Chapter 13

# Data sources

## 13.1 Introduction and synopsis

The engineer, in selecting a material for a developing design, needs data for its properties. Engineers are often conservative in their choice, reluctant to consider material with which they are unfamiliar. One reason is this: that data for the old, well-tried materials are reliable, familiar, easily found; data for newer, more exciting, materials may not exist or, if they do, may not inspire confidence. Yet innovation is often made possible by new materials. So it is important to know where to find material data and how far it can be trusted. This chapter gives information about data sources. Chapter 14, which follows, describes case studies which illustrate data retrieval.

As a design progresses from concept to detail, the data needs evolve in two ways (Figure 13.1). At the start the need is for low-precision data for all materials and processes, structured to facilitate screening. At the end the need is for accurate data for one or a few of them, but with the richness of detail which assists with the difficult aspects of the selection: corrosion, wear, cost estimation and the like. The data sources which help with the first are inappropriate for the second. The chapter surveys data sources from the perspective of the designer seeking information at each stage of the design process. Long-establisihed materials are well documented; less-common materials may be less so, posing problems of checking and, sometimes, of estimation. The chapter proper ends with a discussion of how this can be done.

So much for the text. Half the chapter is contained in the Appendix, Section 13A. It is a catalogue of data sources, with brief commentary. It is intended for reference. When you *really* need data, this is the section you want.

## 13.2 Data needs for design

### Data breadth versus data precision

Data needs evolve as a design develops (Figure 13.1). In the conceptual stage, the designer requires approximate data for the widest possible range of materials. At this stage all options are open: a polymer could be the best choice for one concept, a metal for another, even though the function is the same. Breadth is important; precision is less so. Data for this first-level screening is found in wide-spectrum compilations like the charts of this book, the *Materials Engineering 'Materials Selector'* (1997), and the *Chapman and Hall Materials Selector* (1997).* More effective is software based on these data sources such as the *CMS* and *CPS* (1992, 1998) selection system. The easy access gives the designer the greatest freedom in considering alternatives.

* Details in Further reading.

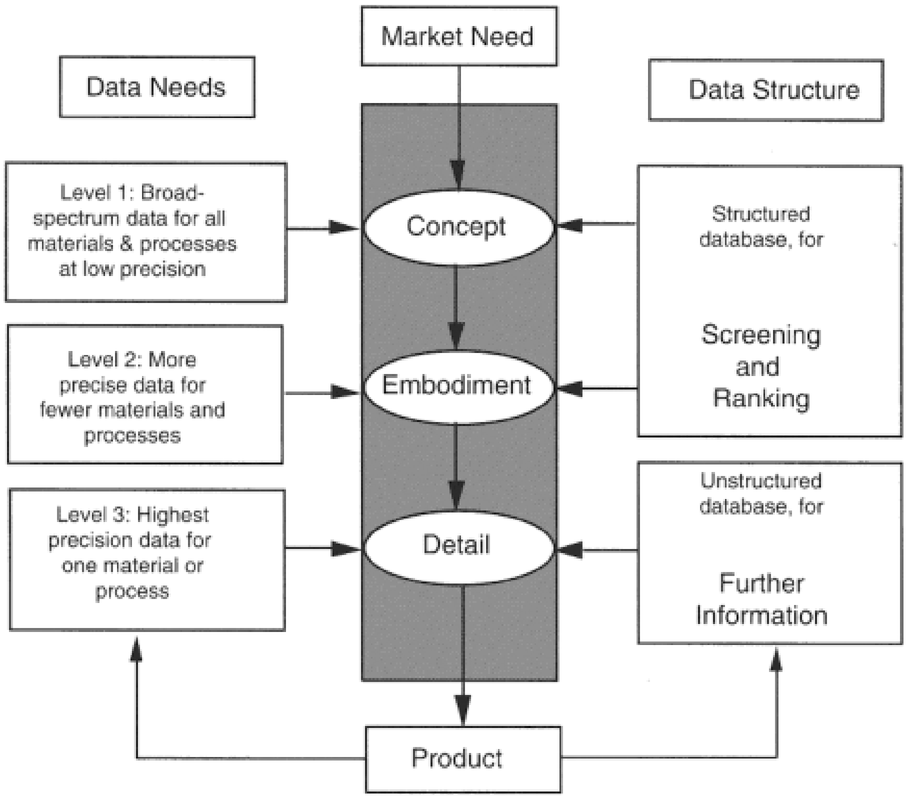
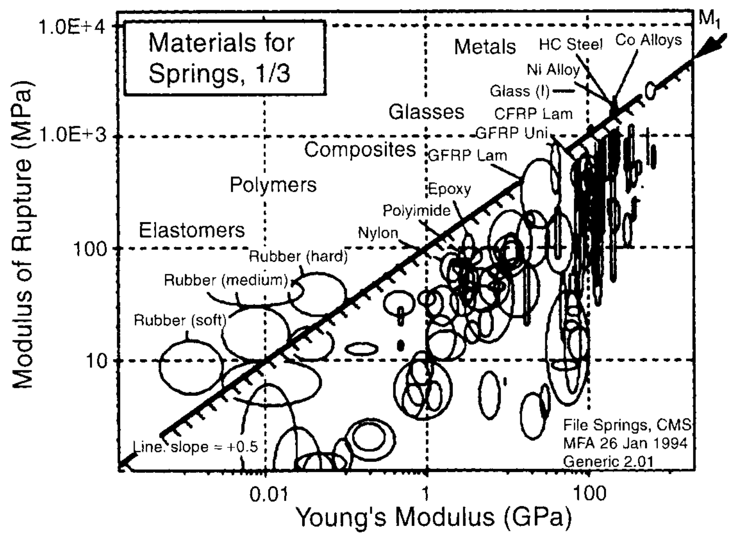



**Fig. 13.1** Data needs and data structure for screening and for further information.

The calculations involved in deciding on the scale and lay-out of the design (the embodiment stage) require more complete information than before, but for fewer candidates. Data allowing this second-level screening are found in the specialized compilations which include handbooks and computer databases, and the data books published by associations or federations of material producers. They list, plot and compare properties of closely related materials, and provide data at a level of precision not usually available in the broad, level 1, compilations. And, if they are doing their job properly, they provide further information about processability and possible manufacturing routes. But, because they contain much more detail, their breadth (the range of materials and processes they cover) is restricted, and access is more cumbersome.

The final, detailed design, stage requires data at a still higher level of precision and with as much depth as possible, but for only one or a few materials. They are best found in the data sheets issued by the producers themselves. A given material (low-density polyethylene, for instance) has a range of properties which derive from differences in the way different producers make it. At the detailed-design stage, a supplier should be identified, and the properties of his product used in the design calculation. But sometimes even this is not good enough. If the component is a critical one (meaning that its failure could be disastrous) then it is prudent to conduct in-house tests, measuring the critical property on a sample of the material that will be used to make the component itself. Parts of power-generating equipment (the turbine disc for instance), or aircraft (the wing spar, the landing gear) and nuclear reactors (the pressure vessel) are like this; for

**Table 13.1** Material data types

| *Data type* | *Example* |
|---|---|
| **Numeric point data** | Atomic number of magnesium: $N_a = 12$ |
| **Numeric range data** | Thermal conductivity of polyethylene: $\lambda = 0.28$ to $0.31$ W/m K |
| **Boolean (yes/no) data** | 304 stainless steel can be welded: Yes |
| **Ranked data** | Corrosion resistance of alumina in tap water (scale A to E): A |
| **Text** | Supplier for aluminium alloys: Alcan, Canada... |
| **Images** |  |



these, every new batch of material is tested, and the batch is accepted or rejected on the basis of the test.

Properties are not all described in the same way. Some, like the atomic number, are described by a single number ('the atomic number of copper = 29'); others, like the modulus or the thermal conductivity are characterized by a range ('Young's modulus for low-density polyethylene = 0.1–0.25 GPa', for instance). Still others can only be described in a qualitative way, or as images. Corrosion resistance is a property too complicated to characterize by a single number; for screening purposes it is ranked on a simple scale: A (very good) to E (very poor), but with further information stored as text files or graphs. The forming characteristics, similarly, are attributes best described by a list ('mild steel can be rolled, forged, or machined'; 'zirconia can be formed by powder methods') with case studies, guidelines and warnings to illustrate how it should be done. The best way to store information about microstructures, or the applications of a material, or the functioning of a process, may be as an image — another data type. Table 13.1 sets out the data types which are typically required for the selection of materials and processes.

## 13.3 Screening: data structure and sources

### Data structure for screening and ranking

To 'select' means: 'to choose'. But from what? Behind the concept of selection lies that of a *kingdom of entities* from which the choice is to be made. The kingdom of materials means: all metals, all polymers, all ceramics and glasses, all composites as in Figure 5.2. If it is *materials* we mean to select, then the kingdom is all of these; leave out part, and the selection is no longer one of materials but of some subset of them. If, from the start, the choice is limited to polymers, then the kingdom becomes a single class of materials, that of polymers. A similar statement holds for processes, based on the kingdom of Figure 11.26.

There is a second implication to the concept of selection; it is that all members of the kingdom must be regarded as candidates — they are, after all, *there* — until (by a series of selection stages) they are shown to be otherwise. From this arises the requirement of a data structure which is *comprehensive* (it includes all members of the kingdom) and the need for characterizing attributes which are *universal* (they apply to all members of the kingdom) and *discriminating* (they have recognizably different values for different members of the kingdom). Similar considerations apply to any selection exercise. We shall use it, in a later chapter, to explore the selection of manufacturing processes.

In the kingdom of materials, many attributes are universal and discriminating: density, bulk modulus and thermal conductivity are examples. Universal attributes can be used for *screening and ranking*, the initial stage of any selection exercise (Figure 13.2, upper half). But if the values of one or more screening attributes are grossly inaccurate or missing, that material is eliminated by

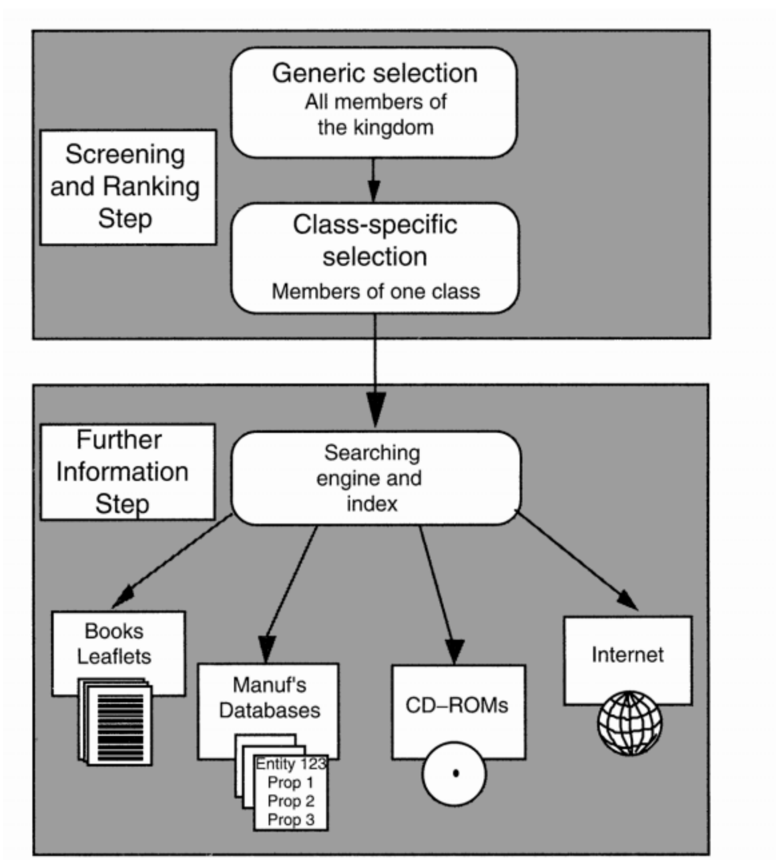



**Fig. 13.2** Summary of the selection strategy. The upper box describes screening, the lower one the search for further information.

default. It is important, therefore, that the database be *complete* and be of high *quality*, meaning that the data in it can be trusted. This creates the need for data checking and estimation, tackled by methods described later in this chapter.

The attribute-limits and index methods introduced in Chapters 5 and 11 are examples of the use of attributes to screen, based on design requirements. They provide an efficient way of reducing the vast number of materials in the materials kingdom to a small manageable subset for which further information can be sought.

