Metals I

Anne Mertens

LIÈGE
université

M.M.S
Metallic Materials Science

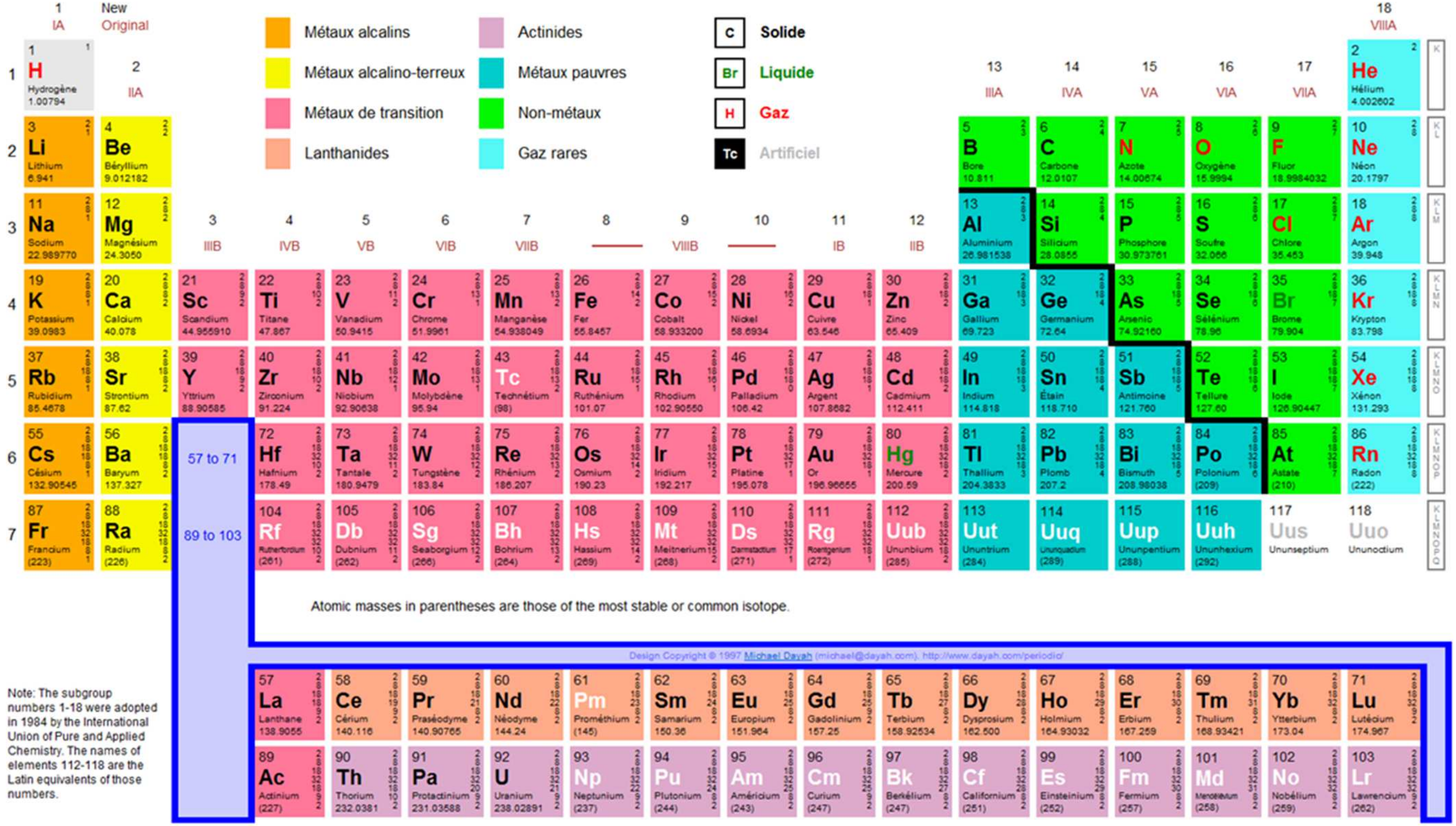
Outline

- Introduction
    - Metallic materials
    - Materials Selection: case studies in metallic materials
- Metal structures
- Equilibrium constitution and phase diagrams
- Case studies in phase diagrams

Introduction

Metallic materials

Introduction - Metals (1)



- 🟧 Métaux alcalins
- 🟨 Métaux alcalino-terreux
- 🟥 Métaux de transition
- Lanthanides
- Actinides
- Métaux pauvres
- 🟩 Non-métaux
- Gaz rares

- C Solide
- Br Liquide
- H Gaz
- Tc Artificiel

New Original	1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8 —	9 VIIIB	10 —	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA	
1	1 H Hydrogène 1.00794																	2 He Hélium 4.002602	K
2	3 Li Lithium 6.941	4 Be Béryllium 9.012182											5 B Bore 10.811	6 C Carbone 12.0107	7 N Azote 14.00674	8 O Oxygène 15.9994	9 F Fluor 18.9984032	10 Ne Néon 20.1797	K L
3	11 Na Sodium 22.989770	12 Mg Magnésium 24.3050											13 Al Aluminium 26.981538	14 Si Silicium 28.0855	15 P Phosphore 30.973761	16 S Soufre 32.066	17 Cl Chlore 35.453	18 Ar Argon 39.948	K L M
4	19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.955910	22 Ti Titane 47.867	23 V Vanadium 50.9415	24 Cr Chrome 51.9961	25 Mn Manganèse 54.938049	26 Fe Fer 55.8457	27 Co Cobalt 58.933200	28 Ni Nickel 58.6934	29 Cu Cuivre 63.546	30 Zn Zinc 65.409	31 Ga Gallium 69.723	32 Ge Germanium 72.64	33 As Arsenic 74.92160	34 Se Sélénium 78.96	35 Br Brome 79.904	36 Kr Krypton 83.798	K L M N
5	37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90585	40 Zr Zirconium 91.224	41 Nb Niobium 92.90638	42 Mo Molybdène 95.94	43 Tc Technétium (98)	44 Ru Ruthénium 101.07	45 Rh Rhodium 102.90550	46 Pd Palladium 106.42	47 Ag Argent 107.8682	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Étain 118.710	51 Sb Antimoine 121.760	52 Te Tellure 127.60	53 I Iode 126.90447	54 Xe Xénon 131.293	K L M N O
6	55 Cs Césium 132.90545	56 Ba Baryum 137.327	57 to 71	72 Hf Hafnium 178.49	73 Ta Tantale 180.9479	74 W Tungstène 183.84	75 Re Rhénium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platine 195.078	79 Au Or 196.96655	80 Hg Mercure 200.59	81 Tl Thallium 204.3833	82 Pb Plomb 207.2	83 Bi Bismuth 208.98038	84 Po Polonium (209)	85 At Astate (210)	86 Rn Radon (222)	K L M N O P
7	87 Fr Francium (223)	88 Ra Radium (226)	89 to 103	104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (266)	107 Bh Bohrium (264)	108 Hs Hassium (269)	109 Mt Meitnerium (268)	110 Ds Darmstadtium (271)	111 Rg Roentgenium (272)	112 Uub Ununbium (285)	113 Uut Ununtrium (284)	114 Uuq Ununquadium (289)	115 Uup Ununpentium (288)	116 Uuh Ununhexium (292)	117 Uus Ununseptium	118 Uuo Ununoctium	K L M N O P Q

Atomic masses in parentheses are those of the most stable or common isotope.

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57 La Lanthane 138.9055	58 Ce Cérium 140.116	59 Pr Praséodyme 140.90765	60 Nd Néodyme 144.24	61 Pm Prométhium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.92534	66 Dy Dysprosium 162.500	67 Ho Holmium 164.93032	68 Er Erbium 167.259	69 Tm Thulium 168.93421	70 Yb Ytterbium 173.04	71 Lu Lutécium 174.967
89 Ac Actinium (227)	90 Th Thorium 232.0381	91 Pa Protactinium 231.03588	92 U Uranium 238.02891	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Américium (243)	96 Cm Curium (247)	97 Bk Berkélium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendélévium (258)	102 No Nobélium (259)	103 Lr Lawrencium (262)

Note: The subgroup numbers 1-18 were adopted in 1984 by the International Union of Pure and Applied Chemistry. The names of elements 112-118 are the Latin equivalents of those numbers.

Large variety of metallic materials!

