Engineering Materials and Their Applications

THIRD EDITION

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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.

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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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R.A.F.
P.K.T.

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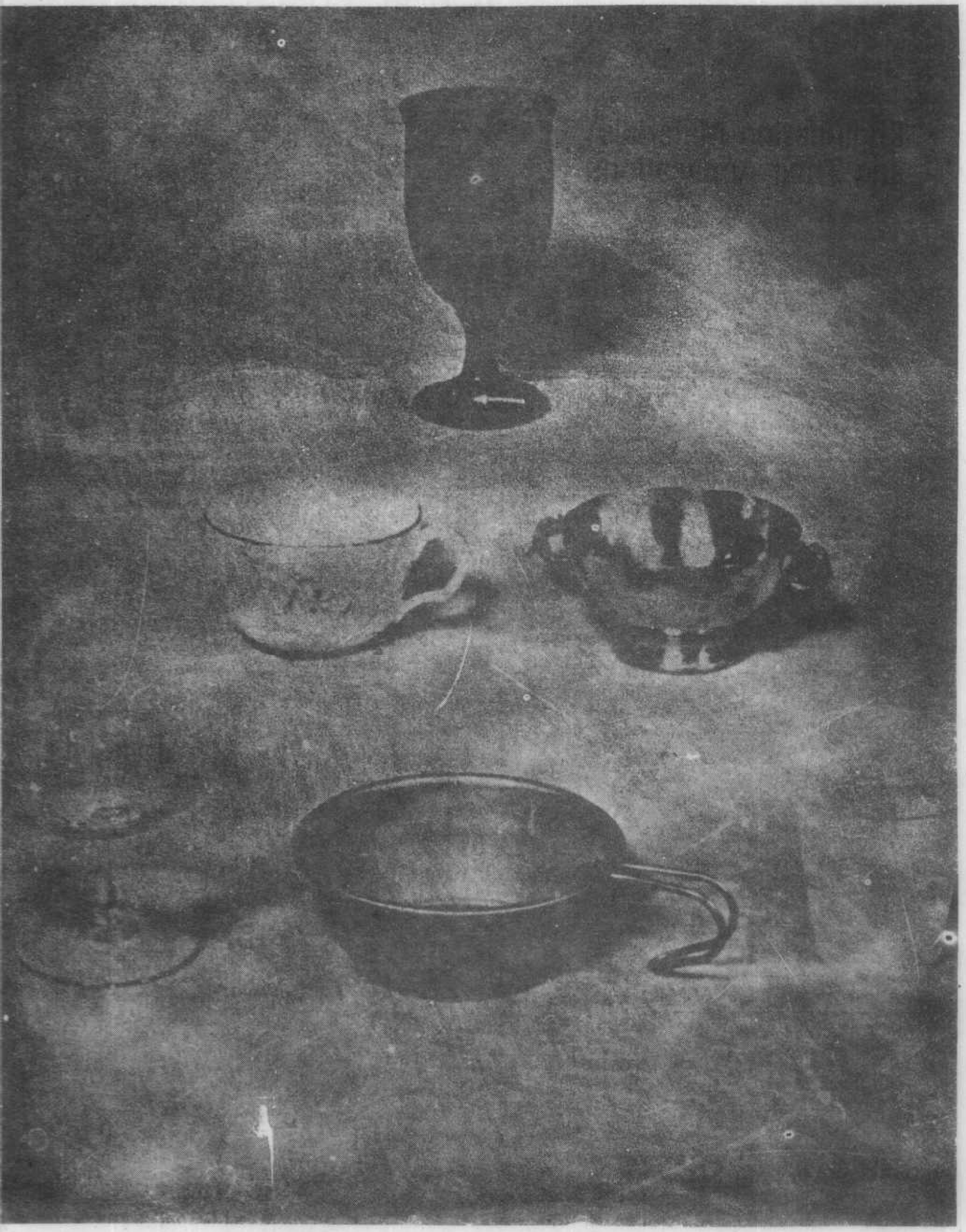

chapter 1

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.

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