THIRD EDITION

Materials

ENGINEERING, SCIENCE, PROCESSING AND DESIGN

Michael Ashby, Hugh Shercliff and David Cebon

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Materials: engineering, science, processing and design

Third edition

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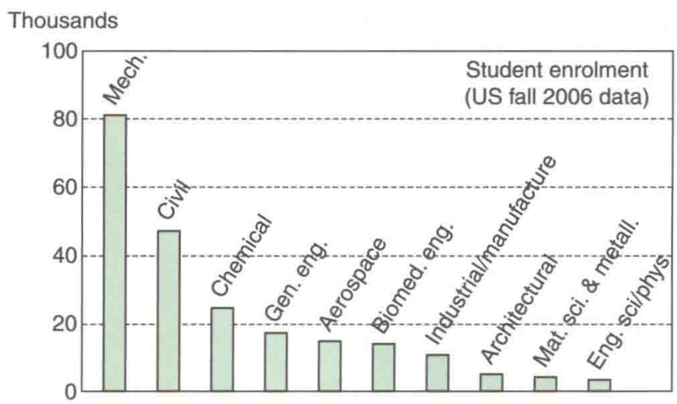
Preface to 3rd edition

Science-led or design-led? Two approaches to materials teaching

Most things can be approached in more than one way. In teaching this is especially true. The way to teach a foreign language, for example, depends on the way the student wishes to use it—to read the literature, say, or to find hotel accommodations, order meals and buy beer. So it is with the teaching of this subject, Materials.

The figure shows the enrolment in engineering and materials-related departments in US Universities in 2006. Mechanical, Civil and Chemical Engineering account for two-thirds of the total. Aerospace, Manufacturing and General Engineering account for a further 20%. The more science-related subjects—Materials Science, Engineering Science and Physics—total 3%. All of these courses carry requirements for Materials teaching, but the way the students in some courses will use it differs from those in others.



Enrolment in engineering-related courses in US universities.

The traditional approach to Materials teaching starts with fundamentals: the electron, the atom, atomic bonding, and packing, crystallography and crystal defects. Onto this is built alloy theory, the kinetics of phase transformations and the development of microstructure on scales made visible by electron and optical microscopes. This sets the stage for the understanding and control of properties at the millimeter or centimeter scale at which they are usually measured. This science-led approach emphasises the physical basis but gives little emphasis to the behaviour of structures and components in service or methods for material selection and design.

The alternative approach is design-led. The starting point is the requirements that materials must meet if they are to perform properly in a given design. To match material to design requires a perspective on the range of properties they offer, how these properties combine to limit performance, the influence of manufacturing processes on properties, and ways of accessing the data needed to evaluate all of these. Once the importance of certain properties is established there is good reason and a clear context from which to 'drill down', so to speak, to examine the science that lies behind them—valuable because an understanding of the fundamentals itself informs material choice, processing and usage.

Each approach has its place. The choice depends on the way the student will wish to use the information. If the intent is pure scientific research, the first is the logical way to go. If it is engineering design and applied industrial research, the second makes better sense. This book follows the second.

What is different about this book?

There are many books about the science of engineering materials; many more about design. What is different about this one?

First is its *design-led approach*, specifically developed to guide material selection and understanding for a wide spectrum of engineering courses. The approach is systematic, leading from design requirements to a prescription for optimised material choice. The approach is illustrated by numerous case studies. Practice in using it is provided by worked Examples in the text and Exercises at the end of each Chapter.

Second is its emphasis on *visual communication* through a unique graphical presentation of material properties as *material property charts* and numerous *schematics*. These are a central feature of this approach, helpful in utilising visual memory as a learning tool, understanding the origins of properties, their manipulation and their fundamental limits, and providing a tool for selection and for understanding the ways in which materials are used.

Third is its *breadth*. We aim here to present the properties of materials, their origins and the way they enter engineering design. A glance at the contents pages will show sections dealing with:

- Physical properties
- Mechanical characteristics
- Thermal behaviour
- Electrical, magnetic and optical response
- Durability
- Processing, and the way it influences properties
- Environmental issues, and the broader issues of Sustainable Technology

Throughout we aim for a simple, straightforward presentation, developing the materials science as far as it is helpful in guiding engineering design, avoiding detail where this does not contribute to this end.

The fourth feature is that of guided self-leaning. Certain topics lend themselves to self-instruction with embedded exercises to build systematic understanding. This works particularly well for topics that involve a contained set of concepts and tools. Thus Crystallography, as an example, involves ideas of symmetry and three-dimensional geometry that are most easily grasped by drawing and problem-solving. And understanding Phase Diagrams and Phase Transformations relies on interpreting graphical displays of compositional and thermodynamic information. Their use to understand and predict microstructure follows procedures that are best learned by application. Both topics can be packaged into self-contained guided learning units, with each new concept being presented and immediately practiced with exercises, thereby building confidence. Students who have worked through a package can feel that they have mastered the topic and know how to apply the ideas it contains. We have chosen to present Crystallography and Phase Diagrams and Phase Transformations in this way here. Both topics appear briefly in the main text to give a preliminary overview. The full Guided Learning Units follow later in the book, providing for those courses that require a deeper understanding.