### Data sources for screening (see also the Appendix, Section 13A)

The traditional source of materials data is the handbook. The more courageous of them span all material classes, providing raw data for generic screening. More specialized handbooks and trade-association publications contain data suitable for second-level screening (Figure 13.2) as well as text and figures which help with further information. They are the primary sources, but they are clumsy to use because their data structure is not well suited to screening. Comparison of materials of different classes is possible but difficult because data are seldom reported in comparable formats; there is too much unstructured information, requiring the user to filter out what he needs; and the data tables are almost always full of holes.

Electronic sources for generic screening can overcome these problems. If properly structured, they allow direct comparison across classes and selection by multiple criteria, and it is possible (using methods described in this chapter) to arrange that they have no holes.

Screening, as we have seen, identifies a set of viable candidates. We now need their family history. That is the purpose of the 'further information' step.

## 13.4 Further information: data structure and sources

### Data structure for further information

The data requirements in the further information step differ greatly from those for screening (Figure 13.2, lower half). Here we seek additional details about the few candidates that have already been identified by the screening and ranking step. Typically, this is information about availability and pricing; exact values for key properties of the particular version of the material made by one manufacturer; case studies and examples of uses with cautions about unexpected difficulties (e.g. 'liable to pitting corrosion in dilute acetic acid' or 'material Y is preferred to material X for operation in industrial environments'). It is on this basis that the initial shortlist of candidates is narrowed down to one or a few prime choices.

Sources of further information typically contain specialist information about a relatively narrow range of materials or processes. The information may be in the form of text, tables, graphs, photographs, computer programs, even video clips. The data can be large in quantity, detailed and precise in nature, but there is no requirement that it be comprehensive or that the attributes it contains be universal. The most common media are handbooks, trade association publications and manufacturers' leaflets and catalogues. Increasingly such information is becoming available in electronic form on CD-ROMs and on the Internet. Because the data is in 'free' format, the search strategies differ completely from the numerical optimization procedures used for the screening step. The simplest approach is to use an index (as in a printed book), or a keyword list, or a computerized full text search, as implemented in many hyper-media systems.

## Data sources for further information (see also the Appendix, Section 13A)

By 'further information' we mean data sources which, potentially, can contain everything that is known about a material or a process, with some sort of search procedure allowing the user to find and extract the particular details that he seeks. The handbooks and software that are the best sources for screening also contain further information, but because they are edited only infrequently, they are seldom up to date. Trade organizations, listed in the Appendix, Section 13A, do better, providing their members with frequent updates and reports. The larger materials suppliers (Dow Chemical, Ciba-Geigy, Inco, Corning Glass, etc.) publish design guides and compilations of case studies, and all suppliers have data sheets describing their products.

There is an immense resource here. The problem is one of access. It is overcome by capturing the documents on CD-ROM, keyworded and with built-in 'hot-links' to related information, addressed through a search-engine which allows full-text searching on topic strings ('aluminium bronze *and* corrosion *and* sea water', for example).

## Expert systems

The main drawback of the simple, common-or-garden, database is the lack of qualification. Some data are valid under all conditions, others are properly used only under certain circumstances. The qualification can be as important as the data itself. Sometimes the question asked of the database is imprecise. The question: 'What is the strength of a steel?' could be asking for yield strength or tensile strength or fatigue strength, or perhaps the least of all three. If the question were put to a materials expert as part of a larger consultation, he would know from the context which was wanted, would have a shrewd idea of the precision and range of validity of the value, and would warn of its limitations. An ordinary database can do none of this.

Expert systems can. They have the potential to solve problems which require reasoning, provided it is based on rules that can be clearly defined: using a set of geometries to select the best welding technique, for instance; or using information about environmental conditions to choose the most corrosion-resistant alloy. It might be argued that a simple checklist or a table in a supplier's data sheet could do most of these things, but the expert system combines qualitative and quantitative information using its rules (the 'expertise'), in a way which only someone with experience can. It does more than merely look up data; it qualifies it as well, allowing context-dependent selection of material or process. In the ponderous words of the British Computer Society: 'Expert systems offer intelligent advice or take intelligent decisions by embodying in a computer the knowledge-based component of an expert's skill. They must, on demand, justify their line of reasoning in a manner intelligible to the user.'

This context-dependent scheme for retrieving data sounds just what we want, but things are not so simple. An expert system is much more complex than a simple database: it is a major task to elicit the 'knowledge' from the expert; it can require massive programming effort and computer power; and it is difficult to update. A full expert system for materials selection is decades away. Success has been achieved in specialized, highly focused applications: guidance in selecting adhesives from a limited set, in choosing a welding technique, or in designing against certain sorts of corrosion. It is only a question of time before more fully developed systems become available. They are something about which to keep informed.

## Data sources on the Internet

And today we have the Internet. It contains an expanding spectrum of information sources. Some, particularly those on the World-Wide Web, contain information for materials, placed there by standards organizations, trade associations, material suppliers, learned societies, universities, and individuals — some rational, some eccentric — who have something to say. There is no control over the contents of Web pages, so the nature of the information ranges from useful to baffling, and the quality from good to appalling. The Appendix, Section 13A includes a list of WWW sites which contain materials information, but the rate of change here is so rapid that it cannot be seen as comprehensive.

## 13.5 Ways of checking and estimating data

The value of a database of material properties depends on its precision and its completeness — in short, on its quality. One way of maintaining or enhancing quality is to subject data to validating procedures. The property ranges and dimensionless correlations, described below, provide powerful tools for doing this. The same procedures fill a second function: that of providing estimates for missing data, essential when no direct measurements are available.

### Property ranges

Each property of a given class of materials has a characteristic *range*. A convenient way of presenting the information is as a table in which a low ($L$) and a high ($H$) value are stored, identified by the material class. An example listing Young's modulus, $E$, for the generic material classes is shown in Table 13.2, in which $E_L$ is the lower limit and $E_H$ the upper one.

All properties have characteristic ranges like these. The range becomes narrower if the classes are made more restrictive. For purposes of checking and estimation, described in a moment, it is helpful to break down the class of *metals* into cast irons, steels, aluminium alloys, magnesium alloys, titanium alloys, copper alloys and so on. Similar subdivisions for polymers (thermoplastics, thermosets, elastomers) and for ceramics and glasses (engineering ceramics, whiteware, silicate glasses, minerals) increases resolution here also.

**Table 13.2** Ranges of Young's modulus $E$ for broad material classes

| *Material class* | *$E_L$ (GPa)* | *$E_H$ (GPa)* |
|---|---|---|
| All solids | 0.00001 | 1000 |
| Classes of solid | | |
| Metals: ferrous | 70 | 220 |
| Metals: non-ferrous | 4.6 | 570 |
| Fine ceramics* | 91 | 1000 |
| Glasses | 47 | 83 |
| Polymers: thermoplastic | 0.1 | 4.1 |
| Polymers: thermosets | 2.5 | 10 |
| Polymers: elastomers | 0.0005 | 0.1 |
| Polymeric foams | 0.00001 | 2 |
| Composites: metal-matrix | 81 | 180 |
| Composites: polymer-matrix | 2.5 | 240 |
| Woods: parallel to grain | 1.8 | 34 |
| Woods: perpendicular to grain | 0.1 | 18 |

*Fine ceramics are dense, monolithic ceramics such as SiC, $Al_2O_3$, $ZrO_2$, etc.

## Correlations between material properties

Materials which are stiff have high melting points. Solids with low densities have high specific heats. Metals with high thermal conductivities have high electrical conductivities. These rules-of-thumb describe correlations between two or more material properties which can be expressed more quantitatively as limits for the values of *dimensionless property groups*. They take the form

$$C_L < P_1 P_2^n < C_H \tag{13.1}$$

or

$$C_L < P_1 P_2^n P_3^m < C_H \tag{13.2}$$

(or larger groupings) where $P_1$, $P_2$, $P_3$ are material properties, $n$ and $m$ are simple powers (usually $-1$, $-1/2$, $1/2$ or 1), and $C_L$ and $C_H$ are dimensionless constants — the lower and upper limits between which the values of the property-group lies. The correlations exert tight constraints on the data, giving the 'patterns' of property envelopes which appear on the material selection charts. An example is the relationship between expansion coefficient, $\alpha$ (units: $K^{-1}$), and the melting point, $T_m$ (units: K) or, for amorphous materials, the glass temperature $T_g$:

$$C_L \le \alpha T_m \le C_H \tag{13.3a}$$

$$C_L \le \alpha T_g \le C_H \tag{13.3b}$$

— a correlation with the form of equation (13.1). Values for the dimensionless limits $C_L$ and $C_H$ for this group are listed in Table 13.3 for a number of material classes. The values span a factor to 2 to 10 rather than the factor 10 to 100 of the property ranges. There are many such correlations. They form the basis of a hierarchical data checking and estimating scheme (one used in preparing the charts in this book), described next.

## Data checking

The method is shown in Figure 13.3. Each datum is associated with a material class, or, at a higher level of checking, with a sub-class. It is first compared with the range limits $L$ and $H$ for that class and property. If it lies within the range limits, it is accepted; if it does not, it is flagged for checking.

**Table 13.3** Limits for the group $\alpha T_m$ and $\alpha T_g$ for broad material classes*

| *Correlation** $C_L < \alpha T_m < C_H$ | $C_L(\times 10^{-3})$ | $C_H(\times 10^{-3})$ |
|---|---|---|
| All solids | 0.1 | 56 |
| Classes of solid | | |
| Metals: ferrous | 13 | 27 |
| Metals: non-ferrous | 2 | 21 |
| Fine ceramics* | 6 | 24 |
| Glasses | 0.3 | 3 |
| Polymers: thermoplastic | 18 | 35 |
| Polymers: thermosets | 11 | 41 |
| Polymers: elastomers | 35 | 56 |
| Polymeric foams | 16 | 37 |
| Composites: metal-matrix | 10 | 20 |
| Composites: polymer-matrix | 0.1 | 10 |
| Woods: parallel to grain | 2 | 4 |
| Woods: perpendicular to grain | 6 | 17 |

*For amorphous solids the melting point $T_m$ is replaced by the glass temperature $T_g$.

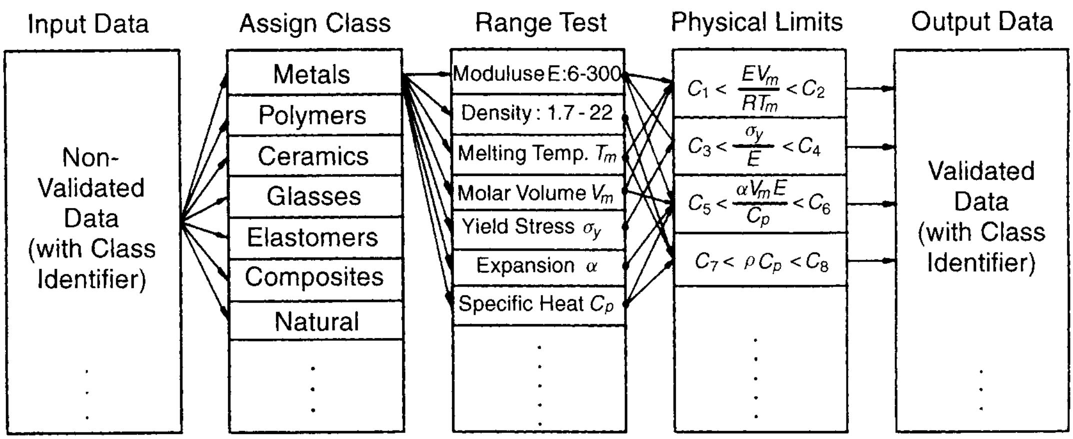



**Fig. 13.3** The checking procedure. Range checks catch gross errors in all properties. Checks using dimensionless groups can catch subtler errors in certain properties. The estimating procedure uses the same steps, but in reverse order.

Why bother with such low-level stuff? It is because in compilations of material or process properties, the commonest error is that of a property value which is expressed in the wrong units, or is, for less obvious reasons, in error by one or more orders of magnitude (slipped decimal point, for instance). Range checks catch errors of this sort. If a demonstration of this is needed, it can be found by applying them to the contents of almost any standard reference data books; none among those we have tried has passed without errors.

In the second stage, each of the dimensionless groups of properties like that of Table 13.3 is formed in turn, and compared with the range bracketed by the limits $C_L$ and $C_H$. If the value lies within its correlation limits, it is accepted; if not, it is checked. Correlation checks are more discerning than range checks and catch subtler errors, allowing the quality of data to be enhanced further.

