

# Engineering Materials and Their Applications

THIRD EDITION

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PAUL K. TREJAN

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# Engineering Materials and Their Applications

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**Richard A. Flinn**  
*University of Michigan, Ann Arbor*

**Paul K. Trojan**  
*University of Michigan, Dearborn*

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# Preface

## To the student

When a student takes this course, he or she has been exposed to texts in science in which a particular problem with exact conditions is analyzed and there is only one correct answer. In this text we bring the student into contact with the type of problems he or she will encounter in professional life. Engineering is the bridge between science and society, and the role of the engineer is to apply the latest findings of science to solve engineering problems.

Engineers are concerned with the proper selection of materials. For example, one can look up handbook values of strength, but there are very few problems in which strength is the only factor affecting the choice of material. Often corrosion, wear resistance, and electrical and magnetic properties of materials are more important considerations. To illustrate the decision-making responsibilities of engineers, we have incorporated two types of problems: (1) *engineering science* problems, labeled [ES], for which there is a unique answer to each question; and (2) *engineering judgment* problems, labeled [EJ], for which there may be several possible answers. Engineering science problems can be solved quantitatively, whereas solutions to engineering judgment problems also involve considerations of relative cost, safety, and producibility.

For the first time in this text, a full-color section has been included. What have these photographs to do with the selection of materials for a component? They are used to establish the concept that components must be regarded not only as shapes to be made but also in terms of the service they are to perform. For a given component, the performance depends on the *internal structure* and how it reacts to stress, wear, and corrosion. At the same time we study these effects, there is the added dividend in viewing the inherent beauty of the material and understanding how the structures were formed.

Let us be specific about the contents of this text and why an engineering materials course is important to a future engineer. It would be easy to put together some grandiose statements about the importance of metallurgy, ceramics, and plastics in society. Instead, let's take a hard-headed engineering approach. Let's extract from each chapter one important idea or principle and see how it puts the engineer in a position to understand, specify, and even develop new materials.

In the first chapter we find that all engineering materials may be divided into three classes: *metals*, *ceramics*, and *plastics*. The different properties we encounter in these groups depend basically on the structure of the particular material, that is, the way the atoms are arranged and bonded.

Chapters 2 through 6 are devoted to *metallic* structures and their properties. In Chapter 2 we learn that a grain (or crystal) of metal is built up of just simple molecules (unit cells) that give rise to planes of atoms. These planes of atoms form the structural framework of the metal, just as planes of steel beams form the skeleton of a skyscraper. This may seem a little academic at first, but in Chapter 3 we find that this model enables us to explain the effects of stress and temperature on a metal. A metal is ductile because *slip* rather than rupture occurs between the planes of atoms. When a metal that has been deformed is heated, this causes recrystallization into new grains so that the metal can be further worked and deformed to a desired shape.

Chapter 4 introduces phase diagrams. There is no quicker way for a metallurgist to stupefy or disperse the average engineering audience than to say, "We will now have a few slides of the phase diagrams on which our new alloy is based." However, in this text we use the phase diagram very simply as a map to show the effects of alloying elements on the basic structure. For example, we find that the addition of 8% nickel and 18% chromium to iron changes the usual structure of iron at room temperature to a totally new structure—that of austenitic stainless steel. This example shows that the alloys nickel and chromium are added not because of their individual chemical properties, but because of their effect on the structure of the iron alloy, as indicated by the phase diagram.

Chapters 5 and 6 examine the structures and properties of the important nonferrous and ferrous alloys from this point of view.

At the end of the first six chapters you should understand the structures of more than 95% of metallic materials and should be aware of how properties depend on structures. An added bonus comes in the form of numerous examples of the selection of alloys for different applications.

Chapters 7 and 8 deal with ceramics. Ceramics are not just the brittle stuff dishes are made of. Because of covalent or ionic bonds, ceramics have the greatest hardness and strength and the highest melting points of all materials, but usually the lowest toughness or ductility. For a long time ceramics have been used alone in vital applications, such as in diamond-cutting tools or concrete. However, only recently have ceramics been used in combination with other materials, in everything from cemented carbide tools to delicate graphite-plastic fishing rods and optical fibers.

Chapters 9 and 10 investigate the third group of materials—the plastics. The important point here is that we need to understand the *molecules* of the polymer instead of the unit cell. There are two great families of plastics. In the thermosetting class, of which a typical type is used to make bowling balls, we have one hard, strong giant molecule made up of carbon, hydrogen, and oxygen atoms. In the other class of plastics, of which a typical example is used to make polyethylene bags, we have a mass of many separate large molecules that can be readily formed and liquefied by heating.

