Case studies: use of data sources

14.1 Introduction and synopsis

Screening requires data sources with one structure, further information, sources with another. This chapter illustrates what they look like, what they can do and what they cannot.

The procedure follows the flow-chart of Figure 13.2, exploring the use of handbooks, databases, trade-association publications, suppliers data sheets, the Internet, and, if need be, in-house tests. Examples of the use of all of these appear in the case studies which follow. In each we seek detailed data for one of the materials short-listed in various of the case studies of earlier chapters. Not all the steps are reproduced, but the key design data and some indication of the level of detail, reliability and difficulty are given. They include examples of the output of software data sources, of suppliers data sheets and of information retrieved from the World-wide Web.

Data retrieval sounds a tedious task, but when there is a goal in mind it can be fun, a sort of detective game. The problems in Appendix B at the end of this book suggests some to try.

14.2 Data for a ferrous alloy – type 302 stainless steel

An easy one first: finding data for a standard steel. A spring is required to give a closing torque for the door of a dishwasher. The spring is exposed to hot, aerated water which may contain food acids, alkalis and salts. The performance indices for materials for springs

$$M_1 = \frac{\sigma_f^2}{E} \qquad \text{(small springs)}$$

or

$$M_2 = \frac{\sigma_f^2}{EC_{R\rho}} \qquad \text{(cheap springs)}$$

A screening exercise using the appropriate charts, detailed in Case Study 6.8, led to a shortlist which included elastomers, polymers, composites and metals. Elastomers and polymers are eliminated here by the additional constraint on temperature. Although composites remain a possibility, the obvious candidates are metals. Steels make good springs, but ordinary carbon steels would corrode in the hot, wet, chemically aggressive environment. Screening shows that stainless steels can tolerate this.

The detailed design of the spring requires data for the properties that enter M_1 or M_2, — the strength σ_f (in the case of a metal, the yield strength σ_y), the modulus E, the density ρ and the cost C_m — and data for the resistance to corrosion. The handbooks are the place to start.

Table 14.1 Data for hard drawn type 302 stainless steels*

Property	*Source A**	*Source B**	*Source C**
Density (Mg/m^3)	7.8	7.9	7.86
Modulus E (GPa)	210	215	193
0.2% Strength σ_y (MPa)	965	1000	—
Tensile strength (MPa)	1280	1466	1345
Elongation (%)	9	6	—
Corrosion resistance	'Good'	'Highly resistant'	No information
Cost	No information	No information	No information

*Source A: *ASM Metals Handbook*, 10th Edition, Vol. 1 (1990); Source B: Smithells (1987); Source C: http.//www.matweb.com. All data have been converted to SI units.

Source A, the *ASM Metals Handbook* and Source B Smithells (1987) both have substantial entries listing the properties of some 15 stainless steels. Hard-drawn Type 302 has a particularly high yield strength, promising attractive values of the indices M_1 and M_2. Information for Type 302 is abstracted in Table 14.1. Both handbooks give further information on composition, heat treatment and applications. The *ASM Metals Handbook* adds the helpful news: 'Type 302 has excellent spring properties in the fully hard or spring-temper condition, and is readily available'. The World-wide Web yields Source C, broadly confirming what we already know.

No problems here: the mechanical-property data from three quite different sources are in substantial agreement; the discrepancies are of order 2% in density and modulus, and 10% in strength, reflecting the permitted latitude in specification on composition and treatment. To do better than this you have to go to suppliers data sheets.

One piece of information is missing: cost. Handbooks are reluctant to list it because, unlike properties, it varies. But a rough idea of cost would be a help. We turn to the databases. MatDB is hopelessly cumbersome and gives no help. The *CMS* gives the property profile shown in Figure 14.1; it includes the information: 'Price: Range 1.4 to 1.6 £/kg' (or 1.1 to 1.3 $/lb). Not very precise, but enough to be going on with.

Postscript

We are dealing here with a well-bred material with a full pedigree. Unearthing information about it is straightforward. That given above is probably sufficient for the dishwasher design. If more is wanted it must be sought from the steel company or the local supplier of the material itself, who will advise on current availability and price.

Related case studies

Case Study 6.9: Materials for springs

14.3 Data for a non-ferrous alloy — Al–Si die-casting alloys

Candidate materials determined in Case Study 6.6 for the fan included aluminium alloys. Processing charts (Chapter 12) establish that the fan could be made with adequate precision and smoothness by die casting. To proceed with detailed design we now need data for density, ρ, and strength σ_f;

Name: Wrought austenitic stainless steel, AISI 302

State: HT grade D
Composition Fe/<.15C/17-19Cr/8-11Ni/<2Mn/<1Si/<.045P/<.03S

Similar Standards
UK (BS): 302S25; UK (former BS): En 58A; ISO: 683/XIII Type 12; USA (UNS): S30200; Germany (W.-Nr.): 1.4300; Germany (DIN): X12 CrNi 18 8; France (AFNOR): Z12 CN 18.10; Italy (UNI): X15 CrNi 18 09; Sweden (SIS): 2332; Japan (JIS): SUS 302;