Introduction : Metals (2)

- Cohesion due to metallic bond
  - Electrostatic attractive force between an electron cloud of delocalized electrons and positively charged metal ions
  - Non directional
- Metallic materials:
  - Generally good conductor of electricity and heat
  - Relatively ductile $\Rightarrow$ good formability

Introduction

Materials Selection :
Case studies in metallic materials

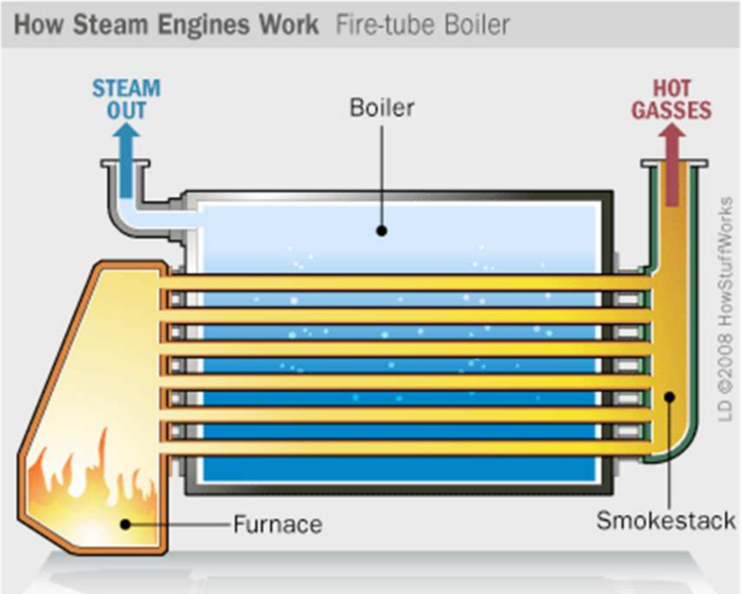
Materials selection for model steam engine (1)

[http://www.hobbydownloads.com/steamgeneral.html]

Fully working model

- ≠ components
- ≠ requirements
- ≠ materials

Ex: Boiler components must withstand high T



[http://www.hobbydownloads.com/boilers.html]

Materials selection for model steam engine (2)

Use of ferrous alloys

Wheels, frame

- low loads (σ_y~220 MPa)
- easy to cut, bend...
- cheap

Table 1.1 Generic iron-based metals

Metal	*Typical composition (wt%)*	*Typical uses*
Low-carbon ("mild") steel	Fe + 0.04 to 0.3 C (+ ≈ 0.8 Mn)	Low-stress uses. General constructional steel, suitable for welding.
Medium-carbon steel	Fe + 0.3 to 0.7 C (+ ≈ 0.8 Mn)	Medium-stress uses: machinery parts – nuts and bolts, shafts, gears.
High-carbon steel	Fe + 0.7 to 1.7 C (+ ≈ 0.8 Mn)	High-stress uses: springs, cutting tools, dies.
Low-alloy steel	Fe + 0.2 C 0.8 Mn 1 Cr 2 Ni	High-stress uses: pressure vessels, aircraft parts.
High-alloy ("stainless") steel	Fe + 0.1 C 0.5 Mn 18 Cr 8 Ni	High-temperature or anti-corrosion uses: chemical or steam plants.
Cast iron	Fe + 1.8 to 4 C (+ ≈ 0.8 Mn 2 Si)	Low-stress uses: cylinder blocks, drain pipes.

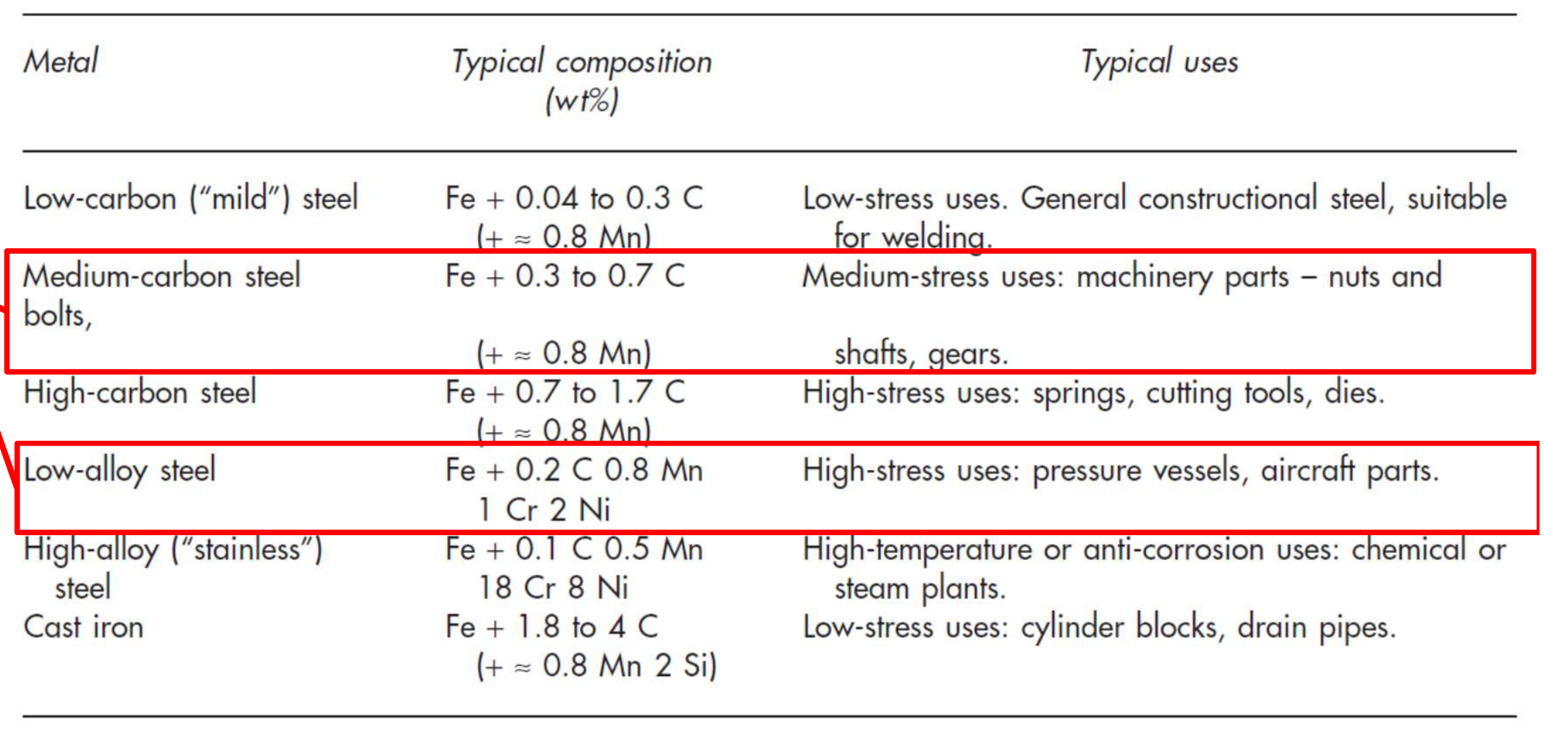
[M.F. Ashby and D.R.H. Jones, Engineering Materials, vol. 2]

Materials selection for model steam engine (3)

Use of ferrous alloys

Drive shafts, gear-wheel teeths

- higher stresses (σ_y~400 MPa)



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[M.F. Ashby and D.R.H. Jones, Engineering Materials, vol. 2]

Materials selection for model steam engine (3)

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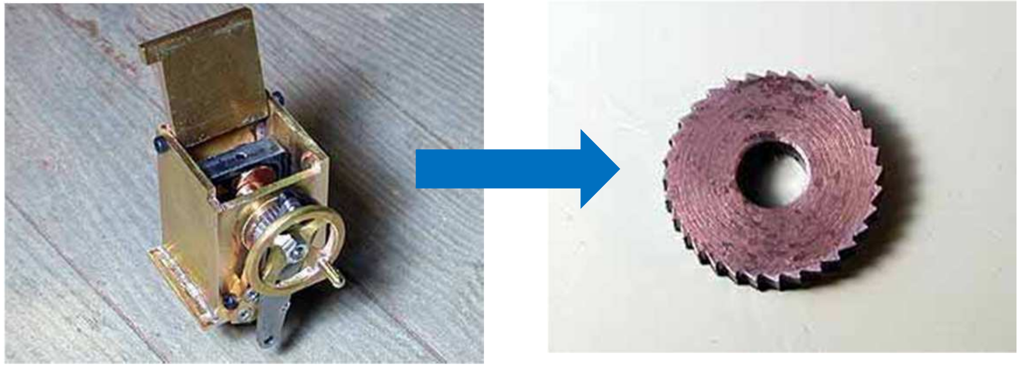
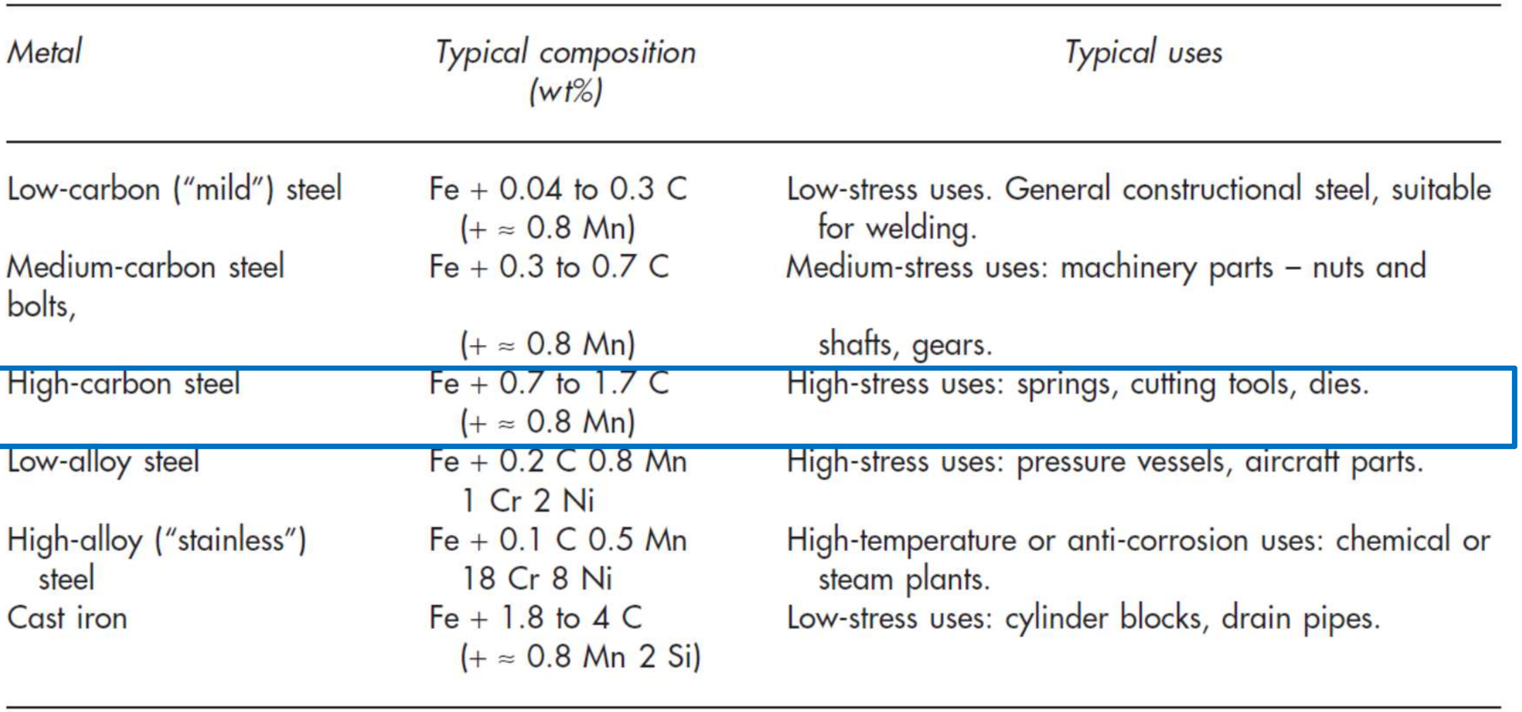


