Engineering Materials 1

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An Introduction to Properties, Applications, and Design

Fourth Edition

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Contents

PREFACE TO THE FOURTH EDITION xiii
GENERAL INTRODUCTION xv

CHAPTER 1 Engineering Materials and Their Properties 1
1.1 Introduction 1
1.2 Examples of Materials Selection 3

Part A Price and Availability

CHAPTER 2 The Price and Availability of Materials 15
2.1 Introduction 15
2.2 Data for Material Prices 15
2.3 The Use-Pattern of Materials 18
2.4 Ubiquitous Materials 19
2.5 Exponential Growth and Consumption Doubling-Time 20
2.6 Resource Availability 21
2.7 The Future 23
2.8 Conclusion 24

Part B The Elastic Moduli

CHAPTER 3 The Elastic Moduli 29
3.1 Introduction 29
3.2 Definition of Stress 30
3.3 Definition of Strain 34
3.4 Hooke's Law 36
3.5 Measurement of Young's Modulus 36
3.6 Data for Young's Modulus 38
Worked Example 38
A Note on Stresses and Strains in 3 Dimensions 42

Elastic Bending of Beams 47
Mode 1 Natural Vibration Frequencies 50
Elastic Buckling of Struts 52

CHAPTER 4 Bonding between Atoms 55
4.1 Introduction 55
4.2 Primary Bonds 56
4.3 Secondary Bonds 61
4.4 The Condensed States of Matter 62
4.5 Interatomic Forces 63

CHAPTER 5 Packing of Atoms in Solids 67
5.1 Introduction 67
5.2 Atom Packing in Crystals 68
5.3 Close-Packed Structures and Crystal Energies 68
5.4 Crystallography 70
5.5 Plane Indices 72
5.6 Direction Indices 72
5.7 Other Simple Important Crystal Structures 74
5.8 Atom Packing in Polymers 75
5.9 Atom Packing in Inorganic Glasses 77
5.10 The Density of Solids 77

CHAPTER 6 The Physical Basis of Young's Modulus 83
6.1 Introduction 83
6.2 Moduli of Crystals 83
6.3 Rubbers and the Glass Transition Temperature 86
6.4 Composites 87
Worked Example 90

CHAPTER 7 Case Studies in Modulus-Limited Design 95
7.1 Case Study 1: Selecting Materials for Racing Yacht Masts 95
7.2 Case Study 2: Designing a Mirror for a Large Reflecting Telescope 98
7.3 Case Study 3: The *Challenger* Space Shuttle Disaster 102
Worked Example 108

Part C Yield Strength, Tensile Strength, and Ductility

CHAPTER 8 Yield Strength, Tensile Strength, and Ductility 115
8.1 Introduction 115
8.2 Linear and Nonlinear Elasticity 116
8.3 Load–Extension Curves for Nonelastic (Plastic) Behavior 117
8.4 True Stress–Strain Curves for Plastic Flow 119
8.5 Plastic Work 121
8.6 Tensile Testing 121
8.7 Data 122
8.8 A Note on the Hardness Test 125
Revision of Terms and Useful Relations 129

CHAPTER 9 Dislocations and Yielding in Crystals 135
9.1 Introduction 135
9.2 The Strength of a Perfect Crystal 135
9.3 Dislocations in Crystals 137
9.4 The Force Acting on a Dislocation 140
9.5 Other Properties of Dislocations 143

CHAPTER 10 Strengthening Methods and Plasticity of Polycrystals 147
10.1 Introduction 147
10.2 Strengthening Mechanisms 148
10.3 Solid Solution Hardening 148
10.4 Precipitate and Dispersion Strengthening 149
10.5 Work-Hardening 150
10.6 The Dislocation Yield Strength 151
10.7 Yield in Polycrystals 151
10.8 Final Remarks 154

CHAPTER 11 Continuum Aspects of Plastic Flow 157
11.1 Introduction 157
11.2 The Onset of Yielding and the Shear Yield Strength, k 158
11.3 Analyzing the Hardness Test 160
11.4 Plastic Instability: Necking in Tensile Loading 161
Plastic Bending of Beams, Torsion of Shafts, and Buckling of Struts 168

CHAPTER 12 Case Studies in Yield-Limited Design 171
12.1 Introduction 171
12.2 Case Study 1: Elastic Design—Materials for Springs 171
12.3 Case Study 2: Plastic Design—Materials for Pressure Vessels 176
12.4 Case Study 3: Large-Strain Plasticity—Metal Rolling 178

Part D Fast Fracture, Brittle Fracture, and Toughness

CHAPTER 13 Fast Fracture and Toughness 187
13.1 Introduction 187
13.2 Energy Criterion for Fast Fracture 187
13.3 Data for G_c and K_c 192
Y Values 198
K Conversions 203