General				
Density	7.81	—	8.01	Mg/m^3
Price	1.75	—	2.55	£/kg
Mechanical				
Bulk Modulus	134	—	146	GPa
Compressive Strength	760	—	900	MPa
Ductility	0.05	—	0.2	
Elastic Limit	760	—	900	MPa
Endurance Limit	436	—	753	MPa
Fracture Toughness	68	—	185	$MPa\,m^{1/2}$
Hardness	3.50E+3	—	5.70E+3	MPa
Loss Coefficient	2.90E-4	—	4.80E-4	
Modulus of Rupture	760	—	900	MPa
Poisson's Ratio	0.265	—	0.275	
Shear Modulus	74	—	78	GPa
Tensile Strength	1.03E+3	—	2.24E+3	MPa
Young's Modulus	189	—	197	GPa
Thermal				
Latent Heat of Fusion	260	—	285	kJ/kg
Maximum Service Temperature	1.02E+3	—	1.20E+3	K
Melting Point	1.67E+3	—	1.69E+3	K
Minimum Service Temperature	1	—	2	K
Specific Heat	490	—	530	J/kg K
Thermal Conductivity	15	—	17	W/m K
Thermal Expansion	16	—	20	$10^{-6}/K$
Electrical				
Resistivity	65	—	77	10^{-8} ohm m

Typical uses
Exhaust parts; internal building fasteners; sinks; trim; washing-machine tubs; water tubing, springs

References
Elliot, D. and Tupholme, S.M. 'An Introduction to Steel, Selection: Part 2, Stainless Steels', OUP (1981);
'Iron & Steel Specifications', 8th edition (1995), BISPA, 5 Cromwell Road, London, SW7 2HX;
Brandes, E.A. and Brook, G.R. (eds.) 'Smithells Metals Reference Book' 7th Edition (1992), Butterworth-Heinemann, Oxford, UK.
ASM Metals Handbook (9th edition), Vol. 3, ASM International, Metals Park, Ohio, USA (1980);
'Design Guidelines for the Selection and Use of Stainless Steel', Designers' Handbook Series no.9014, Nickel Development Institute (1991);

Fig. 14.1 Part of the output of the PC-format database *CMS* for Type 302 stainless steel. Details of this and other databases are given in the Appendix to Chapter 13, Section 13A.5.

in this case we might interpret σ_f as the fatigue strength. Prudence suggests that we should check the yield and ultimate strengths too.

Aluminium alloys, like steels, have a respectable genealogy. Finding data for them should not be difficult. It isn't. But there *is* a problem: a lack of harmony in specification. We reach for the handbooks again. Volume 2 of the *ASM Metals Handbook* reveals that 85% of all aluminium die-castings are made of Alloy 380, a highly fluid (i.e. castable) alloy containing 8% silicon with a little iron and copper. It gives the data listed under Source A in Table 14.2.

So far so good. But when we turn to Smithells (1987) we find no mention of Alloy 380, or of any other with the same composition. Among die-casting alloys, Alloy LM6 (alias 3L33 and LM20) features. It contains 11.5% silicon, and, not surprisingly, has properties which differ from those of Alloy 380. They are listed under Source B in Table 14.2. The density and modulus of the two alloys are the same, but the fatigue strength of LM6 is less than half that of Alloy 380.

This leaves us vaguely discomforted. Are they really so different? Are the data to be trusted at all? Before investing time and money in detailed design, we need corroboration of the data. A third handbook — the *Chapman and Hall Materials Selector* — gives data for LM6 (Source C, Table 14.2); it fully corroborates Smithells. This looks better, but just to be sure we seek help from the Trade Federations: the Aluminium Association in the US; the Aluminium Federation (ALFED) in the UK. We are at this moment in the UK — we contact ALFED — they mail their publication *The Properties of Aluminium and its Alloys*. It contains everything we need for LM6, including its seven equivalent names in Europe, Russia and Australasia. The data for moduli and strength are identical with those of Source C in the Table — Mr Chapman and Ms Hall got their data from ALFED, a sensible thing to have done. A similar appeal to the US Aluminium Association reveals a similar story — their publication was the origin of the ASM data of Source A.

So there is nothing wrong with the data. It is just that die-casters in the US use one alloy; those in Europe prefer another. But what about cost? None of the handbooks help. A quick scan through the WWW sites listed in Chapter 13 directs us to the London Metal Exchange http://www.metalprice.com./. Todays quoted price for aluminium alloy is Al-alloy 1.408 to 1.43 \$/kg.

Postscript

Discord in standards is a common problem. Committees charged with the task of harmonization sit late into the EU night, and move slowly towards a unifying system. In the case of both steels and aluminium alloys, the US system of specification, which has some reason and logic to it, is likely to become the basis of the standard.

Table 14.2 Data for aluminium alloys 380 and LM6

Property	*Source A**	*Source B**	*Source C**
Density (Mg/m^3)	2.7	2.65	2.65
Modulus (GPa)	71	70.6	71
0.2% Yield strength (MPa)	165	77	80
Ultimate strength (MPa)	330	216	200
Fatigue strength (MPa)	145	62	68
Elongation (%)	3	10	13

*Source A: *ASM Metals Handbook*, 10th Edition, Volume 2 (1990); Source B: Smithells (1987); Source C: *Chapman and Hall Materials Selector* (1997) and ALFED (1981). All data have been converted to SI units.

