volume one

Engineering Materials

R L TIMINGS

Second Edition

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Volume 1

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Preface

Engineering Materials, Volume 1 was originally written to provide a comprehensive text on engineering materials to satisfy the requirements of the Business and Technician Education Council (BTEC) standard units for students studying for an engineering qualification at the OND/ONC ('N' level).

Whilst still satisfying the original aims, this new edition has been rewritten to include additional material in order to give comprehensive coverage of the materials requirements for the Advanced GNVQ Engineering qualification. For example, there is now a chapter on material selection for engineered products. To make room for this additional material, the chapter on bearings and bearing materials has been moved to the new edition of *Engineering Materials*, Volume 2. At the same time, the opportunity has been taken to:

- Make the language less formal and more 'reader friendly'.
- Expand some of the explanations to improve their clarity.
- Correct some errors and omission.
- Modernise the general format of the book.
- Introduce self-assessment exercises at key points in the text.
- Make more use of bulleted summaries.

Each chapter is now prefaced by a summary of the topic areas to be covered and finishes with a selection of practice exercises.

This book leads naturally into *Engineering Materials*, Volume 2, intended for students studying at the HNC/HND level and beyond. The broad coverage of *Engineering Materials*, Volumes 1 and 2 ensures that they not only satisfy the requirements of technician engineers up to the highest level, but also provide an excellent technical background for undergraduates studying for a degree in Mechanical Engineering, Materials Engineering or Combined Engineering.

R. L. Timings
1998

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Hodder and Stoughton for our Fig. 2.14 (from *Engineering Metallurgy* by R. A. Higgins); The Castings Development Centre for our Figs 6.2, 6.3, 6.4, 6.6, 6.7 & 6.8; B & S Massey Ltd for our Figs 10.15 & 10.16; Davey-Loewy Ltd for our Fig. 10.18; Sir James Farmer Norton & Co. (International) Ltd for our Fig. 10.21; Samuel Denison Ltd (Denison Mays Group) for our Figs 11.1(a), 11.17, 11.26 & 11.27; TecQuipment Ltd for our Fig. 11.1(b).

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Introduction – How to use this book

There are many ways of using a text book. You can read through it from cover to cover and try to remember all that you have read. This is rarely successful unless you have a photographic memory, and few of us have. You may consider using it just as a reference book by looking up individual topics as and when you need that specific information. This can be useful as a reminder once you know the subject thoroughly but until then it can lead to misconceived ideas.

So, here are a few thoughts on how to maximise the benefit that you can get from this book.

This book consists of a number of chapters. Each chapter covers a major syllabus area. For example, **Chapter 4** covers plain carbon steels. It is divided up into sections. If you turn back to the Contents page you will find that:

- **Section 4.1** deals with ferrous metals.
- **Section 4.2** deals with the iron–carbon system.
- **Section 4.3** deals with critical change points, and so on.

Sometimes it is necessary to divide these sections up further. For example, Section 4.2 subdivides into:

- **Section 4.2.1**, which deals with cooling transformations for a steel with a eutectoid composition.
- **Section 4.2.2**, which deals with cooling transformations for a steel with hypo-eutectoid composition, and so on.

Don't let the technical jargon words put you off! To understand this chapter you need to have some prior knowledge of basic science, material properties, phase equilibrium diagrams, etc. So, where do you get this prior knowledge and how is the book organised for you to obtain the maximum benefit from it?

It may seem obvious, but start at the beginning. The first two chapters lay the foundations for all that is to follow. As with all the chapters, these two chapters are prefaced with lists of the main topic areas you are going to find in them.

As you work through the chapters, you will come across **self-assessment tasks** at key points. If you have understood what you have read previously, you should be able to complete these exercises *without looking back* at the text. If you have to look back, then you are not yet sure of your ground and there is no point in moving on. Try again and, if you are still not sure, have a chat with your tutor to clear up your difficulty.

At the end of each chapter there is a selection of more extended **exercises**. Your tutor will guide you as to their use and check your responses to ensure that you have the background knowledge required to understand the next topic area to be studied.

