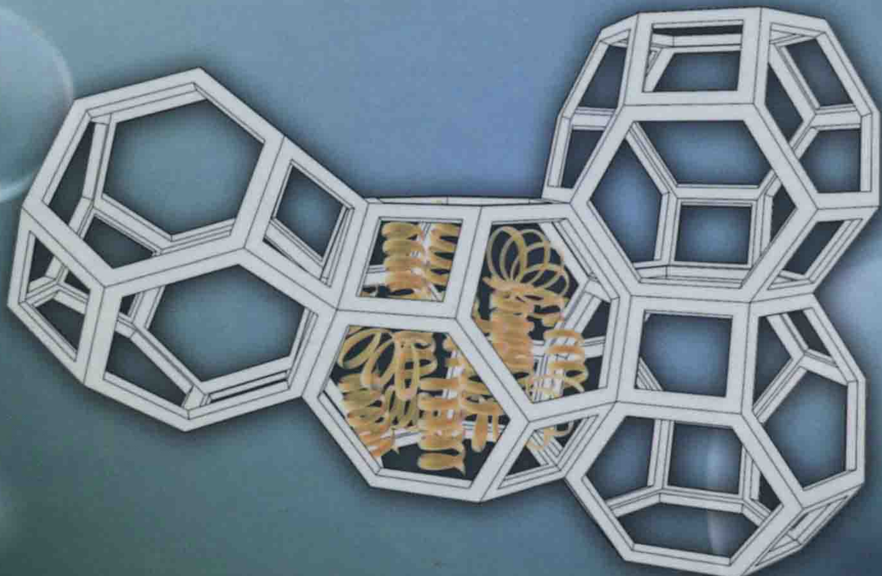
BIOFOAMS

Science and Applications of Bio-Based Cellular and Porous Materials



Edited by

SALVATORE IANNACE
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Preface

In the recent past, there has been a confluence of fundamental research and development work being conducted on biofoams and porous systems by a variety of very different research communities. A large number of innovative routes have been explored, generating new materials with wide-ranging technological applicability. As the need for cellular and porous materials with more complex structures and functions has increased, so has the ability to synthesize such systems with tuneable mechanical properties, well-defined pore sizes, pore wall functionalities, and controlled pore size distribution and interconnectivity.

Written for students, professors, and professionals, this book deals with bio-based materials for the development of biodegradable and sustainable polymeric foams, foams in food, foams in biomedical applications, and bio-inspired foams. It represents a coordinated effort by international experts and provides an integrated, forward-looking perspective. By joining together the most active groups representing diverse fields of study, the editors offer a unified approach on biofoams. Scientists and technologists working in the fields of material science and technology, chemical and biomedical engineering, food technology, and polymers and composites may take advantage of such a unified approach, where the most relevant theoretical and experimental aspects governing the formation of cellular and porous materials are presented in the context of specific applications.

This book describes how gas bubbles can form and grow in a viscous medium leading to the development of products for the plastic (e.g., seats, packaging, insulating material), food (e.g., beers, mousse, ice cream, snacks, cakes), and biomedical (e.g., implants, artificial organs, products for surgery) industries. It also shows how to use renewable resources to develop more sustainable lightweight materials and discusses how scientists and engineers are inspired by nature when designing novel technologies for the production of complex and multifunctional structures.

OVERVIEW OF THE BOOK

Chapter 1 introduces the building blocks used in nature to create hierarchical structures in cellular solids. Bio-based polymers, including biodegradable polymers, used to develop sustainable foams and cellular structures for biomedical applications are also presented. Some of them, such as starch and cellulose, are well known and actively used in products today, while many others are known only in very specific sectors and remain underutilized despite the great potential.

Chapter 2 focuses on the methods employed to develop organic–inorganic hybrid materials derived by solgel reactions of alkoxysilane compounds, as well on the aspects related to the preparation of porous hybrid materials with particular attention to systems obtained from biopolymers.

In Chapter 3, the challenging issues related to the production of porous polymers are reviewed in an effort to pinpoint the requirements that should be met by prospect thermodynamic models to be used for describing and, ultimately, designing such processes. The role of external conditions of temperature, pressure, and composition of solvent or antisolvent is discussed, and the polymer foaming processes are categorized accordingly. The role of the glassy state or the (semi)crystalline state for stabilizing the final porous polymer structure is also discussed.

Chapter 4 shows that proper qualitative and quantitative description of polymer foaming process is a multiphysics problem involving mass and heat transport and momentum transfer, as well as sorption thermodynamics in a high-pressure polymer-penetrant system. There are several material and thermodynamic properties playing a major role, ranging from volumetric, rheological, and mass transport behavior to interfacial properties of the binary mixtures of polymer and foaming agent. The general problem of gas foaming where gas solubility and diffusivity, as well as the effect of gas concentration on interfacial properties and viscosity of the gas–polymer mixture, rule the whole process of bubble nucleation and growth is considered here. In particular, the focus is on the properties of gas–molten polymer mixture.

Chapter 5 discusses the cell nucleation mechanisms in PLA foaming by taking into account (1) the fundamental studies on heterogeneous cell nucleation, (2) the mechanisms of cell nucleation in PLA foams through micro-/nano-sized additives and crystals, and (3) the influence of crystallization on cell nucleation behavior of PLA foams through various foaming processing technologies such as bead foaming, extrusion foaming, and foam injection molding.

