Chapter 1
Introduction: materials – history and character

Professor James Stuart, the first Professor of Engineering at Cambridge (1875-1890).

A few hundred materials were available to engineers in Stuart's time
Now more than 160000

1.1 Materials, processes, and choice

- Engineers design and make things and must select materials to perform functions (support loads, insulate, reflect light, resist corrosion, etc.).
- These choices are influenced not only by technical performance but by cost, environmental impact, safety, etc.
- To actually make a product (not just 'design' it) a process must also be selected and coupled to the appropriate material. Sometimes the process dominates.
- The challenge of choosing the best material (and process) for a given job has become increasingly complicated in the last 100 years (from a few hundred possibilities to several hundred thousand).
- A design-driven approach to materials and manufacturing process selection is needed.

www.ancienttouch.com/ 1200.jpg

Roman glass; 1st century

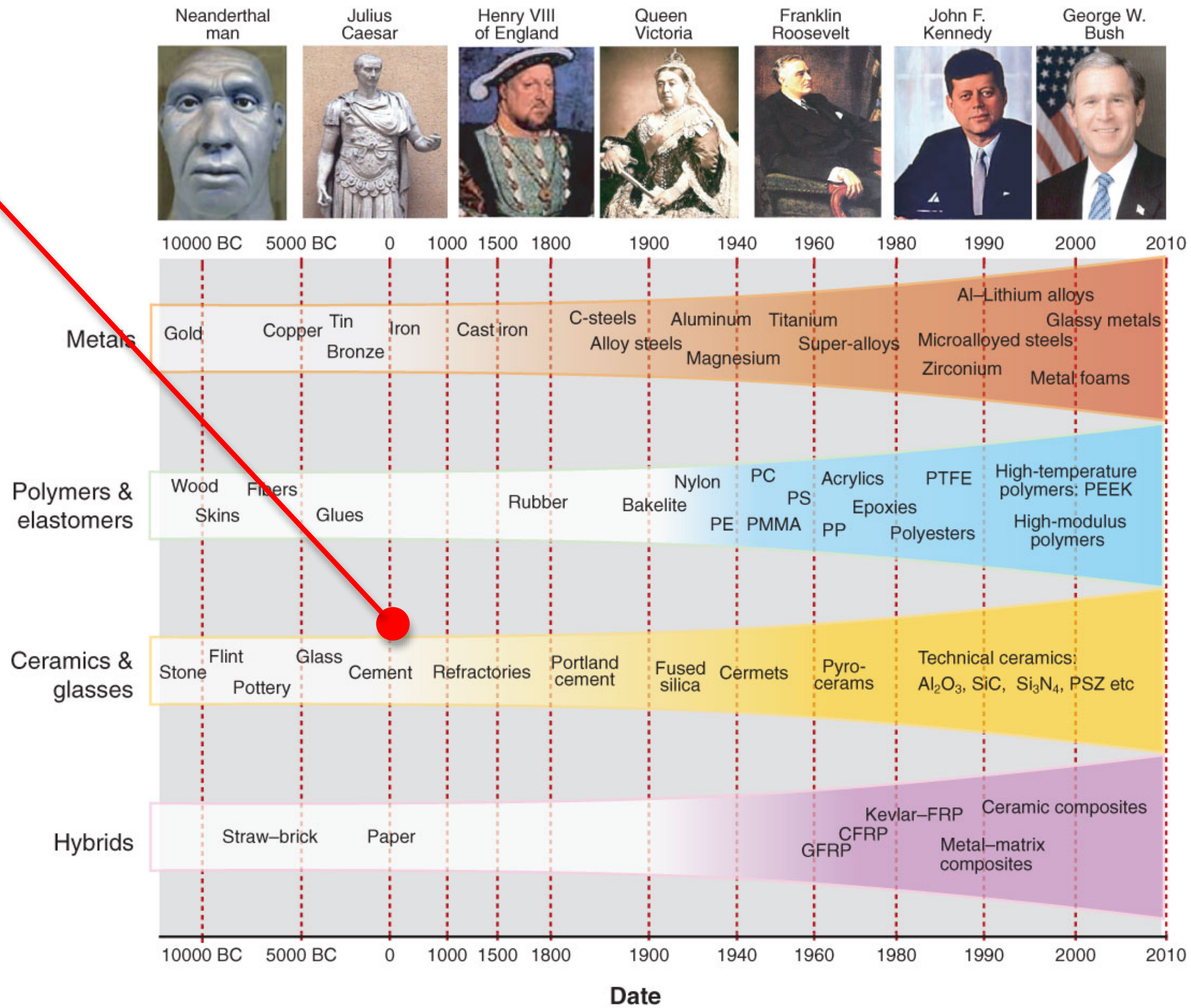


Figure 1.1 The development of materials over time. The materials of pre-history, on the left, all occur naturally; the challenge for the engineers of that era was one of shaping them. The development of thermochemistry and (later) of polymer chemistry enabled man-made materials, shown in the colored zones. Three - stone, bronze and iron - were of such importance that the era of their dominance is named after them.

1.2 Materials properties

Mechanical properties

- Elastic modulus, E. 'Elastic' – returns to original shape when the load is removed. High E – intrinsically 'stiff' (steel). Shape is also important.

- Permanent deformation – related to 'strength' not stiffness, typically quantified by the yield strength, σ_y. Materials like titanium alloys have high σ_y even though they have modest E.

- Hardness – resistance to *localized* permanent deformation. Ch. 6.

- For metals deformation leads to an increase in strength ('work hardening') but there is an ultimate limit, the tensile strength, σ_{ts}, beyond which the material fails.

1.2 Materials properties

Mechanical properties

- Ductility – the amount of stretch before breaking.

- Consider a PMMA (plexiglas) ruler – negligible bending before sudden fracture ('brittle'). If there is no permanent deformation, yielding is not relevant. The right property to consider is the resistance to cracking and fracture which is measured by the fracture toughness, K_{1c}.

  Steels are generally tough, glass is brittle.

- The role of density, ρ. For moving objects especially, weight carries a penalty.

