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Book Review

Fundamentals of Materials Science: The Microstructure-Property Relationship Using Metals as Model Systems, 2nd Edition, by Eric J. Mittemeijer, Springer Nature Switzerland AG 2021

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At its core, materials science is the study of the structure and properties of the materials we use. Understanding the relationship between the structure and properties is central to the discipline of materials science. In one way or another, it is weaved into almost every academic course in materials science, and I introduce the concept in the very first lecture of my Introduction to Materials Science course. Outside the classroom, these relationships are used to synthesize the materials we use every day, to understand why they sometimes unexpectedly fail in operation, and most all we use those relationships to develop brand-new materials that bring advanced technologies to life.

Structure–property relationships are ubiquitous across all material classes. In polymers, changing the structure of the side groups can result in dramatic changes in properties (e.g., polyethylene to polyvinylchloride). In ceramics, small changes in structure can have a significant impact on properties. For example, subtle changes in the symmetry of the perovskite structure underpin the piezoelectric effect. Similar examples could be made for semiconductors, composites, biological materials, and other classes of materials. However, of all material classes, structure–property relationships are most apparent in metallic materials. I, myself, am a ceramic scientist, but my academic training in materials science started by

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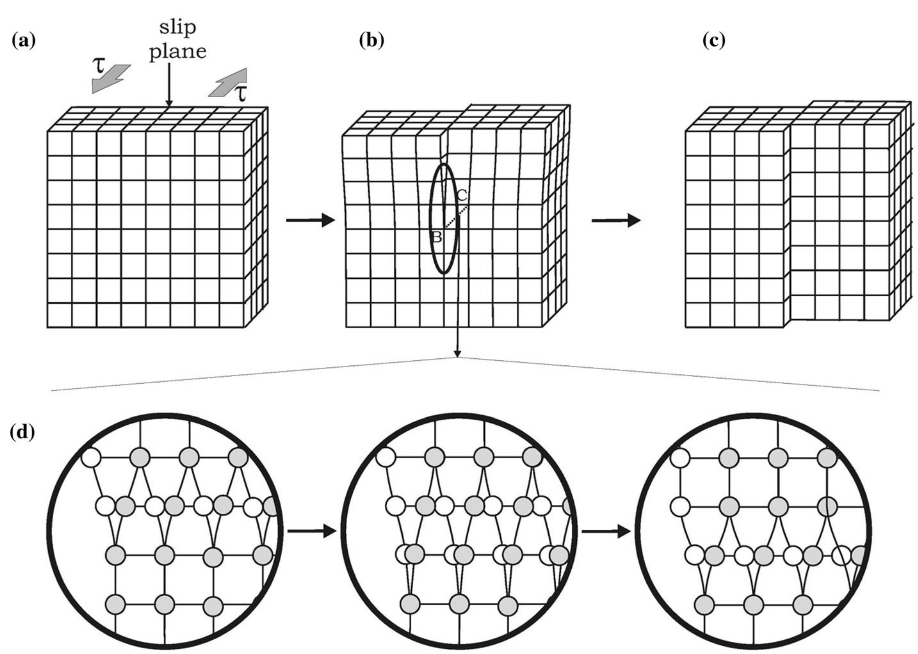
learning the fundamental structure–property relationships in metals. Thus, there is no better way to understand, on a deeply fundamental level, the intricate linkages between the properties of the materials we observe (hardness, elastic modulus, density, plasticity, and fracture) and the chemical and physical interactions that are present in the arrangements of atoms that ultimately determine these properties.

This is the primary motivation behind this book, *Fundamentals of Materials Science: The Microstructure-Property Relationship Using Metals as Model Systems*, by Eric J. Mittemeijer. From the preface, this book aims to serve as the launching point for the study of materials science and engineering. The target audience is quite broad, for both undergraduates and graduate students new to materials science. This is the second edition, having gone through significant revisions and updates from the first edition.

Overall, this is a quite comprehensive book with over 700 pages and excellent integration of figures, tables, and equations. There are references at the end of each chapter for further reading and a detailed index at the end of the book. The text also includes *intermezzos* interspersed throughout the text. These contribute interesting historical context to the chapters or sometimes provide greater technical depth for the reader. For example, the chapter on Crystallography includes a short story on the controversy surrounding the discovery of quasicrystals. Stories like these help textbooks feel like living documents. As materials science is a relatively new discipline, the fundamental science is still being written and stories like this help students recognize that.

In evaluating the scope of this book, from my experience teaching introductory materials science courses for many years the text books I am most familiar with are Callister, *Materials Science and Engineering: An Introduction*, and Shackleford, *Introduction to Materials Science for Engineers*. Thus, these books serve as my frame of reference for evaluating this book. This book begins with an almost philosophical discussion of what is a material, the role of experiments and observations, and the idea that with observations, models can be used to make predictions. This is the philosophical essence of structure–property relationships and serves as an excellent motivation for the reader.