Having completed Chapters 1 and 2, you have to decide where to go next:

- If your interest lies in metals you will need Chapter 3 as well.
- For plain carbon steels and their heat treatment you will also require Chapters 4 and 5, but if you want cast irons you can go straight to Chapter 6.
- On the other hand, if you want non-ferrous metals and their alloys you can go to Chapter 7.
- If your interest lies in polymeric (plastic) materials you can turn to Chapters 8 and after completing Chapters 1 and 2.

Whether you work through the book systematically from beginning to end, or through the foundation chapters and then move on to one of the specialist areas, you must complete the self-assessment tasks and end-of-chapter exercises as you come to them. This will ensure that you will understand the next stage of your journey through your study of engineering materials.

Although, as just indicated, this book is organised so that you can take short-cuts through the text to specific areas of interest, it is strongly recommended that, given the time, you should work through the whole book from beginning to end. This is because all engineers and materials scientists should have a general, background knowledge of materials before specialising in a particular field.

Finally, once you have qualified, you can still obtain benefit from this book. The numbering of the sections and subsections, the comprehensive list of contents and the extended index, all aid you to use this text as a quick reference book in your future career in engineering.

Contents

1 Introduction to materials and their properties

The topic areas covered in this chapter are:

- How material properties affect the selection of materials for any given application.
- The basic properties of materials and how these affect the performance of materials in service.
- The grouping of materials into their main categories.

1.1 Introduction

Since the earliest days of the evolution of mankind, the main distinguishing feature between human beings and other mammals has been the ability to use and develop materials to satisfy our human requirements. Initially this was to fashion simple weapons for hunting for food and for territorial defence. Then came tools and implements to cultivate the land and to manufacture the artefacts (such as cooking utensils) required for more civilised living. Woven cloths took the place of animal skins, and manufactured goods became increasingly more sophisticated. Nowadays we use many types of materials, fashioned in many different ways, to satisfy our requirements for housing, heating, furniture, clothes, transportation, entertainment, medical care, defence and all the other trappings of a modern, civilised society.

In the past, mankind looked upon the material resources of the planet Earth as being limitless and these resources were exploited with no thought for the future. However, the rapidly expanding world population and the mass production techniques required to satisfy its needs are using up what are now understood to be finite resources at an alarming rate. Therefore conservation of these resources is an ever-increasing and important issue that must be addressed. Wherever possible waste materials must be reclaimed and recycled, and materials from renewable sources must be used.

Engineers can play an important part in this conservation of material resources by a thorough understanding of the materials they use. This understanding is necessary in order to enable them select the most appropriate materials and to use them with the greatest efficiency, in minimum quantities whilst causing minimum pollution in their extraction, refinement and manufacture.

1.2 Selection of materials

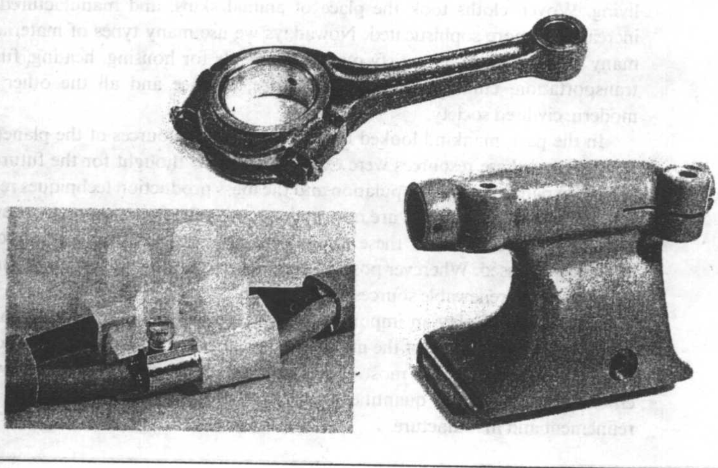
Let's now start by looking at the basic requirements for selecting materials that are suitable for a particular application. This topic area will be returned to in the final chapter of this book in greater detail when all the requirements have been covered. Figure 1.1 shows three objects. The first is a connector joining electric cables. The plastic casing has been partly cut away to show the metal connector. Plastic is used for the outer casing because it is a good electrical insulator and prevents electric shock if a person touches it. It also prevents the conductors touching each other and causing a short circuit. As well as being a good insulator the plastic is cheap, tough, and easily moulded to shape. It has been selected for the casing because of these properties – that is, the properties of toughness, good electrical insulation, and ease of moulding to shape. It is also a relatively low cost material that is readily available.

