K. GAWDZIŃSKA, J. GRABIAN, M. GUCMA, B. KWIECIŃSKA

ISSN 0543-5846
METABK 55(1) 37-40 (2016)
UDC – UDK 621.747:669.7.0.666.3/7:661.185:541.124.539.37=111

DEFORMATION MECHANISMS IN METAL COMPOSITE FOAMS

Received – Primljeno: 2015-02-16
Accepted – Prihvaćeno: 2015-07-10
Original Scientific Paper – Izvorni znanstveni rad

The paper presents mechanisms leading to the deformation of the spatial structure of composite foams and phases of foam destruction. Various types of deformation depending on the structure of foam are discussed. The relevant description makes use of recognized elementary models of a cuboidal open and closed cells. The production of foam by blowing a gas into a liquid composite (AlSi9–SiC) allows to control the quantity of energy absorbed during the destruction of foams subject to free one-axis compression.

Key words: cast, metal-ceramic, composite foams, mechanisms of deformation

INTRODUCTION

Metal foams are characterized by high porosity, usually ranging from 75 to 95 %. Consequently, their density is 5 – 25 % of the density of metal used to produce them.

Pores in metal foams, like in ceramic and polymer foams, may be open or closed [1 – 3], depending mainly on the manufacturing method. There is a strong relation between the foam making method and its structure (distribution, size, open/closed pores, shape of pores, thickness of pore walls etc.), thus the properties of these materials vary. In many cases the material used for foaming determines the choice of technology.

The proper method of making metal foams from pure metals or their alloys leads to a rather restricted scope of changes in foam properties. The range of functional properties of foams and the capability of controlling these properties may be extended by using multiphase materials. These include composite materials made by combining at least two physically and chemically different materials in such a manner that, as per definition [4] – “with good mutual connection, there should be a visible boundary between them and the distribution of the reinforcement phase should be possibly homogeneous across the whole volume of the matrix”. Metal-ceramic composites, with wide ranges of components, may be used for making foams of specific properties, which, satisfying the principles of material engineering, broaden design opportunities.

The Department of Marine Materials Engineering, Maritime University of Szczecin, has carried out research into metal composites technologies, focusing on composite aluminium foams stabilized with ceramic particles. The metal composite foam casting technology of blowing a gas into a liquid metal [3 – 6] allows to efficiently and flexibly control, in terms of foam structure scope, their foam properties. The method requires precise control of process parameters, maintaining a stable temperature in particular, as well as precise input of gas into metal as this affects the density and size of bubbles, strictly related to the compressive strength of composite foams.

All authors from Maritme University of Szczecin, Szczecin, Poland

FORMATION OF COMPOSITE FOAM STRUCTURE AND STRAIN MECHANISMS

During metal foam making the following elementary phenomena occur in the technology of gas blowing into a liquid composite at a temperature higher than the melting point: formation and growth of bubbles as the gas flows out of the barrier, bubble breaking off from the substrate, rising of the bubble, joining of a bubble with the gaseous phase, formation of a layer of many bubbles (foam).

Besides, the metal changes its state of aggregation as the temperature drops below the solidification point, which can be defined as foam stabilization.

The spatial structure is the essential feature of the specific material such as a composite foam. Geometrical characteristics of the structure strongly determine foam functional properties. Therefore, for a selected composite we can obtain various values of parameters describing functional properties. The most important of these properties are static and dynamic strength (the character and course of destruction is important), as well as vibration damping, electric, electromagnetic and thermal properties.

The precise and unequivocal description of the spatial structure of foam is vital. Its internal structure, strongly determining strength properties in particular, requires the knowledge of, apart from base material it is made of, precise geometry of foam constituents. This basically means the relation in the foam space between the material making up the walls and the gas-filled void. Depending on the expected application of foam, rele-

