EEE 163
System Design Analysis

Lecture 2 – Engineering Materials

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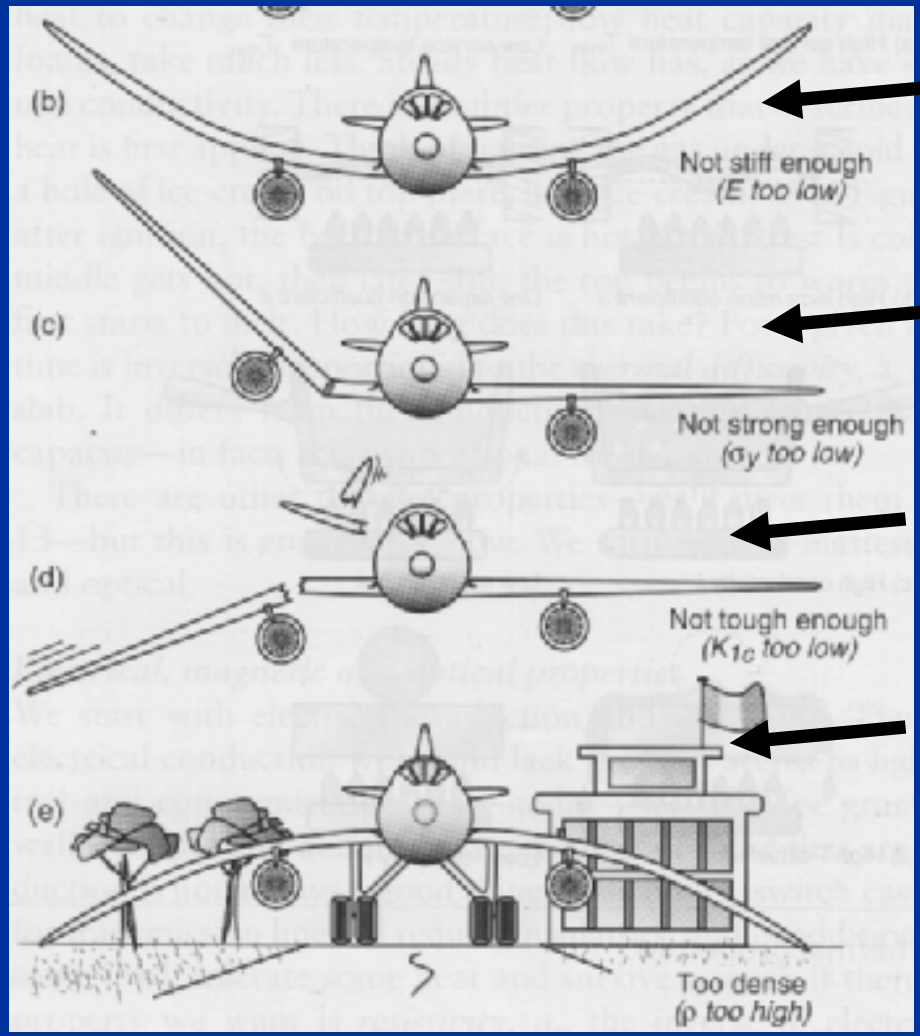
Engineering Materials

- Useful properties
- Material families
- Property comparisons
- Manufacturing methods