## Data estimation

The relationships have another, equally useful, function. There remain gaps in our knowledge of material properties. The fracture toughness of many materials has not yet been measured, nor has the electric breakdown potential; even moduli are not always known. The absence of a datum for a material would falsely eliminate it from a selection which used that property, even though the material might be a viable candidate. This difficulty is avoided by using the correlation and range limits to estimate a value for the missing datum, adding a flag to alert the user that they are estimates.

In estimating property values, the procedure used for checking is reversed: the dimensionless groups are used first because they are the more accurate. They can be surprisingly good. As an example, consider estimating the expansion coefficient, $\alpha$, of polycarbonate from its glass temperature $T_g$. Inverting equation (13.3) gives the estimation rule:

$$\frac{C_L}{T_g} \leq \alpha \leq \frac{C_H}{T_g} \tag{13.4}$$

Inserting values of $C_L$ and $C_H$ from Table 13.3, and the value $T_g = 420\,\mathrm{K}$ for a particular sample of polycarbonate gives the mean estimate

$$\overline{\alpha} = 63 \times 10^{-3}\,\mathrm{K}^{-1} \tag{13.5}$$

The reported value for polycarbonate is

$$\alpha = 54 - 62 \times 10^{-3}\,\mathrm{K}^{-1}$$

The estimate is within 9% of the mean of the measured values, perfectly adequate for screening purposes. That it is an estimate must not be forgotten, however: if thermal expansion is crucial to the design, better data or direct measurements are essential.

Only when the potential of the correlations is exhausted are the property ranges invoked. They provide a crude first estimate of the value of the missing property, far less accurate than that of the correlations, but still useful in providing guide-values for screening.

## 13.6 Summary and conclusions

The systematic way to select materials or processes (or anything else, for that matter) is this.

(a) Identify the taxonomy of the *kingdom* from which the selection is to be made; its *classes*, *subclasses* and *members*.
(b) Identify the *attributes* of the members, remembering that they should be *universal* and *discriminating* within this kingdom; resolution is increased by defining second-level 'sub-kingdoms' allowing an expanded set of attributes, universal within the sub-kingdom.
(c) Assess the *quality* and *completeness* of the data sources for the attributes; both can be increased by techniques of checking and estimation described in the previous section.
(d) Reduce the large population of the kingdom to a shortlist of potential candidates by *screening* on attributes in the first and second-level kingdoms.
(e) Identify sources of *further information* for the candidates: texts, design guides, case studies, suppliers' data sheets or (better) searchable electronic versions of these, including the Internet.
(f) Compare full character profiles of the candidates with requirements of the design, taking into account local constraints (preferences, experience, compatibility with other activities, etc.).

To do all this you need to know where to find data, and you need it at three levels of breadth and precision. Conceptual design requires a broad survey at the low accuracy offered by the selection charts of Chapters 4 and 11, and by other broad-spectrum data tabulations. Embodiment design needs more detail and precision, of the kind found in the handbooks and computer databases listed in the Appendix, Section 13A. The final, detailed, phase of design relies on the yet more precise (and attributable) information contained in material suppliers' data sheets.

The falling cost and rising speed of computing makes databases increasingly attractive. They allow fast retrieval of data for a material or a process, and the selection of the subset of them which have attributes within a specified range. Commercially available databases already help enormously in selection, and are growing every year. Some of those currently available are reviewed in the Appendix, Section 13A.

Expert systems lurk somewhere in the future. They combine a database with a set of rules for reasoning to permit simple, logical deductions to be made by the computer itself, allowing it to retrieve relevant information which the operator did not know or forgot to ask for. They combine the data of a handbook with some of the expertise of a materials consultant. They are difficult to create and demand much computer power, but the selection process lends itself well to expert-systems programming; they will, sooner or later, be with us.

Don't leave this chapter without at least glancing at the compilation of data sources in the next section. It is probably the most useful bit.

## 13.7 Further reading

Ashby, M.F. (1998) 'Checks and estimates for material properties', Cambridge University Engineering Department, *Proc. Roy. Soc. A* **454**, 1301–1321.

Bassetti, D., Brechet, Y. and Ashby, M.F. (1998) 'Estimates for material properties: the method of multiple correlations', *Proc. Roy. Soc. A* **454**, 1323–1336.

Cebon, D. and Ashby, M.F. (1992) 'Computer-aided selection for mechanical design', *Metals and Materials*, January, 25–30.

Cebon, D. and Ashby, M.F. (1996) 'Electronic material information systems', *I. Mech. E. Conference on Electronic Delivery of Design Information*, October, 1996, London, UK.

*CMS (Cambridge Materials Selector)* (1992), Granta Design, Trumpington Mews, 40B High Street, Trumpington, Cambridge CB2 2LS, UK.

*CPS (Cambridge Process Selector)* (1998), Granta Design, Trumpington Mews, 40B High Street, Trumpington, Cambridge CB2 2LS, UK.

The Copper Development Association (1994) *Megabytes on Coppers*, Orchard House, Mutton Lane, Potters Bar, Herts EN6 3AP, UK; and Granta Design Limited, 20 Trumpington St., Cambridge CB2 1PZ, UK, 1994.

# 13A Appendix: Data sources for material and process attributes

## 13A.1 Introduction

### Background

This appendix tells you where to look to find material property data. The sources, broadly speaking, are of three sorts: hard copy, software and the Internet. The hard copy documents listed below will be found in most engineering libraries. The computer databases are harder to find: the supplier is listed, with address and contact number, as well as the hardware required to run the database. Internet sites are easy to find but can be frustrating to use.

Section 13A.2 lists sources of information about database structure and functionality. Sections 13A.3 catalogues hard-copy data sources for various classes of material, with a brief commentary where appropriate. Selection of material is often linked to that of processing; Section 13A.4 provides a starting point for reading on processes. Section 13A.5 gives information about the rapidly growing portfolio of software for materials and process data and information. Section 13A.6 — the last — lists World-wide Web sites on which materials information can be found.

## 13A.2 General references on databases

Waterman, N.A., Waterman, M. and Poole, M.E. (1992) 'Computer based materials selection systems', *Metals and Materials* **8**, 19–24.

Sargent, P.M. (1991) *Materials Information for CAD/CAM*, Butterworths-Heinemann, Oxford. A survey of the way in which materials data-bases work. No data.
Demerc, M.Y. (1990) *Expert System Applications in Materials Processing and Manufacture*. TMS Publications, 420 Commonwealth Drive, Warrendale, Penn. 15086, USA.

## 13A.3 Hard-copy data sources

### Data sources, all materials

Few hard-copy data sources span the full spectrum of materials and properties. Six which, in different ways, attempt to do so are listed below.

*Materials Selector* (1997), Materials Engineering, Special Issue. Penton Publishing, Cleveland, Ohio, USA. Tabular data for a broad range of metals, ceramics, polymers and composites, updated annually. Basic reference work.
*The Chapman and Hall 'Materials Selector'* (1996), edited by N.A. Waterman and M.F. Ashby. Chapman and Hall, London, UK. A 3-volume compilation of data for all materials, with selection and design guide. Basic reference work.
*ASM Engineered Materials Reference Book*, 2nd edition (1994), editor Bauccio, M.L., ASM International, Metals Park, Ohio 44073, USA. Compact compilation of numeric data for metals, polymers, ceramics and composites.
*Materials Selector and Design Guide* (1974), Design Engineering, Morgan-Grampian Ltd, London. Resembles the *Materials Engineering 'Materials Selector'*, but less detailed and now rather dated.
*Handbook of Industrial Materials* (1992) 2nd edition, Elsevier, Oxford, UK. A compilation of data remarkable for its breadth: metals, ceramics, polymers, composites, fibres, sandwich structures, leather...
*Materials Handbook* (1986) 12th edition, editors Brady, G.S. and Clauser, H.R., McGraw-Hill, New York, USA. A broad survey, covering metals, ceramics, polymers, composites, fibres, sandwich structures and more.
*Handbook of Thermophysical Properties of Solid Materials* (1961) Goldsmith, A., Waterman, T.E. and Hirschhorn, J.J. MacMillan, New York, USA. Thermophysical and thermochemical data for elements and compounds.
*Guide to Engineering Materials Producers* (1994) editor Bittence, J.C. ASM International, Metals Park, Ohio 44037, USA. A comprehensive catalog of addresses for material suppliers.

### Data sources, all metals

Metals and alloys conform to national and (sometimes) international standards. One consequence is the high quality of data. Hard copy sources for metals data are generally comprehensive, well-structured and easy to use.

*ASM Metals Handbook* (1986) 9th Edition, and (1990) 10th Edition. ASM International, Metals Park, Ohio, 44073 USA. The 10th Edition contains Vol. 1: Irons and Steels; Vol 2: Non-ferrous Alloys; Vol 3: Heat Treatment; Vol 4: Friction, Lubrication and Wear; Vol 5: Surface Finishing and Coating; Vol 6: Welding and Brazing; Vol 7: Microstructural Analysis; more volumes are planned for release in 1992/93. Basic reference work, continuously upgraded and expanded.
*ASM Metals Reference Book*, 3rd edition (1993) ed. M.L. Bauccio, ASM International, Metals Park, Ohio 44073, USA. Consolidates data for metals from a number of ASM publications. Basic reference work.
Brandes, E.A. and Brook, G.B. (1997) *Smithells Metals Reference Book*, 7th edition, Butterworth-Heinemann, Oxford. A comprehensive compilation of data for metals and alloys. Basic reference work.
*Metals Databook* (1990), Colin Robb. The Institute of Metals, 1 Carlton House Terrace, London SW1Y 5DB, UK. A concise collection of data on metallic materials covered by the UK specifications only.
*ASM Guide to Materials Engineering Data and Information* (1986). ASM International, Metals Park, Ohio 44073, USA. A directory of suppliers, trade organizations and publications on metals.
*The Metals Black Book, Volume 1, Steels* (1992) ed. J.E. Bringas, Casti Publishing Inc. 14820–29 Street, Edmonton, Alberta T5Y 2B1, Canada. A compact book of data for steels.

*The Metals Red Book, Volume 2, Nonferrous Metals* (1993) ed. J.E. Bringas, Casti Publishing Inc. 14820–29 Street, Edmonton, Alberta T5Y 2B1, Canada.

## Data sources, specific metals and alloys

In addition to the references listed under Section 13A.2, the following sources give data for specific metals and alloys

### Pure metals

Most of the sources listed in the previous section contain some information on pure metals. However, the publications listed below are particularly useful in this respect.

Winter, M. 'WebElements', http://www.shef.ac.uk/~chem/web-elements/, University of Sheffield. A comprehensive source of information on all the elements in the Periodic Table. If it has a weakness, it is in the definitions and values of some mechanical properties.

Emsley, J. *The Elements*, Oxford University Press, Oxford, UK (1989). A book aimed more at chemists and physicists than engineers with good coverage of chemical, thermal and electrical properties but not mechanical properties. A new edition is expected early in 1997.

Brandes, E.A. and Brook, G.B. (eds) *Smithells Metals Reference Book* (7th edition), Butterworth-Heinemann, Oxford (1997). Data for the mechanical, thermal and electrical properties of pure metals.

Goodfellow Catalogue (1995–6), Goodfellow Cambridge Limited, Cambridge Science Park, Cambridge, CB4 4DJ, UK. Useful though patchy data for mechanical, thermal and electrical properties of pure metals in a tabular format. Free.

Alfa Aesar Catalog (1995–96) Johnson Matthey Catalog Co. Inc., 30 Bond Street, Ward Hill, MA 01835–8099, USA. Coverage similar to that of the Goodfellow Catalogue. Free.

Samsonov, G.V. (ed.) *Handbook of the Physiochemical Properties of the Elements*, Oldbourne, London (1968). An extensive compilation of data from Western and Eastern sources. Contains a number of inaccuracies, but also contains a large quantity of data on the rarer elements, hard to find elsewhere.

Gschneidner, K.A. 'Physical properties and interrelationships of metallic and semimetallic elements', *Solid State Physics*, **16**, 275–426 (1964). Probably the best source of its time, this reference work is very well referenced, and full explanations are given of estimated or approximate data.

### Non-ferrous metals

### Aluminium alloys

*Aluminium Standards and Data*, The Aluminium Association Inc., 900, 19th Street N.W., Washington, DC 20006, USA (1990).