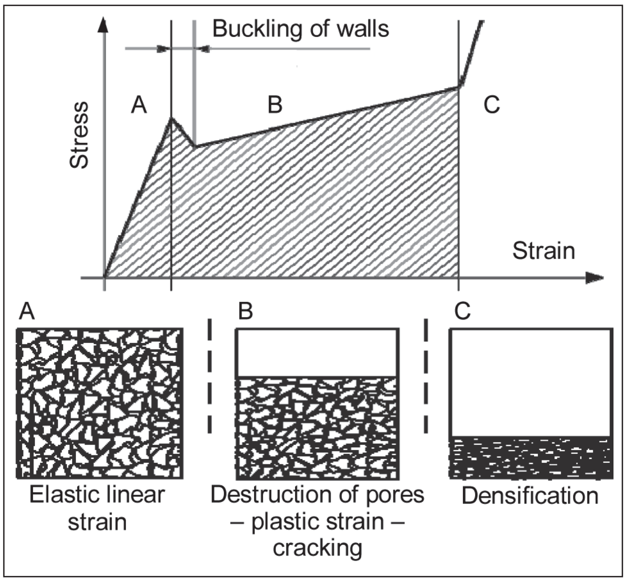


Figure 1 Schematic densification of foam – strain dependent on stress

vant mechanical tests are performed, using static and dynamic loads. Figure 1 schematically presents changes of stress and strain (deformation) during macro scale axial compression tests. Tested samples have pores filled with air. Foams are characterized by the so called plateau, area B, within which the process of destruction and corresponding energy absorption take place.

Characterizing the foam strength, we should pay attention to the size of tested samples, because the relation between pore (cell) size and sample size is essential. The minimum sample dimension is assumed to be seven diameters of a cell. For the projection of foam properties, we have to apply proper mathematical models, reflecting the reaction to mechanical or thermal loads [5]. Models reproducing the behavior of foam under load allow to predict its ability to absorb energy. Based on the properties of a material subjected to foaming and on images of macro- and microstructures of real geometrical structures of foams, such models allow to determine foam characteristics by calculations and simulations, often using advanced computer programs. If we assume that in a specific volume of foam the scatter of pore sizes and orientation is not significant (not too large), the network of model cells can be sufficiently approximated as a homogeneous and regular. Analyzing the model, on the basis of estimated temperature and mechanical parameters of foam model, we can optimize the selection of material, apparent density and parameters of real foam structure to suit specific applications. Two models of metal foams are presently in use: a cuboidal model of a closed cell and a cuboidal model of an open cell (Figure 2a, b). In both cases cell size is described by side length *l*, edge thickness t_e, or t_f for the closed cell.

The model choice heavily depends on the ratio of the part of material contained in cell edges to the remaining part making up cell walls. If the walls are much thinner than the edges, the foam is modeled as an elastic skeleton (spatial crate), like in case of open pore foams.

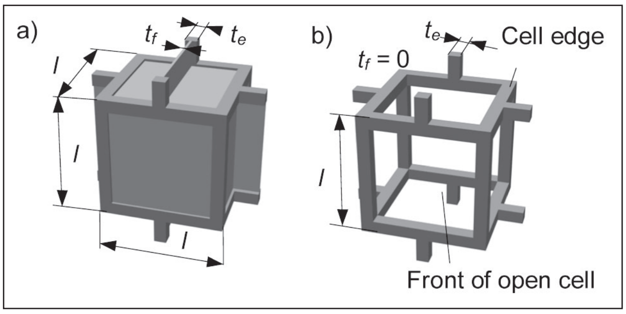


Figure 2 A model of an elementary cuboidal cell: a) closed, b) open (based on [2, 3, 7])

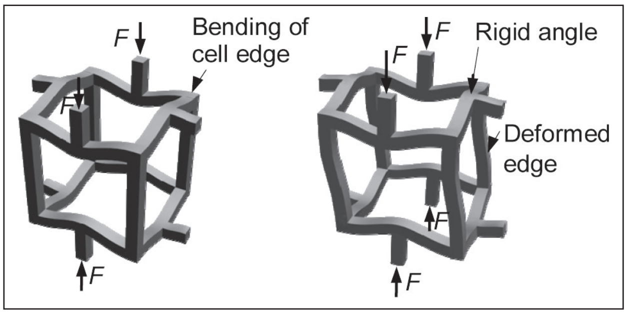


Figure 3 Possible deformations of foams as a result of the material subjected to load: model of an elementary open cell (developed on the basis of [2, 3, 7])