Related case studies

Case Study 6.7: Materials for high-flow fans
Case Study 12.2: Forming a fan
Case Study 12.6: Economical casting

14.4 Data for a polymer — polyethylene

Now something slightly less clear cut: the selection of a polymer for the elastic seal analysed in Case Study 6.10. One candidate was low-density polyethylene (LDPE). The performance index

$$M = \frac{\sigma_f}{E}$$

required data for modulus and for strength; we might reasonably ask, additionally, for density, thermal properties, corrosion resistance and cost.

Start, as before, with the handbooks. The *Chapman and Hall Materials Selector* compares various grades of polyethylene; its data for LDPE are listed in Table 14.3 under Source A. The *Engineered Materials Handbook, Vol. 2, Plastics*, leaves us disappointed. The *Polymers for Engineering Applications* (1987) is rather more helpful, but gives values for strength and thermal properties which differ by a factor of 2 from those of Source A, and no data at all for the modulus. The *Handbook of Polymers and Elastomers* (1975), after some hunting, gives the data listed under Source B — big discrepancies again. The *Materials Engineering 'Materials Selector'* (Source C) does much the same. None give cost. Things are not wholly satisfactory: we could do this well by simply reading data off the charts of Chapter 4. We need something better.

How about computer databases? The PLASCAMS and the *CMS* systems both prove helpful. We load PLASCAMS. Some 10 keystrokes and two minutes later, we have the data shown in Figure 14.2. They include a modulus, a strength, cost, processing information and applications: we are reassured to observe that these include gaskets and seals. The same database also contains the address and phone number of suppliers who will, on request, send data sheets. All much more satisfactory.

Table 14.3 Data for low-density polyethylene (LDPE)

Property	*Source A**	*Source B**	*Source C**
Density (Mg/m^3)	0.92	0.91–0.93	0.92
Modulus (GPa)	0.25	0.1–0.2	0.2
Heat deflection temp (°C)	50	43	—
Max service temp (°C)	50	82	69
T-expansion ($10^{-6}\,K^{-1}$)	200	100–200	160–198
T-conductivity (W/m K)	—	0.33	0.33
Tensile strength (MPa)	9	4–15	13
Rockwell hardness	D48	D41–50	D50
Corrosion in water/dilute acid	satisfactory	resistant	excellent

*Source A: *Chapman and Hall Materials Selector* (1997); Source B: *Handbook of Polymers and Elastomers* (1975); Source C: *Materials Engineering Materials Selector* (1997). All data have been converted to SI units.

Material: 119 LDPE

Resin type: TP S.Cryst. Cost/tonne: 600 S.G. 0.92

Max. Operating Temp	°C	50	Surface hardness		SD48
Water absorption	%	0.01	Linear expansion	E-5	20
Tensile strength	MPa	10	Flammability	UL94	HB
Flexural modulus	GPa	0.25	Oxygen index	%	17
Elongation at break	%	40	Vol. Resist.	log Ω cm	16
Notched Izod	kJ/m	1.06+	Dielect. strength	MV/m	27
HDT @ 0.45 MPa	°C	50	Dielect. const. 1kHz		2.3
HDT @ 1.80 MPa	°C	35	Dissipation Fact. 1kHz		0.0003
Matl. drying	hrs @ °C	NA	Melt temp. range	°C	220–260
Mould shrinkage	%	3	Mould temp. range	°C	20–40

ADVANTAGES Cheap, good chemical resistance. High impact strength at low temperatures. Excellent electrical properties.

DISADVANTAGES Low strength and stiffness. Susceptible to stress cracking. Flammable.

APPLICATIONS Chemically resistant fittings, bowls, lids, gaskets, toys, containers packaging film, film liners, squeeze bottles. Heat-seal film for metal laminates. Pipe, cable covering, core in UHF cables.

Fig. 14.2 Part of the output of PLASCAMS, a PC database for engineering polymers, for low-density polyethylene. It also gives trade names and addresses of UK suppliers. Details of this and other databases are given in the Appendix to Chapter 13, Section 13A.5.

But is it up to date? Not, perhaps, as much so as the World-wide Web. A search reveals company-specific web sites of polymer manufacturers (GE, Hoechst, ICI, Bayer and more). It also guides us to sites which collect and compile data from suppliers data sheets. One such is http://www.matweb.com./ from which Figure 14.3 was downloaded.

Postscript

There are two messages here. The first concerns the properties of polymers: they vary from supplier to supplier much more than do the properties of metals. And the way they are reported is quirky: a flexural modulus but no Young's modulus; a Notched Izod number instead of a fracture toughness, and so on. These we have to live with for the moment. The second concerns the relative ease of use of handbooks and databases: when the software contains the information you need, it surpasses, in ease, speed and convenience, any handbook. But software, like a book, has a publication date. The day after it is published it is, strictly speaking, out of date. The World-wide Web is dynamic; a well maintained site yields data which has not aged.

Related case studies

Case Study 6.10: Elastic hinges
Case Study 6.11: Materials for seals

Polyethylene, Low Density; Molded/Extruded

Polymer properties are subject to a wide variation, depending on the grade specified.