CHAPTER 14 Micromechanisms of Fast Fracture 205
14.1 Introduction 205
14.2 Mechanisms of Crack Propagation 1: Ductile Tearing 206
14.3 Mechanisms of Crack Propagation 2: Cleavage 208
14.4 Composites, Including Wood 210
14.5 Avoiding Brittle Alloys 211
Worked Example 212

CHAPTER 15 Probabilistic Fracture of Brittle Materials 219
15.1 Introduction 219
15.2 The Statistics of Strength 220
15.3 The Weibull Distribution 222
15.4 The Modulus of Rupture 224
Worked Example 225

CHAPTER 16 Case Studies in Fracture 229
16.1 Introduction 229
16.2 Case Study 1: Fast Fracture of an Ammonia Tank 229
16.3 Case Study 2: Explosion of a Perspex Pressure Window During Hydrostatic Testing 233

16.4 Case Study 3: Cracking of a Foam Jacket on a Liquid Methane Tank 235
Worked Example 240

Part E Fatigue Failure

CHAPTER 17 Fatigue Failure 249
17.1 Introduction 249
17.2 Fatigue of Uncracked Components 250
17.3 Fatigue of Cracked Components 254
17.4 Fatigue Mechanisms 255
Worked Example 259

CHAPTER 18 Fatigue Design 265
18.1 Introduction 265
18.2 Fatigue Data for Uncracked Components 266
18.3 Stress Concentrations 266
18.4 The Notch Sensitivity Factor 267
18.5 Fatigue Data for Welded Joints 269
18.6 Fatigue Improvement Techniques 270
18.7 Designing Out Fatigue Cycles 272
Worked Example 274

CHAPTER 19 Case Studies in Fatigue Failure 287
19.1 Case Study 1: The Comet Air Disasters 287
19.2 Case Study 2: The Eschede Railway Disaster 293
19.3 Case Study 3: The Safety of the Stretham Engine 298

Part F Creep Deformation and Fracture

CHAPTER 20 Creep and Creep Fracture 311
20.1 Introduction 311
20.2 Creep Testing and Creep Curves 315
20.3 Creep Relaxation 318
20.4 Creep Damage and Creep Fracture 319
20.5 Creep-Resistant Materials 320
Worked Example 321

CHAPTER 21 Kinetic Theory of Diffusion 325
21.1 Introduction 325
21.2 Diffusion and Fick's Law 326
21.3 Data for Diffusion Coefficients 332
21.4 Mechanisms of Diffusion 334

CHAPTER 22 Mechanisms of Creep and Creep-Resistant Materials 337
22.1 Introduction 337
22.2 Creep Mechanisms: Metals and Ceramics 338
22.3 Creep Mechanisms: Polymers 343
22.4 Selecting Materials to Resist Creep 345
Worked Example 345

CHAPTER 23 The Turbine Blade—A Case Study in Creep-Limited Design 351
23.1 Introduction 351
23.2 Properties Required of a Turbine Blade 352
23.3 Nickel-Based Super-Alloys 354
23.4 Engineering Developments—Blade Cooling 357
23.5 Future Developments: High-Temperature Ceramics 359
23.6 Cost Effectiveness 359
Worked Example 361

Part G Oxidation and Corrosion

CHAPTER 24 Oxidation of Materials 367
24.1 Introduction 367
24.2 The Energy of Oxidation 368
24.3 Rates of Oxidation 368
24.4 Data 371
24.5 Micromechanisms 372

CHAPTER 25 Case Studies in Dry Oxidation 377
25.1 Introduction 377
25.2 Case Study 1: Making Stainless Alloys 377
25.3 Case Study 2: Protecting Turbine Blades 378
25.4 A Note on Joining Operations 382

CHAPTER 26 Wet Corrosion of Materials....385
26.1 Introduction....385
26.2 Wet Corrosion....386
26.3 Voltage Differences as the Driving Force for Wet Oxidation....387
26.4 Pourbaix (Electrochemical Equilibrium) Diagrams....388
26.5 Some Examples....390
26.6 A Note on Standard Electrode Potentials....394
26.7 Localized Attack....395
Rates of Uniform Metal Loss....399

CHAPTER 27 Case Studies in Wet Corrosion....401
27.1 Case Study 1: Protecting Ships' Hulls from Corrosion....401
27.2 Case Study 2: Rusting of a Stainless Steel Water Filter....405
27.3 Case Study 3: Corrosion in Reinforced Concrete....408
27.4 A Note on Small Anodes and Large Cathodes....410
Worked Example....411

Part H Friction, Abrasion, and Wear

CHAPTER 28 Friction and Wear....417
28.1 Introduction....417
28.2 Friction between Materials....418
28.3 Data for Coefficients of Friction....420
28.4 Lubrication....422
28.5 Wear of Materials....423
28.6 Surface and Bulk Properties....425