Material Properties – Mechanical



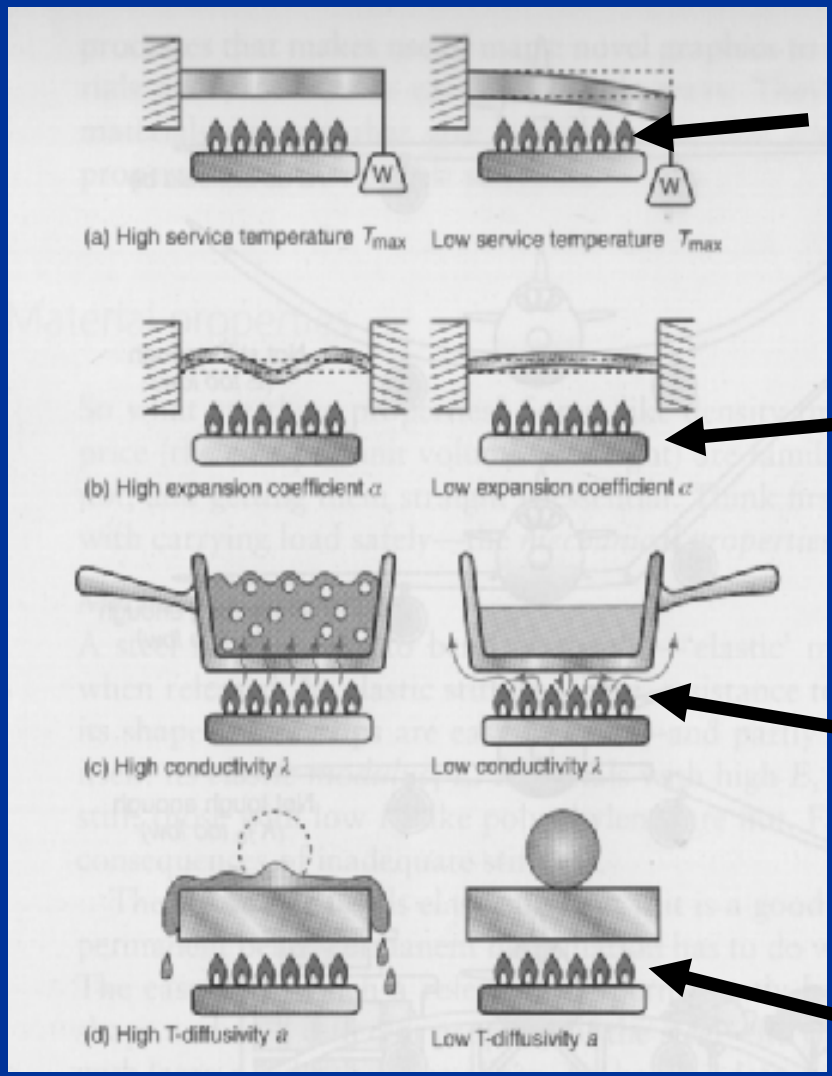
Elasticity

Strength

Fracture toughness

Density

Materials Properties - Thermal



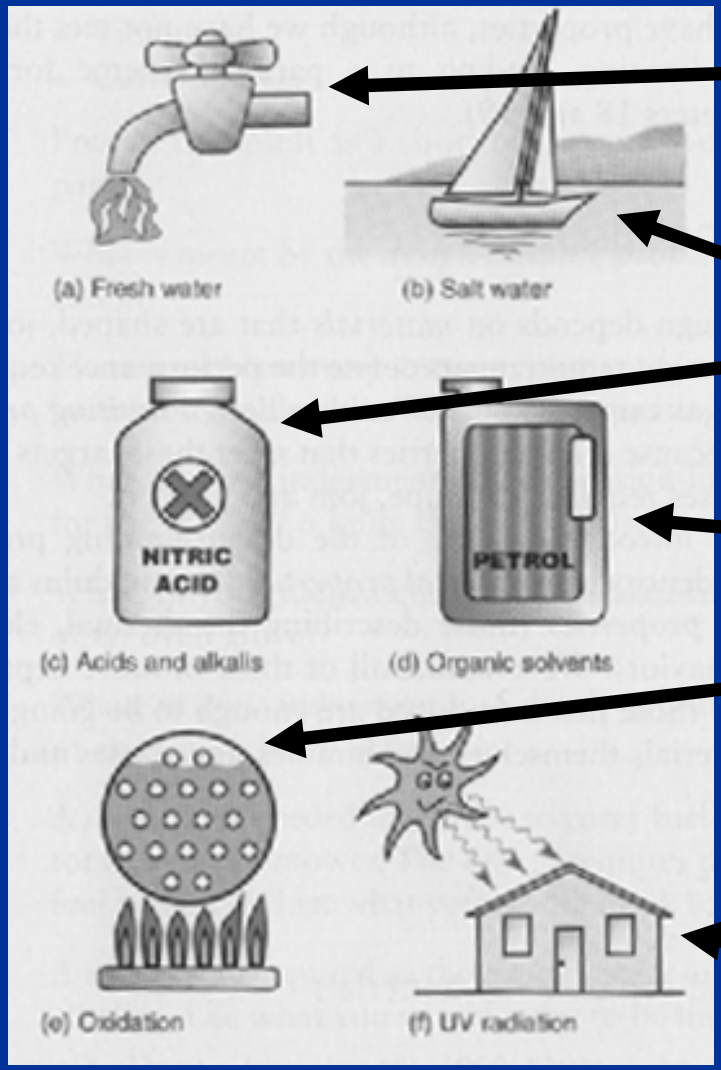
Max. operating temperature T_{max} (°C)

Thermal expansion coefficient α (ppm/°C)

Thermal conductivity k_{th} (W/m°C)

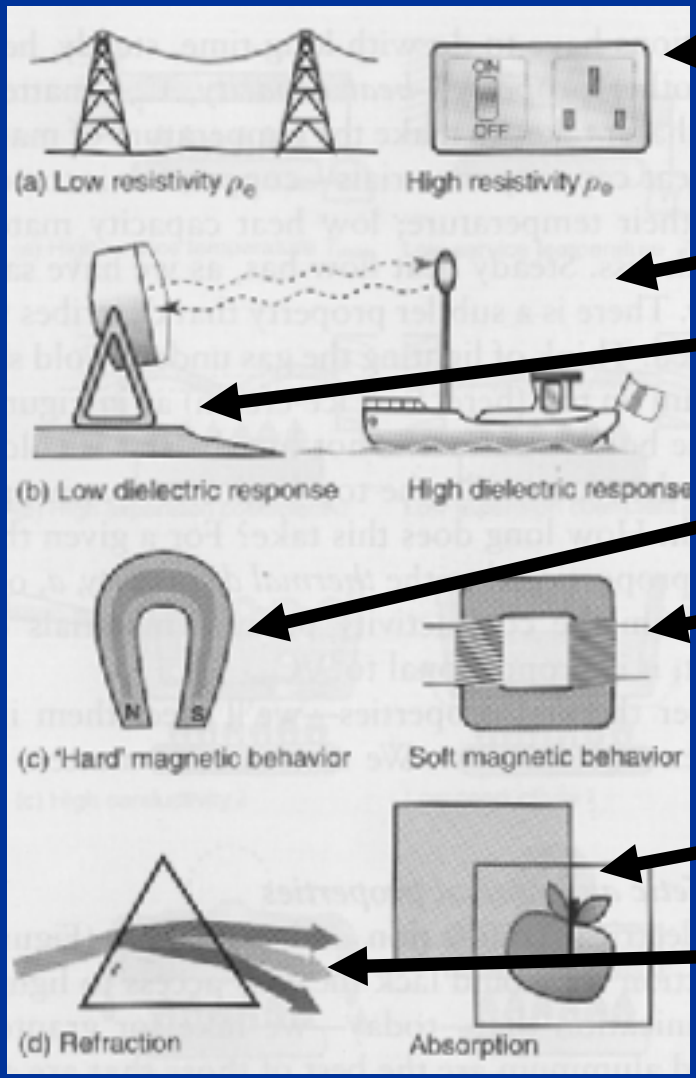
Heat capacity C_p (J/kg°C)

Materials Properties - Chemical



- Fresh water
- Salt water
- Acids and alkalis
- Organic solvents
- Atmospheric oxidation/tarnishing
- Ultra-violet radiation

Materials Properties - Electromagnetic



Electrical resistance R (Ω)

Dielectric response (ε_D)

Magnetic -

- 'Hard' (permanent magnet)
- 'Soft'

Optical:

- Absorption
- Dispersion

Engineering Materials Families

Metal

gold, copper, alloys (steel, solder)

