EXPERIMENTAL TECHNIQUES in MATERIALS and MECHANICS

C. Suryanarayana

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Preface

Materials are pervasive and everyone has to deal with some type of material or other. A majority of the undergraduate students of engineering (aerospace, chemical, electrical, materials, mechanical, etc.) go through a first course on materials, usually titled *Structure and Properties of Materials*, to enable them to appreciate the basic principles and applications of different types of materials—metals, ceramics, polymers, and composites. The market is currently flooded with a large number of textbooks dealing with different aspects of materials and at different levels. However, the emphasis in most of these textbooks has been to "load" the student with theoretical information. Very rarely, if at all, a laboratory component is included as part of this course, wherein it will be possible to experimentally determine the properties and relate them to the structure and processing behavior of materials. Also, the course content for this elementary course is so heavy that it is almost impossible to cover the full text, let alone having a laboratory component.

The materials engineer is often called upon to design, select, and recommend usage of materials for diverse applications. One may also be asked to investigate the reasons for failure of materials. For all these purposes, a thorough knowledge of the basic principles of materials science and engineering is essential. Even though materials engineers and, for that matter some mechanical engineers and aerospace engineers, go through additional courses on materials; a practical knowledge of the correlations between crystal structure, microstructure, and properties is deemed very much necessary.

This book has evolved from teaching a lecture-cum-laboratory course, *Experimental Techniques in Mechanics and Materials*, to undergraduate mechanical and materials engineering students at the University of Central Florida. The topics chosen for inclusion in the book are based on the possibility of completing them in a one-semester course. Emphasis is placed on practical aspects of crystal structure determination, microstructural observation, heat treatment, and mechanical testing. As an experienced instructor would realize, the microstructure, heat treatment, and mechanical properties are completely interrelated. Therefore, samples used in one experiment would be useful in another experiment. For example, specimens prepared for microscopic observation could be used for hardness testing. Similarly, samples used for tensile or impact testing could be used for scanning electron microscopic examination to determine the type of failure.

Although a large number of textbooks are available on structure and properties of materials and these explain the basic phenomena in some detail, they do not explain the practical aspects in sufficient detail to enable the student to go into the laboratory and perform the experiment. Thus, for example, even though one may know the theoretical background, one may have little understanding of how to prepare a specimen in the laboratory for optical microscopic examination and how to derive useful information from the microstructures. The primary aim of this book is to enable students to understand the practical aspects of the different techniques

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discussed here and derive the maximum possible information from the results obtained. The book has placed emphasis on techniques that are commonly available in most laboratories and those that are accessible to undergraduate students.

The book contains 12 chapters that deal with crystal structure determination, optical and scanning electron microscopy, phase diagrams and heat treatment, and different types of mechanical testing methods. The format of the chapters is fairly uniform, but not identical. Some variation has been brought in depending on the contents of the chapter. The importance of the technique is first introduced. This is followed by reasonably detailed background information to provide the student with the necessary theory to fully understand the experiment. In this sense, the book is self-contained and the student need not go to another book for the required theoretical background. A number of examples have been worked out in every chapter to further clarify the concepts explained. This is followed by a detailed description of the experiment to be conducted and how the data could be tabulated and interpreted. A special feature of the book is that a large number of illustrations, figures, and micrographs, wherever possible, have been included in each chapter. At the end of the chapter, a number of exercises have been provided; by answering, the student will realize the extent to which the subject matter was clear. If any student is interested in knowing much more about the topics covered in any chapter, references for further reading are also given.

This book is primarily intended for undergraduate students majoring in materials science and engineering or mechanical engineering. All the topics covered in the book can be covered in a one-semester course. It is realized that not *all* the techniques used by materials scientists and engineers are included in the book. For example, techniques such as differential thermal analysis or differential scanning calorimetry, temperature measurement, vacuum systems, and so on are not included. Even though these are all useful techniques, a choice had to be made, depending on the time available in one semester.

The book should also be useful for practicing engineers or technicians involved in microscopy, crystal structure determination, and mechanical testing. Preliminary knowledge of materials science and engineering will be useful but not essential because the concepts have been explained in easy-to-understand terms in the background information.

Sufficient care has been taken to ensure that the information presented is correct, clear, and easy to understand for the students; accuracy has not been sacrificed. But if the discerning reader notices any mistakes, I would be most grateful if these are communicated to me at Challapalli.Suryanarayana@ucf.edu

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Acknowledgments

During the preparation of this book I had the good fortune of receiving help from many people and I take pleasure in acknowledging their assistance. First of all I would like to acknowledge the large number of students who used the draft copy of the book and acted as involuntary reviewers during the lecturing and laboratory sessions over the years.

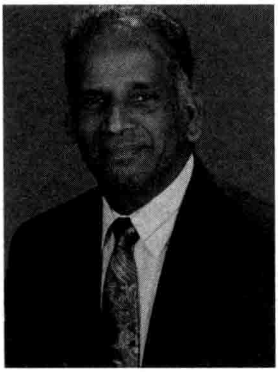
A number of friends and students have read parts of the book and provided helpful comments to improve the clarity and/or readability. I am very grateful to them for sparing their time to read the chapters and to comment on the contents of the book. I would like to particularly mention Professor Thomas Klassen of Helmut-Schmidt University, Hamburg, Germany, Dr. C. L. Mendis of National Institute for Materials Science, Tsukuba, Japan, and Dr. Raj Vaidyanathan of the University of Central Florida, Orlando, for several constructive comments on the early versions of the chapters. Some chapters of the book were also informally read by others and I am grateful to all of them for their comments. Particular mention should be made of Professor J. J. Moore of Colorado School of Mines, Golden and Professor K. L. Murty of North Carolina State University, Raleigh for their encouragement.