CHAPTER 29 Case Studies in Friction and Wear....431
29.1 Introduction....431
29.2 Case Study 1: The Design of Journal Bearings....431
29.3 Case Study 2: Materials for Skis and Sledge Runners....437
29.4 Case Study 3: High-Friction Rubber....438

CHAPTER 30 Final Case Study: Materials and Energy in Car Design 443
30.1 Introduction 443
30.2 Energy and Carbon Emissions 444
30.3 Ways of Achieving Energy Economy 444
30.4 Material Content of a Car 445
30.5 Alternative Materials 445
30.6 Production Methods 451
30.7 Conclusions 453

APPENDIX Symbols and Formulae 455
REFERENCES 465
INDEX 467

Preface to the Fourth Edition

In preparing this fourth edition of *Engineering Materials 1*, I have taken the opportunity to make significant changes, while being careful not to alter the essential character of the book. At the most obvious level, I have added many new photographs to illustrate both the basic coursework and also the case studies—many of these have been taken during my travels around the world investigating materials engineering problems. These days, the Internet is the essential tool of knowledge and communication—to the extent that textbooks should be used alongside web-based information sources.

So, in this new edition, I have given frequent references in the text to reliable web pages and video clips—ranging from the Presidential Commission report on the space shuttle *Challenger* disaster, to locomotive wheels losing friction on Indian Railways. And whenever a geographical location is involved, such as the Sydney Harbour Bridge, I have given the coordinates (latitude and longitude), which can be plugged into the search window in Google Earth to take you right there. Not only does this give you a feel for the truly global reach of materials and engineering, it also leads you straight to the large number of derivative sources and references, such as photographs and web pages, that can help you follow up your own particular interests.

I have added Worked Examples to many of the chapters to develop or illustrate a point without interrupting the flow of the chapter. These can be what one might call "convergent"—like putting numbers into a specific data set of fracture tests to calculate the Weibull modulus (you need to be able to do this, but it is best done offline)—or "divergent," such as recognizing the fatigue design details in the traffic lights in Manhattan and thus challenging you to look around the real world and think like an engineer.

I have made some significant changes to the way in which some of the subject material is presented. So, in the chapters on fatigue, I have largely replaced the traditional stress-based analysis with the total strain approach to fatigue life. In the creep chapters, the use of creep maps is expanded to show strain-rate contours and the effect of microstructure on creep régimes. In the corrosion chapters, Pourbaix diagrams are used for the first time in order to show the regions of immunity, corrosion, and passivation, and how these depend on electrochemical potential and pH.

In addition, I have strengthened the links between the materials aspects of the subject and the "user" fields of mechanics and structures. Thus, at the ends of the relevant chapters, I have put short compendia of useful results: elastic bending, vibration, and buckling of beams after Chapter 3; plastic bending and torsion after Chapter 11; stress intensity factors for common crack geometries after Chapter 13; and data for calculating corrosion loss after Chapter 26. A simple introductory note on tensor notation for depicting stress and strain in three dimensions has also been added to Chapter 3.

Many new case studies have been added, and many existing case studies have either been replaced or revised and updated. The number of examples has been significantly expanded, and of these a large proportion contain case studies or practical examples relevant to materials design and avoidance of failure. In general, I have tried to choose topics for the case studies that are interesting, informative, and connected to today's world. So, the new case study on the *Challenger* space shuttle disaster—which derives from the earlier elastic theory (Hooke's law applied to pressurized tubes and chain sliding in rubber)—is timeless in its portrayal of how difficult it is in large corporate organizations for engineers to get their opinions listened to and acted on by senior management. The *Columbia* disaster 17 years later, involving the same organization and yet another materials problem, shows that materials engineering is about far more than just materials engineering.

Materials occupy a central place in all of engineering for without them, nothing can be made, nothing can be done. The challenge always is to integrate an intimate knowledge of the characteristics of materials with their applications in real structures, components, or devices. Then, it helps to be able to understand other areas of engineering, such as structures and mechanics, so that genuine collaborations can be built that will lead to optimum design and minimum risk. The modern airplane engine is one of the best examples, and the joints in the space shuttle booster one of the worst. In-between, there is a whole world of design, ranging from the excellent to the terrible (or not designed at all). To the materials engineer who is always curious, aware and vigilant, the world is a fascinating place.