Ceramic

Porcelain, alumina

Polymer

plastic bags, rubber bands

Vitreous (glass)

windows, optical fibres

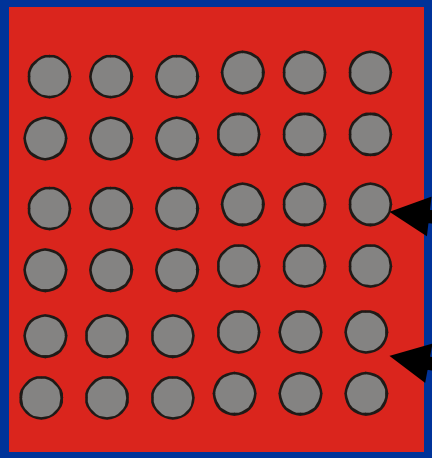
Hybrid (i.e. items from different families)

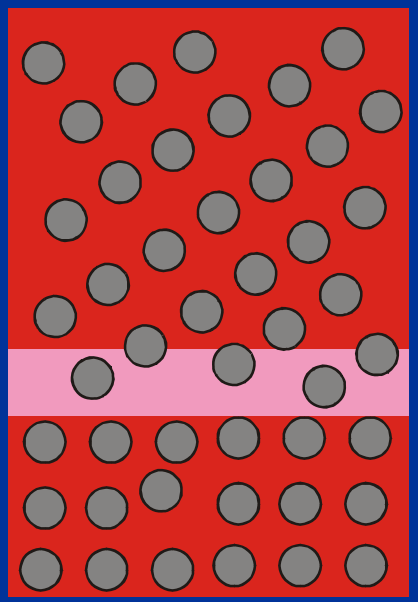
Natural structural materials e.g. bone = polymer + ceramic

fibre-glass, foam

N.B. Not salts – generally too soluble

Metal - Structure

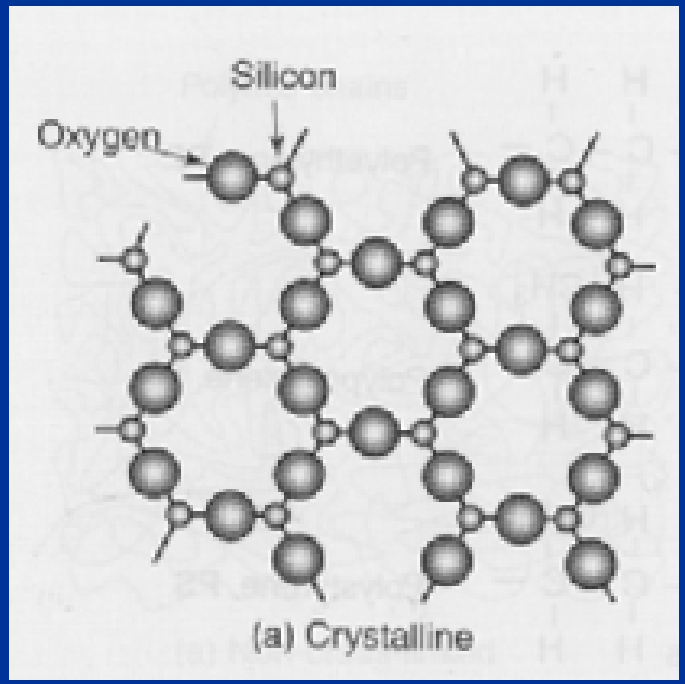




- Single crystal
  - atomic nuclei in regular periodic lattice
  - electrons delocalised

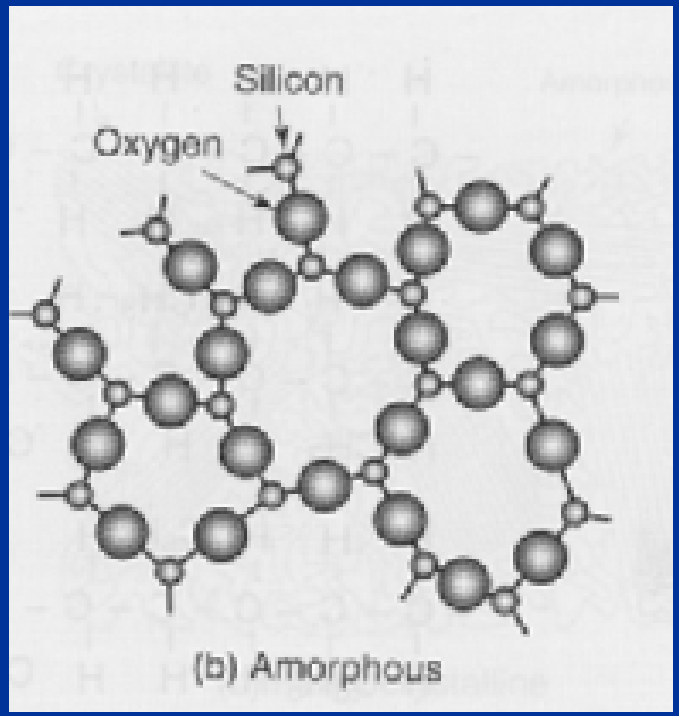
- Polycrystalline
  - -grain boundaries
  - -non-uniform electron density

Ceramic - Structure



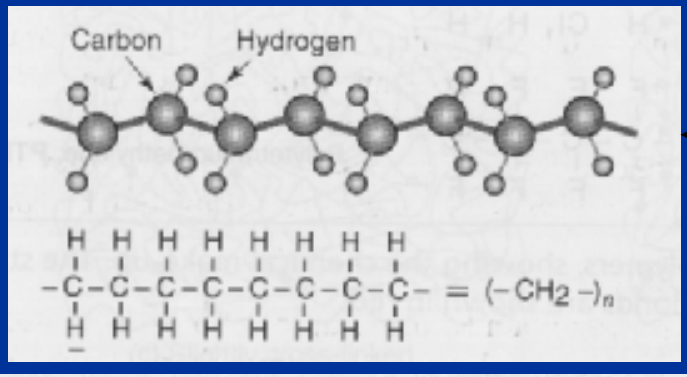
- Regular 3d crystal lattice with strong inter-atomic bonds:
  - Covalent (electron sharing)
- Oxide, nitride, carbide, etc…
- Single crystal
  - e.g. gemstone – rare!
- Polycrystalline
  - e.g. rock – common!
  - many grain boundaries

