

Series Editors' Preface

The Indian Institute of Metals Series is an institutional partnership series focusing on metallurgy and materials sciences.

About the Indian Institute of Metals

The Indian Institute of Metals (IIM) is a premier professional body (since 1947) representing an eminent and dynamic group of metallurgists and materials scientists from R&D institutions, academia, and industry mostly from India. It is a registered professional institute with the primary objective of promoting and advancing the study and practice of the science and technology of metals, alloys, and novel materials. The institute is actively engaged in promoting academia–research and institute–industry interactions.

Genesis and History of the Series

The study of metallurgy and materials science is vital for developing advanced materials for diverse applications. In the last decade, the progress in this field has been rapid and extensive, giving us a new array of materials, with a wide range of applications, and a variety of possibilities for processing and characterizing the materials. In order to make this growing volume of knowledge available, an initiative to publish a series of books in metallurgy and materials science was taken during the Diamond Jubilee year of the Indian Institute of Metals (IIM) in the year 2006. IIM entered into a partnership with Universities Press, Hyderabad, and as part of the IIM book series, 11 books were published, and a number of these have been copublished by CRC Press, USA. The books were authored by eminent professionals in academia, industry, and R&D with outstanding background in their respective domains, thus generating unique resources of validated expertise

of interest in metallurgy. The international character of the authors' and editors has enabled the books to command national and global readership. This book series includes different categories of publications: textbooks to satisfy the requirements of undergraduates and beginners in the field, monographs on select topics by experts in the field, and proceedings of select international conferences organized by IIM after mandatory peer review. An eminent panel of international and national experts constitutes the advisory body in overseeing the selection of topics, important areas to be covered, in the books and the selection of contributing authors.

Current Series Information

To increase the readership and to ensure wide dissemination among global readers, this new chapter of the series has been initiated with Springer. The goal is to continue publishing high value content on metallurgy and materials science, focusing on current trends and applications. Readers interested in writing for the series may contact the undersigned series editor or the Springer publishing editor, Swati Meherishi.

About This Book

This book has two volumes, one on "Biomaterials for Musculoskeletal regeneration: Concepts" by Prof. Bikramjit Basu and another on "Biomaterials for Musculoskeletal Regeneration: Applications" by Prof. B. Basu and Prof. S. Ghosh. The volume on "Biomaterials for Musculoskeletal regeneration: Concepts" has comprehensive coverage on biological and material concepts in bone tissue engineering. It comprises of 12 chapters covering basics of biological sciences relevant to biocompatibility; an overview of biomaterials and concepts of bone tissue engineering; desired mechanical properties of biomaterials and osteogenic tissues; aspects of ceramic processing; scope of additive manufacturing; concepts of fracture toughness; toughening mechanisms and friction and wear behavior; fundamental aspects of experimental techniques to evaluate degradation, toxicity, and *in vivo* biocompatibility of biomaterials; properties of 3D porous scaffolds and simulator studies; new design concepts for developing multifunctional biomaterial; and newer approaches for enhancement of biocompatibility properties. The next volume on "Biomaterials for Musculoskeletal Regeneration: Applications" jointly authored by Prof. B. Basu and Prof. S. Ghosh provides important features demonstrating opportunity of biomaterial development using various conventional and advanced fabrication techniques, prototype development, and clinical trials. This book

comprises of 12 chapters with 10 chapters exclusively presenting case studies of illustrative examples of biomaterials development. Toughness enhancement of hydroxyapatite based-bioceramic implants without compromising on cytocompatibility; new design concepts and newer approaches for development of multifunctional biomaterials and with multiscale porosity; osseointegration and implant stability of strontium containing glass ceramics; injection molding route; and 3D print cartilage-based prototype development are all described in detail. As a whole, this textbook with both volumes is providing a new horizon for the readers to develop the basic and advanced understanding of the bone tissue engineering and applications, without any inhibitions of a non-biology background. The author and the editors are of conviction that this book will motivate students and researchers to develop new bioengineering strategies that trigger novel biomaterial development. We wish all readers' enrichment in knowledge and motivation. Also, we await the feedback for improving the book when it goes to second edition.

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Preface

In the last couple of decades, biomaterials science has been perceived as one of the societally relevant area of research and the significant innovation in this field has immense impact on human health care at large. Such impacts are possible only through strong connections with clinicians and can therefore be realized in discovering alternative treatment modalities to address clinically relevant problems in diseases related to orthopedics, neural, cardiovascular, etc. It is therefore quite likely that ongoing research on biomaterials and biomedical applications will soon revolutionize personalized health care. The field of *biomaterials* is therefore being perceived as one of the fastest growing areas in research funding, volume, quality, and societal impact.

The success of this specific research area of societal importance clearly requires the intelligent blending of the fundamental concepts of engineering sciences (materials science, electrical engineering, etc.) and basic sciences (mainly chemistry and physics) with that of biological sciences (cell and molecular biology) and biomedical engineering. Apart from quantitative experimental methods, the research in this field also involves theory/simulation approaches together with preclinical studies to yield a critical insight into how cells/tissues interact with a synthetic material surface. To this end, the phenomenological interaction of a biological cell on a material substrate is therefore of central importance and an improved understanding has constantly evolved in last few decades. A better understanding will enable researchers to tailor the cellular microenvironment to guide the cell functionality in a desired manner, leading to new bioengineering strategies to trigger novel biomaterials development.