[http://ww3.tiki.ne.jp/~hwata/eW-lubricator.htm]

Mechanical lubricator

- High friction and wear
- Quenched and tempered high carbon steels (σ_y~1000MPa)

Table 1.1 Generic iron-based metals



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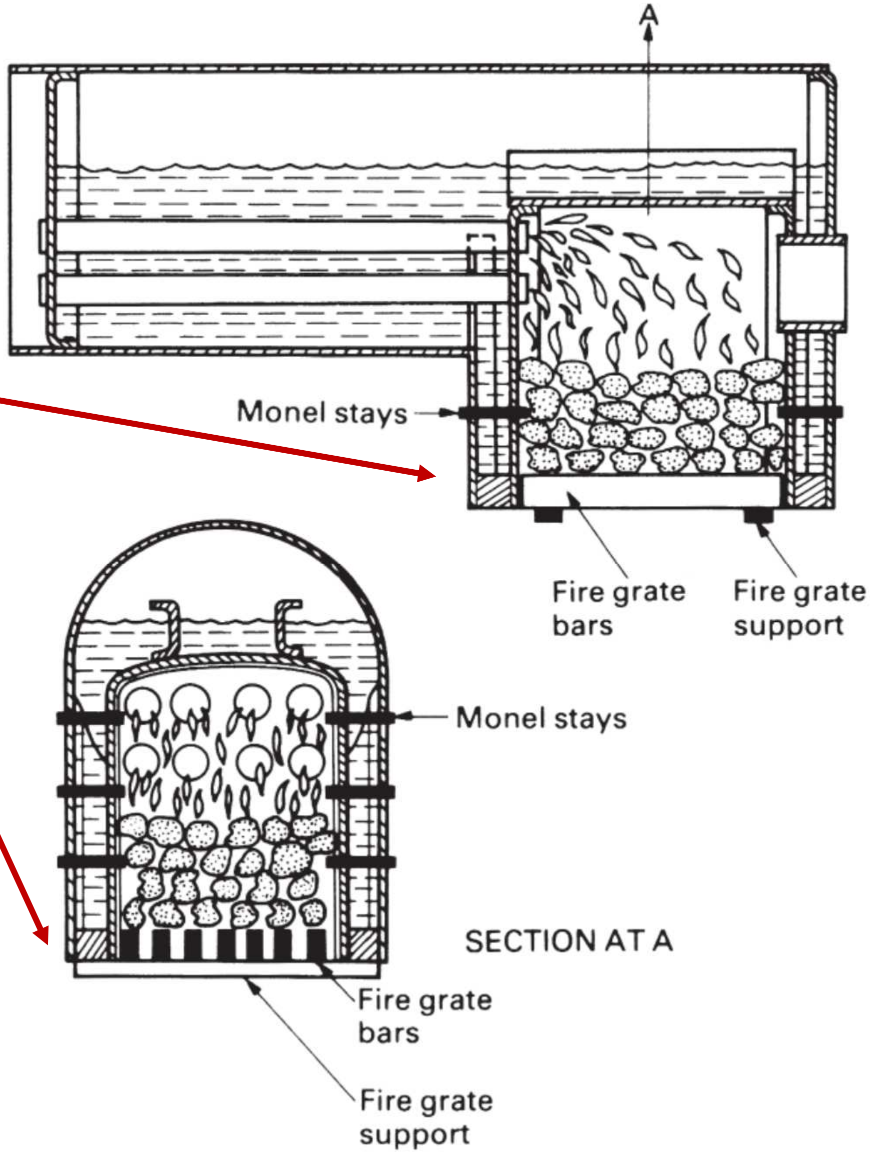
[M.F. Ashby and D.R.H. Jones, Engineering Materials, vol. 2]

Materials selection for model steam engine (4)

Use of ferrous alloys

Fire grates, in direct contact with burning coal

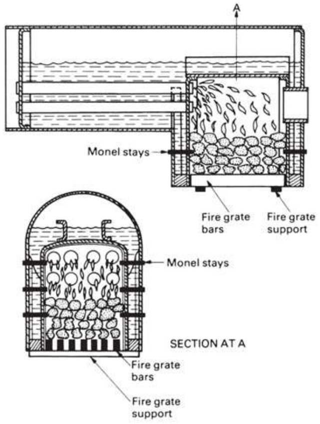
- High T
- Oxidation
- Creep



[M.F. Ashby and D.R.H. Jones, Engineering Materials, vol. 2]

Materials selection for model steam engine (5)

Use of ferrous alloys



Fire grates
- High T
- Oxidation
- Creep

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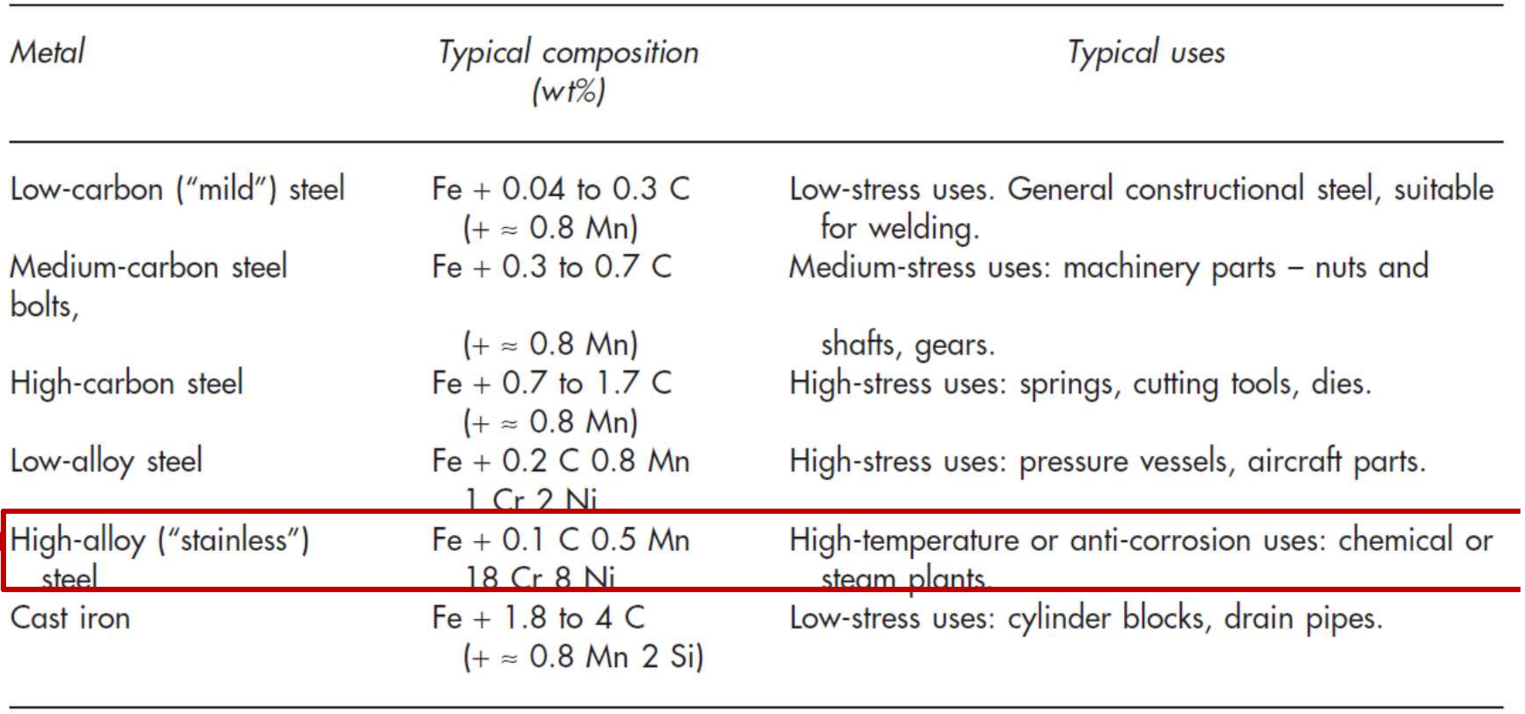

