Materials: engineering, science, properties, and design
3e Solution manual

Chapter 2. Exercises with worked solutions

Exercise E2.1 ***Material properties from experience.*** List the six main classes of engineering materials. Use your own experience to rank them approximately:

(a) by stiffness (modulus, E). A sheet of a material that has a high modulus is hard to bend when in the form of sheet. A sheet of material with a low modulus is floppy.

(b) by thermal conductivity (λ). Materials with high conductivity feel cold when you pick them up on a cold day. Materials with low conductivity may not feel warm, but they don't freeze your hands.

Answer. The main classes of engineering materials are ceramics, glasses, metals, polymers, elastomers and hybrids that include composites, foams and natural materials.

(a) Metals, ceramics and glasses and composites are stiff; polymers, elastomers and foams are less stiff.

(b) Metals are cold to touch - they conduct heat well; polymers, many hybrids (like wood and foams) have low thermal conductivity.

Exercise E2.2 ***Classification (1).*** A good classification looks simple – think, for instance, of the periodic table of the elements. Creating it in the first place, however, is another matter. This chapter introduced two classification schemes that work, meaning that every member of the scheme has a unique place in it, and any new member can be inserted into its proper position without disrupting the whole. Try one for yourself. Here are some scenarios. Make sure that each level of the hierarchy properly contains all those below it. There may be more than one way to do this, but one is usually better than the others. Test it by thinking how you would use it to find the information you want.

How many different ways can two sheets of paper be attached to each other, temporarily or permanently? Classify these, using 'Mechanism of joining' as the top level of the classification. Then try to develop the next level, based on your observations of the ways in which sheets of paper are joined.

Possible answer

- **Adhesives**
  - Water based
  - Solvent based
- **Staples**
  - Steel
  - Brass
- **Paper clips**
  - Metal
  - Plastic
- **Sewing**
  - Natural fibers
  - Man-made fibers

Exercise E2.3 ***Classification (2).*** In how many ways can wood be treated to change its surface appearance? Classify these, using the generic finishing technique as the top level of the classification. Then try to develop the next level, based on your observations of the ways in which wood products are finished.

Possible answer

- **Varnish**
  - Clear
  - Tinted
- **Paint**
  - Water-based
  - Solvent based
- **Polish**
  - Wax
  - Spray
- **Dye, stain**
  - Natural,
  - Synthetic
- **Texture**
  - Sanded, sand-blasted
  - Weathered.

Exercise E2.4 ***Classification (3).*** You run a bike shop that stocks bikes of many types (children's bikes, street bikes, mountain bikes, racing bikes, folding bikes etc), prices and sizes. You need a classification system to allow customers to look up your bikes on the internet. How would you do it?

Possible answer.

Bicycles
- **Racing**
  - Steel
    - 24 inch
    - 26 inch
    - 28 inch
  - Alloy
  - Titanium
  - Carbon fiber
- **Mountain**
- **Street**
- **Folding**
- **Children's etc**

Exercise E2.5 ***Classification (4).*** You are asked to organize the inventory of fasteners in your company. There are several types (snap, screw, bolt, rivet) and within each, a range of materials and sizes. Devise a classification scheme to store information about them.

Possible answer

Fasteners
- **Bolts**
  - Steel
    - 4 mm
    - 5 mm
    - 6 mm etc
  - Stainless
  - Brass
  - High tensile
- **Rivets**
- **Screws**
- **Snap etc**

Exercise E2.6 ***Shaping.*** What is meant by a shaping process? Look around you and ask yourself how the things you see were shaped.

Answer. A shaping process takes a raw material and gives it shape (eg casting or molding), or modifies the shape of an already shaped component (eg machining or grinding).

Exercise E2.7 ***Joining.*** Almost all products involve several parts that are joined. Examine products immediately around you and list the joining methods used to assemble them.

Answer. Find examples of joining by: adhesives, fasteners, snap-fits and welding.

Exercise E2.8 ***Surface treatment.*** How many different surface treatment processes can you think of, based on your own experience? List them and annotate the list with the materials to which they are typically applied.

Possible answers. Painting (applied to most materials); electroplating (e.g. chromium plating for appearance and protection); polishing (of wood, brass, silver); anodizing (of aluminium); texturing (metals, polymers); enameling (of copper, cast iron cooking ware, steel).

Exercise E2.9 ***Use of bar-charts.*** Examine the material property chart of Figure 2.8. By what factor, on average, are polymers less stiff than metals? By what factor is Neoprene less stiff than Polypropylene (PP)?

Answer. On average polymers are about 50 times less stiff than metals. Neoprene has a modulus that is about 1000 times smaller than that of polypropylene.

Exercise E2.10 ***Use of bar and bubble-charts (1).*** Wood is a natural polymer, largely made up of cellulose and lignin, and they, like engineering polymers, are almost entirely hydrogen, carbon, oxygen and a little nitrogen. Has nature devised a cocktail of these elements that has a higher modulus than any bulk man-made polymer? Engineering polymers and woods appear on the charts of Figures 2.8 and 2.9. Use either one to answer the question.