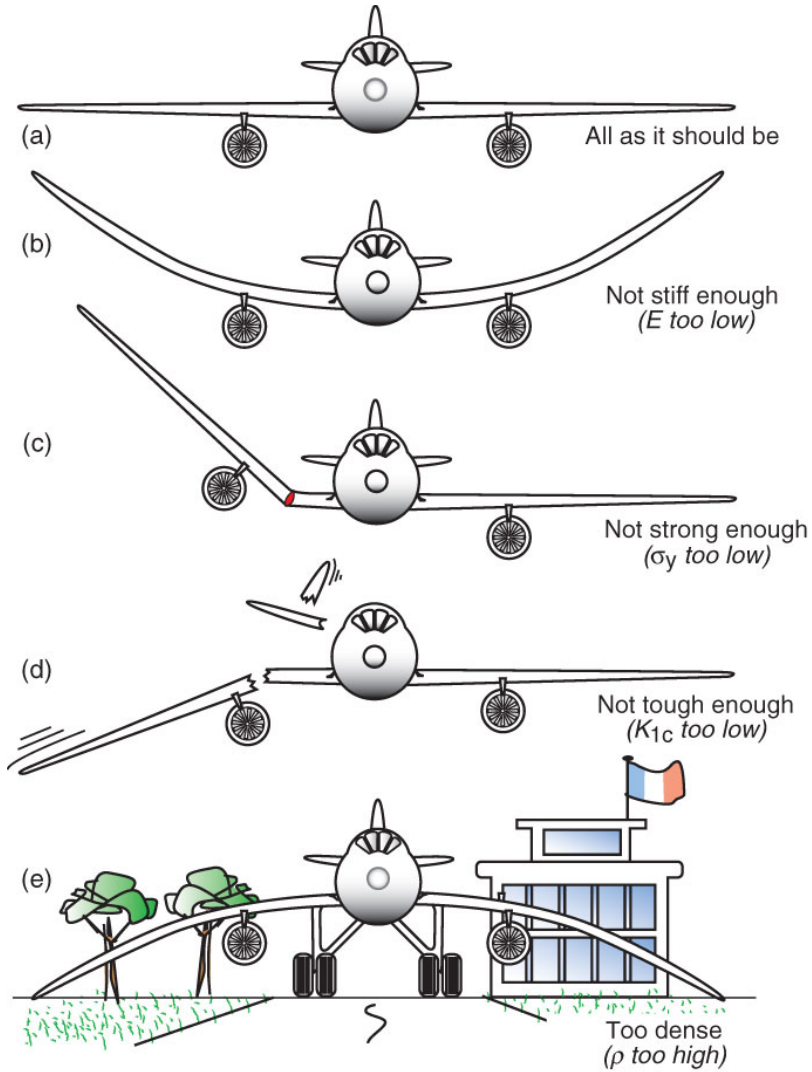


Figure 1.2 Mechanical properties.

1.2 Materials properties

Thermal properties

- Generally, properties decline with increasing T.
- Maximum service temperature, T_{max}. Stainless steel (~800°C), polymers (<~150°C).
- Most materials expand with T; quantified by the thermal expansion coefficient, α.
- Thermal conductivity, λ, measures the rate that heat flows along a temperature gradient. Relevant to steady, long-time heat flow.