Glass - Structure

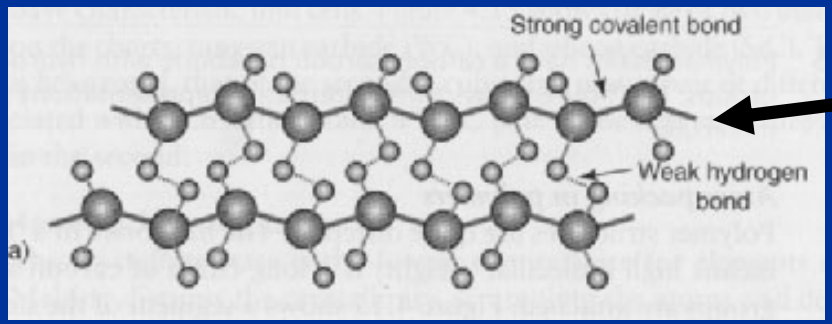


- Non-regular 3d lattice
- Covalent bonds, since these allow bond angle distortion
- *Not* ionic bonds, since these don't allow bond angle distortion
- 'Infinite' single crystal
  - no grain boundaries
  - good optical properties

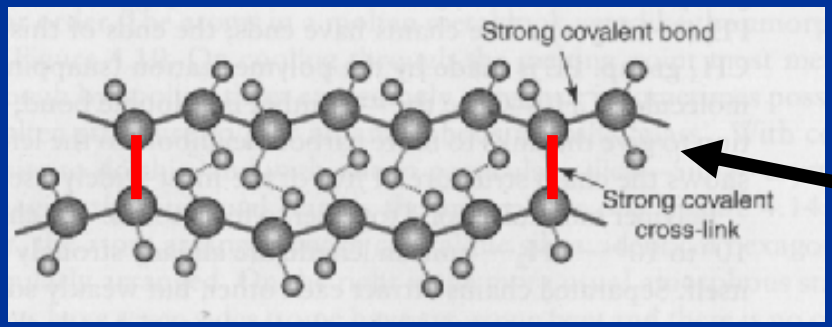
Polymer - Structure



Long chain molecule with carbon backbone

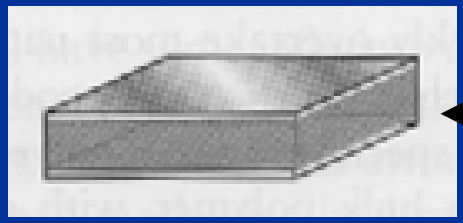


Thermoplastic – only weak hydrogen bonds between the chains



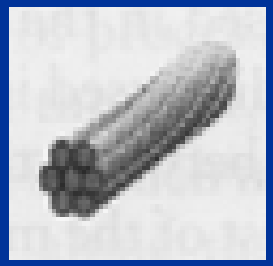
Thermoset – strong covalent bond between the chains