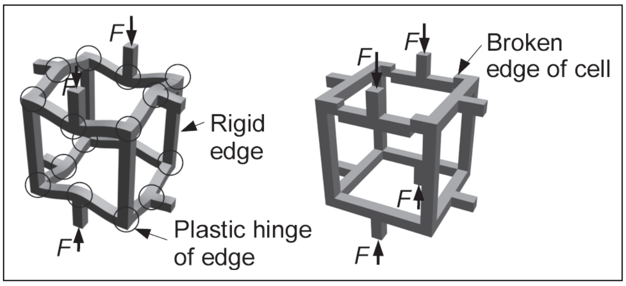


Figure 4 Possible deformations of foams as a result of the material subjected to load: model of an elementary open cell (developed on the basis of [2, 3])

When cells are compressed, the material is subject to strain. Examples of such strains in the foam structure (model of an elementary open cell) are shown in Figures 3 and 4.

Strength tests of composite foams

The actual verification of the above analysis included four types of foam, each made of a different material, denoted, respectively: H – aluminium alloy AlSi9, A, B and C – composite foams with AlSi9 matrix and SiC particles as reinforcement, 15 % by weight, differing in pore size. Three samples were chosen from each group, and the results were averaged. The different size pores are displayed in Figure 5. The tested foams were made at the Marine Materials Engineering Department, Maritime University of Szczecin, by the method of gas blowing into liquid metal [1 – 3].

Foam H had a density 0,228 g/cm^3, while the respective densities of the composite foams were as follows: A

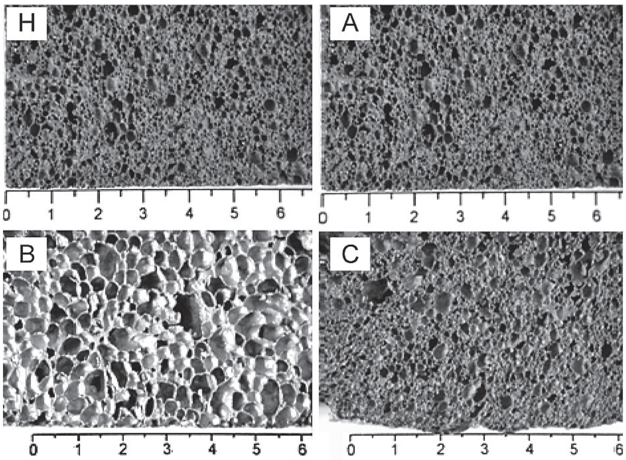


Figure 5 Metal foams with different pore sizes used for tests described in this study (notations explained in the text)

– 0,455; B – 0,250; C – 0,301 g/cm^3. Assuming the true density of AlSi9 alloy as 2,65 g/cm^3, the density of SiC being 3,21 g/cm^3, we could calculate the true density of composite material of foam: 2,72 g/cm^3. These data allow to calculate apparent densities and porosities of all tested foams. The calculated results are given in Table 1.

Table 1 **Densities and porosities of the tested materials (metal foam H and metal composite foams A, B, C)**

Material	Apparent density / g/cm^3	True density / g/cm^3	Relative density / % theoretical	Porosity / %
H	0,228	2,65	8,60	91,60
A	0,455	2,72	16,73	83,27
B	0,250	2,72	9,19	90,81
C	0,301	2,72	11,07	88,93

The foam was tested for static load by axial compression to examine how the geometry of bubbles affects the stress in foamed composite. The tests of cuboidal samples of foams, sized 40 × 40 × 20 cm were performed using an H10K-T strength testing machine [4]. The results are shown in Figure 6.