The end of Chapter 10 marks the three-quarter point of the text. We understand the structures and properties of metals, ceramics, and polymers—and some applications. But prospective engineers are never told (or should not be), “Find the best *plastic* for this application.” They should always think, “What is the best *material*?” Therefore, we need to compare, contrast, and combine the different materials. This is done in the last quarter of the book. Chapter 11 discusses composite materials. Chapter 12 examines the effects of corrosion on materials. Then we go on in Chapter 13 to analyze the ways in which materials fail and how failure may be prevented. Finally, Chapters 14, 15, and 16 take up electrical, magnetic, thermal, and optical properties of materials. We find that these properties, like tensile strength and hardness, depend on the structure.

And now we come to the bottom line of this preface. How are students who take this course better equipped to deal with professional problems as a result? First, they will be better able to specify a material for a given application. By understanding the structure, they can go far beyond the tensile and hardness data of the handbook in predicting what will happen if the material is welded, pounded, twisted, corroded, or heated. If failure occurs, they will be able to analyze the reason why and suggest improvements in materials or processing. Finally, they will have a firmer basis for understanding new materials as they are developed.

### **To our colleagues**

First we would like to express our appreciation to an ever-widening group of colleagues at other institutions who support our principal contention that a course in materials should present not only the principles of materials science but also their application to real engineering problems. It is much easier to teach and grade problems exclusively in science but this does not prepare the engineer for the real world. In the past, there has been some confusion and even consternation about the less quantitative engineering judgment problems, but we hope our earlier comments and the discussion in the instructor's manual will clarify this point.

In response to many helpful comments, we have made the following changes and additions:

The chapters on polymers have been revised and expanded. Chapter 9 is now devoted to structures and properties, and Chapter 10 covers processing and includes new material on laminates and adhesives.

The chapter on electronic materials has been improved with a clearer discussion of topics such as the *p-n* junction.

Half of the problems are new. All problems are designated as [ES], [EJ], or [ES/EJ] and include references to the sections of text to which they apply.

In response to those requesting a shorter text, a compromise was necessary because of the differing opinions as to what should be omitted. A vertical line runs along the right-hand margin of material that may be omitted without leaving out concepts that are necessary for understanding later chapters. These lines identify a portion of the text that can be omitted but is still available for later reference by the student. (The instructor's manual contains further suggestions for planning as well as optional laboratory experiments.)

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# Contents

Preface xv

## 1 The Problem of Materials Selection and Development 3

1.1 General plan of action 4      1.2 The three families of materials: metals, ceramics, polymers 4      1.3 The structure of materials 5      1.4 Bonding forces in different materials 8      1.5 Outline of the text 13      1.6 Problems in the text 15  
SUMMARY 16      DEFINITIONS 17      PROBLEMS 18

## 2 Metallic Structures; The Unit Cell 21

2.1 General overview 22      2.2 Metal atoms 22      2.3 The periodic table 27      2.4 Crystals and grains 31      2.5 The unit cell 33  
2.6 Correlation of data on unit cells with measurements of density 38  
2.7 Other unit cell calculations: atomic radius, planar density, and linear density 39      2.8 Close-packed hexagonal metals 42      2.9 Determination of crystal structure; x-ray diffraction 44      2.10 Definition of a phase; solid phase transformations in metals 47      2.11 Effects of the addition of other elements on the structure of pure metals 50      2.12 Solid solutions 51      2.13 New phases, intermediate phases 52  
SUMMARY 54      DEFINITIONS 55      PROBLEMS 56

## 3 Effects of Stress and Temperature on Simple Metal Structures 61

3.1 General 62      3.2 Effects of stress on metal structures 62      3.3 Plastic strain, permanent deformation, slip 64      3.4 Critical resolved shear stress for plastic deformation 64      3.5 Twinning 67      3.6 Engineering stress-strain curves 68      3.7 True stress-true strain relations 75  
3.8 Dislocations 78      3.9 Cold work, or work hardening 80  
3.10 Methods of work hardening 81      3.11 Hardness testing 82



3.12 Correlation of hardness, tensile strength, and cold work	85
3.13 Solid-solution strengthening	85
3.14 Fatigue	87
3.15 Impact testing and effects of low temperatures	88
3.16 Effects of elevated temperature on work-hardened structures	91
3.17 Recovery, recrystallization, and grain growth	94
3.18 Selection of annealing temperature	96
3.19 Effect of grain size on properties	97
3.20 Engineering application of cold work and annealing	97
3.21 Hot working	98
3.22 Properties in single-phase alloys	100
3.23 Creep and stress relief	102
SUMMARY	103
DEFINITIONS	104
PROBLEMS	106