- Heat capacity, C_p, measures the amount of heat it takes to increase the T by a certain amount. Shorter time scale.
- The time required to heat the top of a slab of given thickness when heated from one side is proportional to λ/C_p which is inversely proportional to the thermal diffusivity, *a*.

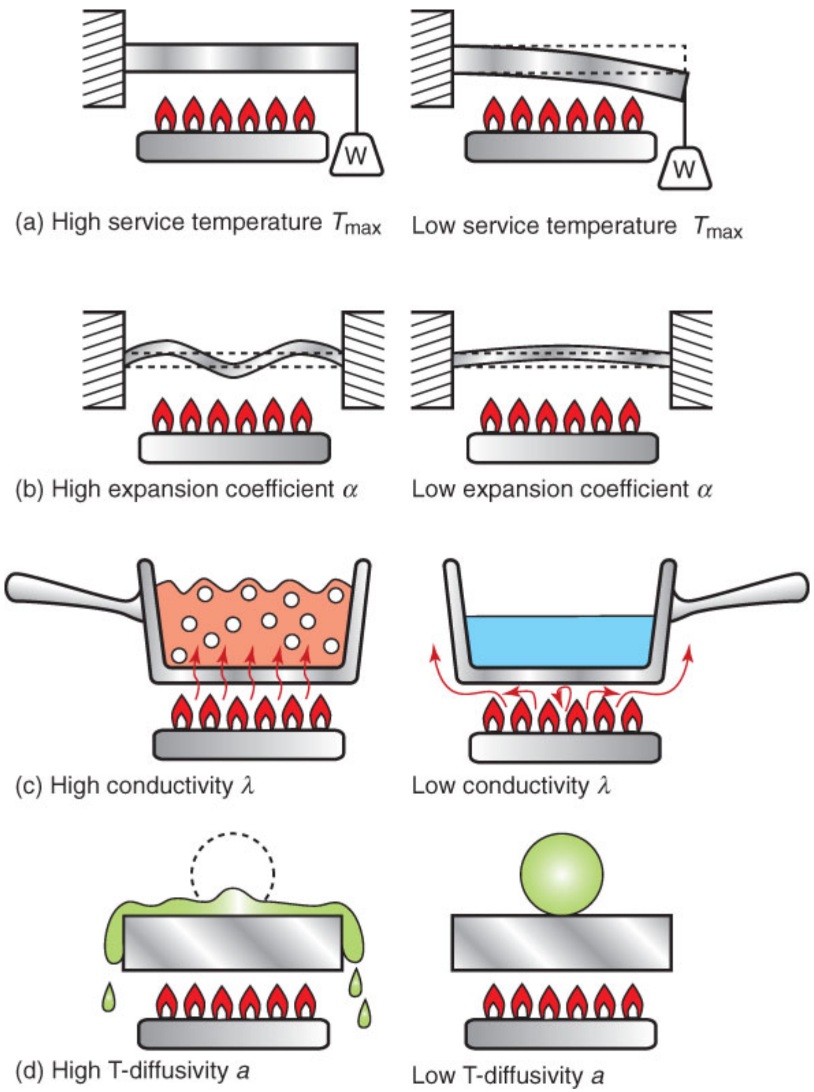


Figure 1.3 Thermal properties.