The examined samples differed in pore sizes and average porosity, which had to affect the results of strength tests. Nevertheless, analyzing the changes in the strain-stress relationship recorded during the tests of all materials, it can make a qualitative comparison. All curves have

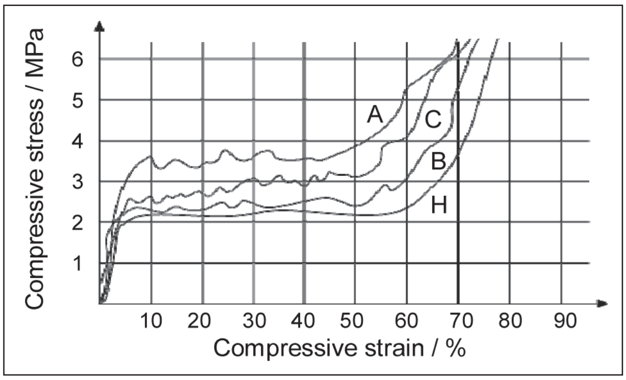


Figure 6 Values of compressive stress dependent on compressive strain for all types of foam: H, A, B, C

a roughly similar shape, in which three stages can be distinguished, related to the progress of destruction of foam microstructures during the test. The first stage represents a single figure percentage of strain, a range in which the strain-stress relation is linear. Then the strain increases up to 50 – 60 %, within which the average stress remains steady or slightly rises. In the final stage, upon reaching a substantial degree of strain, over 60 %, the stress also rises significantly with smaller changes of strain.

This is confirmed by the foregoing considerations and the literature [1 – 3]. Values of strain read out from the examined curves in Figure 6 clearly show that the lower total porosity is, the higher stress is necessary for strain to occur. However, another difference can be noticed in how the curves run. In the second stage the curve illustrating the strain of aluminium foam is relatively "smooth", while those for composite foams have considerable fluctuations of stress. This is most probably due to a retarding effect of inclusions that block the plastic strain in metal, causing a local accumulation of stresses. The amplitude of the fluctuations is related to foam density – the greater the density, the larger fluctuations of stress occur during strain.

SUMMARY

In the foam making process, the blowing of varying amounts of gas into liquid composite may lead to varied effects. Gas moves in the form of bubbles rising to the surface. The bubbles either break and release gas or remain in the metal keeping gas closed by thin layers (walls) of initially liquid, then solidified metal, making up a layer of foam. To produce foam, the created physical and chemical conditions should be such that gas bubbles flowing up to the surface of liquid metal will not be breaking up. The basic parameter that affects physical and chemical properties of the system is the temperature-dependent viscosity of liquid being foamed. When the temperature is lowered, the liquid viscosity increases, which stabilizes bubbles remaining at the boundary of the two phases. By selecting geometrical parameters and those referring to liquid metal properties of the system, and parameters of the injected gas, we can affect the size and distribution of gaseous bubbles (pores in the solid state) in produced foams. The chosen method of foaming a liquid metal broadens the capability of changing properties of the produced foam by varying the foam structure. The ranges of parameters describing the structure depend on physical and chemical properties of the system, technological parameters and the geometry of the foaming device elements. Functional properties of foams result from: type and properties of the material being foamed (metal); spatial geometrical structure, effect of foaming; possibility of modifying the produced metal foam. This is described in a flow chart (Figure 7).

The discussed method comprises a wide spectrum of factors that can affect practically functional properties

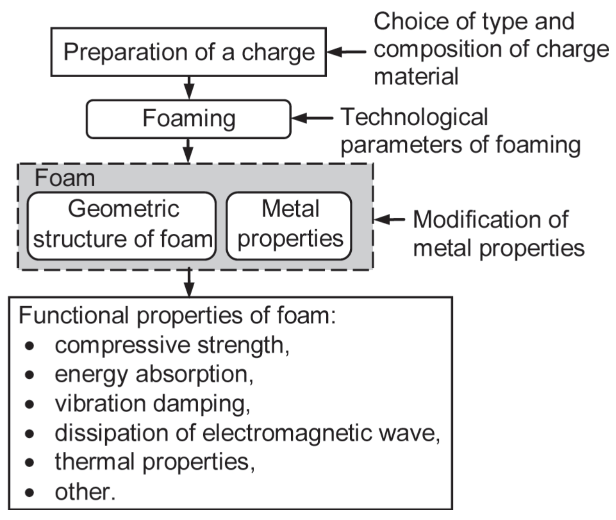


Figure 7 Possibilities of controlling foam properties at various stages of the technological process

