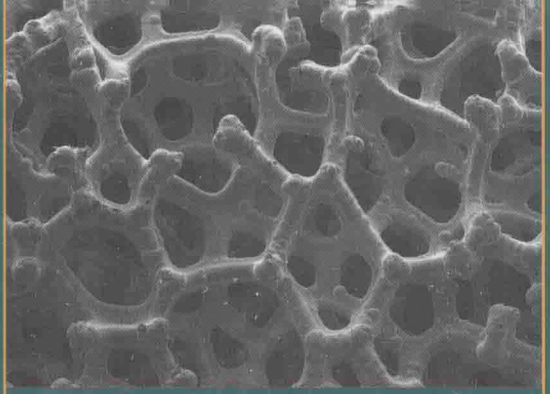

Porous Materials

Processing and Applications

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[中] P. S. Liu　[中] G. F. Chen

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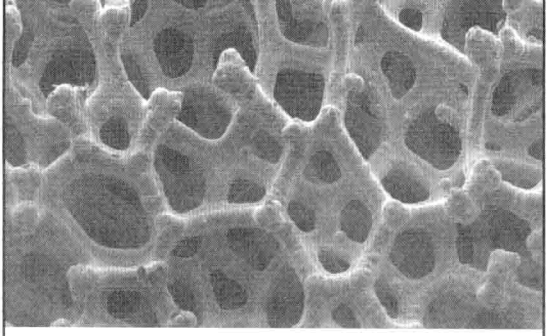

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内容简介

多孔材料具有优秀的物理和力学性能，特别是在功能结构一体化方面展示出优异的综合性能。本书系统介绍了此类材料的概念、制备、应用和表征等基本知识以及近年来的相关研究进展。全书共分 10 章：在第 1 章对多孔材料作了整体性的概述，第 2 章至第 8 章依次论述了多孔金属、多孔陶瓷、泡沫塑料三大类多孔材料的各种制备方法和不同用途，第 9 章和第 10 章分别介绍多孔材料的几个基本参量的表征，包括孔隙因素和基本物理性能。本书可供材料领域的科研人员、工程技术人员参考，也可作为高等院校材料类和相关专业（如物理、化学、生物、医学、机械、冶金、建筑等专业）的教材。

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PREFACE

Porous materials are a class of functional-structural materials with the optimal index of physical and mechanical properties, thanks to their porous structure. This book systematically introduces the basic concept behind these materials, as well as their major types, characteristics, applications, and main parameters. In addition, it presents various methods that can be used to process porous metals, porous ceramics, and polymer foams (foamed plastics) in accordance with their respective categories.

The concept of porous materials has been known for a number of years, but its radiation is far less successful than that of other materials. By the end of the 20th century, studies on porous materials have made a number of important discoveries. Based on this background, we spent a good deal of time and energy on collecting relevant literatures, combining with our own accumulated work experience, to write the Chinese version of the book, *Introduction to Porous Materials*, published in 2004 by Tsinghua University Press. This book focuses on production methods and applications of porous materials, considering that a classic work about porous materials, *Cellular Solids: Structure and Properties,"* by L. J. Gibson and M. F. Ashby , has made a great contribution to expounding the structure and properties of porous solids. This is aimed at providing more information to scientific researchers and engineering or technical personnel who interact with porous materials (including the present authors themselves, of course). The formation and the publication of Introduction to Porous Materials were quite hasty at that time, with some immature viewpoints. In addition, at that time, there were only a few researchers in China studying porous materials. However, the results of our previous effort (including its reception) far exceeded our expectations, and that development further encouraged our future work. In turn, the publication of this book may play a part in promoting the development in China of the porous material field, as well as research in relevant or potential relevant fields. Because we have seen that research into porous materials has been growing rapidly in recent years in China, and the number of the scientific research institutes, universities, and companies involved in this area also have increased rapidly.

In order not to let down the readers, the publisher and the author jointly determined to revise the original book for a second edition, published in

Chinese, to better meet the needs of the wider readership. In the second edition published in 2012, we corrected some errors and inappropriate content that appeared in the first edition, and we added relevant new content reflecting the research progress made over the previous decade. In addition, we readjusted the layout of the book to give it a scientific and reasonable arrangement; in particular, we devoted a lot of time to revising chapters 2, 3, and 4.

