Engineering Materials

Carolin Koerner

Integral Foam Molding of Light Metals

Technology, Foam Physics and Foam Simulation

With 143 Figures and 8 Tables

Springer

Dr. Carolin Koerner
Univ. Erlangen-Nürnberg
Inst. Werkstoffwissenschaften
Martensstr. 5
91058 Erlangen
Germany

ISBN: 978-3-540-68838-9 e-ISBN: 978-3-540-68839-6

Engineering Materials ISSN: 1612-1317

Library of Congress Control Number: 2008929338

Cover Design: Mönnich, Max

Printed on acid-free paper

9 8 7 6 5 4 3 2 1

springer.com

for Viktor and Walter

Preface

A person with a new idea is a crank until the idea succeeds.
Mark Twain

Metal foams show outstanding properties: Low weight, high rigidity, high energy absorption capacity, high damping capacity, etc. They have attracted strong industrial and scientific interest during the last decade. A variety of methods has been developed to produce foams and the development of new, more sophisticated methods is still going on.

On the one hand, there are only very few applications where metal foams can be directly employed without further processing. On the other hand, established metal foam production methods have one feature in common, they produce foam and not metal parts containing metal foam. In the majority of cases additional shaping and joining steps are necessary to transform the metal foam into a working functional element. In addition, the cellular structure demands for appropriate joining technologies which are often not yet available or expensive. As a result, the whole processing sequence is in general long and expensive.

The logical consequence of the requirement to develop cost-effective techniques to produce metal parts with integrated cellular structure is the newly developed process of integral foam molding. Integral foam consists of a solid skin and a cellular core. This is the fundamental construction principle which is ubiquitous in biological systems, e. g. the human skull, as well as in technical solutions, e. g. sandwich constructions. The concentration of the material within the skin optimizes the moment of inertia and thus stiffness and strength.

The development of metal based integral foam follows analogous paths as that of polymers where integral foam was commercially introduced in the late 1960s. Polymer integral foam parts are now accepted as a material system with characteristic properties which simplifies designs, reduces production costs and weight, and which increases stiffness and overall strength. Starting from low-pressure injection of polymers with small amounts of gas content, highly sophisticated processes have been developed where injection takes place at very high pressures into mold cavities with moving elements.

Metal integral foams represent – analogous to polymers – an own class of structures with specific properties such as high structural rigidity, high energy absorption capacity or high damping. They are not thought to substitute standard die castings but open new applications and also demand a specific component design. Compared to polymers, the development of metal integral foam molding is just at the beginning. The time delay of four decades between commercialization of polymer integral foam molding and the current onset of investigations with respect to metals can hardly be explained. Although we have made enormous progress during the last years of metal integral foam molding research there are still many challenges left which have to be solved in the future to get integral foam components made from light metals into broad industrial application. Nevertheless, we presume a large economical potential for metal integral foam molding technologies in the future.

Surprisingly, integral foam molding of metals shows much more similarities than differences to polymer integral foam molding. This is not only true for the applied molding technologies but also for the resultant integral foam structures and their properties. The intention of this book is to introduce the technological principles of metal integral foam molding. In addition, its purpose is to reveal the underlying physical mechanisms which govern the foam evolution process and which are essential in view of a successful process development.

Usually, a first step to gain a physical picture of the integral foam molding process would be to observe it. Unfortunately, in situ experimental observations are impossible since the foaming process takes place in a permanent steel mold within a fraction of a second. Thus, information of the foam formation process has to be extracted from ex situ investigations. This limited information does not help very much to understand the underlying physics. Nevertheless, in combination with theoretical investigations and numerical simulation the experimental findings reveal the underlying physical principles.

The book is organized in three parts:

- Part I: Technology
  Part I describes the technological foundation of integral foam molding of metals, a technology that has been conceived and developed in our research group at the University of Erlangen throughout the last 6 years. For the first time it is shown that foaming of metals is possible by applying molding techniques very similar to polymer integral foam molding. A low pressure and a high pressure integral foam molding process are introduced and discussed. The molded parts show compact skins and foamed cores with porosities up to 80%. Thermodynamics and kinetics of the blowing agent as well as the low viscosity of metal melts turn out to be the key for the success of the molding process. Although non-conditioned metal melts are employed, which are generally believed to be not foamable, the resulting structures are in fact foams. Integral foam molding appears to be the only known process where non-conditioned metal melts may be used to produce foam. An explanation of this finding is given on the basis of the theoretical background presented in Part II and Part

III. The fact that standard casting alloys may be applied has enormous advantages with respect to casting behavior, properties, recycling and, last but not least, costs.

- Part II: Physics
  This part is devoted to the physics of foaming with special emphasis on the very short time scale which is characteristic for integral foam molding. Although very complex in detail, foam formation is shown to underlie simple evolution laws determined by the way how foam stabilization is realized. Basis for these investigations is a numerical approach which is described in Part III. In order to account for the specific situation during integral foam molding, foam evolution in the presence of solid particles is discussed in detail. The results of these theoretical considerations represent the basis for the interpretation of the experimental observations described in Part I. However, the evolution laws are generally valid and can as well be applied to other foam evolution processes.

- Part III: Numerical Simulation
  The high degree of complexity of foam evolution processes strongly restricts analytical descriptions. Even with the aid of numerical tools, the simulation of foam formation processes is a challenge due to the huge and strongly evolving gas–liquid interface. A new lattice Boltzmann approach for the treatment of free surfaces is developed and applied on foam evolution problems. For the first time, the numerical simulation of foam evolution starting from nucleation until decay is accessible. The interplay between hydrodynamics, capillary forces, gravity and bubble coalescence processes leads to complex phenomena such as topological rearrangements, avalanches, drainage, etc. without further model assumptions.

Even if integral foam molding of light metals will never find general industrial application, we have gained fundamental insights into the main mechanisms of foam evolution, especially into the general principles of metal foam stabilization.

Acknowledgments
This work is based on results obtained during my work as the leader of the lightweight materials group at the Institute of Science and Technology of Metals at the University of Erlangen-Nuremberg.

I appreciate the support and freedom I obtained from Prof. R. F. Singer, the head of the Institute of Science and Technology of Metals, as it enabled me to follow-up and realize own ideas.

I would like to thank all members of the Institute for Materials Science who contributed to this work in one or another way. Although it is impossible to acknowledge all contributors, the work of the following colleagues is especially appreciated: M. Arnold, Dr. M. Hirschmann, Dr. M. Thies, A. Trepper and H. Wiehler.

In addition, I would like to thank Prof. Rüde, Prof. Kaptay, Prof. Greil and Prof. Clyne for the support during the habilitation process and the colleagues of Neue Materialien Fürth GmbH for the assistance with the thixomolder.

Carolin Körner, April 2008

Contents