Hybrid - Structure

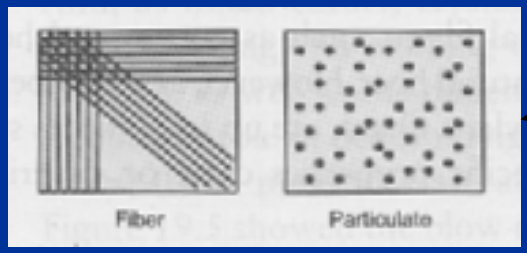


- Layers

- Lattice

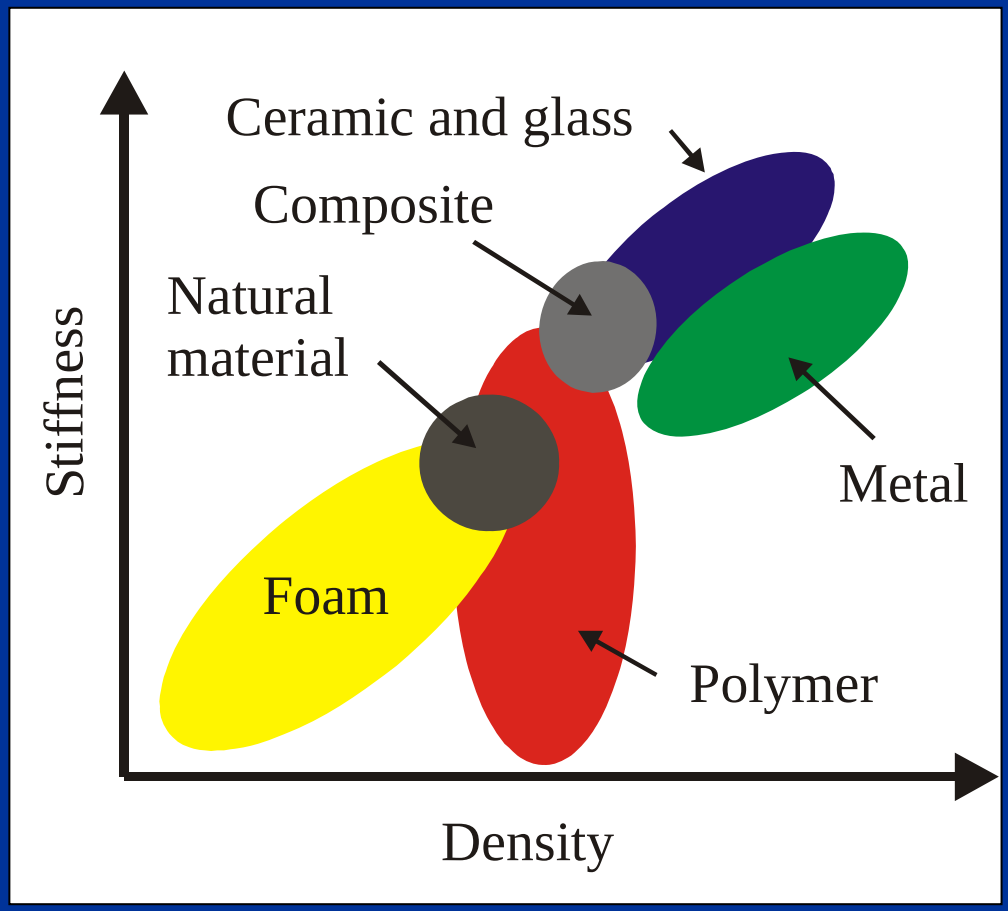


- Segmented



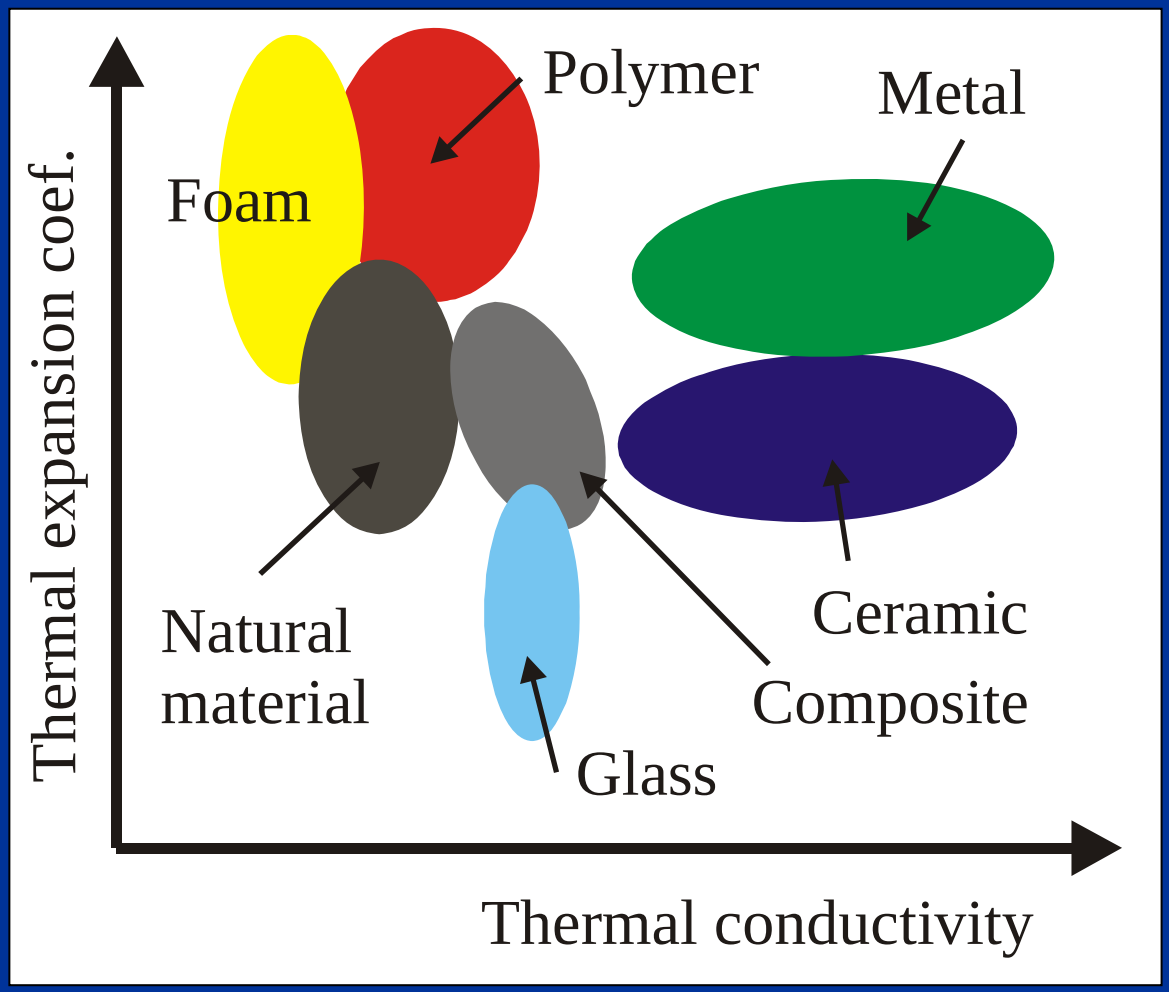
- Composite

