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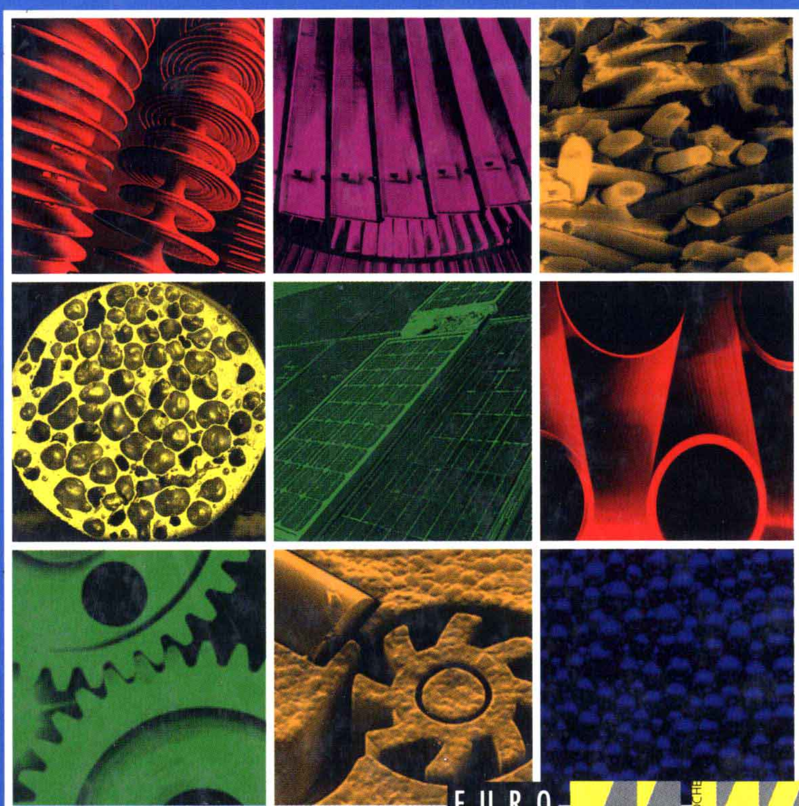
Metal Matrix Composites and Metallic Foams

EUROMAT – Volume 5

Edited by T. W. Clyne and F. Simancik



EURO MAT 99

MATERIALICA WERKSTOFFWOCHE

FEMS

DGM

Editors:
Prof. T. W. Clyne
Department of Materials Science and Metallurgy
Cambridge University
Pembroke Street
Cambridge CB2 3QZ
U.K.

Dr. F. Simancik
Institute of Materials
Slovak Academy of Sciences
Racianska 75
83812 Bratislava 38
Slovakia

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Preface

Engineering progress essentially depends on the availability and the intelligent use of materials. For many key industry areas, Europe constitutes a premier place for the development of new materials and their applications. EUROMAT 99, the biannual meeting of the Federation of European Materials Societies with its 21 member societies across Europe set out to become the most comprehensive European event to demonstrate the wide range of the interdisciplinary performance of materials.

EUROMAT was essentially focused on applications of materials with high innovation potential. At the same time, fundamental approaches and processing related aspects for unconventional materials were addressed. In the frame of the 12 conference topics, 1650 papers were originally submitted to the 52 symposia. A total of 655 have been selected as oral presentation by the international group of chairpersons and were presented in 161 sessions. Further, the chairpersons have selected 65 renowned experts for keynote lectures in the frame of their symposium. Roughly 700 papers were displayed as posters.

The scope of EUROMAT was truly international. Papers originated from 57 countries. Among them the major industrial countries of the world have contributed considerably to the wealth of the programme. An overwhelming Eastern European contingent shows that there is a strong interest of these countries in international cooperation.