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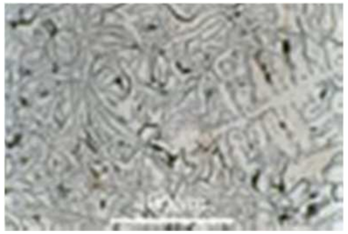
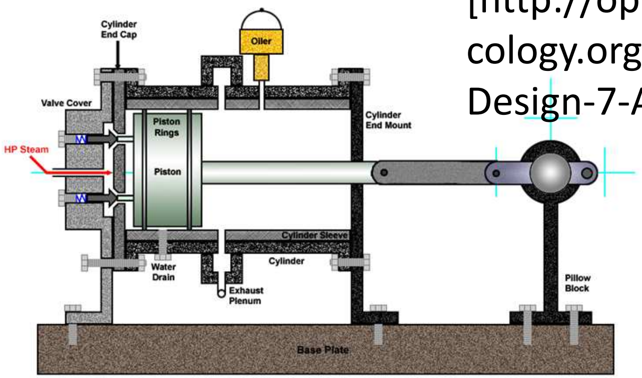
[M.F. Ashby and D.R.H. Jones, Engineering Materials, vol. 2]

Materials selection for model steam engine (6)

Use of ferrous alloys

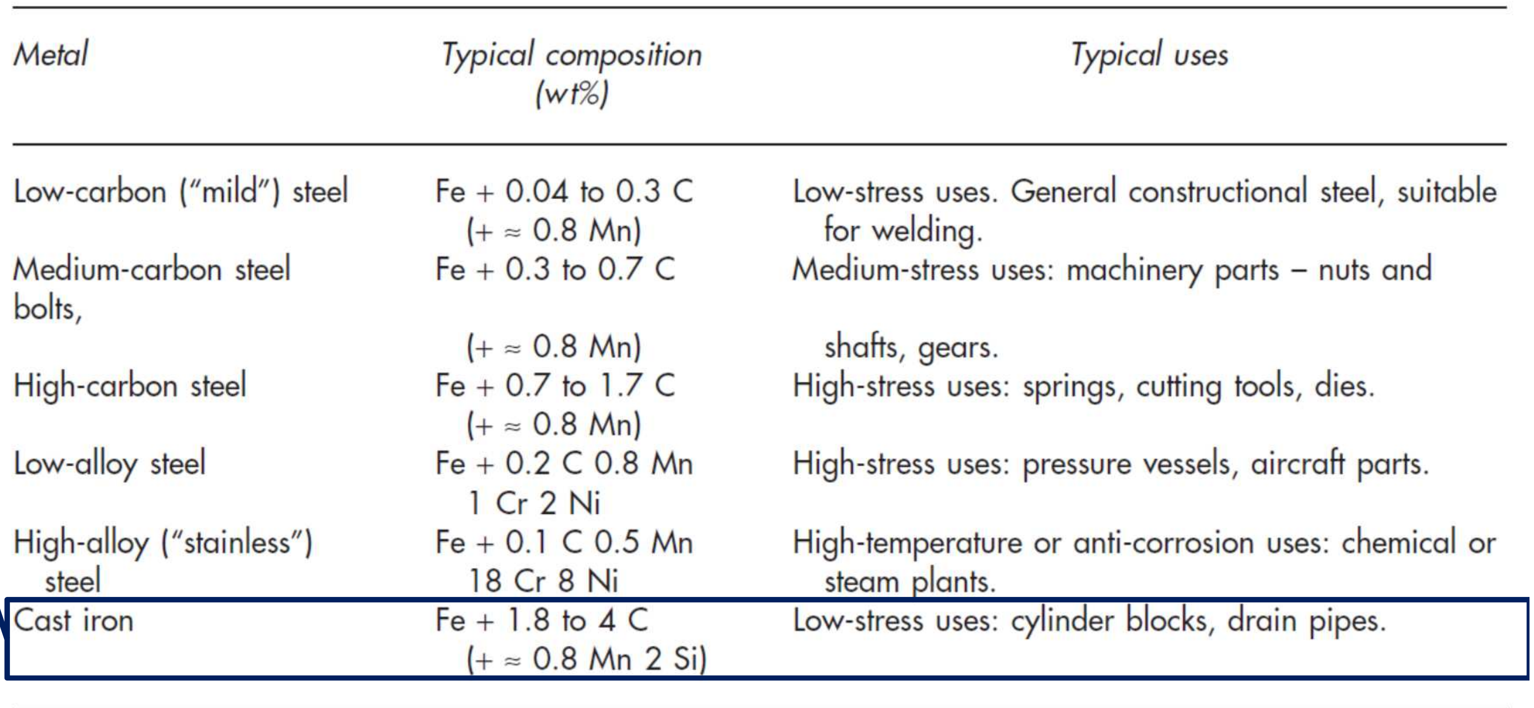


[http://core.materials.ac.uk/SEARCH/detail.php?id=1415]



[http://opensourceecology.org/wiki/File:Design-7-A.png]

Table 1.1 Generic iron-based metals



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Medium-carbon steel bolts,	Fe + 0.3 to 0.7 C (+ ≈ 0.8 Mn)	Medium-stress uses: machinery parts – nuts and shafts, gears.
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Cast iron	Fe + 1.8 to 4 C (+ ≈ 0.8 Mn 2 Si)	Low-stress uses: cylinder blocks, drain pipes.

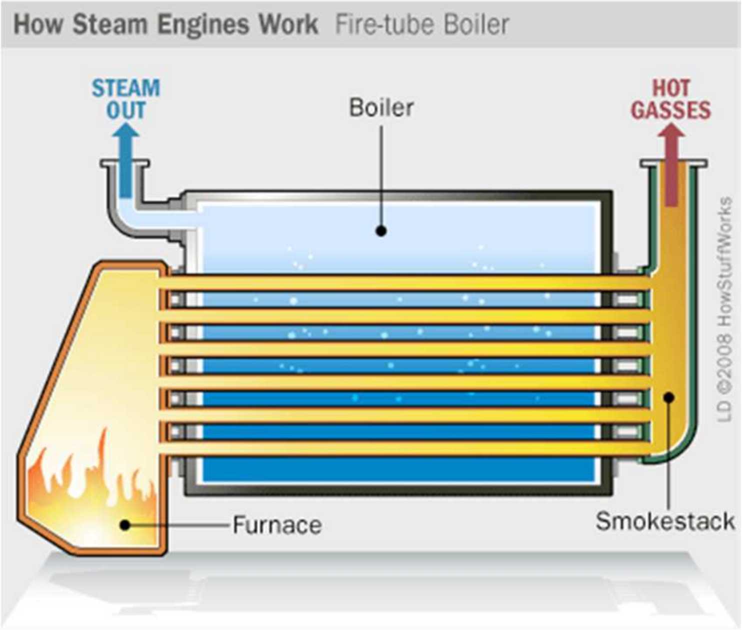
Cylinder block

- Low stresses
- Easy to cast
- Graphite acts as lubricant

[M.F. Ashby and D.R.H. Jones, Engineering Materials, vol. 2]

Materials selection for model steam engine (7)

Use of other alloys



[http://www.hobbydownloads.com/boilers.html]

- Boiler and firetubes
  - – Load from pressurized steam
  - – High thermal conductivity
  - – Corrosion resistance in clean water

Materials selection for model steam engine (8)

Copper alloys

- Boiler and firetubes
  - High thermal conductivity
  - Corrosion resistance in clean water
  - High cost (prohibitive in full size ⇒ mild steel)

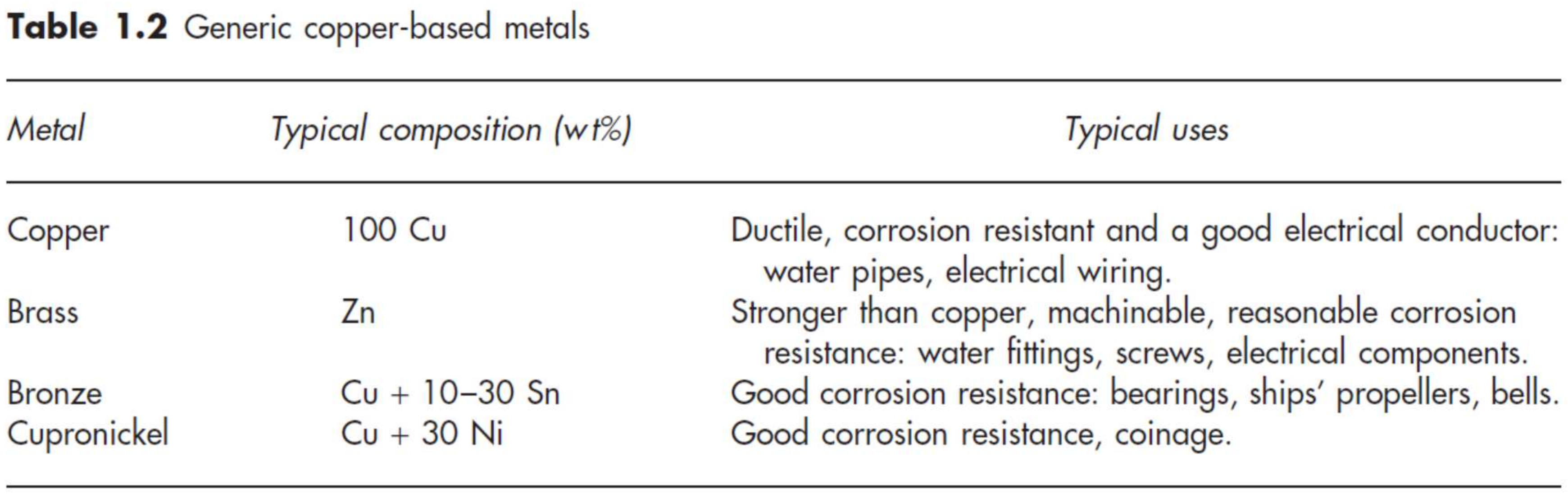


Table 1.2 Generic copper-based metals

Metal	*Typical composition (wt%)*	*Typical uses*
Copper	100 Cu	Ductile, corrosion resistant and a good electrical conductor: water pipes, electrical wiring.
Brass	Zn	Stronger than copper, machinable, reasonable corrosion resistance: water fittings, screws, electrical components.
Bronze	Cu + 10–30 Sn	Good corrosion resistance: bearings, ships' propellers, bells.
Cupronickel	Cu + 30 Ni	Good corrosion resistance, coinage.

