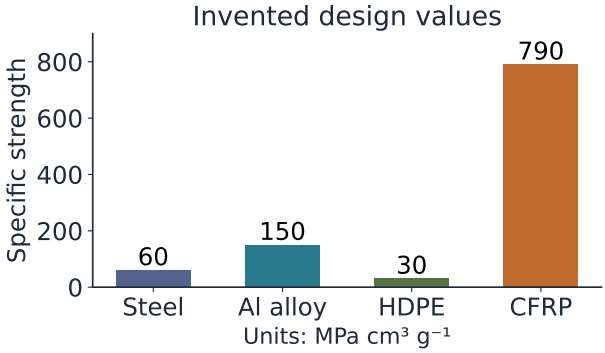
From models to materials

Structure 2.4 · SL and AHL

Why is a racing bike made of carbon fibre?



Choose a material using structure, measured properties and the actual loading conditions.

Three models, one continuum

By electronegativity

Large difference: ionic.

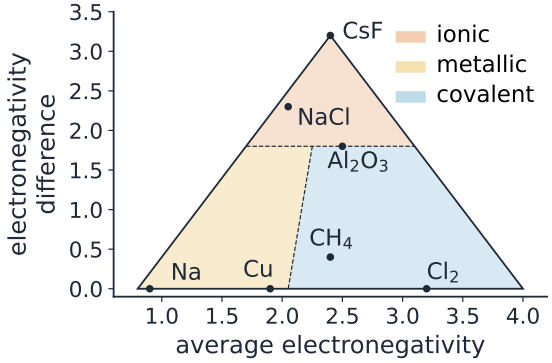
Both high: covalent. Both low: metallic.

Aluminium oxide

Mainly ionic.

Small, highly charged Al^{3+} gives covalent character.

The bonding triangle



The triangle predicts the bonding type, not whether a covalent substance is molecular or a network.

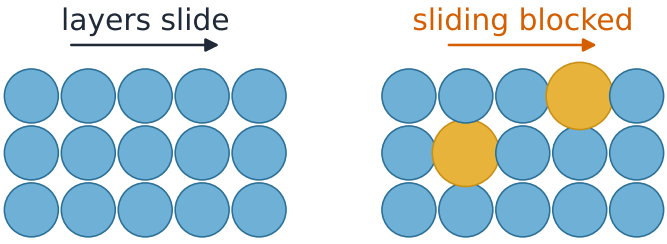
Worked example: MgO

1. **Average.** Supplied Mg 1.3 and O 3.4: average $(1.3 + 3.4)/2 = 2.35$.
2. **Difference.** $3.4 - 1.3 = 2.1$
3. **Region.** The point (2.35, 2.1) lies in the ionic region.

Decision

MgO is mainly ionic; expect ionic conduction when molten, without assuming high water solubility.

How alloying can hinder slip



Alloying changes properties; it does not improve every property automatically.

Alloys and their uses

Alloy	**Composition**	**Improved property**
steel	iron + carbon	harder, stronger
stainless steel	iron + chromium; many grades add nickel	resists corrosion
brass	copper + zinc	harder than copper
duralumin	Al + Cu, Mg	stronger, still light

Chains and networks in polymers

- Monomers join into a macromolecule with a **repeating unit**.
- Natural (starch, proteins, DNA) or synthetic (plastics).
- Intermolecular interactions, entanglement, branching and cross-linking affect properties.

Polymer macromolecular material with many repeating structural units; chains or cross-linked networks

Plastic properties and disposal depend on structure

HDPE

Relatively little branching permits more regular packing.

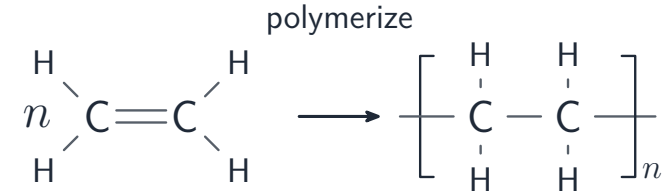
Stronger and denser.

LDPE

Branched chains pack loosely.

Softer and more flexible.

Addition polymerization



The **repeating unit** has the same atoms as the **monomer**, joined by single bonds.

Monomers and repeating units

Monomer	**Polymer**	**Repeating unit**
ethene	poly(ethene)	$-CH_2-CH_2-$
propene	poly(propene)	$-CH_2-CH(CH_3)-$
chloroethene	PVC	$-CH_2-CHCl-$
tetrafluoroethene	PTFE	$-CF_2-CF_2-$

Check: find the monomer

Your turn

Which monomer gives the repeating unit $-CH_2-CH(CN)-$?

A. CH_3CH_2CN
B. $CH_2{=}CHCN$
C. $CH_2{=}C(CN)_2$
D. $CH{\equiv}CCN$

AHL: Condensation polymerization

polyester: -C(=O)-OH + H-O- → -C(=O)-O- + H_2O

polyamide: -C(=O)-OH + H-N(H)- → -C(=O)-NH- + H_2O

every new ester or amide link loses a small molecule (condensation)

PET, nylon-6,6 and Kevlar are condensation polymers; so are proteins and starch.

AHL: Addition against condensation

	alkene addition	**polyester / polyamide**
monomer	contains C=C	two functional groups
other product	none	H_2O or HCl
main chain	C–C only	ester or amide links

Exam tips

> Name the bonding first, then explain the property from it.

- Use both triangle coordinates; bonding is a continuum.
- Alloys: different-sized atoms distort the layers.
- Addition unit: C=C becomes C–C, side groups off the chain, n.
- AHL. Name the small molecule lost and the link formed.

Composites transfer loads between components

CFRP

Graphitic fibres carry tension mainly along their length.

Polymer matrix transfers load; layer directions affect performance.

Reinforced concrete

Concrete matrix supports compression.

Steel helps carry tension and limit cracks; the interface transfers load.

Softening is not chemical decomposition

Thermoplastic

Uncross-linked chains can become mobile on heating.

Can often be reshaped under suitable conditions.

Thermoset

Covalent cross-links retain a connected network.

Strong heating commonly degrades it rather than melting separate chains.

Worked: use an invented specific strength

1. **Data.** Invented CFRP example: strength 1264 MPa; density 1.6 g/cm^3.
2. **Ratio.** $1264/1.6 = 790\ \mathrm{MPa\,cm^3\,g^{-1}}$.
3. **Limit.** Grade, fibre direction, stiffness, toughness and joints still matter.

Decision

A high ratio does not prove the best design for every loading condition.

AHL: Count links in a finite chain

1. **Start.** 10 diol + 10 diacid molecules: 20 separate molecules.
2. **Connect.** One finite linear chain requires $20 - 1 = 19$ links.
3. **Product.** This ideal route loses 19 water molecules; end groups remain.

Decision

New link count is not automatically equal to repeat-unit count.

Condensation polymers in living things

proteins	**polysaccharides**	**nucleic acids**
amino acids	glucose residues	nucleotides
↓	↓	↓
amide (peptide) links	glycosidic links	phosphodiester links

formal relationship: monomers $- H_2O \rightarrow$ polymer; hydrolysis adds water back
cells actually use activated precursors (e.g. nucleotide triphosphates)

> Each link forms with the loss of water

Check yourself

Try these

Plot NaCl and CH_4; explain why brass has no fixed CuZn molecular formula.

Explain why steel is harder than pure iron.

Draw the repeating unit of poly(propene).

AHL. Name the monomers and the link in nylon-6,6.