PI question *(test)*

Which country is playing an increasingly critical role in controlling the availability of scarce chemical elements?

1. Japan
2. China
3. India
4. Brazil

PI question

Which is the most important thermal property for the protective coating of the sensor in a clinical thermometer?

1. Thermal diffusivity
2. Heat capacity
3. Thermal conductivity
4. Thermal expansion coefficient

1.2 Materials properties

Electrical, magnetic, and optical properties

- Electrical conductivity, K_e, and resistivity, ρ_e. Inverse of each other.
- Dielectric constant, ε_D. High dielectric constant – electric field influences electrons in the material; low – immune to the field.
- Electricity and magnetism are linked – current induces magnetic field, a moving magnet induces a current in conductors.
- ‘Hard’ magnets (ferro and ferri) can trap the magnetic field and are hard to demagnetize (headphones, motors). Key property - remanence (a measure of the intensity of the retained magnetism).

  ‘Soft’ magnets are easy to magnetize and demagnetize (transformer core). Key property – saturation magnetization (how large a field the material can conduct).
- Optical behavior – reflection, refraction, absorption.

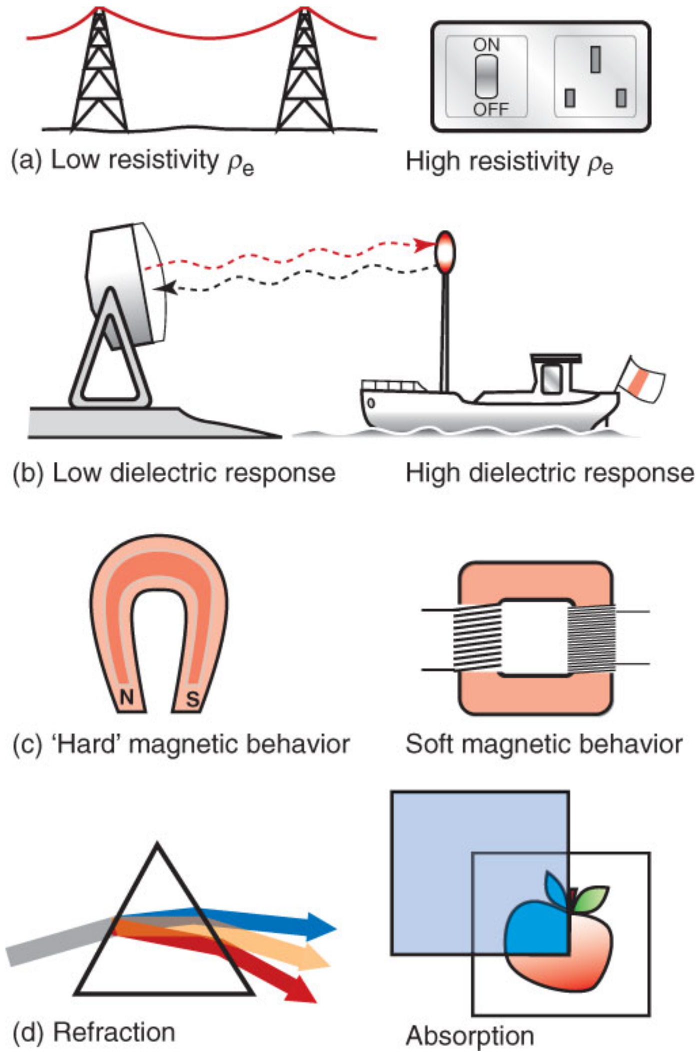


Figure 1.4 Electrical, magnetic and optical properties.