Physical Properties	Values	Comments
Density, g/cc	0.91	0.910–0.925 g/cc
Linear Mold Shrinkage, cm/cm	0.03	1.5–5% ASTM D955
Water Absorption, %	1.5	in 24 hours per ASTM D570
Hardness, Shore D	44	41–46 Shore D

Mechanical Properties	Values	Comments
Tensile Strength, Yield, MPa	10	4–16 MPa; ASTM D638
Tensile Strength, Ultimate, MPa	25	7–40 MPa
Elongation %; break	400	100–800%; ASTM D638
Modulus of Elasticity, GPa	0.2	0.07–0.3 GPa; In Tension; ASTM D638
Flexural Modulus, GPa	0.4	0–0.7 GPa; ASTM D790
Izod Impact in J, J/cm, or J/cm^2	999	No Break; Notched

Thermal Properties	Values	Comments
CTE, linear 20°C, μm/m-°C	30	20–40 μm/m-°C; ASTM D696
HDT at 0.46 MPa, °C	45	40–50°C
Processing Temperature, °C	200	150–320°C
Melting Point, °C	115	
Maximum Service Temp, Air, °C	70	60–90°Cv
Heat Capacity, J/g-°C	2.2	2.0–2.4 J/g-°C; ASTM C351
Thermal Conductivity, W/m-K	0.3	ASTM C177

Electrical Properties	Values	Comments
Electrical Resistivity, Ohm-cm	1E+16	ASTM D257
Dielectric Constant	2.3	2.2–2.4; 50–100 Hz; ASTM D150
Dielectric Constant, Low Frequency	2.3	2.2–2.4; 50–100 Hz; ASTM D150
Dielectric Strength, kV/mm	19	18–20 kV/mm; ASTM D149
Dissipation Factor	0.0005	Upper Limit; 50–100 Hz; ASTM D150
Dissipation Factor, Low Frequency	0.0005	Upper Limit; 50–100 Hz; ASTM D150

Fig. 14.3 Data for low-density polyethylene from the web site http://www.matweb.com.

14.5 Data for a ceramic — zirconia

Now a challenge: data for a novel ceramic. The ceramic valve of the tap examined in Case Study 6.20 failed, it was surmised, because of thermal shock. The problem could be overcome by choosing a ceramic with a greater thermal shock resistance. Zirconia (ZrO_2) emerged as a possibility. The performance index

$$M = \frac{\sigma_t}{E\alpha}$$

contains the tensile strength, σ_t, the modulus E and the thermal expansion coefficient α. The design will require data for these, together with hardness or wear resistance, fracture toughness, and some indication of availability and cost.

Table 14.4 Data for zirconia

Properties	*Source A**	*Source B**	*Source C**	*Source D**	*Source E**
Density (Mg/m^3)	5.0–5.8	5.4	—	6.0	5.65
Modulus (GPa)	200	150	150	200	200
Tensile strength (MPa)	—	240	—	—	—
Modulus of rupture (MPa)	—	83	—	400–800	550
Hardness (MPa)	12 000	11 000	6000	12 000	11 000
Fracture toughness ($MPa\,m^{1/2}$)	2.5–5	7.6	4.7	4.5	8.4
T-expansion ($10^{-6}\,K^{-1}$)	8–9	4.9	7	8–9	7
T-conductivity (W/m K)	1.8	2.4	1.8	1.7–2.0	1.67

*Source A: Morrell, *Handbook of Properties of Technical and Engineering Ceramics* (1985); Source B: *ASM Engineered Materials Reference Book* (1989); Source C: *Handbook of Ceramics and Composites* (1990); Source D: *Chapman and Hall 'Materials Selector'* (1997); Source E: http.//matweb.com./. All data have been converted to SI units.

After some hunting, entries are found in four of the handbooks; the best they can offer is listed in Table 14.4. One (the *ASM Engineered Materials Reference Book*), supplies the further information that zirconia 'has low friction coefficient, good wear and corrosion resistance, good thermal shock resistance, and high fracture toughness'. Sounds promising; but the numeric data show alarming divergence and have unpleasant gaps. No cost data, of course.

There are large discrepancies here. It is not unusual to find that samples of ceramics which are chemically identical can be as strong as steel or as brittle as a biscuit. Ceramics are not yet manufactured to the tight standards of metallic alloys. The properties of a zirconia from one supplier can differ, sometimes dramatically, from those of material from another. But the problem with Source B, at least, is worse: a modulus of rupture (MOR) of 83 MPa is not consistent with a tensile strength σ_t of 240 MPa; as a general rule, the MOR is greater than the tensile strength. The discrepancy is too great to be correct; the data must either have come from two quite different materials or be just plain wrong.

All this is normal; one must expect it in materials which are still under development. It does not mean that zirconia is a bad choice for the valve. It means, rather, that we must identify suppliers and base the design on the properties they provide. Figure 14.4 shows what we get: supplier's data for the zirconia with the tradename AmZirOx. Odd mixture of units, but the conversion factors inside the covers of this book allow them to be restored to a consistent set. The supplier can give guidance on supply and cost (zirconia currently costs about three times more than alumina), and can be held responsible for errors in data. The design can proceed.

Postscript

The new ceramics offer design opportunities, but they can only be grasped if the designer has confidence that the material has a consistent quality, and properties with values that can be trusted. The handbooks and databases do their best, but they are, inevitably, describing average or 'typical' behaviour. The extremes can lie far from the average. Here is a case in which it is best, right from the start, to go to the supplier for help.