What's new in the 3rd edition

The main features that are new to the 3rd edition of this book are:

- The number of worked examples in the text has been increased by 50%, to provide broader illustration of key concepts and equations.
- The number of standard end-of-chapter exercises has been doubled to 400 (complemented with 150 exercises using the CES EduPack software, see below), with a full solution manual available to instructors.
- The text and the figures have been revised and updated throughout, with particular additions in the following topic areas:
  - *Elastic properties*: expanded coverage of elastic stress analysis and polymer moduli, and a new section on acoustic properties (Chapter 4).
  - *Fracture behaviour*: the compressive and tensile failure of ceramics is covered, including Weibull analysis (Chapter 8).
  - *Material behaviour in processing*: discussion of several topics has been extended to the context of manufacturing processes and control of properties, e.g. hot strength in metal forming, friction processing, transient heat flow and diffusion in bulk and surface treatments (Chapters 7, 11, 12, 13, 19).
  - *Material design at temperature*: diffusion and creep are covered in more depth, introducing constitutive modelling for metals and polymers (Chapter 13).
  - *Functional properties*: Chapter 14 (electrical properties) includes a discussion of superconductors, electron mobility and semiconductors; Chapter 15 (magnetic materials) includes flexible magnets and magnets for use above room temperature; Chapter 16 (optical devices) has a new discussion of colour and optical interference.
  - *Electrochemistry*: Chapter 17 (on durability) now includes the Nernst equation and the Faraday equation.
  - *Materials and the environment*: the coverage has been updated, with a new section on Sustainability and Sustainable Technology (Chapter 20).

This book and the CES EduPack Materials and Process Information software

Engineering design today takes place in a computer-based environment. Stress analysis (finite element method, or FEM, codes for instance), computer-aided design (CAD), design for manufacture (DFM) and product data management (PDM) tools are part of an engineering education. The CES

Materials and Process Information software[1] for education (the CES EduPack) provides a computer-based environment for optimised materials selection.

This book is self-contained and does not depend on computer support for its use. But at the same time it is designed to interface closely with the CES software, which implements the methods developed in it. This enables realistic design problems and selection studies to be addressed, properly managing the multiple constraints on material and process attributes. The methodology also provides the user with novel ways to explore how properties are manipulated. And with sustainability becoming a core topic in most materials-related teaching, the book and the software introduce students to the ideas of life-cycle assessment. Using the book with CES EduPack enhances the learning experience and provides a solid grounding in many of the domains of expertise specified by the various professional engineering accreditation bodies (analysis of components, problem-solving, design and manufacture, economic, societal and environmental impact, and so on). In addition, the CES Elements database documents the fundamental physical, crystallographic, mechanical, thermal, electrical, magnetic and optical properties of all 111 stable elements of the periodic table. This allows the scientific origins and interrelationships between many properties, developed in the text, to be explored in greater depth.

The design-led approach is developed to a higher level in three further textbooks, the first relating to Mechanical design[2], the second to Design for the environment[3] and the third to Industrial design[4].

[1] The CES EduPack, Granta Design Ltd., Rustat House, 62 Clifton Court, Cambridge CB1 7EG, UK. www.grantadesign.com.

[2] Ashby, M. F. (2011), *Materials selection in mechanical design*, 4th edition, Butterworth Heinemann, Oxford, UK. ISBN 978-1-85617-663-7. (An advanced text developing material selection methods in detail.)

[3] Ashby, M. F. (2012), *Materials and the environment: Eco-informed material choice*, 2nd edition, Butterworth Heinemann, Oxford, UK. ISBN 978-0-12-385971-6. (A teaching text introducing students to the concepts and underlying facts about concerns for the environment and the ways in which materials and products based on them can both help and harm it.)

[4] Ashby, M. F., and Johnson, K. (2014), *Materials and design: The art and science of material selection in product design*, 3rd edition, Butterworth Heinemann, Oxford, UK. ISBN 978-0-08-098205-2. (A text that complements those above, dealing with the aesthetics, perceptions and associations of materials and their importance in product design.)

Resources that accompany this book

Exercises Each chapter ends with exercises of three types: the first rely only on information, diagrams and data contained in the book itself; the second makes use of the CES software in ways that use the methods developed here and the third explores the science more deeply using the CES Elements database that is part of the CES system.

The CES EduPack CES EduPack is the software-based package to accompany this book, developed by Michael Ashby and Granta Design. Used together, *Materials: Engineering, Science, Processing and Design* and CES EduPack provide a complete materials, manufacturing and design course. For further information please visit www.grantadesign.com.

Resources available to adopting instructors who register on the Elsevier textbook website, http://textbooks.elsevier.com:

Instructor's manual The book itself contains a comprehensive set of exercises. Worked-out solutions to the exercises are freely available online to teachers and lecturers who adopt this book.

Image Bank The Image Bank provides adopting tutors and lecturers with various electronic versions of the figures from the book that may be used in lecture slides and class presentations.

PowerPoint Lecture Slides Use the available set of lecture slides in your own course as provided, or edit and reorganise them to meet your individual course needs.

Interactive Online Materials Science Tutorials To enhance students' learning of materials science, instructors adopting this book may provide their classes with a free link to a set of online interactive tutorials. There are 12 available modules, including Bonding, Tensile Testing, Casting and Recrystallization, Fracture and Fatigue, Corrosion, Phase Equilibria, Wear, Ceramics, Composites, Polymers, Light Alloys and Dislocations. Each module includes a selection of self-test questions. The link is available to instructors who register on the Elsevier textbook website.

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