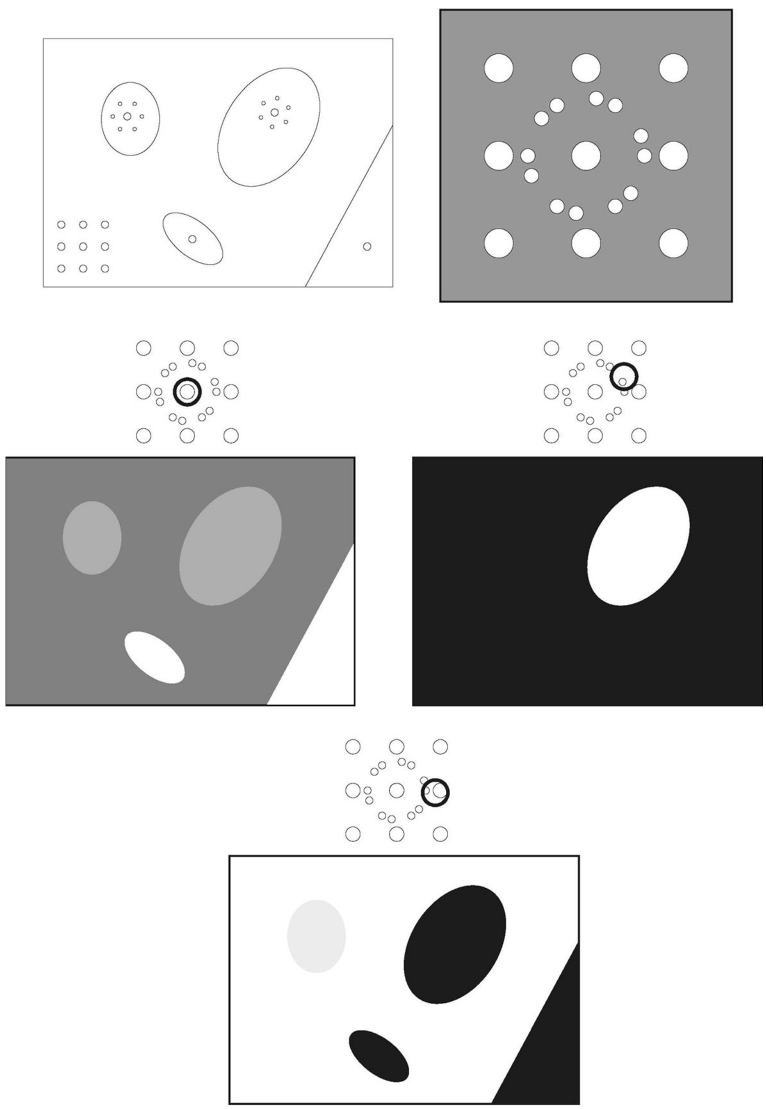
The main technical content of *Fundamentals of Materials Science* by Eric J. Mittemeijer starts in Chapter 2 and follows a common approach establishing the knowledge base of materials science starting from atoms and the periodic table. The proceeding chapters build on the concepts of atoms to introduce the concepts of bonding, crystallography, and point defects. There are excellent schematics and illustrations throughout these chapters to help reinforce the key concepts. For one example, this is a schematic that shows plastic deformation by motion of a screw dislocation. In particular, it clearly shows



the changing atomic positions as the dislocation moves. In general, this is a difficult concept for students to visualize and this figure is well designed to show the atomic-scale mechanisms that contribute to macroscopic plastic deformation.

It is important to note that these chapters deviate quite dramatically from the approach in Callister and Shackleford. In *Fundamentals of Materials Science*, the approach to these topics is aimed at a much greater technical depth that incorporates concepts in atomic and solid-state physics. Examples include discussions of probability functions, the particle-in-a-box model, Madelung potentials, elementary band theory, Brillouin zones, and other topics. While this is normally not included in texts aimed at general engineering students, this content is well suited to students in materials science because it highlights the fundamental scientific principles behind these materials science concepts.

In the next chapter, the book covers microstructure analysis, but it does so from the vantage point of the array of experimental techniques that are used to probe the structure of materials. This approach surveys many of characterization techniques, with an emphasis on the basic principles of optics, diffraction,



and scattering processes. Here is an excellent example showing an illustration of the difference between bright- and dark-field imaging modes in TEM.

The following chapters cover the topics of phase equilibria, diffusion, phase transformations, and grain growth with a wealth of examples, including phase diagrams, micrographs, and illustrative diagrams. As with the previous chapters, this book provides great help to materials science students gain a working knowledge of the fundamentals. Furthermore, the text nicely weaves together both theoretical discussions and practical examples that will help students see these concepts more concretely.

The final chapter of the book is focused on mechanical strength of materials. This chapter includes basic definitions of mechanical parameters, highlights strain mechanisms in single crystals and polycrystals, and provides examples of relevant measurement techniques used to probe the mechanical properties of materials. The focus here is mostly on metals, but also describes the mechanical behavior of ceramics and polymers. This chapter draws upon the concepts about microstructure and bonding in previous chapters to help solidify the relationships between structure and properties.

Overall, this book is an excellent comprehensive description of the fundamentals of materials science, exactly as the title implies. While metallic materials are the focus of the book, they provide great insights into the relationships between structure and properties that are fundamental to all materials scientists. Furthermore, the book finds an excellent balance between theory and practical application. In particular, the survey of the different characterization techniques for analyzing microstructures will be no doubt universally valuable to any student or researcher. This book is well suited as a detailed introduction to the fundamentals of materials science, either at the undergraduate or at the graduate level. While the focus is largely on metals, the basic principles are relevant and valuable to materials scientists working on all classes of materials. Overall, *Fundamentals of Materials Science: The Microstructure-Property Relationship Using Metals as Model Systems* (Second Edition) by Eric J. Mittemeijer is an invaluable contribution to materials science.