Being closely linked to the field of materials science, the interdisciplinary field of biomaterials has attracted a large number of materials engineers (more than the biologists) over the last few decades and this research areas has been one of the focus area in many universities around the world. In fact, many Materials Science and Engineering Department in those universities offers the compulsory course on this subject at undergraduate and graduate level. Different textbooks treat this subject in different manner. Being a metallurgist by formal undergraduate and postgraduate training and a ceramicist by virtue of doctoral training, I have

conceptualized this book in a different manner than the existing textbooks on this subject. The book content in terms of various chapters will primarily facilitate easier understanding for students and researchers, who are from non-biology background. In particular, this textbook has the following important features: (a) pertinent discussion on the fundamental of biological science, which is often difficult to understand to an appropriate extent from various available textbooks in general biological sciences, (b) comprehensive coverage of the various conventional and advanced fabrication of materials as well as mechanical properties, and (c) a number of chapters discussing performance limiting properties (corrosion, wear, biomechanical testing) of biomaterials. In view of such important features, this book will be extremely useful for those readers, who do not have a formal knowledge in the area of biomaterials science. While conceiving this textbook, this author wanted to motivate the young researchers primarily from engineering background and to reduce their apprehension to pursue research in biomaterials field because of their limited knowledge of biology. It is believed that this book will enable the readers to overcome the perception that one has to know a lot of biology to penetrate into this important field of relevance to mankind.

This textbook on “Biomaterials for Musculoskeletal Regeneration: Concepts” will consist of one full chapter covering primarily the basics of biological sciences. Considering the significant breadth of the field of biological sciences, the introductory section of this book will describe only the most necessary concepts and techniques of the cell and molecular biology with a particular focus on the application of such knowledge in evaluating the biocompatibility property in a broad sense.

This book contains altogether 12 chapters with the very first chapter introducing the importance of bone tissue engineering. Special emphasis has been placed to motivate the use of biomaterials as a special class of materials for bone implants. This introductory chapter also sets an overview of materials for bone tissue engineering. In Chap. 2, the fundamental definitions and concepts of the biological sciences in the context of bone tissue engineering are discussed. For bone tissue engineering applications, the implantable biomaterials need to have a set of desired bone-mimicking properties. This has been the motivation to discuss the structure and properties of osteogenic tissues in Chap. 3. The fundamental aspects for manufacturing implantable biomaterials with a special emphasis on ceramics processing is carried out in Chap. 4. The consolidation of polymers using molding route is also briefly mentioned. In Chap. 5, fabrication of scaffolds using low-temperature additive manufacturing, with design, structural aspects, and post-processing, is discussed. While the mechanical reliability of metallic implants is well-established, such reliability for ceramic implants is a matter of major concern for many clinicians. To this end, the mechanical properties of synthetic biomaterials, such as deformation, cracking, and fracture of ceramics and polymers, are largely discussed in Chap. 6. An important aspect of this section is the science-based discussion on the origin of brittle fracture and strength variability of ceramics. The concept of fracture toughness, measurement of various mechanical

properties, as well as brief discussion on toughening mechanisms is also presented in Chap. 6.

Concerning the applications in load-bearing articulating joints, the concept of friction and wear behavior along with guidelines for analysis is introduced in Chap. 7. Many researchers without any formal background in corrosion science utilize a number of electrochemical techniques to understand the degradation of implantable materials. This has been the motivation to discuss the fundamentals of friction and wear as well as the experimental evaluation of such properties in Chap. 8. The biocompatibility property is the core concept in the development of biomaterials. After discussing the fundamental basis of this important concept, the experimental techniques to evaluate the cell- or tissue-level compatibility of implantable biomaterials together with the toxicity assessment are mentioned in Chap. 9. A significant part of this chapter discusses the genotoxicity assessment of biomaterials. Also, the *in vivo* biocompatibility assessment is briefly discussed. In Chap. 10, mechanical and biocompatibility properties of 3D porous scaffolds, fabricated using additive manufacturing techniques, are addressed. While test samples of implantable biomaterials may exhibit satisfactory biocompatibility response, *in vitro* and *in vivo*, the clinical acceptability of such materials particularly for musculoskeletal applications would finally demand their satisfactory performance under standard biomechanical testing conditions. In view of this, a brief discussion on biomechanical aspects of articulating hip/knee joints followed by various simulator studies to probe into dynamic fatigue properties of orthopedic biomaterials has been made in Chap. 11. In the concluding chapter of this book, some of the new design concepts for developing implants as well as the perspective on the development of multifunctional biomaterial with multiscale porosity are emphasized. This chapter closes with the brief discussion on some of the newer approaches for the enhancement of biocompatibility properties.

This book is an outcome of the several years of teaching undergraduate and postgraduate level courses in the area of biomaterials, being offered to students of Indian Institute of Technology Kanpur, India, and Indian Institute of Science, Bangalore. Several chapters of this will also reflect on the extensive research from the author's research group, both at IIT Kanpur and IISc, Bangalore, in last one decade, which is being supported by Council of Scientific and Industrial Research (CSIR), Department of Biotechnology (DBT), Department of Science and Technology (DST), Indo-US Science and Technology Forum (IUSSTF), and UK-India Education Research Initiative (UKIERI).

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Concepts

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