*The Properties of Aluminium and its Alloys*, The Aluminium Federation, Broadway House, Calthorpe Road, Birmingham, B15 1TN, UK (1981).

Technical Data Sheets, ALCAN International Ltd, Kingston Research and Development Center, Box 8400, Kingston, Ontario, Canada KL7 4Z4, and Banbury Laboratory, Southam Road, Banbury, Oxon., UK, X16 7SP (1993).

Technical Data Sheets, ALCOA, 1501 Alcoa Building, Pittsburg, PA 15219, USA (1993).

Technical Data Sheets, Aluminium Pechiney, 23 Bis, rue Balzac, Paris 8, BP 78708, 75360 Paris Cedex 08, France (1994).

### Babbitt metal

The term 'Babbitt metal' denotes a series of lead–tin–antimony bearing alloys, the first of which was patented in the USA by Isaac Babbitt in 1839. Subsequent alloys are all variations on his original composition.

ASTM Standard B23-83: 'White Metal Bearing Alloys (Known Commercially as 'Babbitt Metal')', *ASTM Annual Book of Standards*, Vol. 02.04.

### Beryllium

*Designing with Beryllium*, Brush Wellman Inc, 1200 Hana Building, Cleveland, OH 44115, USA (1996).
*Beryllium Optical Materials*, Brush Wellman Inc, 1200 Hana Building, Cleveland, OH 44115, USA (1996).

### Cadmium

International Cadmium Association, *Cadmium Production, Properties and Uses*, ICdA, London, UK (1991).

### Chromium

ASTM Standard A560-89: 'Castings, Chromium-Nickel Alloy', *ASTM Annual Book of Standards*, Vol. 01.02.

### Cobalt alloys

Betteridge, W. *Cobalt and its alloys*, Ellis Horwood, Chichester, UK (1982). A good general introduction to the subject.

### **Columbium alloys:** see Niobium alloys

### Copper alloys

*ASM Metals Handbook* 10th edition, ASM International, Metals Park, Ohio, USA (1990).
*The Selection and Use of Copper-based Alloys*, E.G. West, Oxford University Press, Oxford, UK (1979).
Copper Development Association Data Sheets, 26 (1988), 27 (1981), 31 (1982), 40 (1979), and Publication 82 (1982), Copper Development Association Inc., Greenwich Office, Park No. 2, Box 1840, Greenwich CT 06836, USA, and The Copper Development Association, Orchard House, Mutton Lane, Potters Bar, Herts, EN6 3AP, UK.
*Megabytes on Coppers* CD-ROM, Granta Design Ltd., 20 Trumpington Street, Cambridge CB2 1QA, UK (1994).
*Smithells Metals Reference Book*, 7th edition, eds E.A. Brandes and G.B. Brook, Butterworth-Heinemann, Oxford, UK (1992).

### Dental alloys

O'Brien, W.J. 'Biomaterial Properties Database', http://www.lib.umich.edu/libhome/Dentistry.lib/Dental_tables, School of Dentistry, Univ. of Michigan, USA. An extensive source of information, both for natural biological materials and for metals used in dental treatments.
Jeneric Pentron Inc., 'Casting Alloys', http://www.jeneric.com/casting, USA. An informative commercial site.
ISO Standard 1562:1993, 'Dental casting gold alloys', International Standards Organization, Switzerland.
ISO Standard 8891:1993, 'Dental casting alloys with Noble metal content of 25% up to but not including 75%', International Standards Organization, Switzerland.

### Gold

Rand Refinery Limited, http://www.bullion.org.za/associates/rr.htm, Chamber of Mines Web-site, SOUTH AFRICA. Contains useful information on how gold is processed to varying degrees of purity.
See also the section on Dental alloys, above.

### Indium

The Indium Info Center, http://www.indium.com/metalcenter.html, Indium Corp. of America.

## Lead

ASTM Standard B29-79: 'Pig Lead', *ASTM Annual Book of Standards*, Vol. 02.04.
ASTM Standard B102-76: 'Lead- and Tin-Alloy Die Castings', *ASTM Annual Book of Standards*, Vol. 02.04.
ASTM Standard B749-85: 'Lead and Lead Alloy Strip, Sheet, and Plate Products', *ASTM Annual Book of Standards*, Vol. 02.04.
Lead Industries Association, *Lead for Corrosion Resistant Applications*, LIA Inc., New York, USA.
*ASM Metals Handbook*, 9th edition, Vol. 2, pp. 500–510 (1986).
See also Babbitt metal (above)

## Magnesium alloys

Technical Data Sheets, Magnesium Elektron Ltd., PO Box 6, Swinton, Manchester, UK (1994).
Technical Literature, Magnesium Corp. of America, Div. of Renco, Salt Lake City, UT, USA (1994).

## Molybdenum

ASTM Standard B386-85: 'Molybdenum and Molybdenum Alloy Plate, Sheet, Strip and Foil', *ASTM Annual Book of Standards*, Vol. 02.04.
ASTM Standard B387-85: 'Molybdenum and Molybdenum Alloy Bar, Rod and Wire', *ASTM Annual Book of Standards*, Vol. 02.04.

## Nickel

A major data source for Nickel and its alloys is the Nickel Development Institute (NIDI), a global organization with offices in every continent except Africa. NIDI freely gives away large quantities of technical reports and data compilations, not only for nickel and high-nickel alloys, but also for other nickel-bearing alloys, e.g. stainless steel.

ASTM Standard A297-84, 'Steel Castings, Iron-Chromium and Iron-Chromium-Nickel, Heat Resistant, for General Application', *ASTM Annual Book of Standards*, Vol. 01.02;
ASTM Standard A344-83, 'Drawn or Rolled Nickel-Chromium and Nickel-Chromium-Iron Alloys for Electrical Heating Elements', *ASTM Annual Book of Standards*, Vol. 02.04.
ASTM Standard A494-90, 'Castings, Nickel and Nickel Alloy', *ASTM Annual Book of Standards*, Vol. 02.04.
ASTM Standard A753-85, 'Nickel-Iron Soft Magnetic Alloys', *ASTM Annual Book of Standards*, Vol. 03.04.
Betteridge, W., 'Nickel and its alloys', Ellis Horwood, Chichester, UK (1984). A good introduction to the subject.
INCO Inc., 'High-Temperature, High-Strength Nickel Base Alloys', Nickel Development Institute (1995). Tabular data for over 80 alloys.
Elliott, P. *Practical Guide to High-Temperature Alloys*, Nickel Development Institute, Birmingham, UK (1990).
INCO Inc., *Heat & Corrosion Resistant Castings*, Nickel Development Institute, Birmingham, UK (1978).
INCO Inc., *Engineering Properties of some Nickel Copper Casting Alloys*, Nickel Development Institute, Birmingham, UK (1969).
INCO Inc., *Engineering Properties of IN-100 Alloy*, Nickel Development Institute, Birmingham, UK (1968).
INCO Inc., *Engineering Properties of Nickel-Chromium Alloy 610 and Related Casting Alloys*, Nickel Development Institute, Birmingham, UK (1969).
INCO Inc., *Alloy 713C: Technical Data*, Nickel Development Institute, Birmingham, UK (1968).
INCO Inc., *Alloy IN-738: Technical Data*, Nickel Development Institute, Birmingham, UK (1981).
INCO Inc., *36% Nickel-Iron Alloy for Low Temperature Service*, Nickel Development Institute, Birmingham, UK (1976).
ASTM Standard A658 (Discontinued 1989) 'Pressure Vessel Plates, Alloy Steel, 36 Percent Nickel', *ASTM Annual Book of Standards*, pre-1989 editions.
*ASM Metals Handbook*, 9th ed., Vol. 3, pp. 125–178 (1986).
Carpenter Technology Corp. Website, http//www.cartech.com/

## Niobium (columbium) alloys

ASTM Standard B391-89: 'Niobium and Niobium Alloy Ingots', *ASTM Annual Book of Standards*, Vol. 02.04;
ASTM Standard B392-89: 'Niobium and Niobium Alloy Bar, Rod and Wire', *ASTM Annual Book of Standards*, Vol. 02.04.
ASTM Standard B393-89: 'Niobium and Niobium Alloy Strip, Sheet and Plate', *ASTM Annual Book of Standards*, Vol. 02.04.
ASTM Standard B652-85: 'Niobium-Hafnium Alloy Ingots', *ASTM Annual Book of Standards*, Vol. 02.04.
ASTM Standard B654-79: 'Niobium-Hafnium Alloy Foil, Sheet, Strip and Plate', *ASTM Annual Book of Standards*, Vol. 02.04.
ASTM Standard B655-85: 'Niobium-Hafnium Alloy Bar, Rod and Wire', *ASTM Annual Book of Standards*, Vol. 02.04.
Husted, R, http://www-c8.lanl.gov/infosys/html/periodic/41.html, Los Alamos National Laboratory, USA. An overview of Niobium and its uses.

## Palladium

ASTM Standard B540-86: 'Palladium Electrical Contact Alloy', *ASTM Annual Book of Standards*, Vol. 03.04.
ASTM Standard B563-89: 'Palladium-Silver-Copper Electrical Contact Alloy', *ASTM Annual Book of Standards*, Vol. 03.04.
ASTM Standard B589-82: 'Refined Palladium' *ASTM Annual Book of Standards*, Vol. 02.04.
ASTM Standard B683-90: 'Pure Palladium Electrical Contact Material', *ASTM Annual Book of Standards*, Vol. 03.04.
ASTM Standard B685-90: 'Palladium-Copper Electrical Contact Material', *ASTM Annual Book of Standards*, Vol. 03.04.
ASTM Standard B731-84: '60% Palladium-40% Silver Electrical Contact Material', *ASTM Annual Book of Standards*, Vol. 03.04.
Jeneric Pentron Inc., 'Casting Alloys', http://www.jeneric.com/casting, USA. An informative commercial site, limited to dental alloys.

## Platinum alloys

ASTM Standard B684-81: 'Platinum-Iridium Electrical Contact Material', *ASTM Annual Book of Standards*, Vol. 03.04;
'Elkonium Series 400 datasheets', CMW Inc., Indiana, USA.
*ASM Metals Handbook*, 9th edition, Vol. 2, pp. 688–698 (1986).

## Silver alloys

ASTM Standard B413-89: 'Refined Silver', *ASTM Annual Book of Standards*, Vol. 02.04.
ASTM Standard B 617-83: 'Coin Silver Electrical Contact Alloy', *ASTM Annual Book of Standards*, Vol. 03.04.
ASTM Standard B 628-83: 'Silver-Copper Eutectic Electrical Contact Alloy', *ASTM Annual Book of Standards*, Vol. 03.04.
ASTM Standard B 693-87: 'Silver-Nickel Electrical Contact Materials', *ASTM Annual Book of Standards*, Vol. 03.04.
ASTM Standard B742-90: 'Fine Silver Electrical Contact Fabricated Material', *ASTM Annual Book of Standards*, Vol. 03.04.
ASTM Standard B 780-87: '75% Silver, 24.5% Copper, 0.5% Nickel Electrical Contact Alloy', *ASTM Annual Book of Standards*, Vol. 03.04.
Elkonium Series 300 datasheets, CMW Inc., 70 S. Gray Street, PO Box 2266, Indianapolis, Indiana, USA (1996).
Elkonium Series 400 datasheets, CMW Inc., 70 S. Gray Street, PO Box 2266, Indianapolis, Indiana, USA (1996).
Jeneric Pentron Inc., 'Casting Alloys', http://www.jeneric.com/casting, USA. An informative commercial site, limited to dental alloys.

## Tantalum alloys

ASTM Standard B365-86: 'Tantalum and Tantalum Alloy Rod and Wire', *ASTM Annual Book of Standards*, Vol. 02.04.
ASTM Standard B521-86: 'Tantalum and Tantalum Alloy Seamless and Welded Tubes', *ASTM Annual Book of Standards*, Vol. 02.04.
ASTM Standard B560-86: 'Unalloyed Tantalum for Surgical Implant Applications', *ASTM Annual Book of Standards*, Vol. 13.01.
ASTM Standard B708-86: 'Tantalum and Tantalum Alloy Plate, Sheet and Strip', *ASTM Annual Book of Standards*, Vol. 02.04.
Tantalum Data Sheet, The Rembar Company Inc., 67 Main St., Dobbs Ferry, NY 10522, USA (1996).
*ASM Handbook*, 9th edn., Vol. 3, pp. 323–325 & 343–347 (1986).