Related case studies

Case Study 6.21: Ceramic valves for taps
Case Study 12.5: Forming a ceramic tap valve

TECHNICAL DATA

AmZirOX (Astro Met Zirconium Oxide) is a yttria partially stabilized zirconia advanced ceramic material which features high strength and toughness making it a candidate material for use in severe structural applications which exhibit wear, corrosion abrasion and impact. AmZirOX has been developed with a unique microstructure utilizing transformation toughening which allows AmZirOX to absorb the energy of impacts that would cause most ceramics to shatter. AmZirOX components can be fabricated into a wide range of precision shapes and sizes utilizing conventional ceramic processing technology and finishing techniques.

PROPERTIES	UNITS	VALUE
Color	—	Ivory
Density	g/cm^3	6.01
Water Absorption	%	0
Gas Permeation	%	0
Hardness	Vickers	1250
Flexural Strength	MPa (KPSI)	1075 (156)
Modulus of Elasticity	GPa (10^6 psi)	207 (30)
Fracture Toughness	$MPa\,m^{1/2}$	9
Poisson's Ratio	—	100
Thermal Expansion (25°C – 1000°C)	10^{-6}/°C (10^{-6}/°F)	10.3 (5.8)
Thermal Conductivity	Btu in/ft^2h°F	15
Specific Heat	cal/°C gm	0.32
Maximum Temperature Use (no load)	°C (°F)	2400 (4350)

Fig. 14.4 A supplier's data sheet for a zirconia ceramic. The units can be converted to SI by using the conversion factors given inside the front and back covers of this book.

14.6 Data for a glass-filled polymer — nylon 30% glass

The main bronze rudder-bearings of large ships (Case Study 6.21) can be replaced by nylon, or, better, by a glass-filled nylon. The replacement requires redesign, and redesign requires data. Stiffness, strength and fatigue resistance are obviously involved; friction coefficient, wear rate and stability in sea water are needed too.

Start, as always, with the handbooks. Three yield information for 30% glass-filled Nylon 6/6. It is paraphrased in Table 14.5. The approach of the sources differs: two give a single 'typical' value for each property, and no information about friction, wear or corrosion. The third (Source C) gives a range of values, and encouragement, at least, that friction, wear and corrosion properties are adequate. The things to observe are, first, the consistency: the ranges of Source C contain the values of the other two. But — second — this range is so wide that it is not much help with detailed design. Something better is needed.

The database PLASCAMS could certainly help here, but we have already seen what PLASCAMS can do (Figure 14.2). We turn instead to dataPLAS and find what we want: 30% glass-filled Nylon 6/6. Figure 14.5 shows part of the output. It contains further helpful comments and addresses for

POLYAMIDE 6.6

FERRO

MECHANICAL PROPERTIES	Unit	Value
Tensile Yield Strength	psiE3	—
Ultimate Tensile Strength	psiE3	19.7
Elongation at Yield	%	—
Elongation at Break	%	2.8
Tensile Modulus	psiE3	942
Flexural Strength	psiE3	26.8
Flexural Modulus	psiE3	812
Compressive Strength	psiE3	23
Shear Strength	psiE3	11
Izod Impact Unnotched, 23 ½ C	FLb/in	7
Izod Impact Unnotched, −40 ½ C	FLb/in	6
Izod Impact Notched, 23 ½ C	FLb/in	1.4
Izod Impact Notched, −40 ½ C	FLb/in	0.7
Tensile Impact Unnotched, 23 ½ C	FLP/i^2	—
Rockwell hardness M	—	90
Rockwell hardness R	—	115
Shore hardness D	—	85
Shore hardness A	—	—

THERMAL PROPERTIES	Unit	Value
DTUL @ 264 psi (1.80 MPa)	°F	401
DTUL @ 66 psi (0.45 MPa)	°F	428
Vicat B Temperature, 5 kg	°F	410
Vicat A Temperature, 1 kg	°F	—
Continuous Service Temperature	°F	284
Melting Temperature	°F	424
Glass Transition	°F	—
Thermal Conductivity	W/m K	0.35
Brittle Temperature	−°F	—
Linear Thermal Expansion Coeff.	E-5/F	1.67

Fig. 14.5 Part of the output of dataPLAS, a PC database for US engineering polymers, for 30% glass-filled Nylon 6/6. Details of this and other databases are given in the Appendix to Chapter 13, Section 13A.5.

suppliers (not shown), from whom data sheets and cost information, which we shall obviously need, can be obtained.

Postscript

Glass-filled polymers are classified as plastics, not as the composites they really are. Fillers are added to increase stiffness and abrasion resistance, and sometimes to reduce cost. Data for filled polymers can be found in all the handbooks and databases that include data for polymers.