#### 4 Control of Polyphase Structures in Metals: Under Equilibrium Conditions (Phase Diagrams) and Under Nonequilibrium Conditions (Precipitation Reactions) 115

4.1 General	116	4.2 Phase diagrams for polyphase alloys	118
4.3 Equilibrium diagrams—the aluminum-silicon diagram	119	4.4 Phase compositions (phase analyses)	124
4.5 Amounts of phases	126	4.6 Phase fraction chart of amounts of phases present as a function of temperature	128
4.7 The phase rule	130	4.8 Complex phase diagrams	132
4.9 Ternary diagrams	135	4.10 Representation of temperature in ternaries	136
4.11 Nonequilibrium conditions	138	4.12 Diffusion phenomena	138
4.13 Fick's first law	140	4.14 Fick's second law	141
4.15 Effects of temperature	144	4.16 Other diffusion phenomena	145
4.17 Nucleation and growth	145	4.18 Segregation	148
4.19 Strengthening through nonequilibrium reactions	149	4.20 Control of liquid-to-solid reactions	150
4.21 Control of solid-state precipitation reactions	151	4.22 Summary of strengthening mechanisms in multiphase metals	157
SUMMARY	158	DEFINITIONS	159
PROBLEMS	161		

#### 5 Engineering Alloys in General; Nonferrous Alloys—Aluminum, Magnesium, Copper, Nickel, Titanium, and Zinc 171

5.1 General	172	5.2 Processing methods	174	5.3 Aluminum alloys	178
5.4 Magnesium alloys	186	5.5 Copper alloys in general	190	5.6 Solid-solution copper alloys	192
5.7 Polyphase wrought copper alloys	193	5.8 Cast copper alloys	194	5.9 Nickel alloys in general	198
5.10 Cast nickel alloys	198	5.11 Titanium alloys	199	5.12 Zinc alloys	199
5.13 The less common metals and precious metals	200				
SUMMARY	201	DEFINITIONS	202	PROBLEMS	202

## 6 Ferrous Alloys—Steel, Superalloys, Cast Iron, Ductile Iron, Malleable Iron 211

6.1 Introduction to iron alloys 212	6.2 The iron-iron carbide diagram and its phases 212
<i>Equilibrium Structures of Plain Carbon and Low-Alloy Steels</i> 216	
6.3 Hypoeutectoid steels 218	6.4 Hypereutectoid steels 220
6.5 Specifications 220	
<i>Nonequilibrium Reactions</i> 223	
6.6 Steel hardening 223	6.7 Austenite transformation 223
6.8 Pearlite formation 225	6.9 Bainite formation 226
6.10 Transformation to martensite 228	6.11 Uses of the time-temperature-transformation (TTT) curve 232
6.12 Tempering 233	6.13 Marquenching (martempering) 234
6.14 Austempering 235	6.15 Effects of carbon on transformation of austenite and transformation products 236
6.16 Quenching and the advantages of alloy steels 241	
<i>Choosing the Proper Steel for a Given Part</i> 243	
6.17 Hardenability evaluation 244	6.18 Analysis and properties of typical low-alloy steels 247
6.19 Tempering of alloy and noneutectoid steels 249	6.20 High-strength low-alloy steels (HSLA steels) 250
<i>High-Alloy Steels and Superalloys</i> 251	
6.21 General 251	6.22 Phase diagrams of the high-alloy steels 253
6.23 The stainless steels 253	6.24 Precipitation hardening and maraging steels 256
6.25 Tool steels 257	6.26 Hadfield's manganese steel 259
6.27 Superalloys in general 260	6.28 High-temperature properties of typical superalloys 261
<i>White Iron, Gray Iron, Ductile Iron, and Malleable Iron</i> 263	
6.29 Importance of high-carbon alloys 263	6.30 Relationships among white iron, gray iron, ductile iron, and malleable iron 265
6.31 White cast iron 269	6.32 Gray cast iron 269
6.33 Ductile iron 272	6.34 Malleable iron 272
SUMMARY 273	DEFINITIONS 274
PROBLEMS 277	