Learning of Elsevier's interest in the topic of this book and considering the international demand for it, we comprehensively rewrote and rearranged the book again for a third edition. In so doing, we expanded on the relevant contents with an emphasis on supplementing the information about the processing, applications, and characterization of porous materials.

In the process of writing this book, we referred to the relevant papers and works published in the last 40 years, and especially those from the last 20 years, and made good use of them. Here, we would like to express our heartfelt thanks to all the authors of these documents. However, we should note that due to space and time limitations, we had to leave out a good many worthy books, papers, and articles, and we regret this deeply. Certainly, we also should acknowledge the assistance of many of our colleagues in the field of porous materials, and our friends that have helped and supported us greatly. In the process of writing and publishing this book, P. Liu provided excellent assistance, and C. Y. Yang and Y. J. Guo worked hard to collate the references and draw the figures for this book. The combined effort of all these fine people have allowed this project to reach a successful conclusion.

P.S. Liu, G.F. Chen
October 2013

CONTENTS

CHAPTER ONE

General Introduction to Porous Materials

Porous materials widely exist around us and play a role in many aspects of our daily lives; among the fields they can be found in are energy management, vibration suppression, heat insulation, sound absorption, and fluid filtration. Highly porous solids have relatively high structural rigidity and low density of mass, so porous solids often serve as structural bodies in nature, including in wood and bones [1,2]; but human beings use porous materials more functionally than structurally, and develop many structural and functional integrative applications that use these materials fully [3,4]. This chapter will introduce the elementary concepts and features of this kind of material.

1.1 ELEMENTARY CONCEPTS FOR POROUS MATERIALS

Just as their name implies, porous materials contain many pores. Porous solids are made of a continuously solid phase that forms the basic porous frame and a fluid phase that forms the pores in the solid. The latter can consist of gas, when there is a gaseous medium in the pore, or of liquid, when there is a liquid medium in the pore.

In that case, can all materials with pores be referred to as porous? Perhaps surprisingly, the answer is "no." For instance, holes and crannies that are the result of defects will lower a material's performance. This result is not what designers want, and so these materials cannot be termed porous. So-called porous materials must possess two essential characteristics: one is that the material contains a lot of pores, and the other is that the pores are designed specifically to achieve the expectant index of the material's performance. Thus, the pore of porous materials may be thought as a functional phase what designers and users hope to come forth within the material, and it supplies an optimizing action for the performance of the material.

1.2 MAIN GROUPS OF POROUS MATERIALS

The number of pores (i.e., porosity) will vary for different porous materials. Porous materials can be classified as low porosity, middle porosity, or high porosity based on the number of pores. Generally, porous materials with low and middle porosity have closed pores (Figure 1.1) which behave like a phase of impurity. For porous materials with high porosity (Figures 1.2–1.4), there are two different cases according to various morphologies of the pore and the continuous solid phase. In the first case, the continuous solid constructs a two-dimensional array of polygons; the pore is isolated in space, taking on polygonal columniations accordingly; and the cross-sectional shape of the pore is commonly triangle, quadrangle, or hexagon (Figure 1.2). This structure looks similar to the hexagonal cell of a honeycomb, and such two-dimensional porous materials are called *honeycomb materials*. Porous materials with directional pores [5], which are called *lotus-type porous materials,* have a similar structure as honeycomb materials, but the cross-sectional shape of the pores for these materials is circular or elliptic, and the pore often cannot run through it, resulting in less uniformity of distribution and a lower density of the array. In the second case, the continuous solid presents a three-dimensional reticulated structure (Figure 1.3), and such porous materials can be termed *three-dimensional reticulated foamed*