## Tin alloys

ASTM Standard B32-89: 'Solder Metal', *ASTM Annual Book of Standards*, Vol. 02.04.
ASTM Standard B339-90: 'Pig Tin', *ASTM Annual Book of Standards*, Vol. 02.04.
ASTM Standard B560-79: 'Modern Pewter Alloys', *ASTM Annual Book of Standards*, Vol. 02.04.
Barry, B.T.K. and Thwaites, C.J., *Tin and its alloys and compounds*, Ellis Horwood, Chichester, UK (1983).
*ASM Metals Handbook*, 9th edition, Vol. 2, pp. 613–625.
See also Babbitt metal (above)

## Titanium alloys

Technical Data Sheets, Titanium Development Association, 4141 Arapahoe Ave., Boulder, Colorado, USA (1993).
Technical Data Sheets, The Titanium Information Group, c/o Inco Engineered Products, Melbourne, UK (1993).
Technical Data Sheets, IMI Titanium Ltd. PO Box 704, Witton, Birmingham B6 7UR, UK (1995).

## Tungsten alloys

ASTM Standard B777-87, 'Tungsten Base, High-Density Metal', *ASTM Annual Book of Standards*, Vol. 02.04.
Yih, S.W.H. and Wang, C.T., *Tungsten*, Plenum Press, New York (1979).
*ASM Metals Handbook*, 9th edition, Vol. 7, p. 476 (1986).
Tungsten Data Sheet (1996), The Rembar Company Inc., 67 Main St., Dobbs Ferry, NY 10522, USA.
Royal Ordnance Speciality Metals datasheet, British Aerospace Defence Ltd., PO Box 27, Wolverhampton, West Midlands, WV10 7NX, UK(1996).
CMW Inc. Datasheets, CMW Inc., 70 S. Gray Street, PO Box 2266, Indianapolis, Indiana, USA (1996).

## Vanadium

Teledyne Wah Chang, 'Vanadium Brochure', TWC, Albany, Oregon, USA (1996).

## Zinc

ASTM Standard B6-87: 'Zinc', *ASTM Annual Book of Standards*, Vol. 02.04, ASTM, USA.
ASTM Standard B69-87: 'Rolled Zinc', *ASTM Annual Book of Standards*, Vol. 02.04, ASTM, USA.
ASTM Standard B86-88: 'Zinc-Alloy Die Castings', *ASTM Annual Book of Standards*, Vol. 02.02, ASTM, USA.
ASTM Standard B418-88: 'Cast and Wrought Galvanic Zinc Anodes', *ASTM Annual Book of Standards*, Vol. 02.04, ASTM, USA.
ASTM Standard B791-88: 'Zinc-Aluminium Alloy Foundry and Die Castings', *ASTM Annual Book of Standards*, Vol. 02.04, ASTM, USA.
ASTM Standard B792-88: 'Zinc Alloys in Ingot Form for Slush Casting', *ASTM Annual Book of Standards*, Vol. 02.04, ASTM, USA.

ASTM Standard B793-88: 'Zinc Casting Alloy Ingot for Sheet Metal Forming Dies', *ASTM Annual Book of Standards*, Vol. 02.04, ASTM, USA.
Goodwin, F.E. and Ponikvar, A.L. (eds), *Engineering Properties of Zinc Alloys* (3rd edition), International Lead Zinc Research Organization, North Carolina, USA (1989). An excellent compilation of data, covering all industrially important zinc alloys.
Chivers, A.R.L., *Zinc Diecasting*, Engineering Design Guide no. 41, OUP, Oxford, UK (1981). A good introduction to the subject.
*ASM Metal Handbook*, 'Properties of Zinc and Zinc Alloys', 9th edition, Vol. 2, pp. 638–645.

## Zirconium

ASTM Standard B350-80: 'Zirconium and Zirconium Alloy Ingots for Nuclear Application', *ASTM Annual Book of Standards*, Vol. 02.04, ASTM, USA.
ASTM Standard B352-85, B551-83 and B752-85: 'Zirconium and Zirconium Alloys', *ASTM Annual Book of Standards*, Vol. 02.04, ASTM, USA.
Teledyne Wah Chang, 'Zircadyne: Properties & Applications', TWC, Albany, OR 97231, USA (1996).
*ASM Metals Handbook*, 9th edition, Vol. 2, pp. 826–831 (1986).

## Ferrous metals

Ferrous metals are probably the most thoroughly researched and documented class of materials. Nearly every developed country has its own system of standards for irons and steels. Recently, continental and worldwide standards have been developed, which have achieved varying levels of acceptance. There is a large and sometimes confusing literature on the subject. This section is intended to provide the user with a guide to some of the better information sources.

## Ferrous metals, general data sources

Bringas, J.E. (ed.) *The Metals Black Book — Ferrous Metals*, 2nd edition, CASTI Publishing, Edmonton, Canada (1995). An excellent short reference work.
*ASM Metals Handbook*, 10th edition, Vol. 1 (1990), ASM International, Metals Park, Cleveland, Ohio, USA. Authoritative reference work for North American irons and steels.
*ASM Metals Handbook*, Desk edition, (1985), ASM International, Metals Park, Cleveland, Ohio, USA. A summary of the multi-volume ASM Metals Handbook.
Wegst, C.W., *Stahlschlüssel* (in English: *Key to Steel*), Verlag Stahlschlüssel Wegst GmbH, D-1472 Marbach, Germany. Published every 3 years, in German, French and English. Excellent coverage of European products and manufacturers.
Woolman, J. and Mottram, R.A., *The Mechanical and Physical Properties of the British Standard En Steels*, Pergamon Press, Oxford (1966). Still highly regarded, but is based around a British Standard classification system that has been officially abandoned.
Brandes, E.A. and Brook, G.R. (eds) *Smithells Metals Reference Book*, 7th edition, Butterworth-Heinemann, Oxford, UK (1992). An authoritative reference work, covering all metals.
*Chapman and Hall 'Materials Selector'*, Waterman, N.A. and Ashby, M.F. (eds), Chapman and Hall, London, UK (1996). Covers all materials — Irons and steels are in Vol. 2.
Sharpe, C. (ed.) *Kempe's Engineering Year-Book*, 98th edition (1993), Benn, Tonbridge, Kent, UK. Updated each year — has good sections on irons and steels.

## Iron and steels standards

Increasingly, national and international standards organizations are providing a complete catalogue of their publications on the World-Wide Web. Two of the most comprehensive printed sources are listed below.

*Iron and Steel Specifications*, 9th edition (1998), British Iron and Steel Producers Association (BISPA), 5 Cromwell Road, London, SW7 2HX. Comprehensive tabulations of data from British Standards on irons and steels, as well as some information on European and North American standards. The same information is available on searchable CD.

*ASTM Annual Book of Standards*, Vols 01.01 to 01.07, The most complete set of American iron and steel standards. Summaries of the standards can be found on the WWW at http://www.astm.org/stands.html.

## Cross-referencing of similar international standard grades

It is difficult to match, even approximately, equivalent grades of iron and steel between countries. No coverage of this subject can ever be complete, but the references listed below are helpful.

Gensure, J.G. and Potts, D.L., *International Metallic Materials Cross Reference*, 3rd edition, Genium Publishing, New York (1988). Comprehensive worldwide coverage of the subject, well indexed.

Bringas, J.E. (ed.) *The Metals Black Book — Ferrous Metals*, 2nd edition, CASTI Publishing, Edmonton, Canada (1995). Easy-to-use tables for international cross-referencing. (See General section for more information.)

*Unified Numbering System for Metals and Alloys*, 2nd edition, Society of Automotive Engineers, Pennsylvania (1977). An authoritative reference work, providing a unifying structure for all standards published by US organizations. No coverage of the rest of the world.

*Iron and Steel Specifications*, 7th edition (1989), British Steel, 9 Albert Embankment, London, SE1 7SN. Lists 'Related Specifications' for France, Germany, Japan, Sweden, UK and USA.

## Cast irons

Scholes, J.P., *The Selection and Use of Cast Irons*, Engineering Design Guides, OUP, Oxford, UK (1979).
Angus, H.T., *Cast Iron: Physical and Engineering Properties*, Butterworths, London (1976).
Gilbert, G.N.J., *Engineering Data on Grey Cast Irons* (1977).
Gilbert, G.N.J., *Engineering Data on Nodular Cast Irons* (1986).
Gilbert, G.N.J., *Engineering Data on Malleable Cast Irons* (1983).
Smith, L.W.L., Palmer, K.B. and Gilbert, G.N.J., *Properties of Modern Malleable Irons* (1986).
Palmer, K.B., *Mechanical & Physical Properties of Cast Irons at Sub-zero Temperatures* (1988).
Palmer, K.B., *Mechanical & Physical Properties of Cast Irons up to 500°C* (1986).

## Irons, American Standards

These can all be found in the *Annual Book of ASTM Standards*, Vol. 01.02
ASTM A220M-88: 'Pearlitic Malleable Iron'.
ASTM A436-84: 'Austenitic Gray Iron Castings'.
ASTM A532: 'Abrasion-Resistant Cast Irons'.
ASTM A602-70: (Reapproved 1987) 'Automotive Malleable Iron Castings'.

## Cast irons, International Standards

These are available from ISO Central Secretariat, 1, rue de Varembe, Case postale 56, CH-1211 Geneve 20, Switzerland.

ISO 185:1988 'Grey cast iron — classification'
ISO 2892:1973 'Austenitic Cast Iron'
ISO 5922:1981 'Malleable cast iron'

## Cast irons, British Standards

Compared with steels, there are relatively few standards on cast iron, which makes it feasible to list them all. Standards are available from BSI Customer Services, 389 Chiswick High Road, London, W4 4AL, UK.

BS 1452:1990 'Flake graphite cast iron'.
BS 1591:1975 'Specification for corrosion resisting high silicon castings'.
BS 2789:1985, 'Iron Castings with spheroidal or nodular graphite'.
BS 3468:1986 'Austenitic cast iron'.
BS 4844:1986 'Abrasion resisting white cast iron'.
BS 6681:1986 'Specification for malleable cast iron'.

### Carbon and low alloy steels

*ASM Metals Handbook*, 10th edition, Vol. 1 (1990), ASM International, Metals Park, Cleveland, Ohio, USA. Authoritative reference work for North American irons and steels.

Fox, J.H.E., *An Introduction to Steel Selection: Part 1, Carbon and Low-Alloy Steels*, Engineering Design Guide no. 34, Oxford University Press.

### Stainless steels

*ASM Metals Handbook*, 10th edition, Vol. 1 (1990), ASM International, Metals Park, Cleveland, Ohio, USA. Authoritative reference work for North American irons and steels.

Elliott, D. and Tupholme, S.M., *An Introduction to Steel Selection: Part 2, Stainless Steels*, Engineering Design Guide no. 43, Oxford University Press (1981).

Peckner, D. and Bernstein, I.M., *Handbook of Stainless Steels*, McGraw-Hill, New York (1977).

*Design Guidelines for the Selection and Use of Stainless Steel*, Designers' Handbook Series no. 9014, Nickel Development Institute (1991).

(The Nickel Development Institute (NIDI) is a worldwide organization that gives away a large variety of free literature about nickel-based alloys, including stainless steels. NIDI European Technical Information Centre, The Holloway, Alvechurch, Birmingham, B48 7QB, ENGLAND.)

### Ferrous metals, World-wide Web sites

Details of a few general sites are given below.

http://www.steelnet.org/: Steel Manufacturers Association, which claims to be North America's largest steel trade group. Contains links to the homepages of many US steel companies, but these are currently more likely to provide business information than data on material properties.

http://www.asm-intl.org/: ASM International (American Society of Materials). Linked to a wide range of useful sites.

http://www.astm.org/: American Society of Testing and Materials, publisher of a wide range of American standards.

http://www.iso.ch/: International Standards Organization — has links to all national standards organizations that have a presence on the WWW.

http://www.iso.ch/cate/77.html: Section 77 of the ISO catalogue, which includes descriptions of all their standards on ferrous metals, plus ordering information.

### Polymers and elastomers

Polymers are not subject to the same strict specification as metals. Data tend to be producer-specific. Sources, consequently, are scattered, incomplete and poorly presented. Saechtling is the best; although no single hard-copy source is completely adequate, all those listed here are worth consulting. See also Databases as Software, Section 13A.5; some (Plascams, CMS) are good on polymers.