1.2 Materials properties

Chemical properties

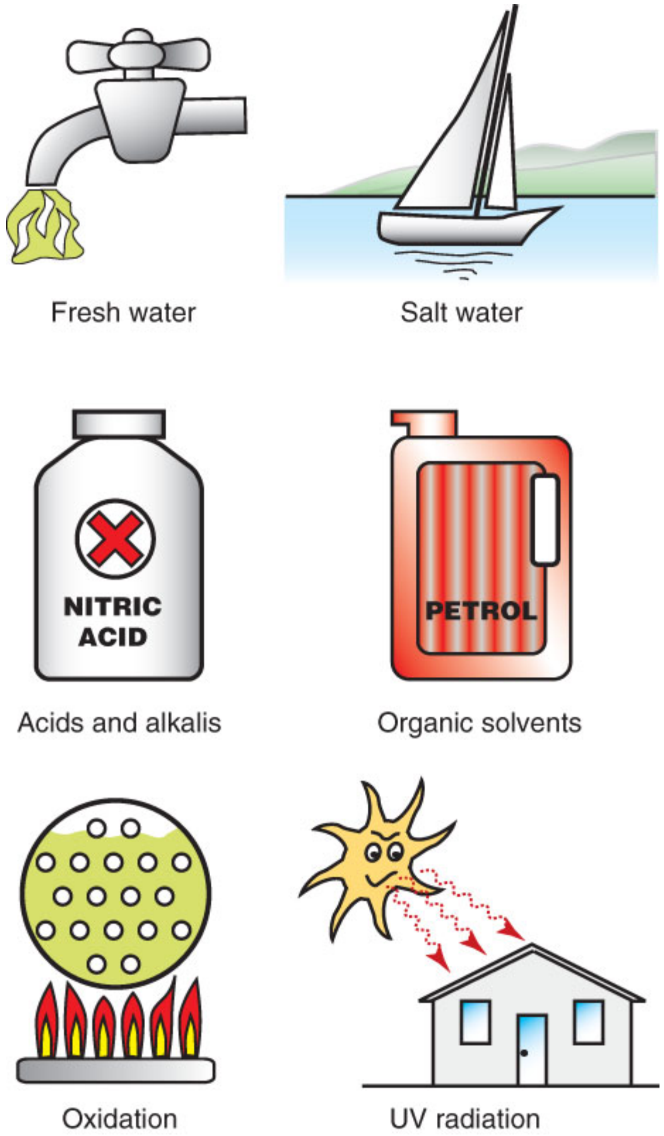


Figure 1.5 Chemical properties: resistance to water, acids, alkalis, organic solvents, oxidation and radiation.

1.3 Design-limiting properties

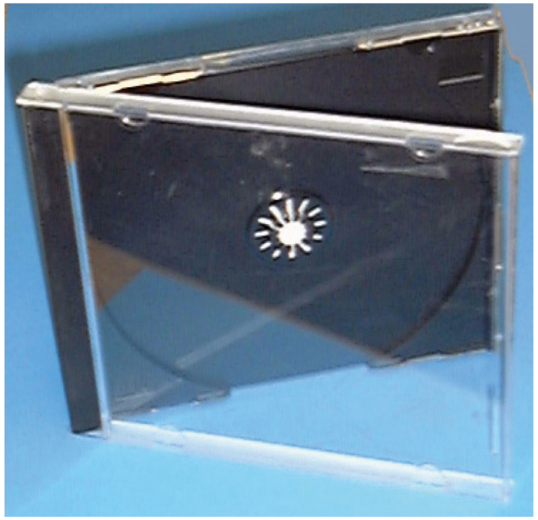
- Performance of a component is limited by certain materials properties.
- The values of design-limiting properties must meet certain targets.
- Materials selected by identifying the design-limiting properties, applying limits, and screening out those that fail. Processes can be treated in an analogous way.

Exercise

E 1.4. What, in your judgment, are the design-limiting properties for the material for the blade of a knife that will be used to gut fish?

PI question

E 1.9. The cases in which most CDs are sold have an irritating way of cracking and breaking. Which design-limiting property has been neglected in selecting the material of which they are made?



1. Fracture toughness
2. Hardness
3. Strength
4. Stiffness