Chapter 6 presents a comprehensive study on microcellular foaming of PLA with CO_2 gas by the solid-state process. All aspects of the process including analysis and testing of the PLA foamed specimens are discussed: gas sorption/desorption, diffusion, foaming behavior, microstructure, crystallization, and mechanical properties. Specific guidance on the optimal processing conditions for food-packaging application is presented.

Chapter 7 describes the general approaches in the preparation of thermoplastic starch by using plasticizers and polymeric processing agents. Technologies developed for the production of starch foams for various nonfood applications are described with particular attention to the multiple roles of water molecules: as a solvent, a processing aids/plasticizer, and a blowing or co-blowing agent.

Chapter 8 describes the technologies used to prepare bio-based aerogel by supercritical carbon dioxide. Due to their importance in the selection of proper process condition, both thermodynamics and kinetics aspects related to aerogel preparation are discussed.

Chapter 9 summarizes recent progresses in the development of biocomposite foams based on clays of diverse nature, emphasizing aspects related to the role of the clay filler on the foam formation, as well as the active and passive properties of the resulting foams. The enhancement of mechanical properties or fire retardancy, adsorption behavior, and other specific functionalities derived from the clay and biopolymer synergy, as well as possible applications of these materials, is presented.

Chapter 10 focuses on the use of bio-based components for the synthesis of polyurethane foams. The chemical aspects and the mechanical and morphological properties of bio-based flexible and rigid polyurethane foams prepared by using vegetable derived oils, fats, and plant fillers are discussed.

Chapter 11 describes several technologies available for the production of foams based on thermoplastic polymers. Foaming technologies of thermoplastics are very broad, and it is not the purpose of this chapter to cover all of them. Some basic aspects, especially related to the use of bio-based thermoplastic polymers, are given here with the purpose of providing the background for those that are not familiar with foaming technologies.

Chapter 12 introduces the commonly used synthetic polymer scaffold fabrication methods, including solvent casting/particle leaching, thermally induced phase separation, electrospinning, gas foaming, and rapid prototyping. Recent progress regarding scaffold fabrication—such as combining different scaffold fabrication methods, combining various materials, and improving current scaffold fabrication methods—is discussed as well.

Chapter 13 focuses on the preparation and properties of polymer-based composite and hybrid scaffolds, which represent a very convenient solution for tissue repair and regeneration, providing a wider set of options and possibilities in implant design with tailored physiochemical and biological features. The crucial roles of chemical/physical properties of constituent materials, that is, degradation, mechanical properties, and bioactivity, on the biological function of porous scaffolds at micro, sub-micro, or nanometric scale are discussed.

Chapter 14 reviews current research trends on composite and nanocomposite materials for tissue engineering, including strategies for fabrication of the scaffolds with highly porous and interconnected pores. Cell–scaffold interaction using the colonization of stem cells and degradation of the scaffolds *in vitro* are discussed.

Chapter 15 examines the fundamental aspects related to the formation of gas bubbles in food and drink products. Bubbles are an integral part of many foods and beverages and the control of the foamed structure is crucial for the modification of food properties and for enhancing product quality of aerated food systems.

Chapter 16 is aimed to identify why food foams are attractive to the consumer and the manufacturer. It examines the prominent mechanisms behind food foam stability, their function, and finally highlights possible new trends. Examples are given of several different mechanisms and molecules that are commonly used to form food foams. The intention was to highlight the variety of structures and structural molecules that are so familiar to us but are still capable of producing the vast array of structures that we enjoy eating; for instance, a beer foam is inherently different from a bread but both use protein as their stabilizer.

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Editors

Salvatore Iannace graduated in chemical engineering (1988) and earned his PhD (1994) from the University of Naples "Federico II," Napoli, Italy. He is the founder and director of the Thermoplastic Composites Manufacturing Laboratory at the Institute of Polymers, Composites and Biomaterials of the National Research Council of Italy. His principal research interests lie in the fields of biodegradable and sustainable multicomponent and multiscale foams with designed structural and functional properties. Dr. Iannace has published more than 300 articles, including 140 in international refereed journals, 18 book chapters, and 4 patents and delivered more than 150 conference papers. Iannace is also a member of the editorial board of the *Journal of Cellular Plastics*. He chaired the first and third International Conferences on Biofoams in Italy (2007 and 2011) and co-chaired the second and fourth editions (2009 and 2013) in Canada. He has been invited as keynote speaker at several major international conferences for his pioneering works on the gas-foaming behavior of biopolymers and their nanocomposites. He has been honored with several awards, including the Nanochallenge and Polymerchallenge Grand Prizes in 2007.

Chul B. Park earned his PhD from MIT in 1993. He holds the Canada Research Chair (Tier 1) in Microcellular Plastics at University of Toronto, Toronto, Canada. He is the founder and director of Microcellular Plastics Manufacturing Laboratory and the Centre for Industrial Application of Microcellular Plastics. He has worked on many foundational research topics that have greatly improved the understanding of the basic physical properties and mechanisms governing the plastics foaming process. He has published more than 900 papers, including 240 refereed journal articles, 2 books, and more than 30 patents and delivered more than 560 conference papers. He is a fellow of three academies: Royal Society of Canada, Canadian Academy of Engineering, and Korean Academy of Science and Technology. He is also a fellow of the American Association for the Advancement of Science, the American Society of Mechanical Engineers, the Canadian Society for Mechanical Engineering, the Engineering Institute of Canada, and the Society of Plastics Engineers. He is the editor-in-chief of the *Journal of Cellular Plastics*. He has international recognition in polymer foaming and has been honored with over 30 major awards.

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