[M.F. Ashby and D.R.H. Jones, Engineering Materials, vol. 2]

Materials selection for beverage can (1)

- Strong requirements
  - – No seam, no leak
  - – Use as little metal as possible
  - – Light
  - – High formability
  - – Recyclable
  - – Not toxic
  - – Corrosion resistance (even in coke that is highly acid)
  - – Cheap

Materials selection for beverage can (2)

- Aluminium alloys

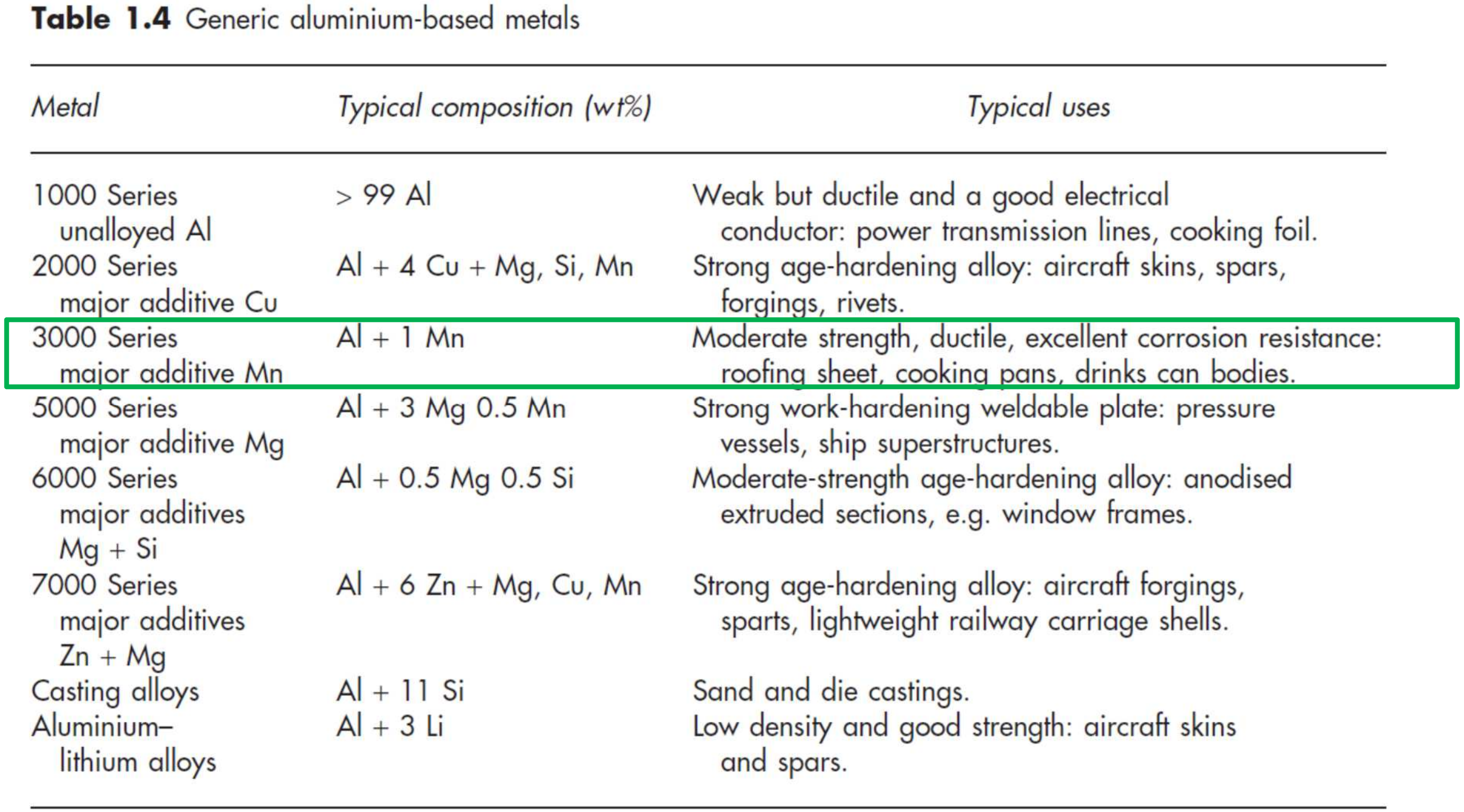


Table 1.4 Generic aluminium-based metals

Metal	*Typical composition (wt%)*	*Typical uses*
1000 Series unalloyed Al	> 99 Al	Weak but ductile and a good electrical conductor: power transmission lines, cooking foil.
2000 Series major additive Cu	Al + 4 Cu + Mg, Si, Mn	Strong age-hardening alloy: aircraft skins, spars, forgings, rivets.
3000 Series major additive Mn	Al + 1 Mn	Moderate strength, ductile, excellent corrosion resistance: roofing sheet, cooking pans, drinks can bodies.
5000 Series major additive Mg	Al + 3 Mg 0.5 Mn	Strong work-hardening weldable plate: pressure vessels, ship superstructures.
6000 Series major additives Mg + Si	Al + 0.5 Mg 0.5 Si	Moderate-strength age-hardening alloy: anodised extruded sections, e.g. window frames.
7000 Series major additives Zn + Mg	Al + 6 Zn + Mg, Cu, Mn	Strong age-hardening alloy: aircraft forgings, sparts, lightweight railway carriage shells.
Casting alloys	Al + 11 Si	Sand and die castings.
Aluminium–lithium alloys	Al + 3 Li	Low density and good strength: aircraft skins and spars.

[M.F. Ashby and D.R.H. Jones, Engineering Materials, vol. 2]

Materials selection for artificial hip joints (1)

- Requirements:
  - Large loads
  - High resistance to bending
  - Resistance to high-cycle fatigue
  - Resistance to corrosion in body fluids
  - Bio-compatibility
  - Light (density prosthesis = density bone)

[https://www.news-medical.net/Accolade-C-Femoral-Component-from-Stryker]

Materials selection for artificial hip joints (2)

- Titanium alloys

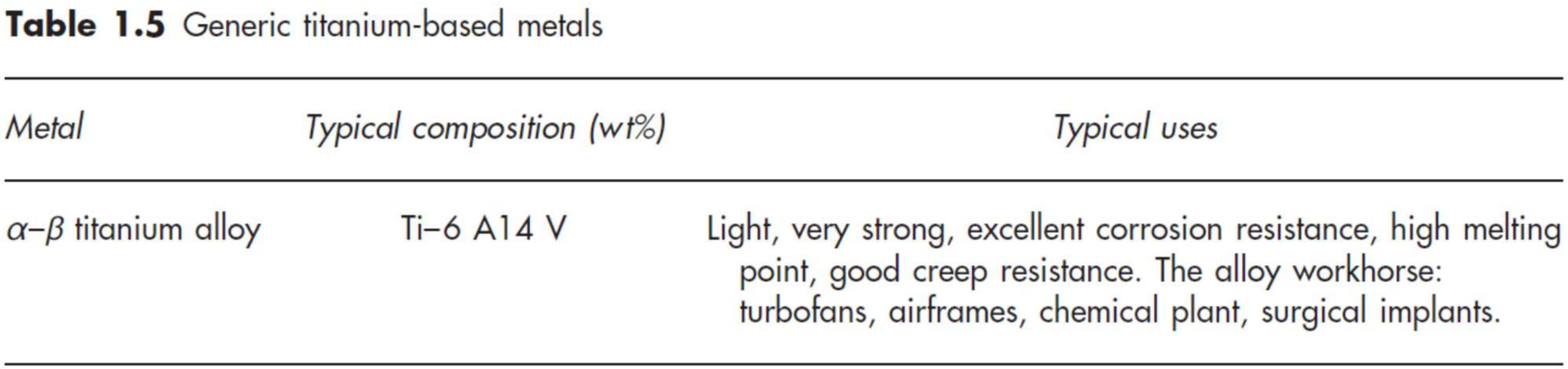


Table 1.5 Generic titanium-based metals

Metal	*Typical composition (wt%)*	*Typical uses*
α–β titanium alloy	Ti–6 A14 V	Light, very strong, excellent corrosion resistance, high melting point, good creep resistance. The alloy workhorse: turbofans, airframes, chemical plant, surgical implants.

[M.F. Ashby and D.R.H. Jones, Engineering Materials, vol. 2]

Partial summary (1)

- Materials selection $\Rightarrow$ ≠ criteria
  - Physical properties (density, conductivity...)
  - Mechanical properties (yield stress, fatigue...)
  - Corrosion resistance
  - Bio-compatibility
  - Processability, formability
  - Cost
  - ...