*Saechtling: International Plastics Handbook*, editor Dr Hansjurgen Saechtling, MacMillan Publishing Co (English edition), London, UK (1983). The most comprehensive of the hard-copy data-sources for polymers.

*Polymers for Engineering Applications*, R.B. Seymour. ASM International, Metals Park, Ohio 44037, USA (1987). Property data for common polymers. A starting point, but insufficient detail for accurate design or process selection.
*New Horizons in Plastics, a Handbook for Design Engineers*, editor J. Murphy, WEKA Publishing, London, UK.
*ASM Engineered Materials Handbook*, Vol. 2. Engineering Plastics (1989). ASM International, Metals Park, Ohio 44037, USA (1991).
*Handbook of Plastics and Elastomers*, editor C.A. Harper, McGraw-Hill, New York, USA (1975).
*International Plastics Selector, Plastics*, 9th edition, Int. Plastics Selector, San Diego, CA, USA (1987).
*Die Kunststoffe and Ihre Eigenschaften*, editor Hans Domininghaus, VDI Verlag, Dusseldorf, Germany (1992).
*Properties of Polymers*, 3rd edition, D.W. van Krevelen, Elsevier, Amsterdam, Holland, (1990). Correlation of properties with structure; estimation from molecular architecture.
*Handbook of Elastomers*, A.K. Bhowmick and H.L. Stephens. Marcel Dekker, New York, USA (1988).
*ICI Technical Service Notes*, ICI Plastics Division, Engineering Plastics Group, Welwyn Garden City, Herts, UK (1981).
Technical Data Sheets, Malaysian Rubber Producers Research Association, Tun Abdul Razak Laboratory, Brickendonbury, Herts. SG13 8NL (1995). Data sheets for numerous blends of natural rubber.

## Ceramics and glasses

Sources of data for ceramics and glasses, other than the suppliers data sheets, are limited. Texts and handbooks such as the ASM's (1991) *Engineered Materials Handbook Vol. 4*, Morell's (1985) compilations, Neville's (1996) book on concrete, Boyd and Thompson (1980) *Handbook on Glass* and Sorace's (1996) treatise on stone are useful starting points. The *CMS Ceramics Database* contains recent data for ceramics and glasses. But in the end it is the manufacturer to whom one has to turn: the data sheets for their products are the most reliable source of information.

## Ceramics and ceramic-matrix composites

*ASM Engineered Materials Handbook*, Vol. 4, Ceramics and Glasses. ASM International, Metals Park, Ohio 44073, USA (1991).
*Chapman and Hall 'Materials Selector'*, editors N. Waterman and M.F. Ashby, Chapman and Hall, London UK (1996).
*Concise Encyclopedia of Advanced Ceramic Materials* editor R.J. Brook, Pargamon Press, Oxford, UK (1991).
Creyke, W.E.C., Sainsbury, I.E.J. and Morrell, R., *Design with Non Ductile Materials*, Applied Science, London, UK (1982).
*Handbook of Ceramics and Composites*, 3 Vols, editor N.P. Cheremisinoff, Marcel Dekker Inc., New York, USA (1990).
*Handbook of Physical Constants*, Memoir 97, editor S.P. Clark, Geological Society of America (1966).
*Handbook of Structural Ceramics*, editor M.M. Schwartz, McGraw-Hill, New York, USA (1992). Lots of data, information on processing and applications.
Kaye, G.W.C. and Laby, T.H., *Tables of Physical & Chemical Constants*, 15th edition, Longman, New York, USA (1986).
Kingery, W.D., Bowen, H.K. and Uhlmann, D.R., *Introduction to Ceramics*, 2nd edition, New York, Wiley (1976).
*Materials Engineering 'Materials Selector'*, Penton Press, Cleveland, Ohio, USA (1992).
Morrell, R., *Handbook of Properties of Technical & Engineering Ceramics*, Parts I and II, National Physical Laboratory, Her Majesty's Stationery Office, London, UK (1985).
Musikant, S., *What Every Engineer Should Know About Ceramics*, Marcel Dekker Inc (1991). Good on data.
Richerson, D.W., *Modern Ceramic Engineering*, 2nd edition, Marcel Dekker, New York, USA (1992).
*Smithells Metals Reference Book*, 7th edition, editors E.A. Brandes and G.B. Brook, Butterworth-Heinemann, Oxford (1992).

## Glasses

*ASM Engineered Materials Handbook*, Vol. 4, Ceramics and Glasses. ASM International, Metals Park, Ohio 44073, USA (1991).

Boyd, D.C. and Thompson, D.A., 'Glass', Reprinted from Kirk-Othmer: *Encyclopedia of Chemical Technology*, Volume 11, third edition, pp. 807–880, Wiley (1980).
*Engineering Design Guide 05: The Use of Glass in Engineering*, Oliver, D.S. Oxford University Press, Oxford, UK (1975).
*Handbook of Glass Properties*, Bansal, N.P. and Doremus, R.H., Academic Press, New York, USA (1966).

### Cement and concrete

Cowan, H.J. and Smith, P.R., *The Science and Technology of Building Materials*, Van Nostrand-Reinhold, New York USA (1988).
Illston, J.M., Dinwoodie, J.M. and Smith, A.A., *Concrete, Timber and Metals*, Van Nostrand-Reinhold, New York USA (1979).
Neville, A.M., *Properties of Concrete*, 4th edition, Longman Scientific and Technical (1996). An excellent introduction to the subject.

### Composites: PMCs, MMCs and CMCs

The fabrication of composites allows so many variants that no hard-copy data source can capture them all; instead, they list properties of matrix and reinforcement, and of certain generic lay-ups or types. The *Engineers Guide* and the *Composite Materials Handbook*, listed first, are particularly recommended.

### Composite, general

*Engineers Guide to Composite Materials*, edited by Weeton, J.W., Peters, D.M. and Thomas, K.L. ASM International, Metals Park, Ohio 44073, USA (1987). The best starting point: data for all classes of composites.
*Composite Materials Handbook*, 2nd edition, editor Schwartz, M.M., McGraw-Hill, New York, USA (1992). Lots of data on PMCs, less on MMCs and CMCs, processing, fabrication, applications and design information.
*ASM Engineered Materials Handbook*, Vol. 1: Composites. ASM International, Metals Park, Ohio 44073, USA (1987).
*Reinforced Plastics, Properties and Applications*, R.B. Seymour. ASM International, Metals Park, Ohio 44073, USA (1991).
*Handbook of Ceramics and Composites*, Volumes 1–3, editor N.P. Cheremisinoff, Marcel Dekker Inc., New York, USA (1990).
*Concise Encyclopedia of Composited Materials*, editor A. Kelly, Pergamon Press, Oxford, UK (1989).
Middleton, D.H., *Composite Materials in Aircraft Structures*, Longman Scientific and Technical Publications, John Wiley, New York, USA (1990).
Smith, C.S., *Design of Marine Structures in Composite Materials*, Elsevier Applied Science, London, UK (1990).

### Metal matrix composites

See, first, the sources listed under 'All Composite Types', then, for more detail, go to:

Technical Data Sheets, Duralcan USA, 10505 Roselle Street, San Diego, CA 92121, USA (1995).
Technical Data Sheets, 3M Company, 3M Xenter, Building 60-1N-001, St Paul MN 55144–1000, USA (1995).

### Foams and cellular solids

Many of the references given in 13A.3 for polymers and elastomers mention foam. The references given here contain much graphical data, and simple formulae which allow properties of foams to be estimated from its density and the properties of the solid of which it is made, but in the end it is necessary to contact suppliers. See also Databases as software (Section 13A.5); some (Plascams, CMS) are good on foams. For Woods and wood-based composites, see below.

*Cellular Polymers* (a Journal), published by RAPRA Technology, Shrewsbury, UK (1981–1996)
*Encyclopedia of Chemical Technology*, Vol. 2, 3rd edition, pp. 82–126. Wiley, New York, USA (1980).
*Encyclopedia of Polymer Science and Engineering*, Vol. 3, 2nd edition, Section C, Wiley, New York, USA (1985).
Gibson, L.J. and Ashby, M.F., *Cellular Solids*, Cambridge University Press, Cambridge, UK (1997). Basic text on foamed polymers, metals, ceramics and glasses, and natural cellular solids.
*Handbook of Industrial Materials*, 2nd edition, pp. 537–556, Elsevier Advanced Technology, Elsevier, Oxford, UK (1992).
*Low Density Cellular Plastics — Physical Basis of Behaviour*, edited by Hilyard, N.C. and Cunningham, A. Chapman and Hall, London, UK (1994). Specialized articles on aspects of polymer-foam production, properties and uses.
Plascams (1995), Version 6, Plastics Computer-Aided Materials Selector, RAPRA Technology Limited, Shawbury, Shrewsbury, Shropshire, SY4 4NR, UK.
Saechtling (1983): *International Plastics Handbook*, editor Dr Hans Jurgen, Saechtling, MacMillan Publishing Co. (English edition), London, UK.
Seymour, R.P. (1987) *Polymers for Engineering Applications*, ASM International, Metals Park, Ohio 44037, USA.

### Stone, rocks and minerals

There is an enormous literature on rocks and minerals. Start with the handbooks listed below; then ask a geologist for guidance.

Atkinson, B.K., *The Fracture Mechanics of Rock*, Academic Press, UK (1987).
*Handbook of Physical Constants*, editor S.P. Clark, Jr, Memoir 97, The Geological Society of America, 419 West 117 Street, New York, USA (1966). Old but trusted compilation of property data for rocks and minerals.
*Handbook on Mechanical Properties of Rocks*, Volumes 1–4, editors R.E. Lama and V.S. Vutukuri, Trans Tech Publications, Clausthal, Germany (1978).
*Rock Deformation*, editors Griggs, D. and Handin, J., Memoir 79, The Geological Society of America, 419 West 117 Street, New York, USA (1960).
Sorace, S., 'Long-term tensile and bending strength of natural building stones' *Materials and Structures*, **29**, 426–435 (August/September 1996).

### Woods and wood-based composites

Woods, like composites, are anisotropic; useful sources list properties along and perpendicular to the grain. The US Forest Products Laboratory 'Wood Handbook' and Kollmann and Côté's 'Principles of Wood Science, and Technology' are particularly recommended.

### Woods, general information

Bodig, J. and Jayne, B.A. (1982) *Mechanics of Wood and Wood Composites*, Van Nostrand Reinhold Company, New York, USA.
Dinwoodie, J.M. (1989) *Wood, Nature's Cellular Polymeric Fibre Composite*, The Institute of Metals, London, UK.
Dinwoodie, J.M., *Timber, its Nature and Behaviour*, Van Nostrand-Reinhold, Wokingham, UK (1981). Basic text on wood structure and properties. Not much data.
Gibson, L.J. and Ashby, M.F. (1997) *Cellular Solids*, 2nd edition, Cambridge University Press, Cambridge, UK.
Jane, F.W. (1970) *The Structure of Wood*, 2nd edition, A. and C. Black, Publishers, London, UK.
Kollmann, F.F.P. and Côté, W.A. Jr. (1968) *Principles of Wood Science and Technology*, Vol. 1 (Solid Wood), Springer-Verlag, Berlin, Germany. The bible.

Kollmann, F., Kuenzi, E. and Stamm, A. (1968), *Principles of Wood Science and Technology*, Vol. 2 (Wood Based Materials), Berlin: Springer-Verlag.
Schniewind, A.P. (ed.) (1989) *Concise Encyclopedia of Wood and Wood-Based Materials*, Pergamon Press, Oxford, UK.

### Woods, data compilations

BRE (1996) 'BRE Information Papers', Building Research Establishment (BRE), Garston, Watford, WD2 7JR, UK.
Forest Products Laboratory (1989), Forest Service, US. Department of Agriculture, *Handbook of Wood and Wood-based Materials*, New York: Hemisphere Publishing Corporation. A massive compilation of data for North-American woods.
Informationsdienst Holz (1996), Merkblattreihe Holzarten, Verein Deutscher Holzeinfuhrhäuser e.V., Heimbuder Strabe 22, D-20148 Hamburg, Germany.
TRADA (1978/1979) *Timbers of the World, Volumes 1–9*, Timber Research and Development Association, High Wycombe, UK.
TRADA (1991) Information Sheets, Timber Research and Development Association, High Wycombe, UK.

## Wood and wood-composite standards

### Great Britain

British Standards Institution (BSI), 389 Chiswick High Road, GB-London W4 4AL, UK (Tel: +44 181 996 9000; Fax: +44 181 996 7400; e-mail: info@bsi.org.uk).