## 7 Ceramic Structures and Their Properties 291

7.1 Ceramics and related materials 292	7.2 Glass products in general 292
7.3 Glass processing and glass products 300	7.4 Crystalline materials in ceramics in general 302
7.5 Bonding forces 303	7.6 Coordination number; interstitial sites 308
7.7 Unit cells 312	7.8 Solid solutions 318
7.9 Defect structures, lattice vacancies 319	7.10 Some properties of ceramics 320
7.11 Simple ceramic materials 324	SUMMARY 333
DEFINITIONS 334	PROBLEMS 335

## 8 Processing, Specifications, and Applications of Ceramics 341

- 8.1 General 342      8.2 Molding followed by firing 343      8.3 Chemical bonding 346      8.4 Single crystals 346      8.5 Cements and cement products 346  
*Portland Cement, High-alumina Cement, and Other Cements* 347  
8.6 General packing in solids 349  
*Ceramic Products* 352  
8.7 Brick and tile 352      8.8 Refractory and insulating materials 352  
8.9 Earthenware, stoneware, china, ovenware, and porcelain 354  
8.10 Abrasives 358      8.11 Molds for metal castings 358      8.12 Residual stresses and contraction 359      8.13 Toughened ceramics 361  
SUMMARY 363      DEFINITIONS 363      PROBLEMS 364

## 9 Plastics (High Polymers): Structures and Properties 369

- 9.1 General 370  
*Formation of Polymer Structures* 373  
9.2 The building blocks, monomers and mers 373      9.3 Bond strengths 380  
9.4 Bonding positions on a monomer, functionality 382      9.5 Polymerization mechanisms 382      9.6 Variations in polymer structures 386  
9.7 Crystallinity 391  
*Modification in Structure and Properties* 394  
9.8 Copolymers, blending, plasticizers 394      9.9 Properties of polymers at ambient temperature 395      9.10 Effect of time and temperature 401  
9.11 Elastomers 407      9.12 Other polymer properties: specific gravity, transparency, coefficient of expansion 408  
SUMMARY 409      DEFINITIONS 410      PROBLEMS 412

## 10 Processing of Polymers: Special Polymer Products, Composites, Laminates 421

- 10.1 General 422      10.2 Origin and preparation of polymers 422  
10.3 Production processes 422  
*Special Production Techniques and Products: Fibers, Foams, Adhesives, Coatings* 429  
10.4 Fibers 429      10.5 Foams 431      10.6 Adhesives in general 435  
10.7 The adhesive bond 435      10.8 Requirements for satisfactory bonding 436  
10.9 Available adhesives 437      10.10 Advantages and disadvantages of adhesive bonds compared to metallic bonds 440      10.11 Coatings in

general	441	10.12 Properties of coatings	441	10.13 Fillers and	
laminates in general	444	10.14 Fillers	444	10.15 Laminates	444
SUMMARY	446	DEFINITIONS	447	PROBLEMS	448

## 11 Composite Materials, Including Concrete and Wood 455

11.1 General	456	11.2 Synthetic composites	456	11.3 Composites	
strengthened by dispersion and particle reinforcement	456	11.4 Fiber		11.5 Concrete in general	467
reinforcement	457	11.6 Components of		11.7 Properties of concrete	473
concrete	468	11.8 Special		11.9 Reinforced and prestressed concrete	480
concretes	478	11.10 Proportioning of concrete mixtures	483	11.11 Asphalt	489
11.12 Wood in general	489	11.13 Wood macrostructure	490	11.14 Wood	
microstructure	492	11.15 Properties of wood	496	11.16 Role of defects	
in wood products	501				
SUMMARY	504	DEFINITIONS	505	PROBLEMS	506

## 12 Corrosion of Materials 513

12.1 Introduction	514	12.2 Corrosion of metals	514
<i>Chemical Principles</i>	515		
12.3 Does the metal react?	515	12.4 Anode and cathode reactions (half-cell reactions)	515
12.5 Cell potentials	517	12.6 Hydrogen half-cell	517
12.7 Cell potentials in different solutions	519	12.8 Corrosion rates	521
12.9 Inhibitors	525	12.10 Passivity	525
<i>Corrosion Phenomena</i>	527		
12.11 Types of corrosion	527	12.12 Corrosion units	527
corrosion	527	12.13 Galvanic	
12.14 Selective leaching (dezincification, etc.)	533	12.15 Hydrogen damage	535
12.16 Oxygen-concentration cells; water-line corrosion	535	12.17 Pit and crevice corrosion	536
12.18 Combined mechanical-corrosive effects	538		
<i>Corrosive Environments</i>	540		
12.19 General	540	12.20 Atmospheric corrosion	540
12.21 Water	540	12.22 Chemical corrosion	541
<i>Corrosion in Gas</i>	544		
12.23 General	544	12.24 Types of scales formed	544
of scale formation	545	12.25 Mechanism	
12.26 Oxidation rates	546	12.27 Scale-resistant	
materials	547	12.28 Special cases	547
<i>Corrosion of Ceramics and Plastics</i>	548		
12.29 General	548	12.30 Atmosphere	549
12.31 Water	549	12.32 Chemicals	549
12.33 Summary of steps used to prevent corrosion	551		
SUMMARY	552	DEFINITIONS	553
		PROBLEMS	554