Data for metals

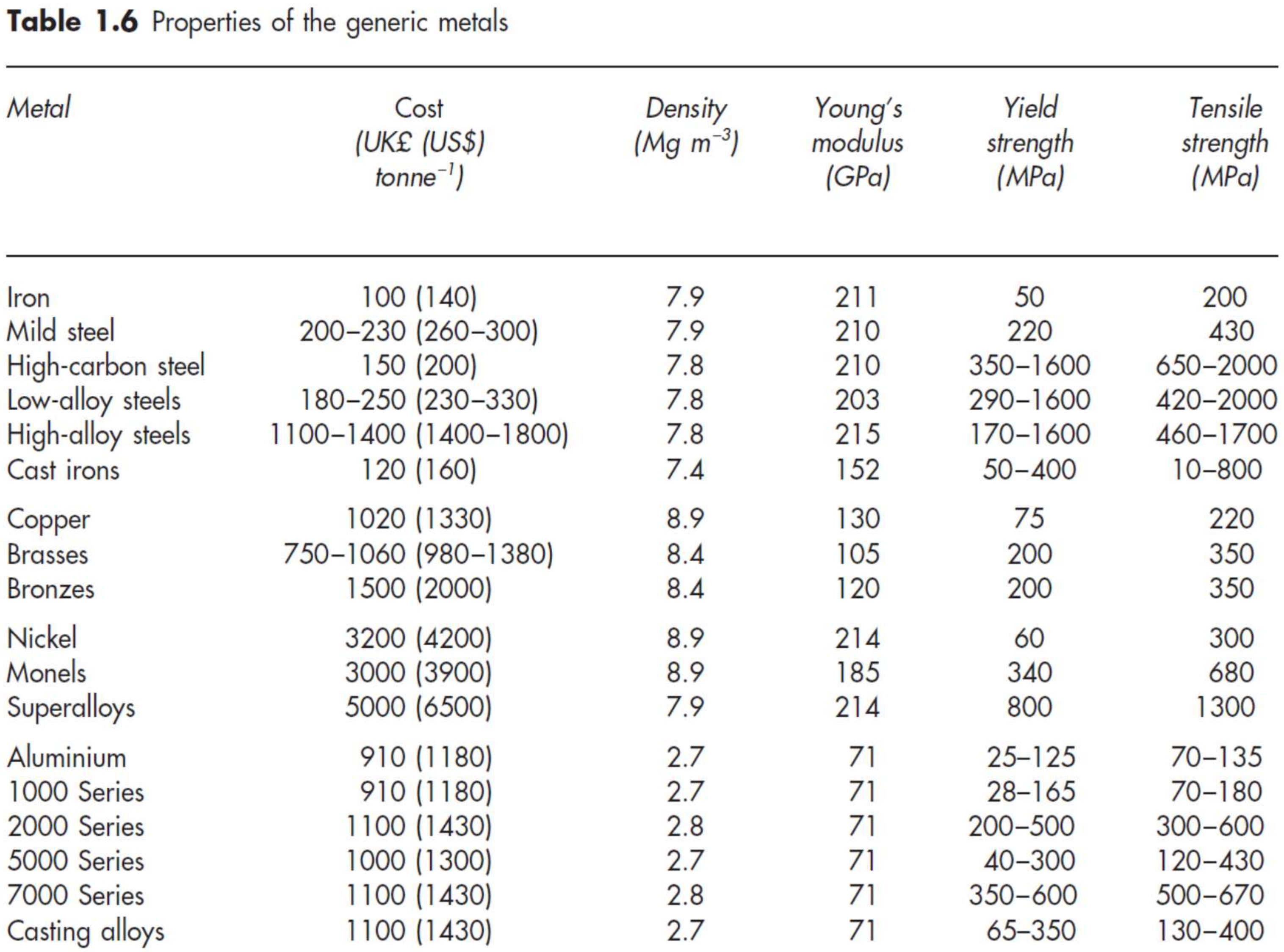


Table 1.6 Properties of the generic metals

Metal	Cost (*UK£ (US$) tonne*$^{-1}$)	*Density (Mg m*$^{-3}$*)*	*Young's modulus (GPa)*	*Yield strength (MPa)*	*Tensile strength (MPa)*
Iron	100 (140)	7.9	211	50	200
Mild steel	200–230 (260–300)	7.9	210	220	430
High-carbon steel	150 (200)	7.8	210	350–1600	650–2000
Low-alloy steels	180–250 (230–330)	7.8	203	290–1600	420–2000
High-alloy steels	1100–1400 (1400–1800)	7.8	215	170–1600	460–1700
Cast irons	120 (160)	7.4	152	50–400	10–800
Copper	1020 (1330)	8.9	130	75	220
Brasses	750–1060 (980–1380)	8.4	105	200	350
Bronzes	1500 (2000)	8.4	120	200	350
Nickel	3200 (4200)	8.9	214	60	300
Monels	3000 (3900)	8.9	185	340	680
Superalloys	5000 (6500)	7.9	214	800	1300
Aluminium	910 (1180)	2.7	71	25–125	70–135
1000 Series	910 (1180)	2.7	71	28–165	70–180
2000 Series	1100 (1430)	2.8	71	200–500	300–600
5000 Series	1000 (1300)	2.7	71	40–300	120–430
7000 Series	1100 (1430)	2.8	71	350–600	500–670
Casting alloys	1100 (1430)	2.7	71	65–350	130–400

[M.F. Ashby and D.R.H. Jones, Engineering Materials, vol. 2]

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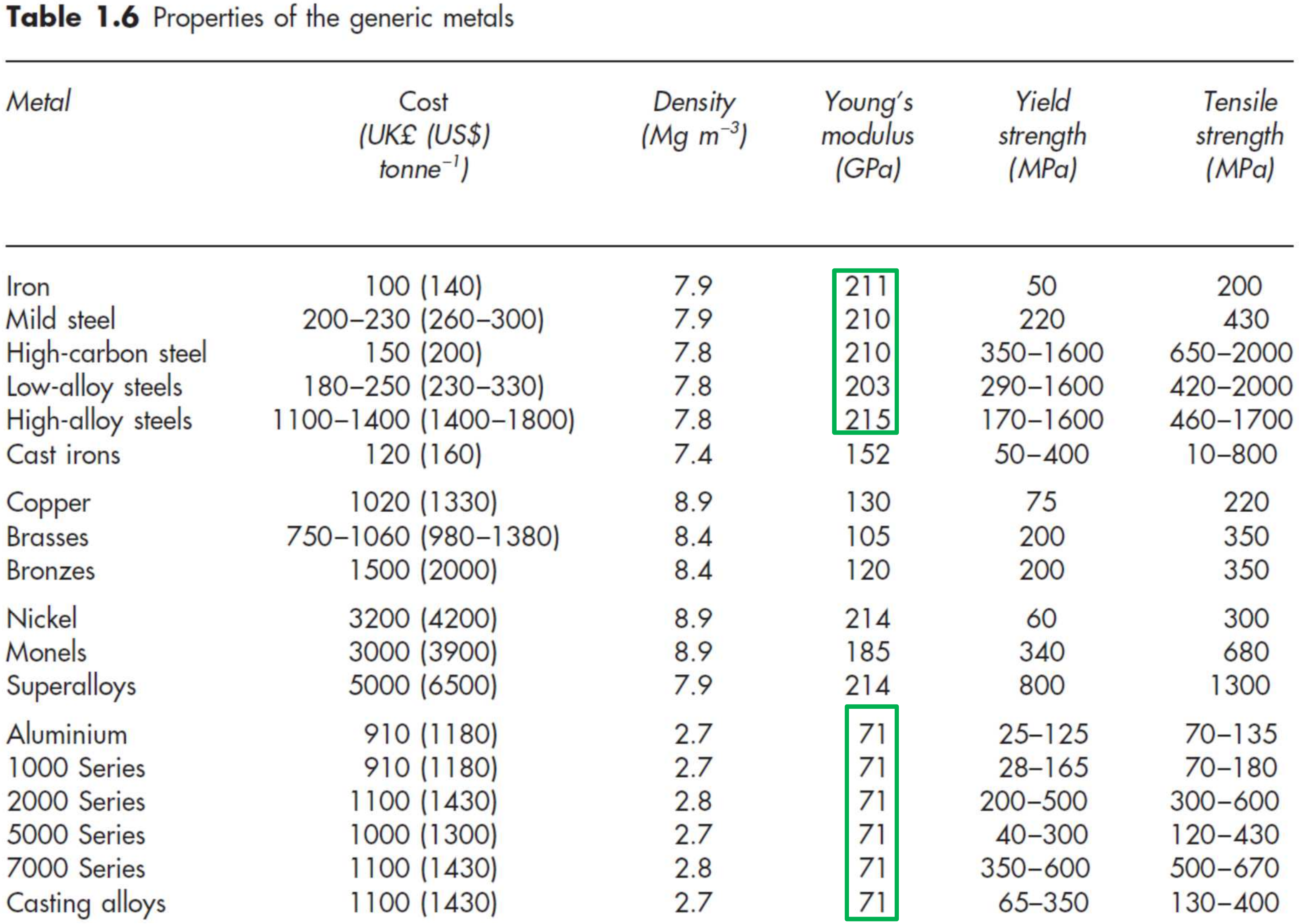