Property comparison 1: Weight v. stiffness

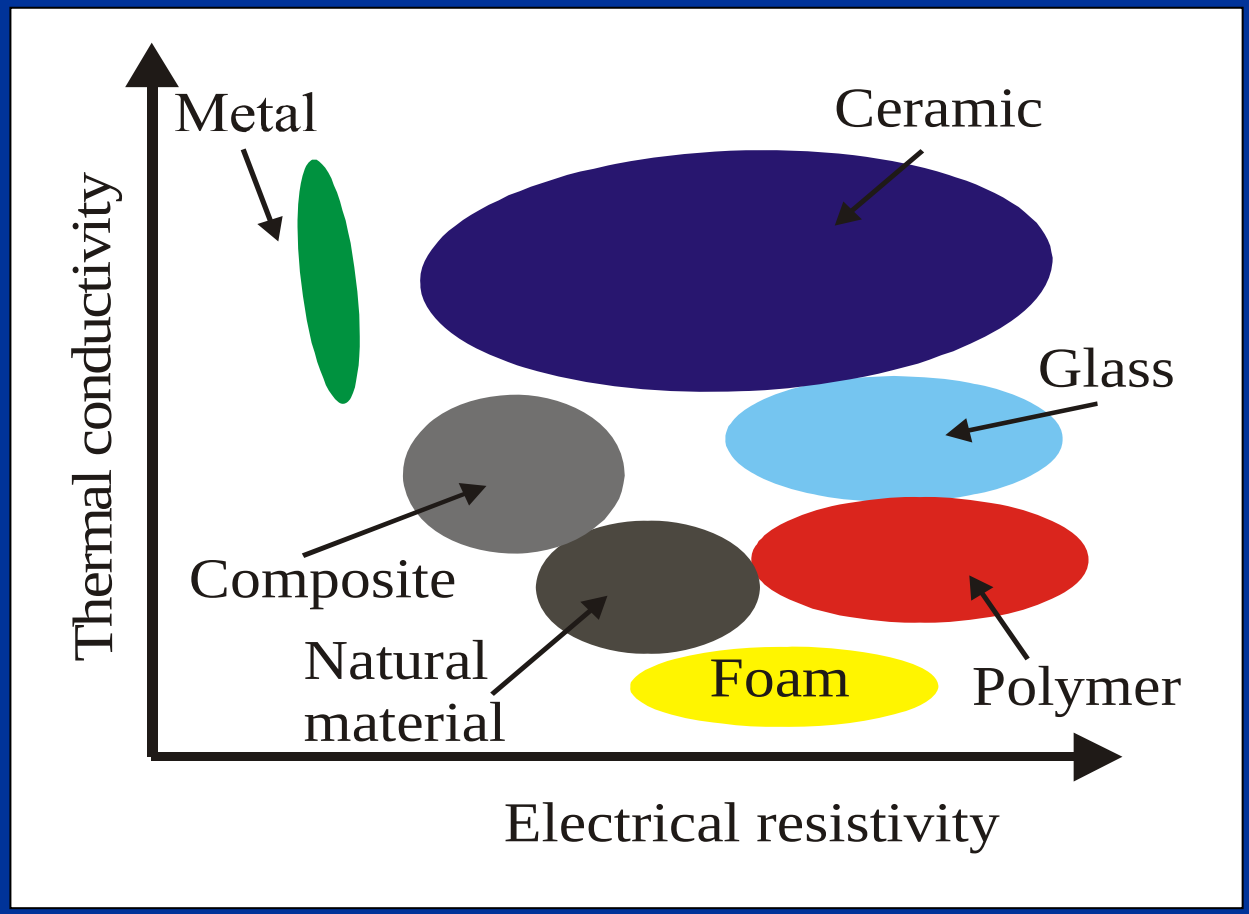


N.B.Logarithmic scales!

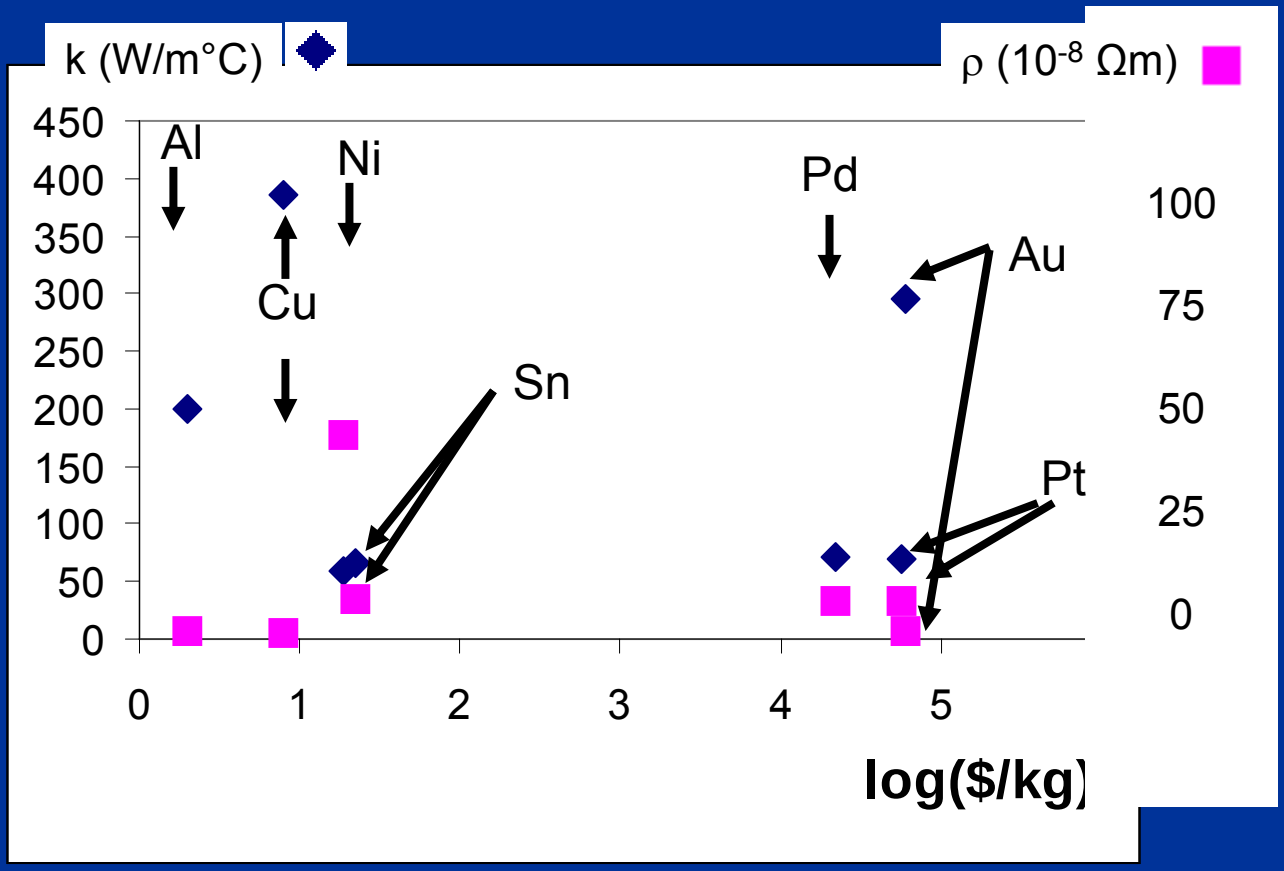
Property comparison 2: Thermal conductivity v. expansion