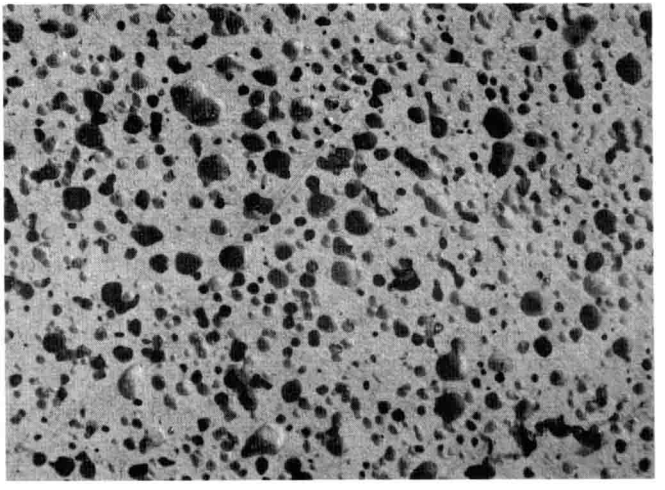
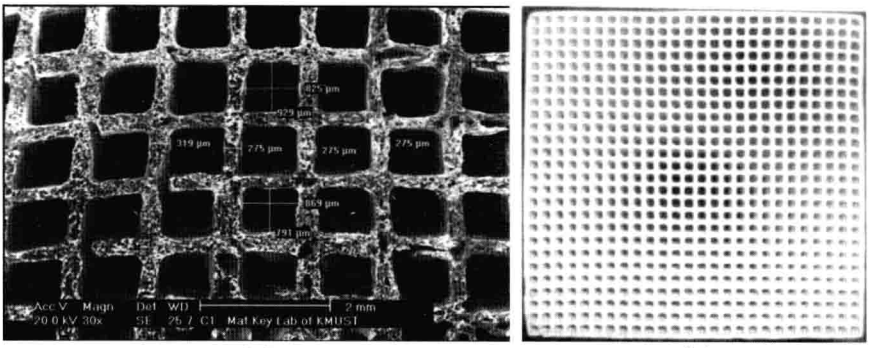
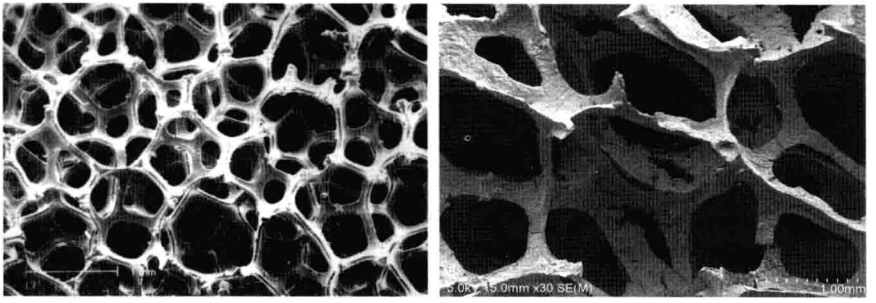


Figure 1.1 Porous composite oxide ceramics, which is a low-porosity material, shown as a cross-sectional image.



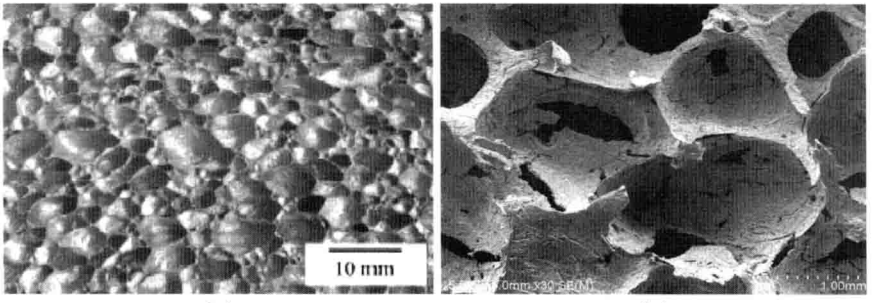
(a) (b)

Figure 1.2 Two-dimensional honeycomb materials: (a) conductive honeycomb TiC ceramics with quasi-square pores [6]; (b) thermal storage of honeycomb ceramics with square pores (with dimensions of 100 mm × 100 mm × 100 mm, cell-wall thickness of 1 mm, and square-pore side length of 2.5 mm) [7].



(a) (b)

Figure 1.3 Three-dimensional reticulated foamed materials: (a) nickel foam; (b) iron foam.



(a) (b)

Figure 1.4 Bubblelike foamed materials: (a) a closed-cell bubblelike foamed material of aluminum foam [8]; (b) an open-cell bubblelike foamed material of iron foam.