-phase structure of a liquid metal by a suspension of solid particles increases foam stability. To yield high porosity foam, spherical bubbles have to be reshaped. This can be obtained when bubbles with low capillary pressure have properly large diameters.

Metal crystallization is an exothermic process, and the crystallization heat contained in a liquid metal passes to the environment, causing mainly the temperature in the foam space to increase. In particular conditions, a large number of emerging bubbles is part of the crystallization process of metal films, while the amount of foam covering the liquid metal increases.

The observed fast transition of external layers of foam into solid state (stabilization) is a consequence of easy transfer of heat to the environment. At the same time, the stabilized external foam layer becomes an insulator that hampers the crystallization heat of subsequent foam portions to pass to the surroundings. For this reason, conditions for crystallization heat transfer get more difficult, and the foaming process can be interrupted. One can observe that thin films separating foam bubbles get substantially heated, crack and make up large voids, as illustrated in Fig. 3.

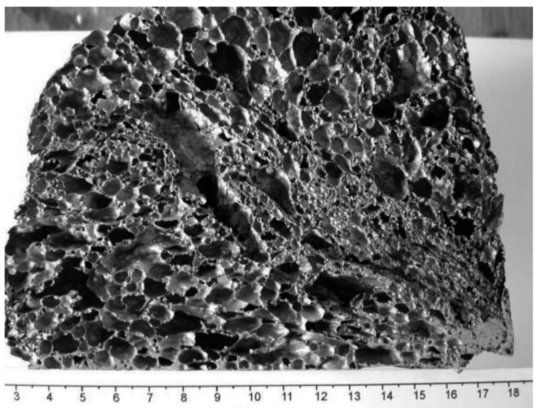

Fig. 3. Large voids, formed in a foam due to the concentration of crystallization heat

Necessary thermal conditions can be maintained by cooling and taking away the produced foam. Another factor decreasing the temperature locally is the movement of liquid metal (metal-ceramic composite) within the foaming space. This movement is naturally caused by rising gas bubbles, but it can also be forced by a rotor with small holes placed on its outside part, supplying gas to the liquid metal (Fig. 4).

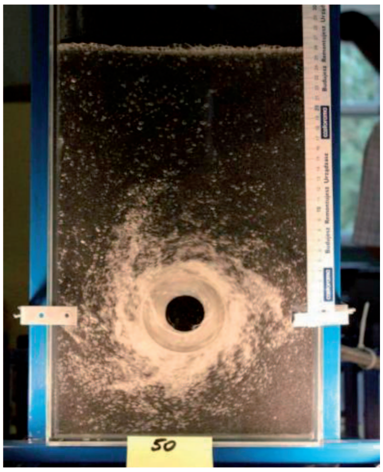

Fig. 4. Liquid movement in a tank forced by a working rotor

Decreasing the foam temperature below metal crystallization temperature causes foam to solidify [8-9]. Such condition can be observed on a conveyor belt receiving the foam, which enables intensive reception of heat and the formation of stabilized foam (Fig. 5).

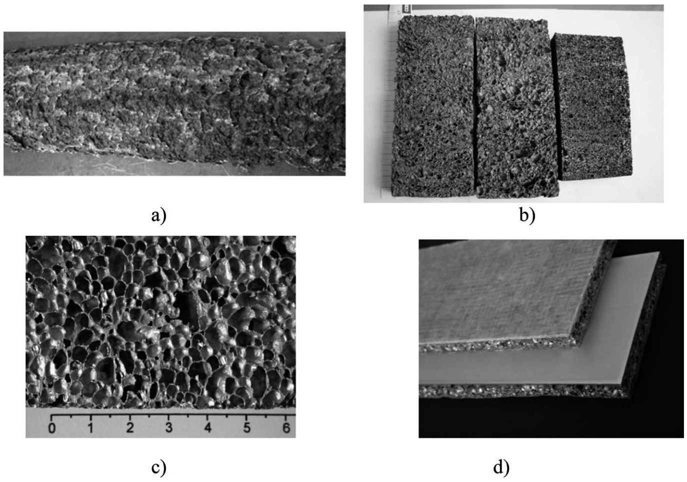

Fig. 5. Metal composite foams made at the Maritime University of Szczecin: a) a band of composite foam, b-c) foams made with various working parameters of the foaming device, d) foam sandwich

3. Summary

Manufacture of foam from metal-ceramic composite materials by the gas injection method involves a number of factors. The following conditions are required for the process to take place continuously:

- stable temperature and physical properties of liquid composite, consisting of metal and ceramic particles;
- fixed parameters of injected gas streams;
- settled movement of liquid composite in the area of foaming;
- stable thermal conditions in the area of foaming;
- proper methods of cooling and pulling off of the foam.

Thus produced foams can have large scale applications, for instance in elements of road infrastructure (side and front barriers), military vehicles or vessels, castings with foam cores. This foaming method enables easy recycling of aluminium scrap metal combined with the process of metallic charge preparation.

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