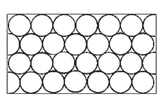
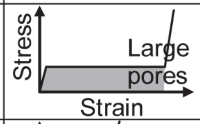
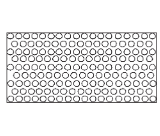
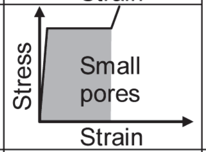
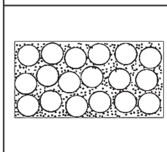
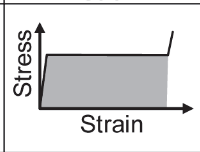
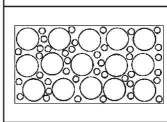
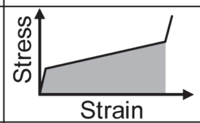
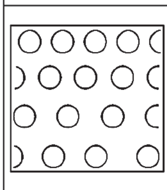
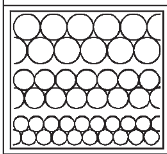
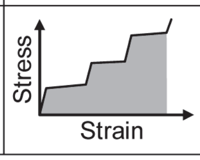
of foams. These factors can be divided into three groups, referring to:

- material:
  - – choice of its standard characteristics (hardness, strength, stiffness etc.);
  - – possibility of introducing ceramic particles (size of particles, volumetric content, shape etc.);
- foaming device:
  - – construction features of the tank where foam is formed;
  - – geometry of the element injecting gas (diameter, number of holes, rate of cutting the bubbles at the hole releasing gas);
  - – controlling the movement of liquid metal in the tank;
  - – selection of operating parameters of the system (pressure, delivery rate and temperature of the foaming gas, temperature of liquid metal);
- produced foam:
  - – change of metal properties by heat treatment (dispersion hardening of aluminium alloys, retrogression);
  - – increase of the volume of ceramic layer on the surface of metal forming pores by special heat treatment;
  - – change in stresses of surface layer by special heat treatment.

Possibilities of controlling functional properties of foams are shown in Table 2, refer to energy absorption, one of essential features of foams.

Foams produced by this method may be widely used, for instance in road infrastructure elements as barriers, and in vehicles, in castings with foam cores. The method is suitable for the recycling of scrap aluminium in the process of preparing a charge of material for foam production.

Table 2 **Control of the properties of foams made by blowing gas into liquid metal, concerning changes of energy absorption, and the destruction of foam subject to free one-axis compression**

Schematic structure of foam	Process of metal foam destruction under static load	Remarks on the control of the course of energy absorption by foam
		Change in pore size
		
		Introduction of ceramic particles into metal – composite foams
		Varied size of pores
		Gradient foams. Constant size of pores. Variable thickness of pore walls
		Gradient layered foams. Variable size of pores

REFERENCES

[1] J. Banhart, J. Baumeister, Proceedings, Materials Research Society Symposium, San Francisco, 1998, D.S. Schwartz, D.S. Shih, A.G. Evans, H.N.G. Wadley (ed.), vol. 521, MRS, Warrendale, 1998, pp. 121-132.

[2] L. Bonaccorsi, E. Proverbio, Advanced Engineering Materials 8 (2006) 9, 864-869.

[3] K. Gawdzińska, J. Grabian, Z. Pędzich, W. Przetakiewicz, Archive of Foundry Engineering 11 (2011), Special issue 1, 11-14.

[4] M. Thunemann, O. Beffort, S. Kleiner, U. Vogt: Comp. Sci. Tech. 67 (2007), 2377-2383.

[5] J. Chen, C. Hao, J. Zhang: Mater. Lett. 60 (2006), 2489-2492.

[6] P.A. Karnezis, G. Durrant, B. Cantor: Mater. Charact. 40 (1998), 97-109.

[7] K.F. Wall, S.H. Bhavnani, R.A. Overfelt, D.S. Sheldon, K. Williams: Metall. Mater. Trans. B. 34 (2003), 843-851

Note: W. Wiśniewski is resposible for English language, Szczecin, Poland