The metal jointing piece and its clamping screws are made from brass. This metal has been chosen because of its special properties. These properties are: good electrical conductivity, ease of extruding to shape, ease of machining (cutting to length, drilling and tapping the screw threads), adequate strength and corrosion resistance. The precious metal silver is an even better conductor, but it would be far too expensive for this application and it would also be too weak and soft. It is also a relatively scarce material.

The second object in Fig. 1.1 is the connecting rod of a motor car engine. This is made from a special steel alloy. This alloy has been chosen because it combines the properties of strength and toughness with the ability to be readily forged to shape and finished by machining.

The third object shown in Fig. 1.1 is part of a machine tool. It is the tailstock casting for a small lathe. The metal used in this example is cast iron. This metal has been chosen because it combines the properties of adequate strength with ease of melting and casting to a complicated shape. It is also relatively easy to machine to its finished dimensions.

Fig. 1.1 *Material selection*



Thus the reasons for selecting the materials in the above example can be summarised as:

- Commercial factors such as:
  (a) cost
  (b) availability
  (c) ease of manufacture
- Engineering properties of materials such as:
  (a) Electrical conductivity
  (b) strength
  (c) toughness
  (d) ease of forming by extrusion, forging and casting
  (e) machinability
  (f) corrosion resistance, etc.

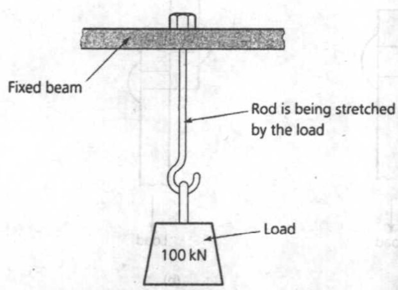
1.3 Mechanical properties of materials

Let's now consider the principal properties of materials which are of importance to the engineer in selecting materials. These can be broadly divided into the *mechanical properties* which are concerned mainly with strength, and the *physical properties* which are concerned with such properties as melting temperature, density, electrical conductivity, thermal conductivity, etc. We will consider the mechanical properties first.

1.3.1 *Tensile strength*

This is the ability of a material to withstand tensile (stretching) loads without breaking. Figure 1.2 shows a heavy load being held up by a rod fastened to a beam. As the force of gravity acting on the load is trying to *stretch* the rod, the rod is said to be in *tension*. Therefore, the material from which the rod is made needs to have sufficient *tensile strength* to resist the pull of the load.

Fig. 1.2 *Tensile strength*

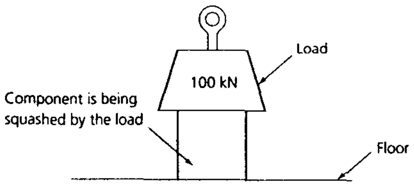


1.3.2 Compressive strength

This is the ability of a material to withstand compressive (squeezing) loads without being crushed or broken. Figure 1.3 shows a component being compressed by a heavy load. Therefore the component needs to be made from a material with adequate *compressive strength* to resist the load.

The applied *stress* is often used instead of the load when comparing the tensile and compressive strengths of materials. Stress is the applied force (load) divided by the cross-sectional area of the component measured at right angles to the direction of application of the force – that is, force per unit area. The units may be N/mm^2 or MN/m^2. The numerical value is the same in both cases; for example, $12\,N/mm^2$ equals $12\,MN/m^2$ (see also Section 11.3).

Fig. 1.3 *Compressive strength*



1.3.3 Shear strength

This is the ability of a material to withstand offset loads, or transverse cutting (shearing actions). Figure 1.4(a) shows a rivet joining two metal bars together. The forces acting on the two bars are trying to pull them apart. Because the loads are not exactly in line, they are

Fig. 1.4 *Shear strength*