## 13 Analysis and Prevention of Failure 563

- 13.1 General 564      13.2 Fracture toughness and fracture mechanics 565  
 13.3 What is fracture toughness? 565      13.4 Fracture energy 566  
 13.5 Stress concentration 568      13.6 Need for fracture mechanics 569  
 13.7 The Griffith analysis: fracture mechanics of glass 570      13.8 Application of fracture mechanics to metals 571  
 13.9 The role of specimen thickness in fracture toughness 573      13.10 Plane stress and plane strain 573  
 13.11 Fracture mechanics and design 577      13.12 Fracture toughness vs. yield strength 578  
 13.13 Delayed failure: fatigue and stress corrosion cracking 580      13.14 Initiation of fatigue cracks 580  
 13.15 Propagation of fatigue cracks 583      13.16 Stress corrosion cracking 589  
*Experimental Methods for Examining Failed Parts* 592  
 13.17 General approach, nondestructive methods 592      13.18 Summary of fracture appearance 594  
 13.19 Destructive methods of analysis 596  
 13.20 Residual stresses—measurement and control 598  
*Defects and Anisotropy Caused by Manufacturing Process* 600  
 13.21 Processing defects 600      13.22 Casting defects 601      13.23 Defects produced during metal working 604  
 13.24 Welding defects 607  
 13.25 Defects due to heat treatment 609      13.26 Wear and abrasion 609  
 13.27 Wear-resistant combinations 612      13.28 Resistance to abrasion 612  
 SUMMARY 613      DEFINITIONS 614      PROBLEMS 615

## 14 Electrical Properties of Materials 623

- 14.1 General 624  
*Electrical Conductivity* 625  
 14.2 Conduction and carriers 625      14.3 Types of carriers 626  
 14.4 Conductivity in metals 628      14.5 Applications 631  
 14.6 Conducting glasses 632      14.7 Superconductivity 633  
 14.8 Semiconductors in general 634      14.9 Semiconductors and insulators 634  
 14.10 Extrinsic vs. intrinsic semiconductors 636      14.11 *p-n* junctions, rectification 639  
 14.12 Solar cells 643      14.13 Amplifier circuits 644  
 14.14 The Hall effect 645      14.15 Production of transistors 646  
 14.16 Effects of temperature on electrical conductivity 649  
*Other Electrical Properties* 651  
 14.17 Dielectric properties 651      14.18 Barium titanate-type dielectrics (ferroelectrics) 656  
 14.19 Interrelated electrical-mechanical effects (electromechanical coupling) 658  
 14.20 Thermocouples; thermoelectric power 659  
 SUMMARY 661      DEFINITIONS 662      PROBLEMS 664

## 15 Magnetic Properties of Materials 671

- 15.1 General 672      15.2 The magnetic circuit and important magnetic properties 672      15.3 Magnetic permeability 676      15.4 Atomic structure of ferromagnetic metals 677      15.5 Magnetic domains 679      15.6 Effect of temperature on magnetization 683      15.7 Magnetic saturation 683  
 15.8 Remanent induction 684      15.9 Metallic magnetic materials 684  
 15.10 Ceramic magnetic materials 686  
 SUMMARY 692      DEFINITIONS 692      PROBLEMS 694