EUROMAT 99 represents a showcase of the competence of the European materials societies. Various European sister societies and federations act as cosponsors of the event. Joining with FEMS, they are about to establish the network MatNet in order to promote and facilitate their communication and cooperation. They have started a dialogue with the European Commission in order to discuss programme goals and priorities for maintaining Europe's global competitiveness. In view of this promising international perspective, the European Community has agreed to sponsor EUROMAT 99 generously for which we are very grateful. EUROMAT 99 was focused to a large extent on the aims of the closing 4th Framework Programme many projects of which were presented.

EUROMAT 99 was hosted by WERKSTOFFWOCHE, a multisociety joint conference project established in Germany in 1996. Among its initiators is the Deutsche Gesellschaft für Materialkunde, one of the founding member societies of FEMS and technical organiser of this year's EUROMAT.

EUROMAT 99 represented an outstanding success. As the President of FEMS, I would hope that it will serve as a model for future meetings, both in terms of organisation and international cooperation. I would like to extend my gratitude to the scientists, chairpersons and coordinators as well as to the various organisations and particularly to the Messe München who have made this success possible.

Dr. Paul Costa
President of the Federation of European Materials Societies

EUROMAT 99 was the biannual meeting of the Federation of European Materials Societies (FEMS) with its 21 member societies across Europe.

The program of the EUROMAT 99 congress was divided into 12 topics. The scientific coordination was managed by topic coordinators. The responsible experts for the individual topics were:

Topic A – Materials for Information Technology
K. Grassie, Philips GmbH, Aachen (D)
Topic B – Materials for Transportation Technology
P. J. Winkler, DaimlerChrysler AG, München (D)
Topic C – Materials for Electrical Power Generation and Energy Conversion
E. Tenckhoff, Siemens AG, Erlangen (D)
Topic D – Materials for Medical Engineering
H. Stallforth, Aesculap AG, Tuttlingen (D)
P. Revell, University College London (UK)
Topic E – Materials for Buildings and Structures
F. H. Wittmann, ETH Zürich (CH)
Topic F1 – Characterization Methods and Procedures
Y. Bréchet, INPG, Grenoble (F)
Topic F2 – Metals
R. Wagner, FZ. Jülich (D)
Topic F3 – Ceramics
G. Müller, Fraunhofer-Inst. f. Silicatforschung ISC, Würzburg (D)
Topic F4 – Polymers
G. Wegner, MPI für Polymerforschung, Mainz (D)
P. J. Lemstra, Univ. of Eindhoven (NL)
Topic F5 – Interface Controlled Materials
M. Rühle, MPI für Metallforschung, Stuttgart (D)
Topic G – Surface Technology
H. Dimigen, Fraunhofer-Inst. f. Schicht- und Oberflächentechnik IST, Braunschweig (D)
Topic H – Nano- and Microtechnology
J. Haußelt, Forschungszentrum Karlsruhe (D)

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Processing of Metal Foams - Challenges and Opportunities

C. Körner, R. F. Singer
University of Erlangen-Nürnberg, Germany

1 Abstract

Considerable progress has been made recently in the production of metallic foams. Scale up has progressed so far that widespread commercial use may become a reality in the near future. The merits of the various fabrication techniques are highlighted. Particular emphasis is placed on the demands of the various applications and the suitability of each process to meet these demands.

2 Introduction

Metal foams are a class of materials with extremely low densities and an outstanding combination of mechanical, electrical, thermal and acoustic properties. They offer a large potential for light-weight structures, energy absorption and thermal management. Their extraordinary property combinations make them interesting for applications where more than only one function must be met e.g. high stiffness and fire resistance or acoustic damping.

Methods to produce metal foams are already known since the fifties. There are two reasons why their use has not spread so far: difficult process control and high costs. Due to the large progress during the last decade with respect to production techniques as well as production costs metal foams experience a kind of renaissance at the moment.