Property comparison 3: Resistivity v. thermal conductivity

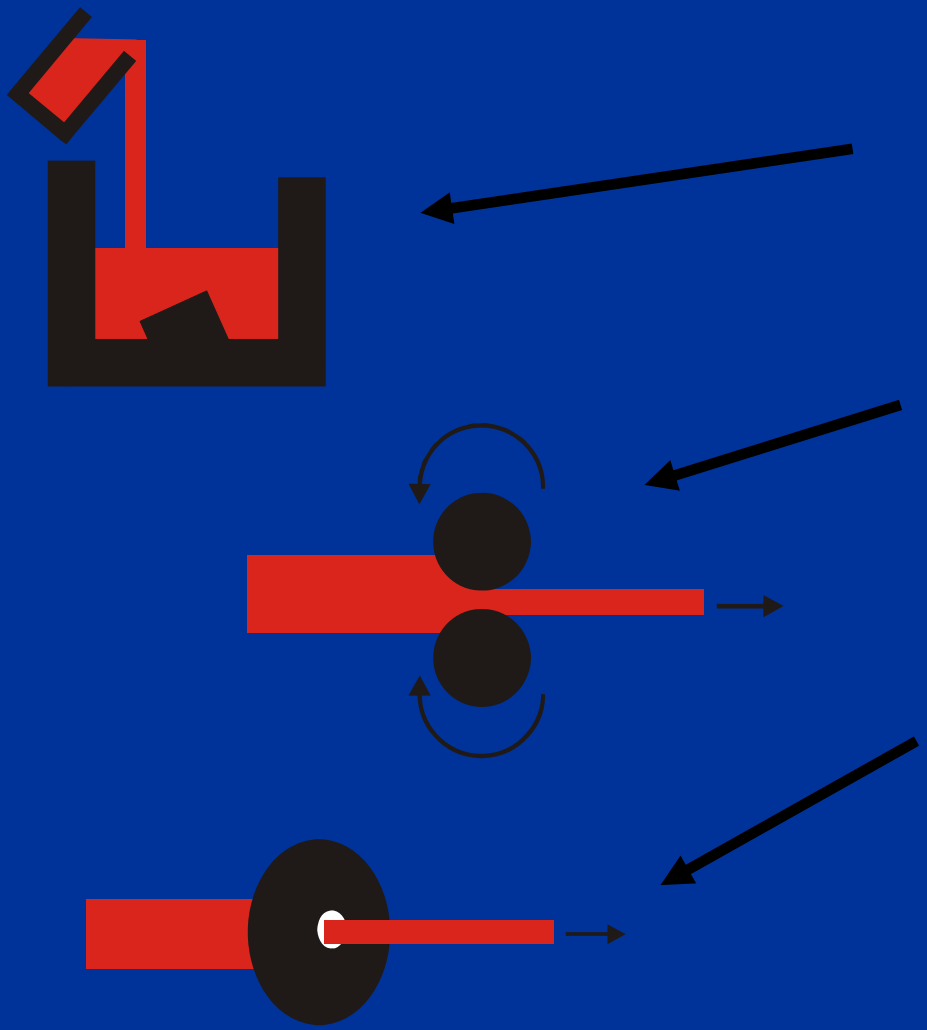


Property comparison 4: Metal prices v. conductivity and resistivity



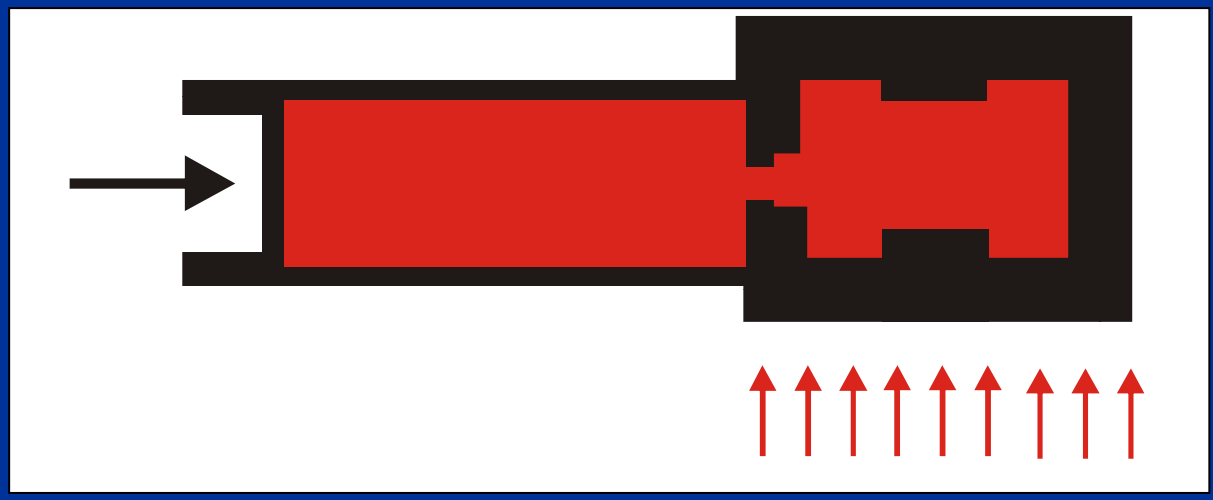
- 10^4 difference in price between metals!
- The cheaper metals will all tarnish (oxidise) in air, hence poor

Metal shaping



- Casting
  - Molten metal
  - Complex shapes
- Rolling mill
  - Solid sheet
  - Followed by bending, stamping
- Extrusion
  - Wire
  - Uniform cross-section rod