Related case studies

Case Study 6.22: Bearings for ships' rudders

Table 14.5 Data for nylon 6/6, 30% glass filled

Property	*Source A**	*Source B**	*Source C**
Density (Mg/m^3)	1.37	1.3	1.3–1.34
Melting point (°C)	265	—	120–250
Heat deflection temp. (°C)	260	260	—
Tensile modulus (GPa)	—	9	9
Tensile strength (MPa)	180	186	100–193
Compressive strength (MPa)	180	165	165–276
Elongation (%)	3	3–4	2.5–3.4
T-expansion ($10^{-6}\,K^{-1}$)	20	107	15–50
T-conductivity (W/m K)	—	0.49	0.21–0.48
Friction, wear, etc.	No comment	No comment	Uses include: unlubricated gears, bearings and anti-friction parts
Corrosion	No comment	No comment	Good in water

*Source A: *Reinforced Plastics: Properties and Applications* (1991); Source B: *Engineers Guide to Composite Materials* (1987); Source C: *ASM Engineered Materials Handbook, Vol. 2* (1989).

14.7 Data for a metal-matrix composite (MMC) – Ai/SiC_p

An astronomical telescope is a precision device; mechanical stability is of the essence. On earth, damaging distortions are caused by the earth's gravitational field — that was the subject of Case Study 6.2. If, like the Hubble telescope, it is to operate in space, gravity ceases to be a problem. Stability, though, is at an even greater premium; adjustments, in space, are difficult. The problem now is thermal and vibrational distortion. These were analysed in Case Study 6.19; they are minimized by high thermal conductivity λ and low expansion coefficient α, high modulus E and low density ρ.

One of the candidates for the precision device was aluminium. If aluminium is good, a metal-matrix composite made of aluminium reinforced with particles of silicon carbide (Al/SiC_p) is probably better; certainly, it is stiffer and it expands less. This composite is a new material, still under development, and for that reason it does not appear on the present generation of Materials Selection Charts. Its potential can be assessed by calculating the values of the two performance indices which appear in Case Study 6.19, and to do that we need data for the four properties listed above: λ, α, E and ρ. There are no accepted standards or specifications for metal matrix composites. Finding data for them could be a problem.

Handbooks published before 1986 will not help much here — most of the development has occurred since then. We turn to the *Engineers Guide to Composite Materials* (1987) and find limited data, part of it derived from a material of one producer, the rest from that of another (Table 14.6, Source A), leaving us uneasy about consistency.

This is a bit thin for something to be shot into space. Minor miscalculations here become major embarrassments, as the history of the Hubble demonstrates. Something better is needed. The resource to tap next is that of the producers' data sheets. BP International manufactures a range of aluminium–SiC composites and provides a standard booklet of properties to potential users. Data for 6061-20%SiC (the same alloy and reinforcement loading as before), abstracted from

Table 14.6 Data for 6061 aluminium with 20% particulate SiC

Properties	*Source A**	*Source B**	*Source C**
Density (Mg/m^3)	2.91	2.9	2.9–2.95
Price (\$/kg)	—	—	100–170
T-expansion (10^{-6} K^{-1})	14.4	13.5	12.4–13.5
T-conductivity (W/m K)	125	—	123–128
Specific heat (J/kg K)	800	—	800–840
Modulus (GPa)	121	125	121–125
Yield strength (MPa)	441	430	430–445
Ultimate strength (MPa)	593	610	590–610
Ductility (%)	4.5	5.0	4.0–6.0

*Source A: *Engineers Guide to Composite Materials* (1987) reporting data from DWA composites and Arco Chemical; Source B: BP Metal Composites Ltd, Technical Data Sheets for Metal Matrix Composites (1989); Source C: *CMS* database for metal matrix composites (1995)

the booklet, are listed under Source B in Table 14.6. The data from the two sources are remarkably consistent: density, modulus and strengths differ by less than 3%. But BP does not give a thermal conductivity; it will still be necessary to assume that it is the same as that of the Arco material.

Finally, a quick look at software. The CMS system contains records for a number of MMCs. That for an Al-20%SiC(p) material is listed under Source C. The ranges bracket the values of the other two sources, and there is an approximate price.

Postscript

Making this assumption, we can calculate values for the two ‘precision instrument’ performance indices of Case Study 6.19. As expected, they are both better than those for aluminium and its alloys, and in high-cost applications like a space telescope the temptation to exploit this improvement is strong.

And herein lies the difficulty in using ‘new’ materials: the documented properties, often, are very attractive, but others, not yet documented (corrosion behaviour; fracture toughness, fatigue strength) may catch you out. Risks exist. Accepting or rejecting them becomes an additional design decision.

Related case studies

Case Study 6.3: Mirrors for large telescopes
Case Study 6.20: Materials to minimize thermal distortion in precision devices

14.8 Data for a polymer-matrix composite — CFRP

If a design calls for a material which is light, stiff and strong (Case Studies 6.2, 6.3, 6.5 and 6.8), it is likely that carbon-fibre reinforced polymer (CFRP) will emerge as a candidate. Here we have a real problem: CFRP is made up of plies which can be laid-up in thousands of ways. It

Table 14.7 Data for 0/90/±45 carbon in epoxy

Properties	*Source A**	*Source B**	*Source C**
Density (Mg/m^3)	1.54	1.55	1.55
Modulus (GPa)	65	72	60
Tensile strength (MPa)	503	550	700
Compressive strength (MPa)	503	400	—
T-expansion (10^{-6} K^{-1})	—	—	20
T-conductivity (W/m K)	—	8	5

*Source A: *ASM Engineers Guide to Composite Materials* (1987); Source B: *Engineered Materials Handbook, Vol. 1*, (1987); Source C: 'Reinforced Plastics, Properties and Applications' 1 (1991).

is not one material, but many. A report of data for CFRP which does not also report the lay-up is meaningless.