3 Production methods and characteristic cell structures

3.1 Production methods

The variety of different production methods can be classified into four groups: foams made from melts, from powders, by sputtering and by deposition ([1] and references therein). Each production method covers a characteristic range of density, cell size and cell topology. There are methods adequate for producing large panels and blocks. Other methods are more suitable for small complex shaped foam parts. Among all methods there are at least some which are cheap. This is especially true for foams made from melts or powders on which we restrict our description (see Fig. 1). Despite of the variety of production methods there are only two different strategies to generate porosity, by *self-formation or predesign*. In the former case, the porosity forms in a self-evolution process according to physical principles. The cell structure has stochastic nature, i.e. it is not predictable within a spatial framework. Methods where the porosity is generated by gas bubbles are self-forming. The cell walls have to be stabilized by additives since pure metals do not foam due to their high surface energy and their low viscosity. The surfactants, typically SiC- or Al_2O_3-patricles, tend to decrease the surface energy and to increase the viscosity thereby increasing the stability of the bubbles. In the case of predesign, the resulting structure is determined by a cell-forming mold. Additives are not necessary since the cell walls are stabilized by the walls of the mold.

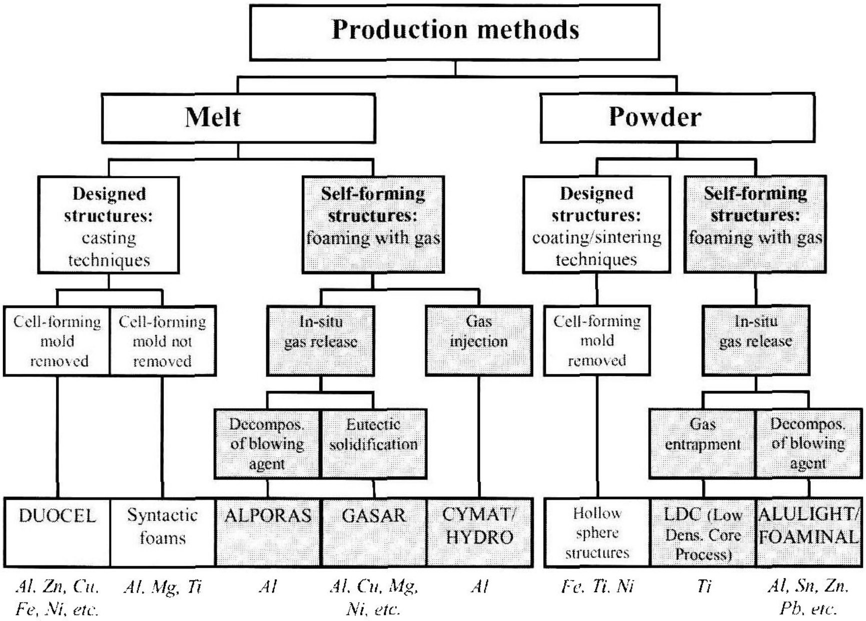

Figure 1: Processing techniques ([1] and references therein) for the production of metallic foams based on melts and powders.

In the following we will describe four production methods for aluminum foams in some detail which have already reached the commercial state.

CYMAT/HYDRO. The CYMAT foam-casting process [2][3] (see Fig. 2) is a continuous method originally developed by ALCAN, now licensed by CYMAT Aluminum Corp. A similar process is employed by HYDRO Aluminium, Norway [4]. A metal matrix composite (Al-wrought or Al-casting alloys + 10 - 20 vol.% SiC or Al_2O_3 particles) is used as starting material. The starting material is melted with conventional foundry equipment and transferred to a tundish where gas (typically air) is introduced. The resulting liquid metal foam is carried away by means of a conveyor belt.

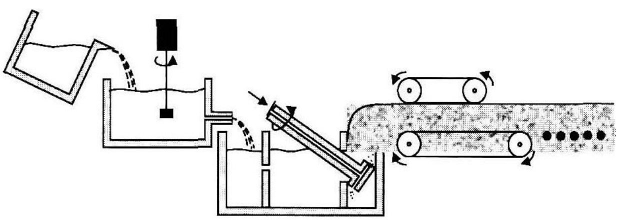

Figure 2: The foam casting process employed by CYMAT for producing flat panels consists of melting and holding furnaces, the foaming box and foaming equipment, and a twin-belt caster [2][3].