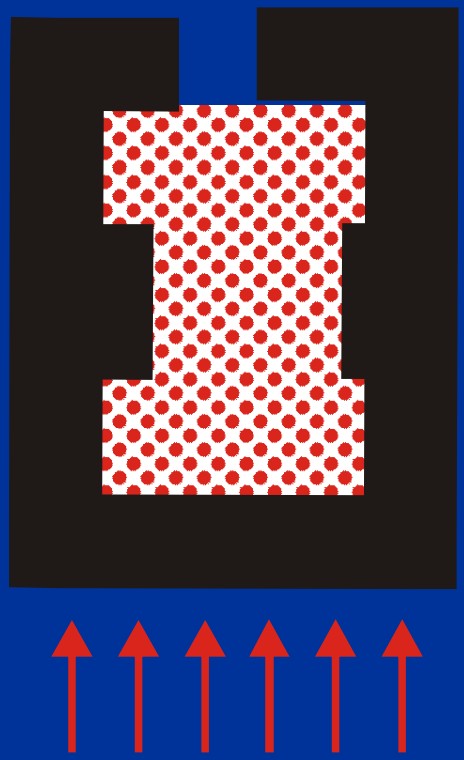
Polymer shaping



Injection moulding

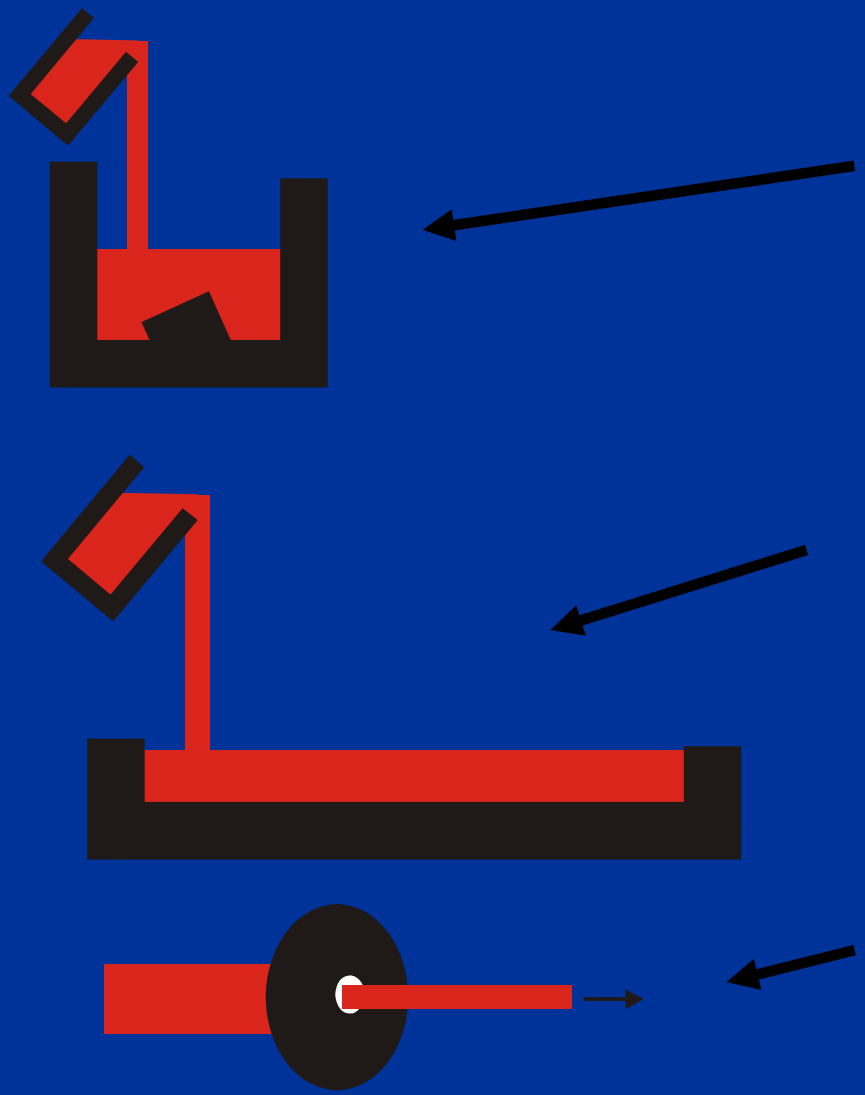
- thermoplastic:
  - liquid or granular precursor
  - heat applied to melt material
- thermoset
  - liquid precursor
  - heat applied to initiate polymerisation and cross-linking

Ceramic shaping



- Very high melting point (T_m)
- Sintering
  - Load mould with ceramic powder
  - Apply heat (and pressure)
  - Diffusion of atoms between grains at $T < T_m$
  - grains fused together to form single object

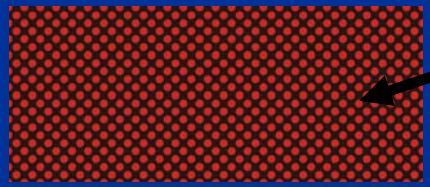
Glass Shaping



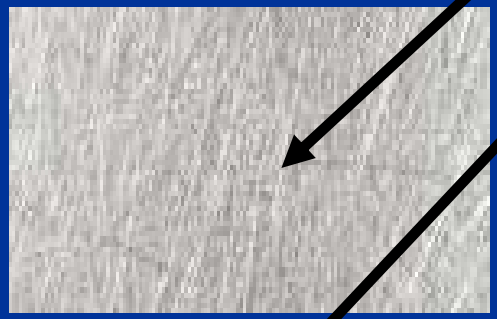
- Moulding
  - complex shapes
- Casting
  - sheets
- Drawing
  - fibres

Hybrid Shaping

Lamination – e.g. printed circuit board

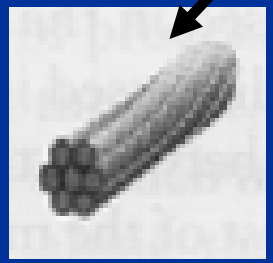


Impregnation – e.g. silica-loaded epoxy

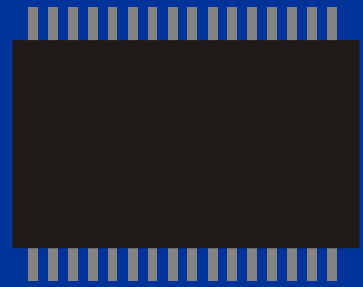


Weaving – e.g. fibre glass

Platting – e.g. cable



2-part moulding – e.g. IC package



Etc…

Materials Joining

- Adhesive
  - organic polymer
  - low service temperature
  - non-hermitic
- Welding
  - metal or alloy (solder)
  - hermitic
- Mechanical fasteners
  - nuts and bolts
  - crimps

Surface finishing

- Mold surface finish may be ok, but if not:
  - Precision machining
  - Grinding and polishing
  - Painting
  - Marking

Lecture 2 Summary

- Engineering materials have many different properties
- Choosing which material to use in a product will always involve compromise
- You will explore the use of these various materials in the laboratory classes

References:

eBook: ‘Materials – Engineering, Science, Processing and Design’ Ashby, Shercliff and Cebon, Elsevier.

Website: www.webelements.com