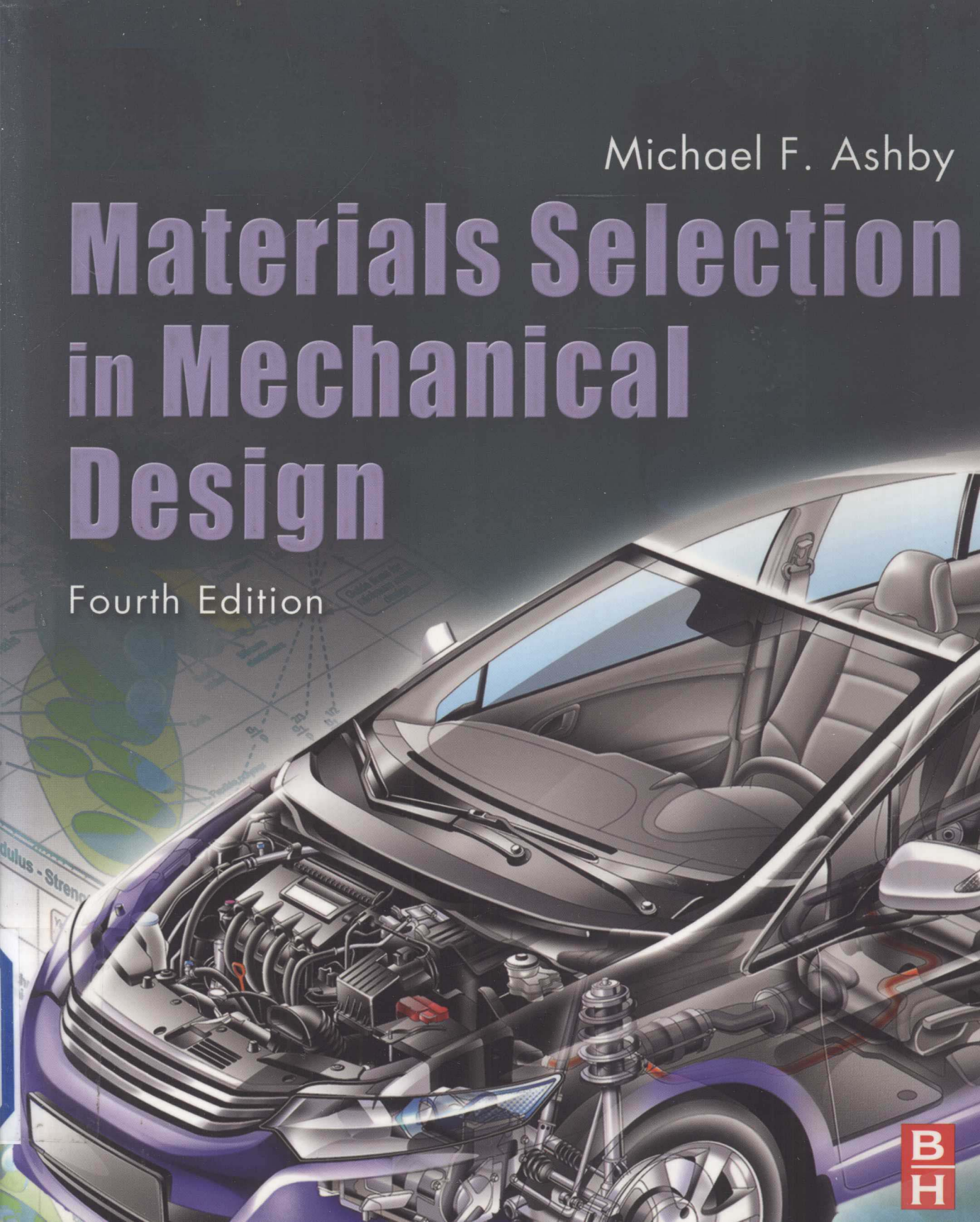
Michael F. Ashby

Materials Selection in Mechanical Design

Fourth Edition



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Preface

Materials, of themselves, affect us little; it is the way we use them which influences our lives.