Parts of this book were written when I was a visiting professor at the King Fahd University of Petroleum and Minerals in Dhahran, Saudi Arabia and also at Vel Tech Dr. RR & Dr. SR Technical University, Chennai, India. I am very grateful to both these institutions for providing the necessary facilities for successfully completing some chapters. I am also grateful to the Chair of the Department of Mechanical, Materials and Aerospace Engineering at the University of Central Florida in Orlando for providing the right environment for completing the book.

I am grateful to several organizations that have provided me with original figures used in this book. A number of figures used in this book were drawn meticulously by Dr. U. M. R. Seelam. I sincerely thank him for his help and his patience in revising the figures until they reached the final stage for inclusion in the book. The aesthetics of the figures is all because of him. But if there are errors in any of them, the responsibility is mine. I thank the staff of CRC Press for their patience and for the high level of cooperation and interest in the production of this book.

Finally, I owe a huge debt of gratitude to my wife Meena for her patience with me during the course of preparation of the book.

Author



C. Suryanarayana is professor of materials science and engineering in the Department of Mechanical, Materials and Aerospace Engineering of the University of Central Florida in Orlando, Florida. He has conducted research investigations in the areas of rapid solidification processing, mechanical alloying, innovative synthesis/processing techniques, metallic glasses, superconductivity, quasicrystals, and nanostructured materials for over 40 years. He has published more than 330 technical papers in archival journals and authored/edited 19 books and conference proceedings. He has extensive teaching experience and has taught at several universities in India, United States, and other countries. Earlier he was a professor of metallurgy at Banaras Hindu University in Varanasi, India. He held visiting assignments at the University of Oxford, United Kingdom; the Atomic Energy Center in Mol, Belgium; the Wright-Patterson Air Force Base in Dayton, Ohio; the University of Idaho in Moscow, Idaho; the Colorado School of Mines in Golden, Colorado; the GKSS Research Center in Geesthacht, Germany; the Helmut Schmidt University in Hamburg, Germany; the Tohoku University in Sendai, Japan; the National Institute for Materials Science in Tsukuba, Japan; the Chungnam National University in Taejon, Korea; and the Shenyang National Laboratory for Materials Science in Shenyang, China.

Professor Suryanarayana is on the editorial boards of several prestigious materials science journals. He has received several awards for his research contributions to nonequilibrium processing of materials including the Young Scientist Medal of the Indian National Science Academy, Pandya Silver Medal of the Indian Institute of Metals, National Metallurgists Day Award of the Government of India, Distinguished Alumnus Award of Banaras Hindu University, and Lee Hsun Research Award from the Chinese Academy of Sciences. Thomson Reuters has just announced that Professor Suryanarayana is one of the top 40 materials scientists who achieved the highest citation impact scores for their papers published since 2000. He is a fellow of ASM International and also of the Institute of Materials, Minerals and Mining, London, United Kingdom. He received the BE degree in metallurgy from the Indian Institute of Science, Bangalore, and MS and PhD degrees in physical metallurgy from Banaras Hindu University, Varanasi, India.

Contents

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1 Introduction

1.1 MATERIALS SCIENCE AND ENGINEERING

Materials science and engineering is a continuously evolving and developing field. Materials are pervasive and all scientists (whether physicists, chemists, or geologists) and engineers (whether civil, mechanical, electrical, chemical, or materials) deal with some type of material or other. Every aspect of our day-to-day life revolves around materials. In fact, the different periods of human civilization have been named after materials—stone, copper, bronze, iron, and so on. The present age can be most aptly named the silicon age.

The discipline of materials science and engineering, which has come into existence since the 1960s, involves establishing interrelationships among the structure, processing, and properties of materials. Even prior to this, engineers were doing similar things independently for metals, ceramics, or polymers. The structure and properties of materials will eventually determine the performance of the material. Thus, the four components—structure, properties, processing, and performance—are typically represented as the four corners of a tetrahedron, emphasizing the interrelationship among these. Figure 1.1 represents the tetrahedron of materials science and engineering with the four corners representing the structure, properties, processing, and performance. It is important to realize that the structure of the material determines the properties. The properties can also be altered by changing the composition and/or processing. In other words, the structure, composition, and processing will determine the final properties of materials. Similarly, the other components are also dependent on each other.

The types of materials of common interest include metals, ceramics, polymers, and composites. As it will become clear in the following chapters, the crystal structure and microstructure, to a great extent, determine the mechanical properties of materials. For example, materials with a face-centered cubic (FCC) structure are more ductile than those with a body-centered cubic (BCC) structure. Further, fine-grained materials are stronger than coarse-grained materials of the same composition. Therefore, determination of the crystal structure and microstructure assumes great importance in selection of materials for applications. The microstructure of materials is determined by the processing stages through which the material passes. It also becomes necessary to determine the properties of materials to enable these materials to be used for appropriate applications. Alternately, if one has to choose and/or design a material for a given application, then the engineer needs knowledge of the crystal structure, microstructure, and properties of the material. The performance of the material will depend on the type of mechanical loads it is subjected to, the type of environment it is exposed to, and the different combinations of

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