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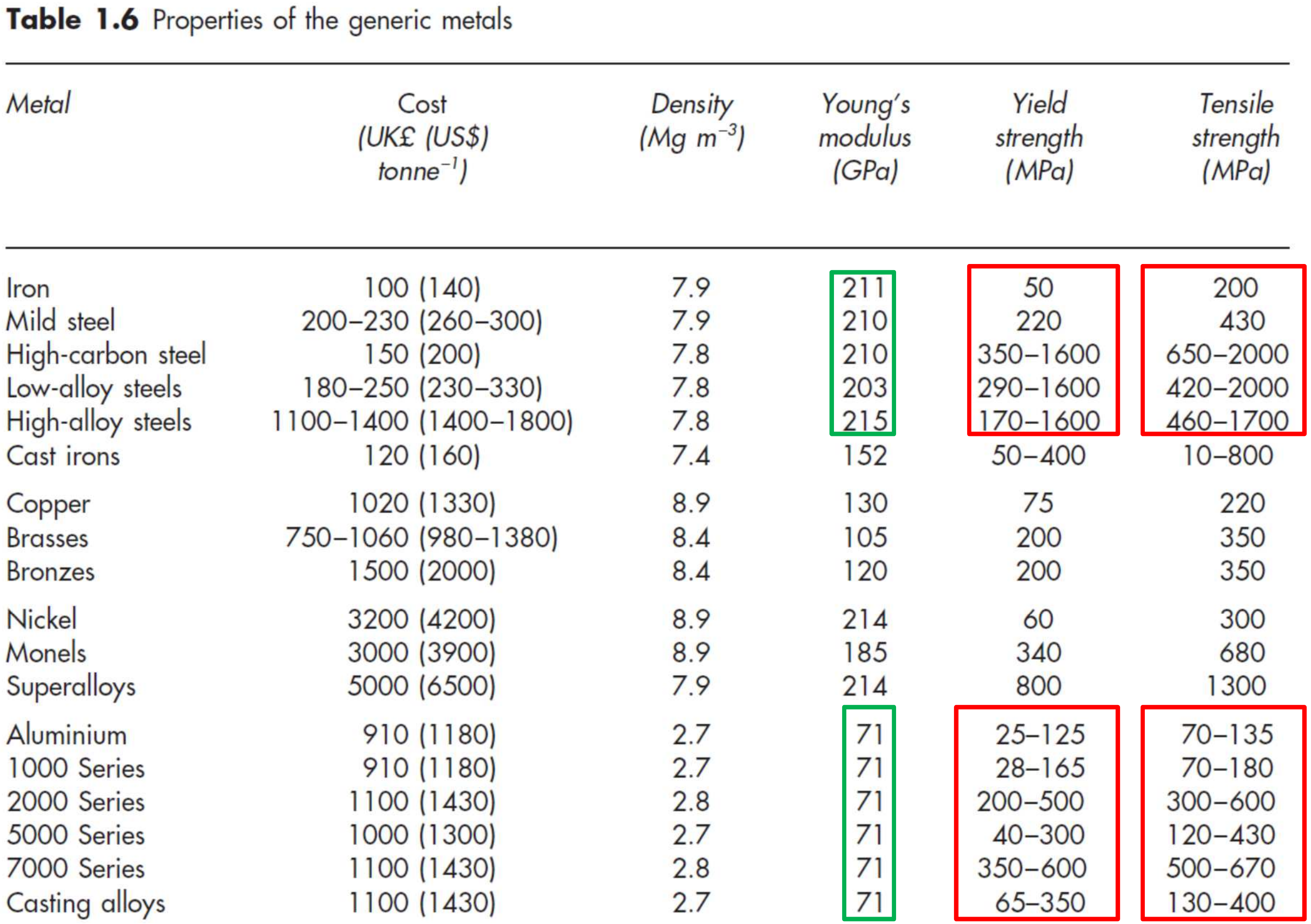

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[M.F. Ashby and D.R.H. Jones, Engineering Materials, vol. 2]

Data for metals

- Properties of metallic materials may be
  - structure independent...
    (= f(composition))
    e.g.: Young's modulus...
  - ... vs structure dependent
    (=f(composition, **(micro)structure** → processing))
    e.g.: yield strength, tensile strength...
- One must be really careful when dealing with structure-dependent properties!
  - influenced by cold deformation, heat treatments...

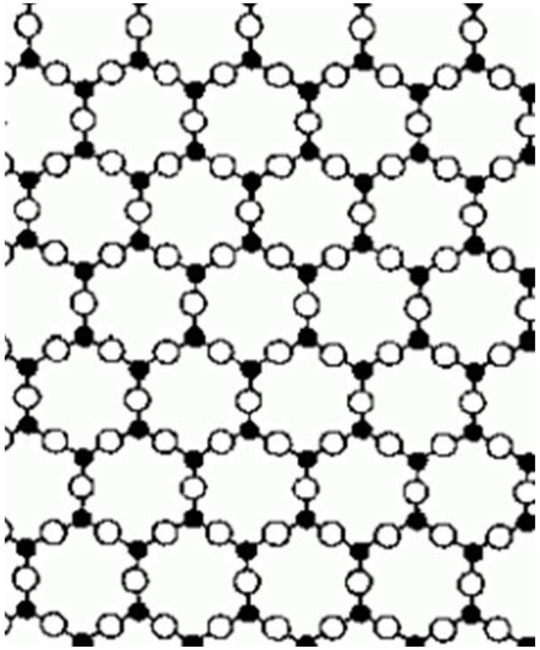
Metal structures

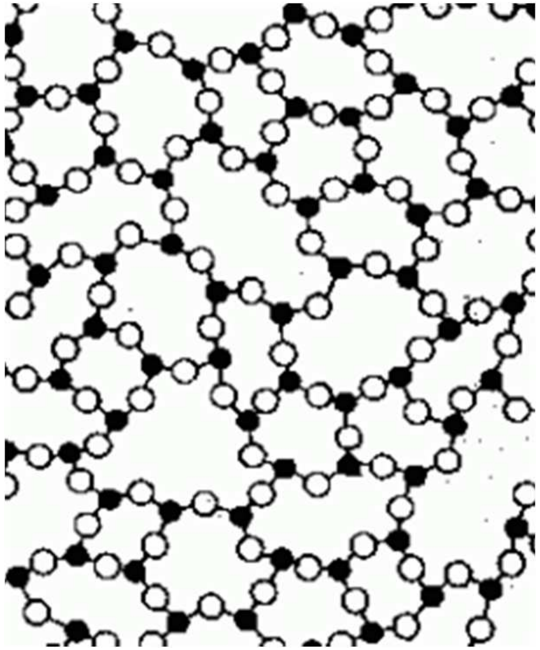
How do we describe the structure of a metal?

Crystal vs glass

Long-range order

Short-range order





[http://www.majordifferences.com/2013/02/difference-between-crystalline-and.html#.Wb42e9E69PY]

- Packing of atoms inside the materials

Common crystalline structures of pure metals

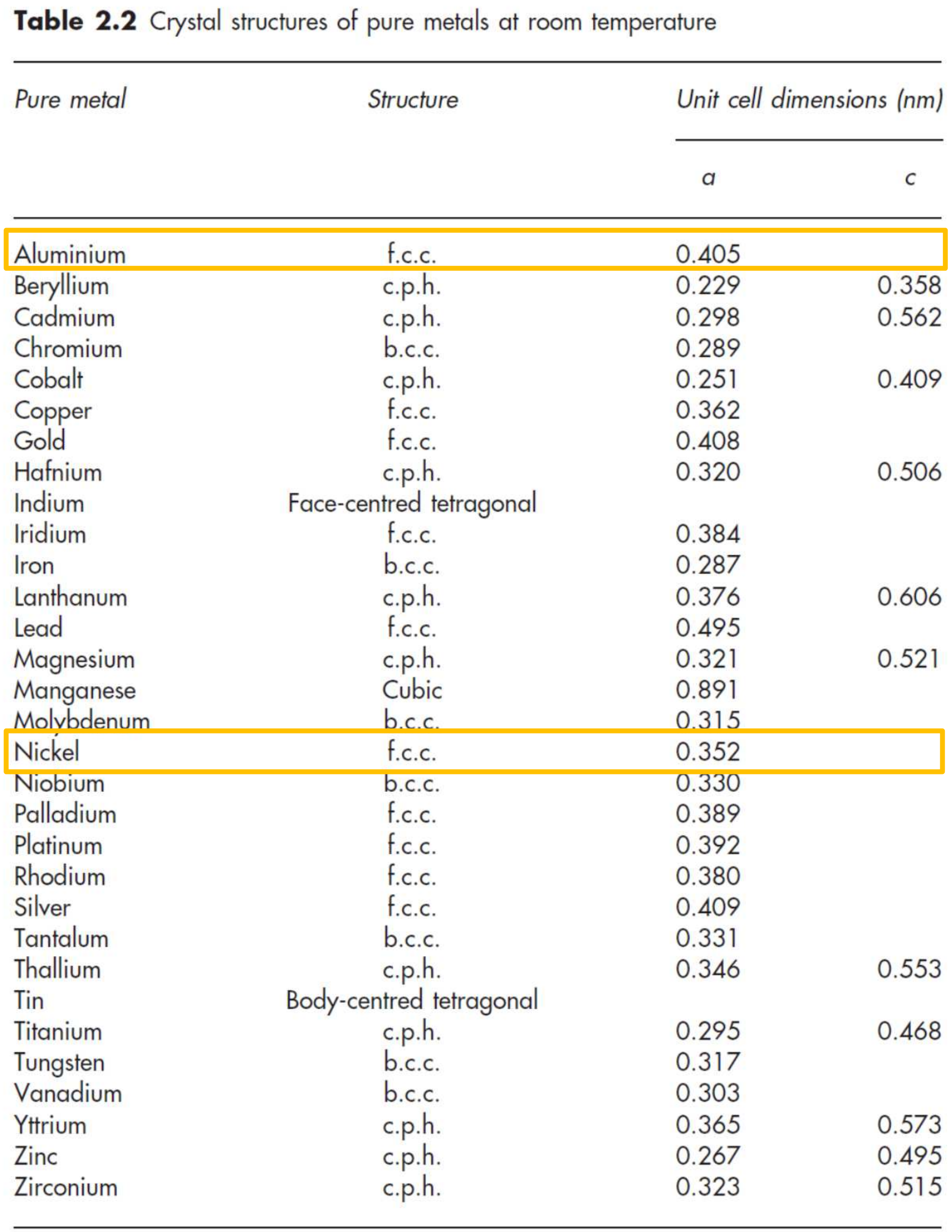


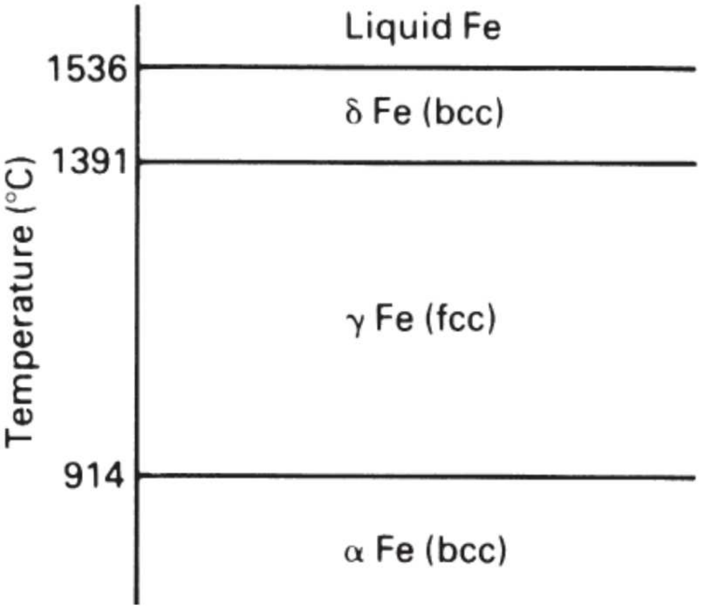
Table 2.2 Crystal structures of pure metals at room temperature