The relative density ranges from 2% - 20% (0.05 - 0.55 Mg/m^3). The average cell size is inversely related to the density and ranges from 25 mm - 3 mm. CYMAT´s production line is capable of casting continuous foam panels at an average rate of 900 kg/h up to 1.5 m wide with a thickness ranging from 25 mm - 150 mm.

ALPORAS. The manufacturing process of the ALPORAS foam is a batch casting process patented by SHINKO WIRE Company Ltd., Japan (see Fig. 3) [5]. For stabilizing the bubbles in the molten aluminum 1.5% Ca is added at 680 °C and stirred for 6 minutes in an ambient atmosphere. The high oxygen affinity of the Ca leads to the quick formation of oxides: CaO, Al_2O_3, $CaAl_2O_4$ etc. The thickened aluminum is poured into a casting mold and stirred with an admixture of 1.6 % TiH_2 as a blowing agent. After stirring the molten material expands and fills up the mold. Then, the foamed material is cooled by fans to solidify in the casting mold. After removal from the casting mold, the aluminum block is sliced into plates. An ALPORAS block is 450 mm wide, 2050 mm long and 650 mm high.

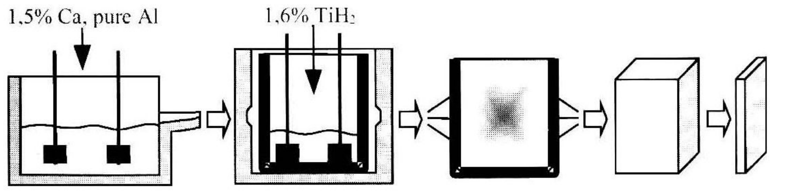

Figure 3: Manufacturing process for ALPORAS foams [5].

DUOCEL. DUOCEL is supplied by ERG Materials and Aerospace Corporation [6]. An open-cell polymer foam is filled with a slurry of heat resistant material. After drying the polymer is removed and a molten aluminum alloy (typically 6101 and A356) is cast into the resulting cavity which corresponds exactly to the original polymer foam structure. After directional solidification the mould material is mechanically removed and a continuously connected, open-celled foam remains. DUOCEL aluminum foam metal is available with relative densities ranging from 3% - 50% and a cell density of 2 - 20 pores per centimeter, with material density and cell size independently variable. The cost of the DUOCEL material is with approx. 90 US $ / liter much higher than that of all other materials discussed in this paper.

ALULIGHT/FOAMINAL. The production of ALULIGHT (ALULIGHT International GmbH (SHW/ECKART)) and FOAMINAL material (SCHUNK/HONSEL) is based on a powder metallurgical method patented by the Fraunhofer-Institut in Bremen [1][7] (Fig. 4). Metal powders – elementary metals, alloys or powder blends – are mixed with a foaming agent and compacted to yield a dense semi-finished product. Compaction methods are uniaxial compression, extrusion or powder rolling. During heating the foaming agent decomposes and the released gas forces the material to expand. The foam parts have a dense surface skin with relative densities ranging from 20% - 40%. Prior to foaming, the precursor material can be processed into sheets, rods, profiles etc. by conventional techniques. Near-net shaped parts are prepared by inserting the precursor material into a mold and expanding it by heating. By injecting the expanding foam into molds quite complicated parts can be manufactured [8]. Sandwich panels consisting of a foamed metal core and fully dense face sheets can be obtained by gluing the face sheets to a sheet of foam. Alternatively, a metallurgical bond is achieved by roll-cladding a sheet of foamable precursor material with conventional aluminum or steel sheets [9]. The cost of the powder metallurgical material, assuming large volume production and simple shapes, will be around 15 US $ / liter.