### Germany

Deutsches Institut für Normung (DIN), Burggrafenstrasse 6, D-10772, Berlin, Germany (Tel +49 30 26 01-0; Fax: +49 30 26 01 12 31; e-mail: postmaster@din.de.

### USA

American Society for Testing and Materials (ASTM), 1916 Race Street, Philadelphia, Pennsylvania 19103-1187 (Tel 215 299 5400; Fax: 215 977 9679).
ASTM European Office, 27–29 Knowl Piece, Wilbury Way, Hitchin, Herts SG4 0SX, UK (Tel: +44 1462 437933; Fax: +44 1462 433678; e-mail: 100533.741@compuserve.com).

### Woods, software data sources

*CMS* WOODS DATABASE, Granta Design, Trumpington Street, Cambridge CB2 1QA, UK. A database of the engineering properties of softwoods, hardwoods and wood-based composites. PC format, Windows environment.
PROSPECT (Version 1.1) (1995), Oxford Forestry Institute, Department of Plant Sciences, Oxford University, South Parks Road, Oxford OX1 3RB, UK. A database of the properties of tropical woods of interest to a wood user; includes information about uses, workability, treatments, origins. PC format, DOS environment.
WOODS OF THE WORLD (1994), Tree Talk, Inc., 431 Pine Street, Burlington, VT 05402, USA. A CD-ROM of woods, with illustrations of structure, information about uses, origins, habitat etc. PC format, requiring CD drive; Windows environment.

### Natural fibres and other materials

Houwink, R., *Elasticity, Plasticity and Structure of Matter*, Dover Publications, Inc, New York, USA (1958).
*Handbook of Industrial Materials*, 2nd edition, Elsevier, Oxford, UK (1992). A compilation of data remarkable for its breadth: metals, ceramics, polymers, composites, fibres, sandwich structures, leather....

*Materials Handbook*, 2nd edition, editors Brady, G.S. and Clauser, H.R., McGraw-Hill, New York, USA (1986). A broad survey, covering metals, ceramics, polymers, composites, fibres, sandwich structures, and more.

## 13A.4 Data for manufacturing processes

Alexander, J.M., Brewer, R.C. and Rowe, G.W., *Manufacturing Technology, Vol. 2: Engineering Processes*, Ellis Horwood Ltd., Chichester, UK (1987).
Bralla, J.G., *Handbook of Product Design for Manufacturing*, McGraw-Hill, New York, USA (1986).
*Chapman and Hall Materials Selector*, Waterman, N.A. and Ashby, M.F. (eds), Chapman and Hall, London, UK (1996).
*CPS Cambridge Process Selector* (1995), Granta Design Ltd, 20, Trumpington Street, Cambridge CB2 1QA, UK (Phone: +44-1223-334755; Fax: +44-1223-332797) Software for process selection.
Dieter, G.E., *Engineering Design, A Materials and Processing Approach*, McGraw-Hill, New York, USA, Chapter 7 (1983).
Kalpakjian, S., *Manufacturing Processes for Engineering Materials*, Addison Wesley, London, UK (1984).
Lascoe, O.D., *Handbook of Fabrication Processes*, ASM International, Metals Park, Columbus, Ohio, USA (1989).
Schey, J.A., *Introduction to Manufacturing Processes*, McGraw-Hill, New York, USA (1977).
Suh, N.P., *The Principles of Design*, Oxford University Press, Oxford, UK (1990).

## 13A.5 Databases and expert systems in software

The number and quality of computer-based materials information systems is growing rapidly. A selection of these, with comment and source, is given here. There has been consumer resistance to on-line systems; almost all recent developments are in PC-format. The prices vary widely. Five price groups are given: free, cheap (less than \$200 or £125), modest (between \$200 or £125 and \$2000 or £1250), expensive (between \$2000 or £1250 and \$10 000 or £6000) and very expensive (more than \$10 000 or £6000). The databases are listed in alphabetical order.

**Active Library on Corrosion**, ASM International, Metals Park, Ohio 44073, USA. PC format requiring CD ROM drive. Graphical, numerical and textual information on corrosion of metals. Price modest.

**Alloy Digest** (1997) ASM International, Metals Park, Ohio 44073, USA. PC format requiring CD ROM drive. 3500 datasheets for metals and alloys, regularly updated. Price: modest/expensive.

**Alloy Finder**, 2nd edition (1997), ASM International, Metals Park, Ohio 44073, USA. PC format requiring CD ROM drive. Lists 70 000 alloys by trade name, composition and designation. Price modest.

**ALUSELECT P1.0:** Engineering Property Data for Wrought Aluminium Alloys (1992). European Aluminium Association, Königsallee 30, P.O. Box 1012, D-4000 Dusseldorf 1, Germany (Tel: 0211-80871; fax 0211-324098). PC format, DOS environment. Mechanical, thermal, electrical and environmental properties of wrought aluminium alloys. Price cheap.

**CAMPUS:** Computer Aided Material Preselection by Uniform Standards (1995): Published separately by eight polymer producers:

Bayer UK Ltd. Bayer House, Strawberry Hill, Newbury, Berks, RG13 1JA, UK.

Hoechst Aktiengesellschaft, Marketing Technische Kunststoffe, D-65926, Frankfurt am Main, Germany (Tel: 06172-87-2755; fax: 01672-87-2761).

DuPont UK Ltd, Maylands Ave., Hemel Hempstead, Herts HP2 7DP, UK.

BASF UK Ltd. PO Box 4, Earl Road, Cheadle Hulme, Cheshire SK8 6QG, UK (Tel: 0161-485-6222; fax: 0161-486-0225).

EMS Grilon UK Ltd., Polymers Division, Walton Manor, Milton Keynes, Bucks MK7 7AJ, UK.

PC format DOS environment. A collection of four databases of Hoechst, BASF, Bayer DuPont, and Dow thermoplastic polymers, containing information on modulus, strength, viscosity and thermal properties. Regularly updated, but limited in scope. Free.

**CETIM-EQUIST II:** Centre Technique des Industries Mécaniques, (1997), BP 67, 60304 Senlis Cedex, France. PC format, DOS environment. Compositions and designations of steels.

**CETIM-Matériaux:** Centre Technique des Industries Mécaniques, (1997), BP 67, 60304 Senlis Cedex, France. On-line system. Compositions and mechanical properties of materials.

**CETIM-SICLOP:** Centre Technique des Industries Mécaniques, (1997), BP 67, 60304 Senlis Cedex, France. On-line system. Mechanical properties of steels.

***CMS* Cambridge Materials Selector** (1995), Granta Design Ltd, 20, Trumpington Street, Cambridge CB2 1QA, UK (Phone: +44-1223-334755; Fax: +44-1223-332797) All materials, PC format, Windows environment. It implements the selection procedures developed in this book, allowing successive application of up to 16 selection stages. System includes a hierarchy of databases, with a 'Generic' database supported by detailed databases for ferrous metals, non-ferrous metals, polymers and composites, ceramics and glasses, and woods. Modest price.

***CPS* Cambridge Process Selector** (1995), Granta Design Ltd, 20, Trumpington Street, Cambridge CB2 1QA, UK (Phone: +44-1223-334755; Fax: +44-1223-332797) All process classes, PC format, Windows environment. It implements the selection procedures developed in this book, allowing successive application of up to 16 selection stages. Modest price.

**CopperSelect:** Computerized System for Selecting Copper Alloys: Copper Development Association Inc, Greenwich Office, Park No. 2, Box 1840, Greenwich CT 06836, USA (Tel: 203-625-8210; Fax: 203-625-0174). PC-format, DOS environment. A database of properties and processing information for wrought and cast-copper alloys. All these and much more are also contained in *Megabytes on Copper*. Free.

**CUTDATA:** Machining Data System; Metcut Research Associates Inc, Manufacturing Technology Division, 11240 Cornell Park Drive, Cincinnati, Ohio 45242 USA (Tel: 513-489-6688). A PC-based system which guides the choice of machining conditions: tool materials, geometries, feed rates, cutting speeds, and so forth. Modest price.

**EASel:** Engineering Adhesives Selector Program (1986): The Design Centre, Haymarket, London SW1Y 4SU, UK. PC and Mac formats. A knowledge-based program to select industrial adhesives for joining surfaces. Modest price.

**SF-CD** (replacing **ELBASE**), Metal Finishing/Surface Treatment Technology (1992): Metal Finishing Information Services Ltd, PO Box 70, Stevenage, Herts SG1 4DF, UK (Tel: 01438-745115; fax: 01438-364536). PC format. Comprehensive information on published data related to surface treatment technology. Regularly updated. Modest price.

**EPOS** Engineering Plastics On Screen (1989): ICI Engineering, Plastics Sales Office, PO Box 90, Wilton, Middlesborough, Cleveland TS6 8JE, UK (Tel: 0642-454144 or 0707-337852). PC format, DOS environment. The software lists general and electrical properties of ICI polymer products, with a search facility. Updated periodically. Free.

**FUZZYMAT 2.0:** Software to Assist the Selection of Materials (1995). SNC Bassetti et Isaac, 91 bis, rue General Mangin, 38100 Grenoble, France (Tel: 04 76 23 35 44, Fax: 04 76 23 35 49). PC format, Windows environment. Materials selection by weight-factors, using fuzzy logic methods. Uses CMS databases and methodology (see ***CMS***) and can be customized to meet special needs. Manual, screen display in French. Modest price.

**IMAMAT** Institute of Metals and Materials, Australasia, PO Box 19, Parkville 3052, Vic, Australia (Tel: 03-347-2544, Fax: 03-348-1208). Price and functionality not known.

**M-VISION** (1990): PDA Engineering, 2975 Redhill Avenue, Costa Mesa, CA 92626, USA (Tel: 714-540-8900; Fax: 714-979-2990). Requires a workstation. An ambitious image and database, with flexible selection procedures. Data for aerospace alloys and composites. Very expensive.

**MAPP** (replacing **Mat.DB** and, before that, **METSEL 2**): Materials Data-base; ASM International, Metals Park, Ohio 44073, USA (Tel: 216-338-5151; Fax: 216-338-4634). PC format, Windows environment and Mac. A Windows-based materials data source using the old Mat.DB data files, with an improved user interface. Data files for settles, aluminium alloys, titanium alloys, magnesium alloys, copper alloys, and a limited range of polymers. Selection based on user-defined target values. Expensive if a full suite of databases is wanted.

**MATUS** Materials User Service: Engineering Information Company Ltd, 23, Cardiff House, Peckham Park Road, London SE15 6TT, UK (Tel +44 0171-538-0096). Formerly an on-line data bank of UK material suppliers, trade names and properties for metals, polymers and ceramics, using data from suppliers' catalogues and data sheets. Much of the information is now available on PC format floppy disks, cheap or free.

**Megabytes on Coppers:** Information on copper and copper alloys, The Copper Development Association (1994), Orchard House, Mutton Lane, Potters Bar, Hertfordshire, EN6 3AP, UK (Tel: 01707-650711; Fax: 01707-642769). A CD-ROM with Windows search engine, containing all the current publications as well as interactive programs published by CDA on topics of electrical energy efficiency, cost effectiveness and corrosion resistance. Cheap.

**PAL II** Permabond Adhesives Locator (1996): Permabond, Woodside Road, Eastleigh, Hants SO5 4EX, UK (Tel: +44 703-629628; Fax: +44 703-629629). A knowledge-based, PC-system (DOS environment) for adhesive selection among Permabond adhesives. An impressive example of an expert system that works. Modest price.

**PLASCAMS Version 6** Plastics Computer-aided Materials Selector (1995), RAPRA Technology Ltd, Shawbury, Shrewsbury, Shropshire SY4 4NR, UK (Tel: +44-1939-250383; Fax: +44-1939-251118). PC format, Windows environment. Polymers only. Mechanical and processing properties of polymers, thermoplastics and thermosets. Easy to use for data retrieval, with much useful information. Selection procedure cumbersome and not design-related. Modest initial price plus annual maintenance fee. Updated regularly.

**Polymerge** Modern Plastics International (1997), Emil-von-Behring-Str 2, D-60439 Frankfurt am Main, Germany (Tel: +49-69-5801-135; fax +49-69-5801-104). Allows CAMPUS discs to be merged, allowing comparison.

**PROSPECT** (Version 1.1) (1995), Oxford Forestry Institute, Department of Plant Sciences, Oxford University, South Parks Road, Oxford OX1 3RB, UK. A database of the properties of tropical woods of interest to a wood user; includes information about uses, workability, treatments, origins. PC format, DOS environment.