Epictetus, AD 50–100, *Discourses*, Book 2, Chapter 5

Materials influenced lives in Epictetus' time and continue to do so today. In his day, the number of materials was small; today it is vast. The opportunities for innovation that materials offer now are equally immense. But advance is possible only if a procedure exists for making a rational choice from the materials on this great menu, and—if they are to be used—a way of identifying ways to shape, join, and finish them. This book develops a systematic procedure for selecting materials and processes, leading to the subset that best matches the requirements of a design. It is unique in the way that the information it contains has been structured. The structure gives rapid access to data and allows the user great freedom in exploring potential choices. The method is implemented in software* to provide greater flexibility.

The approach here emphasizes design with materials rather than materials "science," although the underlying science is used whenever possible to help with the structuring of selection criteria. The first six chapters require little prior knowledge: A first-year grasp of materials and mechanics is enough. The chapters dealing with shape and multiobjective selection are a little more advanced but can be omitted on a first reading. As far as possible, the book integrates materials selection with other aspects of design; the relationships with the stages of design and optimization and with the mechanics of material, are developed throughout. At the teaching level, the book is intended as a text for third- and fourth-year engineering courses on Materials for Design: A 6- to 10-lecture unit can be based on Chapters 1 through 6, 13, and 14; a full 20-lecture course, with project work using the associated software, will require use of the entire book.

* The *CES Edu* materials and process selection platform is a product of Granta Design (*www.grantadesign.com*).

Beyond this, the book is intended as a reference of lasting value. The method, the charts, and the tables of performance indices have application in real problems of materials and process selection; and the table of data and the catalog of "useful solutions" (Appendices A and B) are particularly helpful in modeling—an essential ingredient in optimal design. The reader can use the content (and the software) at increasing levels of sophistication as his or her experience grows, starting with the material indices developed in the book's case studies and graduating to the modeling of new design problems, leading to new material indices and penalty functions, as well as new—and perhaps novel—choices of material. This continuing education aspect is helped by the "Further readings" at the end of each chapter and Appendix E—a set of exercises covering all aspects of the text. Useful reference material is assembled in Appendices A, B, C, and D.

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Many colleagues have been generous with discussion, criticism, and constructive suggestions. I particularly wish to thank Professor Yves Bréchet of the University of Grenoble in France, Professor Anthony Evans of the University of California at Santa Barbara, Professor John Hutchinson of Harvard University, Professor David Cebon, Professor Norman Fleck, Professor Ken Wallace, Professor John Clarkson, Dr. Hugh Shercliff of the Engineering Department of Cambridge University, Professor Amal Esawi of the American University in Cairo, Professor Ulrike Wegst of Drexel University, Dr. Paul Weaver of the Department of Aeronautical Engineering at the University of Bristol, and Professor Michael Brown of the Cavendish Laboratory in Cambridge, UK.

Mike Ashby

Features of the Fourth Edition

Since publication of the third edition of this book, changes have occurred in the field of materials and their role in engineering, as well as in the way these subjects are taught in university- and college-level courses. There is increasing emphasis on *materials efficiency*—design that uses materials effectively and with as little damage to the environment as possible. All this takes place in a computer-based environment; teaching, too, draws increasingly on computer-based tools. This new edition has been comprehensively revised and reorganized to address these. The presentation has been enhanced and simplified; the figures, many of them new, have been redrawn in full color; worked in-text examples illustrate methods and results in chapters that are not themselves collections of case studies; and additional features and supplements have been added. The key changes are outlined next.

Key changes

- Chapter 1, Introduction, has been completely rewritten and illustrated to develop the history of materials and the evolution of materials in engineering.
- Engineering Design, introduced in Chapter 2, has been edited, with a full revision of all figures.
- Material Properties and Property Charts—a unique feature of the book, which appear in Chapters 3 and 4, have been redrawn in full color.
- Chapter 5 and 6—the central chapters that describe and illustrate selection methods—have been extensively revised with new explanations of the essential selection strategy.
- Chapters 7 and 8 (Multiple Constraints) have been revised, with in-text examples and more illuminating case studies.
- Chapters 9 and 10 (Materials and Shape) have been rewritten for greater clarity, with numerous in-text examples in Chapter 9.