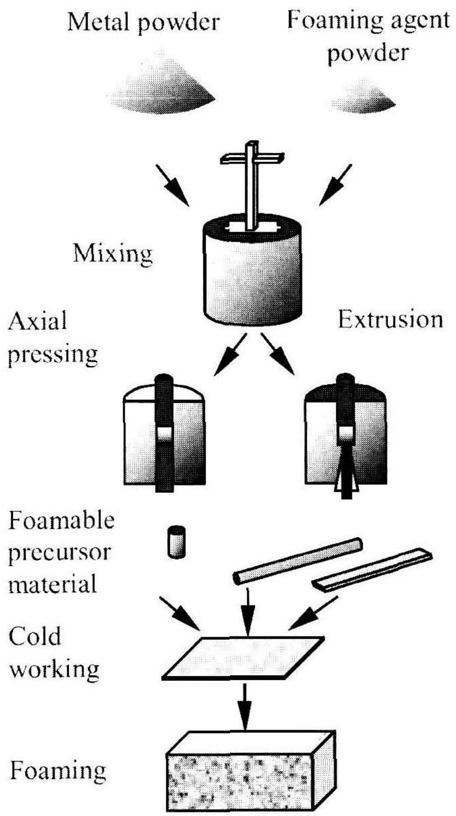

Figure 4: Powder metallurgical process for making foamed metals [1]

3.2 Characteristic cell structures

The most important parameters to characterize a cellular structure are the morphology of the cell (cell geometry, open or closed cell), the topology, the relative density, the mean cell size and the properties of the cell wall material. Each production method results in characteristic structures, densities and also imperfections. These imperfections can be wavy distortions of cell walls, variations in cell wall thickness, non-uniform cell shape, etc. They cause the mechanical properties to remain far below their theoretical limits [10][11].

Self-forming structures. Generally, the cell topology of self-forming structures is different from that of designed structures. The cell structure develops according to minimize the free energy of the system including external forces and boundary conditions. The resulting closed-cell structure strongly depends on the processing conditions. Fig. 5 shows characteristic foam structures for the CYMAT, ALPORAS and ALULIGHT case. The ALPORAS and

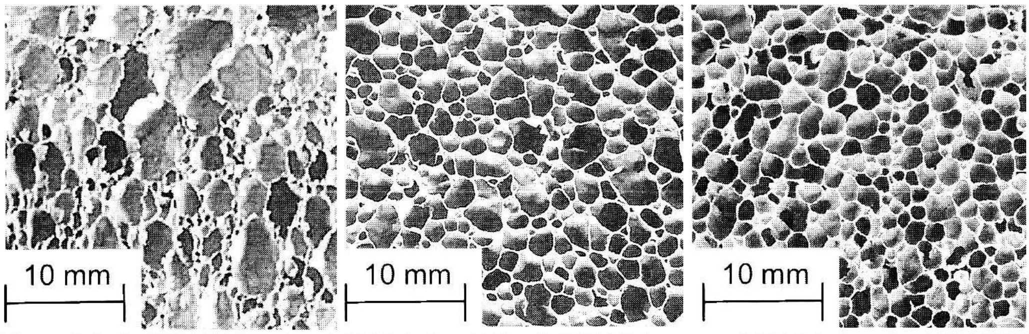

Figure 5: Left: CYMAT foam(ρ = 0.28 Mg/m³), middle: ALPORAS foam (ρ = 0.26 Mg/m³), right: ALULIGHT foam (ρ = 0.34 Mg/m³)

ALULIGHT foam are very similar due to their analogous evolution process consisting of bubble nucleation, bubble growth due to decomposition of the foaming agent (TiH_2) [12] and coarsening as a result of bubble coalescence. The cell shape evolves from spherical to polyhedral with decreasing density. Generally, the cells are closed but there are often small cracks in the cell walls allowing gas to be transferred from one cell to another. The formation process of the CYMAT foam is completely different. Here, the foam is built up from rising gas bubbles. Typical for the CYMAT foam is its heterogeneity, anisotropy and face corrugations in the cell walls [11] attributable to the processing method used.