**SMF** Special Metals Fabrication (1996). See MATUS Data Publications, Engineering Information Co. Ltd. PC format, DOS environment. Properties of refractoriy metals for corrosion resistant and high-temperature applications in the chemical, aerospace, electronic and furnace industries. Useful compilation of data and applications. Free.

**Stainless Steels** A Guide to Stainless Steels (1994). Nickel Development Institute, 214 King Street West, Suite 510, Toronto Canada M5H 3S6 (Tel: 416 591-7999; Fax: 416 591-7987). PC format, DOS environment. Free.

**teCal** Steel Heat-Treatment Calculations; ASM International, Metals Park, Ohio 44073, USA (Tel: 216-338-5151; Fax: 216-338-4634). PC format, DOS environment. Computes the properties resulting from defined heat-treatments of low-alloy steels, using the composition as input. Modest price.

**Stahlschlüssel** 17th edition (1997), Wegst, C.W. *Stahlschlüssel* (in English: *Key to Steel*), Verlag Stahlschlüssel Wegst GmbH, D-1472 Marbach, Germany. CD ROM, PC format. Excellent coverage of European products and manufacturers.

**SOFINE PLASTICS** Société CERAP (1997) 27, Boulevard du 11 november 1918, BP 2132, 69603 Villeurbanne Cedex, France (Tel 04-72-69-58-30; fax: 04-78-93-15-56). Database of polymer properties. Environment and price unknown.

**STRAIN** Plastic Properties of Materials; Rob Bailey, Lawrence Livermore Laboratory, Materials Laboratory, PO Box 808, Livermore, Ca 94550, USA (Tel: 415-422-8512). PC format, DOS environment. Very simple but useful compilation of room-temperature mechanical properties of ductile materials. Free.

**TAPP 2.0** Thermochemical and Physical Properties, (1994). ES Microware, 2234 Wade Court, Hamilton, OH 45013 USA (Tel: 513 738-4773, Fax: 513 738-4407, e-mail: ESMicro@aol.com). PC format, CD ROM, Windows environment. A database of thermochemical and physical properties of solids, liquids and gases, including phase diagrams neatly packaged with good user manual. Modest price.

**THERM** Thermal Properties of Materials; Rob Bailey, Lawrence Livermore Laboratory, Materials Laboratory, PO Box 808, Livermore, Ca 94550, USA (Tel: 415-422-8512). PC format, DOS environment. Very simple but useful compilation of thermal data for materials: specific heat, thermal conductivity, density and melting point. Free.

**Titanium:** Titanium Information Group, (1994), See MATUS Data Publications, Engineering Information Co. Ltd. PC format, DOS environment. Properties of titanium alloys. Useful compilation of data and applications. Free.

**UNSearch** Unified Metals and Alloys Composition Search; ASTM, 1916 Race Street, Philadelphia, PA 19103, USA. PC format, DOS environment. A database of information about composition, US designation and specification of common metals and alloys. Modest price.

**WOODS OF THE WORLD** (1994), Tree Talk, Inc., 431 Pine Street, Burlington, VT 05402, USA. A CD-ROM of woods, with illustrations of structure, information about uses, origins, habitat, etc. PC format, requiring CD drive; Windows environment.

## 13A.6 World-wide Web sites

The number of WWW sites carrying information about materials increases every week. There is almost no control of Web-site contents, which can vary enormously in nature and quality. The best are genuinely useful, establishing the Web as a potent 'further information' source. The sites listed below were accessible at the time of writing (August 1998), but at the time of reading some will have changed, and new sites will have appeared.

### Sites of materials suppliers and producers

| | |
|---|---|
| Carpenter Technology Home Page | http://www.cartech.com/ |
| Cerac Incorporated | http://www.cerac.com/index.html |
| CMW Inc. Home Page | http://www.cmwinc.com/cmw |
| Copper Page | http://www.copper.org/ |
| Elemental Carbon Information | http://fozzie.chem.wisc.edu/curriculum_development/CurrRef/BDGTopic/BDGtext/BDGtoc.html |
| Engelhard Corporation–Electro Metallics Department | http://www.engelhardemd.com/ |
| GE Home Page | http://www.ge.com/index.htm |
| Gold information | http://www.interfaceweb.com/alpine/gold.htm |
| Indium Corporation of America | http://www.indium.com/ |
| Jeneric/Pentron | http://www.jeneric.com/index.html |
| Materials (aeronautics): Lockheed Martin - | http://lmtas.com/AMMC/ |
| Materials (high performance): MatTech | http://www.mat-tech.com/ |
| Materials (research): Alfa Aesar | http://www.alfa.com/ |
| Materials Preparation Center | http://www.ameslab.gov/mat_ref/mpc.html |
| Nickel: INCO Web Site | http://www.incoltd.com/toc-inct.htm |
| Niobium | http://www-c8.lanl.gov/infosys/html/periodic/41.html |
| Rare earths: Pacific Industrial Development Corp. | http://pidc.com/home.html |
| Rare Metals: Stanford Materials Inc. | http://www.stanfordmaterials.com/ |
| Refractory Metals: Teledyne Wah Chang | http://www.twca.com/ |
| Special Metals Corp. | http://www.specialmetals.com/ |
| Steel & nickel based alloys | http://www.specmp.co.uk/ |
| Steel: Bethlehem Steel's Web Site | http://www.bethsteel.com/ |
| Steel: British Steel Home Page | http://www.britishsteel.co.uk/ |
| Steel: Arcus Stainless Steel | http://194.178.135.1/ |
| Steel: Automotive Steel Library | http://www.autosteel.org/home/steelmakers/members/ |
| Steel: Great Plains Stainless | http://www.gpss.com/ |
| Titanium.NET | http://www.titanium.org/ |
| Tungsten: North American Tungsten | http://www.canvest.com/tungsten/strategic.shtml |
| Uranium Information Centre, Australia | http://www.uic.com.au/ |
| Uranium Institute, London | http://www.uilondon.org/ |
| Zinc Industrias Nacionales S.A.-Peru | http://www.zinsa.com/espanol.htm |
| Zinc: Eastern Alloys | http://www.eazall.com/ahome.html |

### Sites that list other sites

| | |
|---|---|
| Granta Design Site Catalog | http://www.granta.co.uk |
| Automotive engineering | http://www.mlc.lib.mi.us/~stewarca/auto.html |
| CASTI Publishing Site Catalog | http://www.casti-publishing.com/intsite.htm |
| Directory of e-Conferences | http://www.n2h2.com/KOVACS/ |
| Potter's Science Gems — Engineering | http://www-sci.lib.uci.edu/SEP/engineer.html |
| IndustryLink Homepage | http://www.industrylink.com/ |
| TWI: WWW sites | http://www.twi.co.uk/links.html#tag14 |
| Industry and Trade Associations | http://www.amm.com/ref/trade.HTM |
| Martindale's: Physics Web Pages | http://133.28.55.52:10080/=@=:www-sci.lib.uci.edu:80/HSG/GradPhysics.html |
| Materials-related sites | http://www.infodex.com/mlinks.html |
| Materials science | http://www.mlc.lib.mi.us/~stewarca/materials.html |
| Metallurgy | http://www.mlc.lib.mi.us/~stewarca/metallurgy.html |
| New sci.engr.: WWW sources | http://members.aol.com/RonGraham1/www.html |
| Product Data Management Info Ctr. | http://www.pdmic.com/ |
| Scientific Web Resources | http://boris.qub.ac.uk/edward/index.html |
| SHAREWARE.COM | http://www.shareware.com/ |
| Steelmaking | http://www.mlc.lib.mi.us/~stewarca/steelmaking.html |
| Forest Products and Wood Science | http://weber.u.washington.edu/~esw/fpm.htm |
| Thomas Register–Home Page | http://www.thomasregister.com:8000/login.cgi |
| Top 50 US/Canadian Metal Co.s | http://www.amm.com/ref/top50.HTM |
| Tree Talk & The Forest Partnership | http://www.woodweb.com/~treetalk/home.html |
| Tribology | http://www.mlc.lib.mi.us/~stewarca/tribology.html |

### Materials database

| | |
|---|---|
| Elements Info on the Web | http://www.shef.ac.uk/~chem/web-elements/ |
| Biomaterials Properties — TOC | http://www.lib.umich.edu/libhome/Dentistry.lib/Dental_tables/toc.html |
| CenBASE Materials on WWW | http://www.sgi.com/Works/iii/index.html |
| Chemscope — Medical Materials | http://chemscope.com/mat.htm |
| Corrosion relevant databases | http://www.clihouston.com/dbase.html |
| Electronic Products from ASM International | http://www.asm-intl.org/www-asm/e-prod/top.htm |
| F*A*C*T 2.1 — COMPOUND–Web | http://www.crct.polymtl.ca/fact/web/compweb.htm |
| Granta Design Limited | http://www.granta.co.uk |
| IDEMAT, Environmental Materials Database | http://www.io.tudelft.nl/research/mpo/general.htm |
| Japanese material database directory | http://fact.jicst.go.jp/~ritu/mdb/mdb.html |
| Periodic Table | http://steele.isgs.uiuc.edu/isgsroot/geochem/analytic/pt/ptable.html |
| Single Element Standards | http://radian.com/standards/el-singl.htm |
| STN Database Catalog | http://info.cas.org/ONLINE/CATALOG/descript.html |

### Metals prices and economic reports

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|---|---|
| American Metal Market On-line | http://www.amm.com/ |
| Business Communications Company | http://www.vyne.com/bcc/ |
| CRU International | http://www.cru-int.com/cruint/index.html#top |
| Daily Economic Indicators | http://www.bullion.org.za/prices.htm |
| Kitco Inc Gold & Precious Metal Prices | http://www.kitco.com/gold.live.html#ourtable |
| London Metal Exchange | http://www.lme.co.uk/ |
| Mineral-Resource | http://minerals.er.usgs.gov/USGSminCommodSpecs.html |
| Precious Metal & Bonds | http://lab.busfac.calpoly.edu/pub/quoter/commoditiesgraph.html |
| Precious metals 5F page | http://www.ccn.cs.dal.ca/~an388/Precious.html#price |
| Rand Refinery | http://www.bullion.org.za/associates/rr.htm#goldprice |
| Roskill Reports from TMS | http://www.tms.org/pubs/Books/Roskill.html |
| The Precious Metal and Gem Connection | http://www.pm-connect.com/images/right.map |
| Trelleborg Metals Prices | http://akropolis.malmo.trab.se/trellgroup/PRI.html |
| Ux Jan 96 Uranium Indicator Update | http://www.uxc.com/ux_u3o8_ind.html |

### Government organizations and professional societies

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|---|---|
| ASM International | http://www.asm-intl.org/ |
| ASME International | http://asme.web.aol.com/index.html |
| ASTM Web Site | http://www.astm.org/ |
| Commonwealth Scientific and Industrial Research Organization(Australia) | http://www.csiro.au |
| DIN Deutsches Institut für Normung e.V | http://www.din.de/frames/Welcome.html |
| Institute of Materials, London, UK | http://www.instmat.co.uk/ |
| International Standards Organization | http://www.iso.ch/ |
| Japanese Learned Societies on the Web | http://wwwsoc.nacsis.ac.jp/index-e.html |
| National Academy Press, USA | http://www.nap.edu/ |
| National Institute for Standards and Technology (USA) - Home Page | http://www.nist.gov/ |
| National Standards Authority of Ireland | http://www.nsai.ie/ |
| Society of Automotive Engineers (SAE) | http://www.sae.org/ |
| The Minerals, Metals & Materials Society | http://www.tms.org/TMSHome.html |
| UK Government Information Service | http://www.open.gov.uk/ |
| US Govt. Info on Minerals | http://minerals.er.usgs.gov:80/minerals/pubs/mcs/ |

### Miscellaneous

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|---|---|
| Common unit of measure conversion | http://www.conweb.com/tblefile/conver.shtml |
| Conversion Factors, Material Properties and Constants Related to Telescope Design | http://www.apo.nmsu.edu/Telescopes/SDSS/eng.papers/19950926_ConversionFactors/19950926.html#aa1 |
| Information for Physical Chemists | http://www.liv.ac.uk/Electrochem/online.html |
| K & K associate's thermal connection | http://www.kkassoc.com/~takinfo/ |
| Thermal data | http://www.csn.net/~takinfo/prop-top.html |