Answer. The charts show that woods, have a higher modulus parallel to the grain than any bulk commercial polymer.

Exercise E2.11 ***Use of bubble-charts (2).*** Windows can be made of glass (houses), polycarbonate, PC (conservatories) or poly-methyl-methacrylate, PMMA (aircraft). Would a glass window be more flexible than a replacement of the same thickness made of polycarbonate? Would it be heavier? Use the bubble chart of Figure 2.9 to find out.

Answer. Polycarbonate, PC, lies in upper end of the blue envelope. Glass lies at the lower left end of the yellow one. Glass has a modulus that is about 30 times greater that PC, so a glass pane is 30 times stiffer than a PC one of the same thickness. The density of glass is about twice that of PC – the glass pane will be twice as heavy as the one made of PC.

Exercise E2.12 ***Use of bubble-charts (3).*** Do zinc alloys have a higher specific stiffness E/ρ than Polypropylene (PP)? Use the bubble chart of Figure 2.9 to find out.

Answer. Yes, zinc alloys lie on a higher line of E/ρ than Polypropylene. Reading values of E and ρ from the chart we find the specific stiffness of zinc alloys is approximately 0.02 GPa/(kg/m^3), that of Polypropylene is approximately 0.003 in the same units.

Exploring design with CES.

Designers need to be able to find data quickly and reliably. That is where the classifications come in. The CES system uses the classification scheme described in this chapter. Before trying these exercises, open the Materials Universe in CES and explore it. The opening menu offers three or more options – take the first, 'Level 1'.

Exercise E2.13 Use the 'Browse' facility in Level 1 of the CES Software to find the record for copper. What is its thermal conductivity? What is its price?

Answer. The thermal conductivity of copper is 160 – 390 W/m.K, depending on purity. Its price is 4.9 – 6.3 $/kg (the price of copper fluctuates considerable – hence the wide range).

Exercise E2.14 Use the 'Browse' facility in Level 1 of the CES Software to find the record for the thermosetting polymer *Phenolic*. Are they cheaper or more expensive than *Epoxies*?

Answer. Phenolics are cheaper.

Exercise E2.15 Use the 'Browse' facility to find records for the polymer-shaping processes *Rotational molding*. What, typically, is it used to make*?*

Answer. Tanks, food and shipping containers, housings, portable lavatories, traffic cones, toys (e.g. balls), dustbins, buckets, boat hulls and pallets.

Exercise E2.16 Use the 'Search' facility to find out what *Plexiglas* is. Do the same for *Pyroceram*.

Answer. Plexiglass is PMMA, polymethyl methacrylate, or acrylic. Pyroceram is a glass ceramic.

Exercise E2.17 Use the 'Search' facility to find out about the process *Pultrusion*. Do the same for *TIG welding*. Remember that you need to search the Process Universe, not the Material Universe. To do this change the Table from 'MaterialUniverse' to 'ProcessUniverse' using the tab at the top of the Browse window.

Answer. Pultrusion is a way of making continuous fiber-reinforced sections such as tube and sheet. TIG welding is Tungsten Inert Gas welding – electric arc welding with a tungsten electrode in an atmosphere of argon.

Exercise E2.18 Compare Young's modulus E (the stiffness property) and thermal conductivity λ (the heat-transmission property) of *aluminum alloys* (a non-ferrous metal), *alumina* (a technical ceramic), *polyethylene* (a thermoplastic polymer) and *neoprene* (an elastomer) by retrieving values from CES Level 1. Which has the highest modulus? Which has the lowest thermal conductivity?

Answer.

Material	Young's modulus , E GPa	T-conductivity λ , W/m.K
Aluminum alloys	112 - 148	160 - 390
Alumina	343 - 390	26 – 38.5
Polyethylene	0.62 – 0.9	0.4 – 0.44
Neoprene	0.0007 – 0.002	0.1 – 0.12

All material properties have ranges. At Level 1 of the software, in which one record describes a class of materials, the ranges are wide because they encompass the whole class. At Level 2 they are a little narrower because it subdivides classes into sub-classes. At Level 3 they are much narrower because a Level 3 record describes a single grade of a material.

The ceramic alumina has by far the highest value of Young's modulus of the four materials. The elastomer neoprene has the lowest value of thermal conductivity.

Exploring the science with CES Elements

The CES system contains a database for the periodic table called 'Elements'. The records contain fundamental data for each of the elements. We will use this in the book to delve a little deeper into the science that lies behind material properties.

Exercise E2.19 Refresh your memory of the periodic table, perhaps the most significant classification system of all time. Open the *Elements* database by clicking on Change in the Browse window and selecting Elements from the menu that is offered. (or go to *File – Change database – Elements*) and double click on Periodic Table to see the table. This database, like the others described in this chapter, has a tree-like structure. Use this to find the record for Aluminum (Row 3, Atomic number 13) and explore its contents. Many of the properties won't make sense yet. We introduce them gradually throughout the book.