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David Jones

General Introduction

To the Student

Innovation in engineering often means the clever use of a new material—new to a particular application, but not necessarily (although sometimes) new in the sense of recently developed. Plastic paper clips and ceramic turbine blades both represent attempts to do better with polymers and ceramics what had previously been done well with metals. And engineering disasters are frequently caused by the misuse of materials. When the plastic bristles on your sweeping brush slide over the fallen leaves on your backyard, or when a fleet of aircraft is grounded because cracks have appeared in the fuselage skin, it is because the engineer who designed them used the wrong materials or did not understand the properties of those used. So, it is vital that the professional engineer should know how to select materials that best fit the demands of the design—economic and aesthetic demands, as well as demands of strength and durability. The designer must understand the properties of materials, and their limitations.

This book gives a broad introduction to these properties and limitations. It cannot make you a materials expert, but it can teach you how to make a sensible choice of material, how to avoid the mistakes that have led to difficulty or tragedy in the past, and where to turn for further, more detailed, help.

You will notice from the Contents that the chapters are arranged in *groups*, each group describing a particular class of properties: elastic modulus; fracture toughness; resistance to corrosion; and so forth. Each group of chapters starts by *defining the property*, describing how it is *measured*, and giving *data* that we use to solve problems involving design with materials. We then move on to the *basic science* that underlies each property and show how we can use this fundamental knowledge to choose materials with better properties. Each group ends with a chapter of *case studies* in which the basic understanding and the data for each property are applied to practical engineering problems involving materials.

At the end of each chapter, you will find a set of examples; each example is meant to consolidate or develop a particular point covered in the text. Try to do the examples from a particular chapter while this is still fresh in your mind. In this way, you will gain confidence that you are on top of the subject.

No engineer attempts to learn or remember tables or lists of data for material properties. But you *should* try to remember the broad orders of magnitude of these quantities. All food stores know that "a kg of apples is about 10 apples"—salesclerks still weigh them, but their knowledge prevents someone from making silly mistakes that might cost the stores money.

In the same way an engineer should know that "most elastic moduli lie between 1 and 10^3 GN m^{-2} and are around 10^2 GN m^{-2} for metals"—in any real design you need an accurate value, which you can get from suppliers' specifications; but an order of magnitude knowledge prevents you from getting the units wrong, or making other silly, possibly expensive, mistakes. To help you in this, we have added at the end of the book a list of the important definitions and formulae that you should know, or should be able to derive, and a summary of the orders of magnitude of materials properties.

To the Lecturer

This book is a course in Engineering Materials for engineering students with no previous background in the subject. It is designed to link up with the teaching of Design, Mechanics, and Structures, and to meet the needs of engineering students for a first materials course, emphasizing design applications.

The text is deliberately concise. Each chapter is designed to cover the content of one 50-minute lecture, 30 in all, and allows time for demonstrations and graphics. The text contains sets of worked case studies that apply the material of the preceding block of lectures. There are examples for the student at the end of the chapters.

We have made every effort to keep the mathematical analysis as simple as possible while still retaining the essential physical understanding and arriving at results, which, although approximate, are useful. But we have avoided mere description: most of the case studies and examples involve analysis, and the use of data, to arrive at solutions to real or postulated problems. This level of analysis, and these data, are of the type that would be used in a preliminary study for the selection of a material or the analysis of a design (or design failure).

It is worth emphasizing to students that the next step would be a detailed analysis, using *more precise mechanics* and *data from the supplier of the material or from in-house testing.* Materials data are notoriously variable. Approximate tabulations like those that are given here, though useful, should never be used for final designs.

Accompanying Resources

The following web-based resources are available to teachers and lecturers who adopt or recommend this text for class use. For further details and access to these resources, please go to *http://www.textbooks.elsevier.com*

Instructor's Manual

A full Solutions Manual with worked answers to the exercises in the main text is available for downloading.

Image Bank

An image bank of downloadable figures from the book is available for use in lecture slides and class presentations.

Online Materials Science Tutorials

A series of online materials science tutorials accompanies *Engineering Materials 1* and *2*. These were developed by Alan Crosky, Mark Hoffman, Paul Munroe, and Belinda Allen at the University of New South Wales (UNSW) in Australia; they are based on earlier editions of the books. The group is particularly interested in the effective and innovative use of technology in teaching. They realized the potential of the material for the teaching of Materials Engineering to their students in an online environment and have developed and then used these very popular tutorials for a number of years at UNSW. The results of this work have also been published and presented extensively.

The tutorials are designed for students of materials science as well as for those studying materials as a related or elective subject—for example, mechanical and/or civil engineering students. They are ideal for use as ancillaries to formal teaching programs and also may be used as the basis for quick refresher courses for more advanced materials science students. In addition, by picking selectively from the range of tutorials available, they will make ideal subject primers for students from related faculties.

The software has been developed as a self-paced learning tool, separated into learning modules based around key materials science concepts.

About the authors of the tutorials

Alan Crosky is a Professor in the School of Materials Science and Engineering, University of New South Wales. His teaching specialties include metallurgy, composites, and fractography.

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