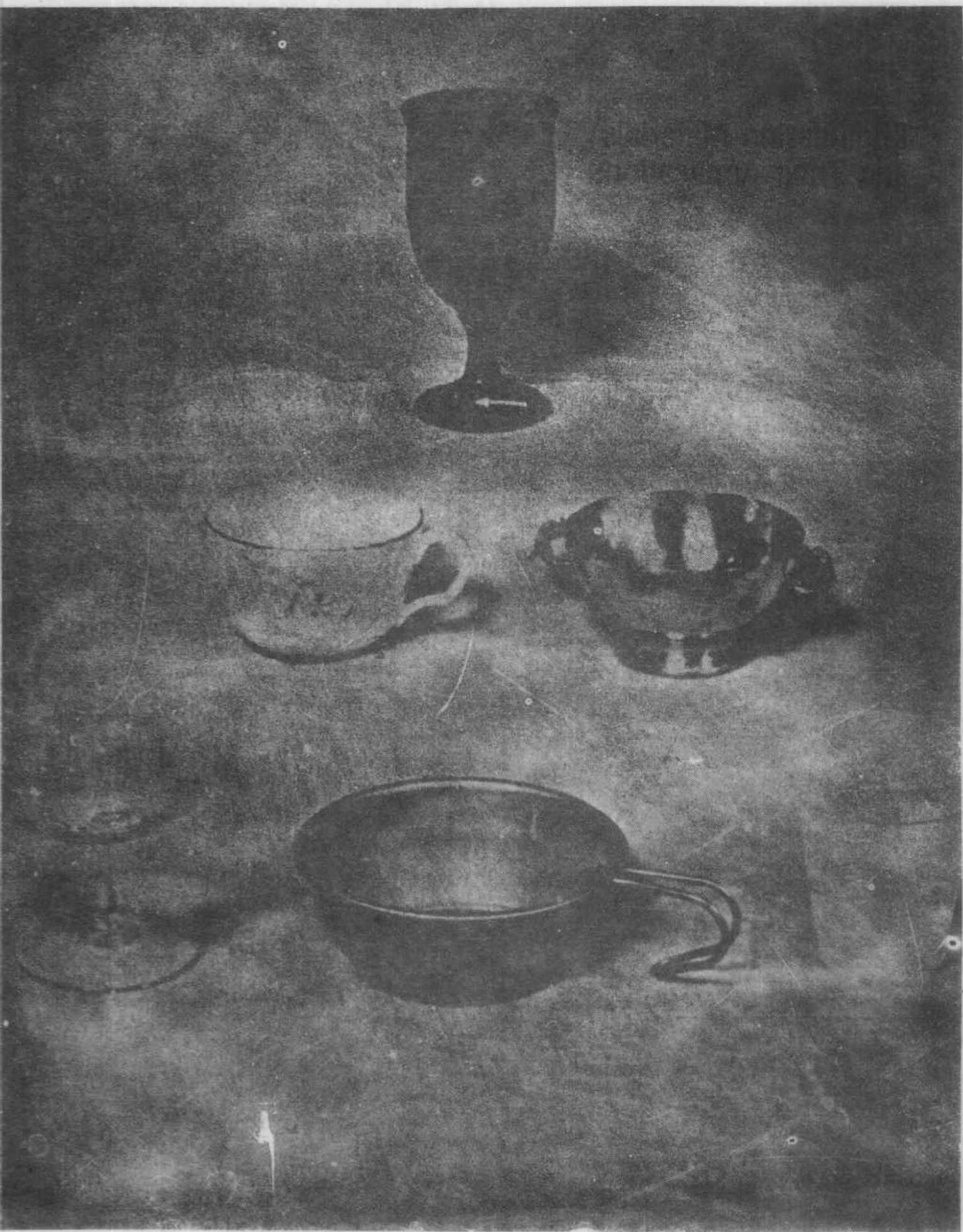
## 16 Optical and Thermal Properties of Materials 699

- 16.1 Introduction 700  
*Optical Properties* 700  
 16.2 Emission 700      16.3 Absorption 706      16.4 Reflection 707  
 16.5 Transmission 707      16.6 Refraction 710  
*Thermal Properties* 711  
 16.7 Introduction 711      16.8 Heat capacity 711      16.9 Thermal conductivity 712      16.10 Thermal expansion 713  
 SUMMARY 717      DEFINITIONS 718      PROBLEMS 719

References 723

Index 727

# **Engineering Materials and Their Applications**





# The Problem of Materials Selection and Development

This photograph illustrates the three important families of materials available to the engineer—the metals, such as steel and silver; the ceramics, such as glass and china; and the plastics or polymers, such as polyethylene and wood.

In this chapter we shall discuss how it is necessary to attain a basic understanding of the *structure* of each of these groups in order to anticipate how they will perform under service conditions. We shall define the word “structure” as indicating (1) the nature of the atoms of which a material is composed, (2) the arrangement of the atoms in structural units called “unit cells” (also “molecules” in the case of the polymers), and (3) the grouping of unit cells to form grains or crystals.