There are, though, some standard lay-ups, and for these, average properties can be measured. There is, in particular, the 'isotropic' lay-up, with equal number of plies with fibres in the 0, 90 and ±45 orientations. Let us suppose, by way of example, that this is what we want.

The best starting point for composite data is the *ASM Engineers Guide to Composite Materials* (Source A, Table 14.7). Comparing these data with those from Sources B and C (identified in the table) illustrates the problem. All are in the 'isotropic' lay up, but values differ by up to 50% — a more detailed analysis of this variability, documented in Source A, shows differences of up to 50% in modulus, 100% in strength.

Computer databases reveal the same problem. Here rescue, via material producers' data sheets, is not to hand: producers deliver epoxy and carbon fibres or prepreg — a premixed but uncured fibre-resin sheet; they do not supply finished laminates. We must accept the fact that published data are usually approximate.

There are two ways forward. The first is computational. Laminate theory allows the stiffness and strength of a given lay-up to be computed when the properties of fibres and matrix are known. Designers in large industries use laminate theory to decide on number and lay-up of plies, but few small industries have the resources to do this. The second is experimental: a trial lay-up is tested, measuring the responses which are critical to the design, and the lay-up is modified as necessary to bring these within acceptable limits.

Postscript

Conventional sources, this time, let us down. It is, perhaps, a mistake to think of CFRP as a 'material' with unique properties. It has 'properties' only when shaped to a component, and they depend on both the material and the shape.

The information for CFRP, GFRP and KFRP provided by the data sources is a starting point only; it should never be used, unchecked, in a critical design.

Related case studies

Case Study 6.3: Mirrors for large telescopes
Case Study 6.4: Materials for table legs
Case Study 6.6: Materials for flywheels
Case Study 6.9: Materials for springs

14.9 Data for a natural material – balsa wood

Woods are the oldest of structural materials. Surely, with their long history, they must be well characterized? They are. But the data are not so easy to find. Although woods are the world's principal material of building (even today), ordinary data books do not list their properties. One has to consult specialized sources.

Take a specific task: that of locating data for balsa, a possible material for the wind-spars of man-powered planes (Section 10.3). Of the data sources for woods listed in the Further reading section Chapter 13; one is particularly comprehensive. It is the massive compilation of the US Department of Agriculture Forest Services (Source A); it lists densities, moduli, strengths, and thermal properties for many different species, including balsa. Some of the others give some data too, but one quickly discovers that they got it from Source A. The scientific literature, some of it reviewed in Source B, gives a second, independent, set of data. The two are compared in Table 14.8. Considering that balsa is a natural material, subject to natural variability, the agreement is not bad.

Can databases help? Surprisingly, there are many, although they differ greatly. Print-out for balsa, from the *CMS*, is shown in Figure 14.6. Examining all this, we learn the following. First, woods are anisotropic: properties along the grain differ from those across it. Balsa is particularly anisotropic: the differences are as great as a factor of 40. Second, woods are variable: nature does not apply tight specifications. This initial variability is made worse by a dependence of the properties on humidity and on age, although these last two effects are documented and their effect can be estimated. Woods, generally, are used in low-performance applications (building, packaging) where safety margins are large; then a little uncertainty in properties does not matter. But there are other examples: balsa and spruce in aircraft; ash in automobile frames, vaulting poles, oars, yew in bows, hickory in skis, and so on. Then attention to these details is important.

Postscript

All natural materials have the difficulties encountered with balsa: anisotropy, variability, sensitivity to environment, and ageing. This is the main reason they are less-used now than in the past, despite

Table 14.8 Data for balsa wood

Properties	*Source A**	*Source B**
Density (Mg/m^3)	0.17	0.2
Modulus ‖ (GPa)	3.8	6.3
⊥ (GPa)	0.1	0.1
Tensile strength ‖ (MPa)	19.3	23
⊥ (MPa)	—	—
Compressive strength, ‖ (MPa)	12	18
⊥ (MPa)	—	1
Fracture toughness ‖ ($MPa^{1/2}$)	—	0.1
⊥ ($MPa^{1/2}$)	—	1.5

*Source A: *Wood Handbook, US Forest Service Handbook No. 72* (1974); Source B: Gibson and Ashby *Cellular Solids* (1997). The symbol ‖ means parallel to the grain; ⊥ means perpendicular.