- Chapters 11 and 12, Hybrid Materials, represent a further development of what was in the earlier edition, with a new development of the treatment of sandwich structures and with enhanced case studies.
- Chapters 13 and 14, Processing, contain sections and figures that emphasize the influence of processing on properties.
- Chapter 15, Materials and the Environment, is revised, with improved examples and links to the new information.[1]
- Chapter 16, Industrial Design, is updated and linked to the second edition of the related text[2] on this subject.
- Chapter 17, Forces for Change, has been updated.
- Appendices with Tables of Materials Properties, Useful Solutions, Indices, and Data Sources are updated, enlarged and reillustrated.
- The final appendix contains Exercises that are listed by chapter number.

Material selection charts

Full color versions of a number of the Material Selection Charts presented in this book are available. Samples can be found at *www.grantadesign.com/ashbycharts.htm*. This web page also provides a link to a page where users of CES EduPack (details follow) can download further charts and other teaching resources, including PowerPoint lectures. Although the author retains the copyright for the charts, users of this book are authorized to download, print, and make unlimited copies of those available on the site; in addition, they can be reproduced for teaching purposes (but not for publication), with proper reference to their source.

Instructor's manual and Image Bank

The book ends with a comprehensive set of exercises in Appendix E. Worked-out solutions to the exercises are available, free of charge, to teachers, lecturers, and professors who adopt the book.

The Image Bank provides tutors and lecturers who have adopted this book with PDF versions of the figures contained in it; they can be used for lecture slides and class presentations.

To access the instructor's manual and Image Bank, please visit *www.textbooks.elsevier.com* and follow the onscreen instructions.

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[1] *Materials and the Environment—Eco-informed materials choice* (2009) by M.F. Ashby, Butterworth-Heinemann, ISBN 978-1-85617-608-8.

[2] *Materials and Design—The art and science of materials selection in Product Design*, 2nd edition (2009), by M.F. Ashby and K. Johnson, Butterworth-Heinemann, ISBN 978-1-85617-497-8.

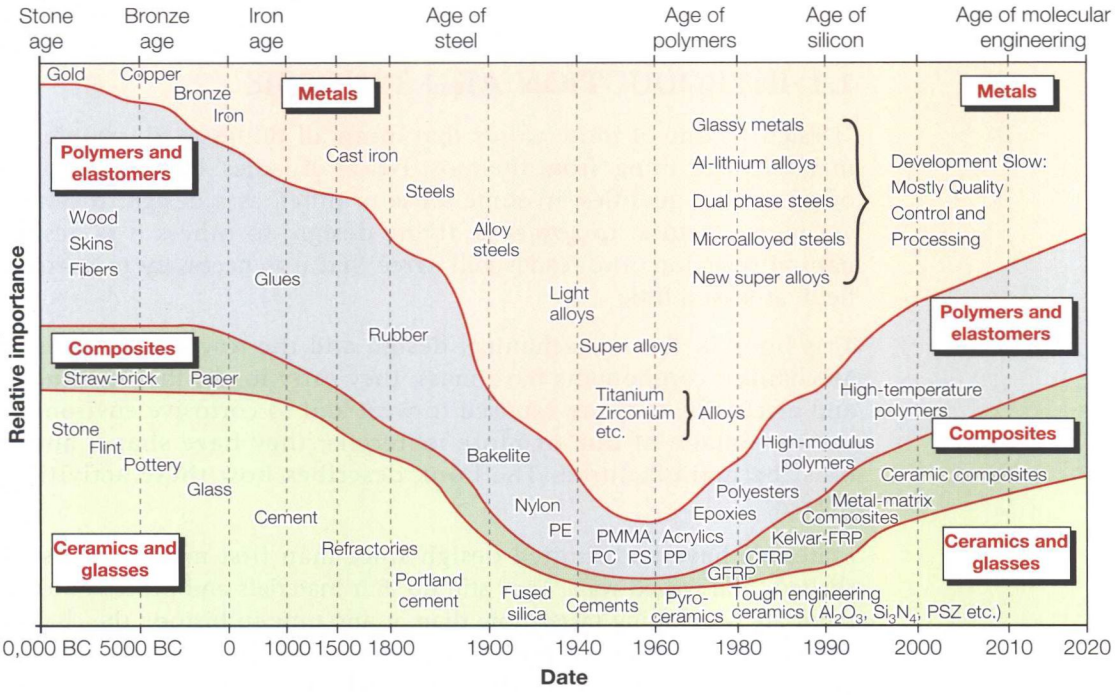
The CES EduPack

The CES EduPack is a widely used software package that implements the methods developed here. The book does not rely on the software, but the learning experience is enhanced by using the two together to create an exciting teaching environment that stimulates exploration, self-teaching, and design innovation. For further information, see the last page of this book or visit *http://www.grantadesign.com/education/*.