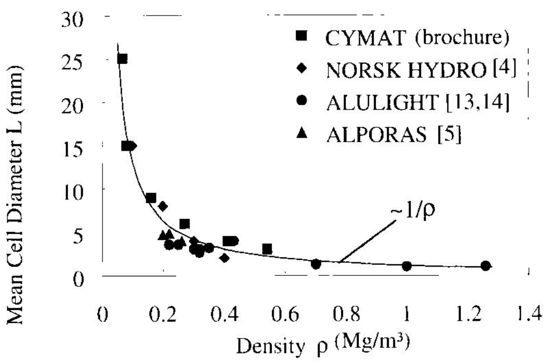

Figure 6: Mean cell size as a function of the relative density for closed cell aluminum foams produced by different methods

The anisotropy and its variation through the panels is due to straining the liquid foam prior to solidification by the conveyor motion [11]. Corrugations have been identified as the mean cause for the mechanical properties lying far below their theoretical possibilities [10][11]. Analyzing foam structures produced by different methods (see figure 6) with respect to their density and mean cell size reveals that these parameters are not independent. That is, the relative density and mean cell size can not be varied separately as illustrated in Fig. 6. This correlation expresses the fact that decreasing the density below certain limits leads to cell wall rupture i.e. the mean cell size increases.

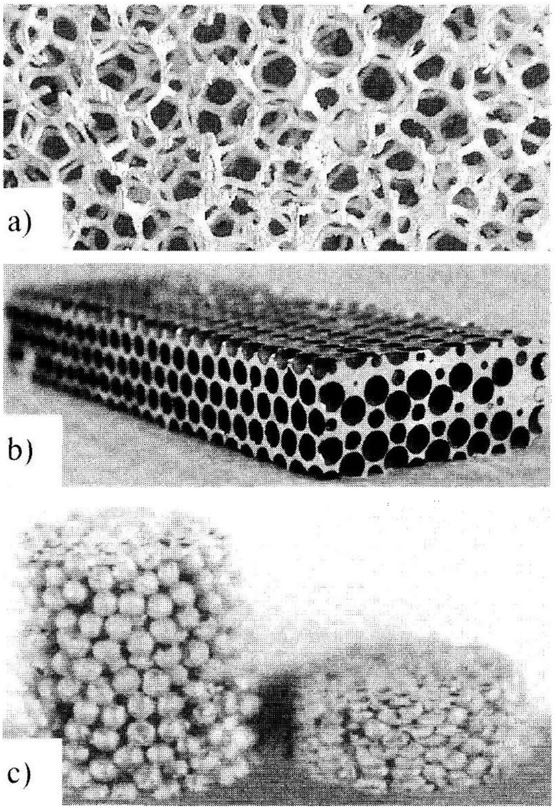

Figure 7: a) DUOCEL open-cell aluminum foam b) Syntactic foam: hollow alumina spheres embedded in a magnesium matrix c) Hollow sphere foam $Fe_{0.88}Cr_{0.12}$ [17] before and after compression

Designed structures. Designed structures offer a much larger spectrum of cell geometry, cell size and relative density than self-forming structures. Due to the fact that they do not underlie statistical laws their homogeneity is in general much better than that of self-forming structures. Consequently, the scatter in the material properties of designed structures is comparatively small. The cell morphology of designed structures is predetermined by a cell forming mold. DUOCEL aluminum foam (Fig. 7a) belongs to the class of designed structures where the cell forming refractory mold is removed. Consequently, the resulting cell structure is open. DUOCEL is available with material density and cell size independently variable. Using processes where the mold is part of the foam closed-cell structures can be produced. Syntactic foams [15][16] where the pores are formed by hollow spheres are an example for such structures (Fig. 7b). Another example for designed structures are sintered metal hollow sphere foams (Fig. 7c) [17][18]. These foams are in a sense closed and open-cell structures at the same time. Pore size, cell arrangement and relative density are completely independent from each other. Pore sizes ranging from 4.5 mm - 0.5 mm at constant porosity of 80% have been realized [18].