Name	**Ochroma spp. (MD), parallel to grain**			
Common Name	**Balsa (MD)L**			
General Properties				
Density	0.17	—	0.21	Mg/m^3
Diff. Shrinkage (Rad.)	0.05	—	0.06	% per % MC
Diff. Shrinkage (Tan.)	0.07	—	0.09	% per % MC
Rad. Shrinkage (green to oven-dry)	3.2	—	7	%
Tan. Shrinkage (green to oven-dry)	3.5	—	5.3	%
Vol. Shrinkage (green to oven-dry)	6	—	9	%
Mechanical Properties				
Brinell Hardness	10.2	—	10.4	MPa
Bulk Modulus	0.08	—	0.1	GPa
Compressive Strength	8.5	—	12.5	MPa
Ductility	0.0103	—	0.0126	
Elastic Limit	11.4	—	14	MPa
Endurance Limit	5.4	—	6.6	MPa
Flexural Modulus	3.4	—	4.2	GPa
Fracture Toughness	0.5	—	0.6	$MPa.m^{1/2}$
Hardness	3.5	—	4.3	MPa
Impact Bending Strength	11.9	—	14.6	
Janka Hardness	0.35	—	0.43	kN
Loss Coefficient	0.0122	—	0.015	
Modulus of Rupture	18	—	22	MPa
Poisson's Ratio	0.35	—	0.4	
Shear Strength	3.2	—	3.9	MPa
Shear Modulus	0.31	—	0.38	GPa
Tensile Strength	16	—	25	MPa
Work to Maximum Strength	13	—	15.9	kJ/m^3
Young's Modulus	4.2	—	5.2	GPa
Thermal Properties				
Glass Temperature	350	—	375	K
Maximum Service Temperature	390	—	410	K
Minimum Service Temperature	200	—	250	K
Specific Heat	1.66E+3	—	1.71E+3	J/kg.K
Thermal Conductivity	0.09	—	0.12	W/m.K
Thermal Expansion	2	—	11	$10^{-6}/K$
Electrical Properties				
Breakdown Potential	4.85	—	4.9	10^6 V/m
Dielectric Constant	2.45	—	3	
Resistivity	6.00E+13	—	2.00E+14	10^{-8} ohm.m
Power Factor	0.021	—	0.026	

Typical uses Cores for sandwich structures; model building; flotation; insulation; packaging.

References Datasheets: Baltek SA
Gibson, L.J. and Ashby, M.F. 'Cellular Solids, Structure and Properties', CUP, Cambridge (1997) US Forestry Commission Handbook 72, (1974).

Supplier Baltek SA, 61 rue de la Fontaine, 75016, Paris, FRANCE; Diab-Barracuda Inc., 1100 Avenue S., Grande Prairie, Texas 75050, USA; Flexicore UK Ltd, Earls Colne Industrial Park, Earls Colne, Colchester, Essex CO6 2NS, UK;

Fig. 14.6 Part of the record of the *CMS* database for the properties of balsa wood, parallel to the grain. *A second record* (not shown) gives the properties in the perpendicular direction.

their sometimes remarkable properties (think of bamboo, bone, antler and shell), their low cost and their environmental friendliness.

Related case studies

Case Study 8.2: Spars for man-powered planes

14.10 Summary and conclusions

One day there may be universal accepted standards and designations for all materials but it is a very long way off. If you want data today, you have to know your way around the sources, and the quirks and eccentricities of the ways in which they work.

Metals, because they have dominated engineering design for so long, are well specified, coded and documented in hard-copy and computerized databases. When data for metals are needed, they can be found; this chapter gave two examples. Organizations such as the American Society for Metals (ASM), the British Institute of Materials (IM), the French Societé de Metallurgie, and other similar organizations publish handbooks and guides which document properties, forming-processes and suppliers in easily accessed form.

Polymers are newer. Individual manufacturers tend to be jealous of their products: they give them strange names and withhold their precise compositions. This is beginning to change. Joint databases, listed at the end of the previous chapter, pool product information; and others, independently produced, document an enormous range of polymer types. But there remain difficulties: no two polyethylenes, for instance, are quite the same. And the data are not comprehensive: important bits are missing. Filled polymers, like the glass-filled nylon of this chapter, are in much the same state.

For ceramics it is worse. Ceramics of one sort have a very long history: pottery, sanitary ware, furnace linings, are all used to bear loads, but with large safety factors — design data can be badly wrong without compromising structural integrity. The newer aluminas, silicon carbides and nitrides, zirconias and sialons are used under much harsher conditions; here good design data are essential. They are coming, but it is a slow process. For the moment one must accept that handbook values are approximate; data from the materials supplier are better.

Metal-matrix composites are newer still. In their use they replace simple metals, for which well-tried testing and documentation procedures exist. Because they are metals, their properties are measured and recorded in well-accepted ways. Lack of standards, inevitable at this stage, creates problems. Further into the future lie ceramic-matrix composites. They exist, but cannot yet be thought of as engineering materials.

For fibre-reinforced polymers, the picture is different. The difficulty is not lack of experience; it is the enormous spread of properties which can be accessed by varying the lay-up. Approximate data for uniaxial and quasi-isotropic composite are documented; any other lay-up requires the use of laminate theory to calculate stiffness, and more approximate methods to predict strength. For critical applications, component tests are essential.

A lot is known about natural materials — wood, stone, bone — because they have been used for so long. Many of these uses are undemanding, with large safety margins, so much of the knowledge is undocumented. Their properties are variable, and depend also on environment and age, for which allowance must be made. Despite this, they remain attractive, not least because they are environmentally friendly (see Chapter 16).

So, in using data sources, it is sensible to be circumspect: the words in one context mean one thing, in another, another. Look for completeness, consistency, and documentation. Anticipate that newer materials cannot be subject to the standards which apply to the older ones. Turn to a supplier for data when you know what you want. And be prepared, if absolutely necessary, to test the stuff yourself.

14.11 Further reading

All the sources referenced in this chapter are detailed in the Appendix to Chapter 13, to which the reader is referred.