Contents

CHAPTER 1

Introduction



The evolution of engineering materials with time. "Relative importance" is based on information contained in the books listed under "Further reading"; plus, from 1960 onward, data for the teaching hours allocated to each material family at U.K. and U.S. universities. The projections to 2020 rely on estimates of material usage in automobiles and aircraft by manufacturers. The time scale is nonlinear. The rate of change is far faster today than at any previous time in history.

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CONTENTS

1.1 INTRODUCTION AND SYNOPSIS

"Design" is one of those words that mean all things to all people. Every manufactured thing, from the most lyrical of ladies' hats to the greasiest of gearboxes, qualifies, in some sense or other, as a design. It can mean yet more. Nature, to some, is divine design; to others it is design by natural selection. The reader will agree that it is necessary to narrow the field, at least a little.

This book is about mechanical design and the role of materials in it. Mechanical components have mass; they carry loads; they conduct heat and electricity; they are exposed to wear and to corrosive environments; they are made of one or more materials; they have shape; and they must be manufactured. The book describes how these activities are related.

Materials have had limited design since man first made clothes, built shelters, and waged wars. They still do. But materials and processes to shape them are developing faster now than at any time in history; the challenges and opportunities they present are greater than ever before. This book develops a strategy for confronting such challenges and seizing those opportunities.

1.2 MATERIALS IN DESIGN

Design is the process of translating a new idea or a market need into the detailed information from which a product can be manufactured. Each of its stages requires decisions about the materials of which the product is to be made and the process for making it. Normally, the choice of material is dictated by the design. But sometimes it is the other way around: The new product, or the evolution of the existing one, was suggested or made possible by a new material.

The number of materials available to engineers is vast: 160,000 or more. Although standardization strives to reduce the number, the continuing appearance of new materials with novel and exploitable properties expands the options further. How, then, do engineers choose, from this vast menu, the material best suited to their purpose? Do they rely on their experience? In the past that was how it was done, passing on this precious commodity to apprentices who, much later in their lives, might themselves assume the role of in-house materials guru.

There is no question of the value of experience. But many things have changed in the world of engineering, and all of them work against the success of this model. There is the drawn-out time scale of apprentice-based learning. There is job mobility, meaning that the guru who is here today is usually gone tomorrow. And there is the rapid evolution of materials information, as already mentioned. A strategy that relies on experience is not in tune with today's computer-based environment. We need a *systematic* procedure—one with steps that can be taught quickly, that is robust in the decisions it reaches, that allows computer implementation, and that is compatible with the other established tools of engineering design.

The choice of material cannot be made independently of the choice of process by which the material is to be shaped, joined, and finished. Cost enters the equation, both in the choice of material and in the way the material is processed. So, too, does the influence of material usage on the environment in which we live. And it must be recognized that good engineering design alone is not enough to sell products. In almost everything from home appliances to automobiles and aircraft, the form, texture, feel, color, beauty, and meaning of the product—the satisfaction it gives the person who owns or uses it—are important. This aspect, known confusingly as *industrial design*, is one that, if neglected, can lose markets. Good design works; excellent design also gives pleasure.

Design problems are almost always open-ended. They do not have a unique or "correct" solution, though some solutions will clearly be better than others. They differ from the analytical problems used in teaching mechanics, or structures, or thermodynamics, which generally do have single, correct answers. So the first tool a designer needs is an open mind: a willingness to consider all possibilities. But a net cast widely draws in many different fish. A procedure is necessary for selecting the excellent from the merely good.

This book deals with the materials aspects of the design process. It develops a methodology that, properly applied, gives guidance through the forest of complex choices the designer faces. The ideas of *material* and *process attributes* are introduced. They are mapped on material and process *selection charts* that show the lay of the land, so to speak, and that simplify the initial