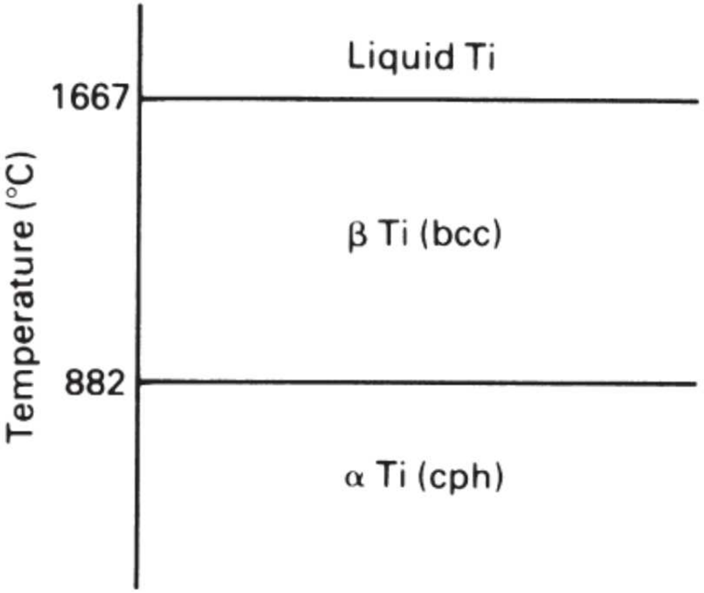
Pure metal	*Structure*	*Unit cell dimensions (nm)*	
		a	*c*
Aluminium	f.c.c.	0.405	
Beryllium	c.p.h.	0.229	0.358
Cadmium	c.p.h.	0.298	0.562
Chromium	b.c.c.	0.289	
Cobalt	c.p.h.	0.251	0.409
Copper	f.c.c.	0.362	
Gold	f.c.c.	0.408	
Hafnium	c.p.h.	0.320	0.506
Indium	Face-centred tetragonal		
Iridium	f.c.c.	0.384	
Iron	b.c.c.	0.287	
Lanthanum	c.p.h.	0.376	0.606
Lead	f.c.c.	0.495	
Magnesium	c.p.h.	0.321	0.521
Manganese	Cubic	0.891	
Molybdenum	b.c.c.	0.315	
Nickel	f.c.c.	0.352	
Niobium	b.c.c.	0.330	
Palladium	f.c.c.	0.389	
Platinum	f.c.c.	0.392	
Rhodium	f.c.c.	0.380	
Silver	f.c.c.	0.409	
Tantalum	b.c.c.	0.331	
Thallium	c.p.h.	0.346	0.553
Tin	Body-centred tetragonal		
Titanium	c.p.h.	0.295	0.468
Tungsten	b.c.c.	0.317	
Vanadium	b.c.c.	0.303	
Yttrium	c.p.h.	0.365	0.573
Zinc	c.p.h.	0.267	0.495
Zirconium	c.p.h.	0.323	0.515

[M.F. Ashby and D.R.H. Jones, Engineering Materials, vol. 2]

Polymorphism

- Some metals may change crystalline structure depending on external conditions (p, T)
  e.g.: Fe and Ti



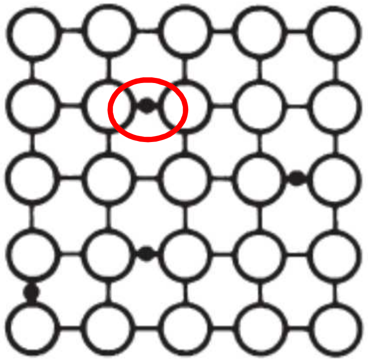


- Polymorphism may be controlled by alloying
  e.g.: addition of Ni in steel ⇒ FCC at Room T

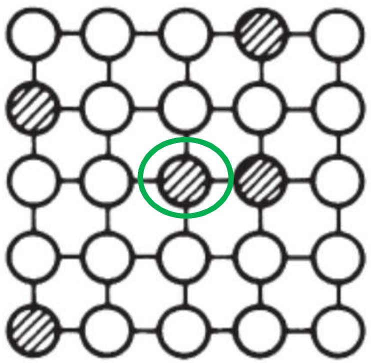
[M.F. Ashby and D.R.H. Jones, Engineering Materials, vol. 2]

Solutions vs compounds (1)

- Metals are rarely used in pure state
  - Addition elements ⇒ Alloys
  - Alloying elements may be dissolved in the crystalline lattice of the main element
  - Up to the solubility limit



Interstitial solution
e.g.: C in Fe

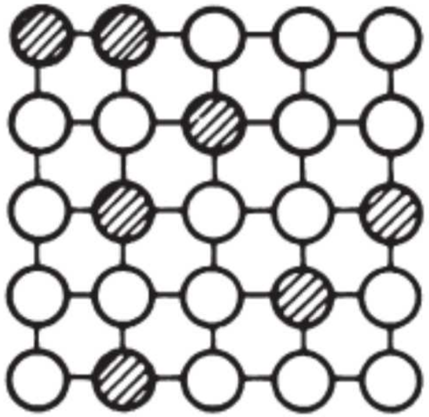


Substitutional solution

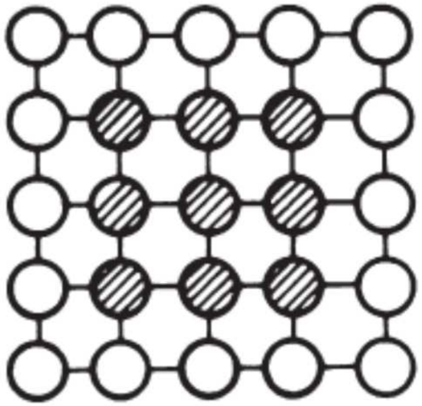
[M.F. Ashby and D.R.H. Jones, Engineering Materials, vol. 2]

Solutions vs compounds (2)

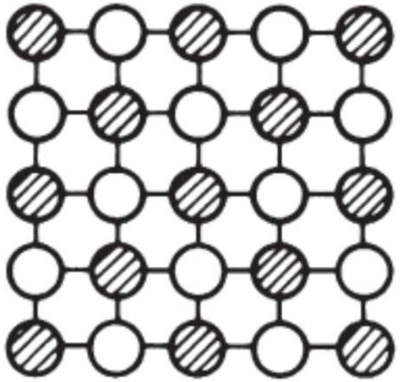
- [alloying element] < solubility limit
- Solutions may be random, but clustering or ordering are also possible



Random



Clustered



Ordered

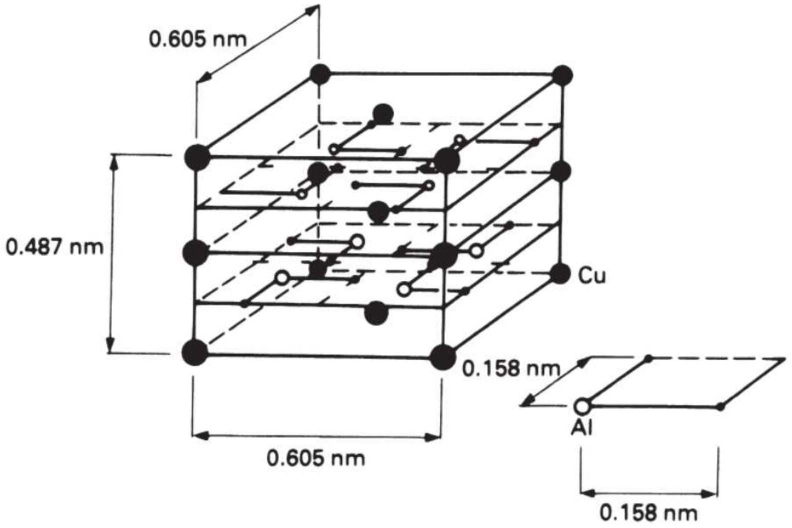
[M.F. Ashby and D.R.H. Jones, Engineering Materials, vol. 2]

Solutions vs compounds (3)

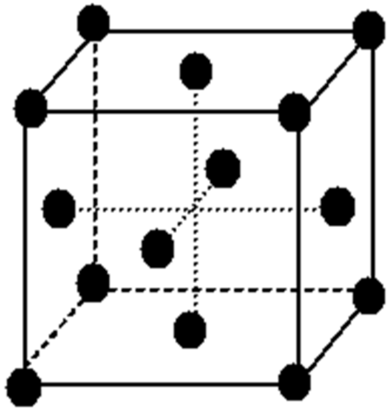
- [alloying element] > solubility limit

➡ Excess precipitates forming a new intermetallic compound (with its own crystalline structure)

- Cu addition in Aluminium:
  Formation of $CuAl_2$



[M.F. Ashby and D.R.H. Jones, Engineering Materials, vol. 2]



FCC structure of Al

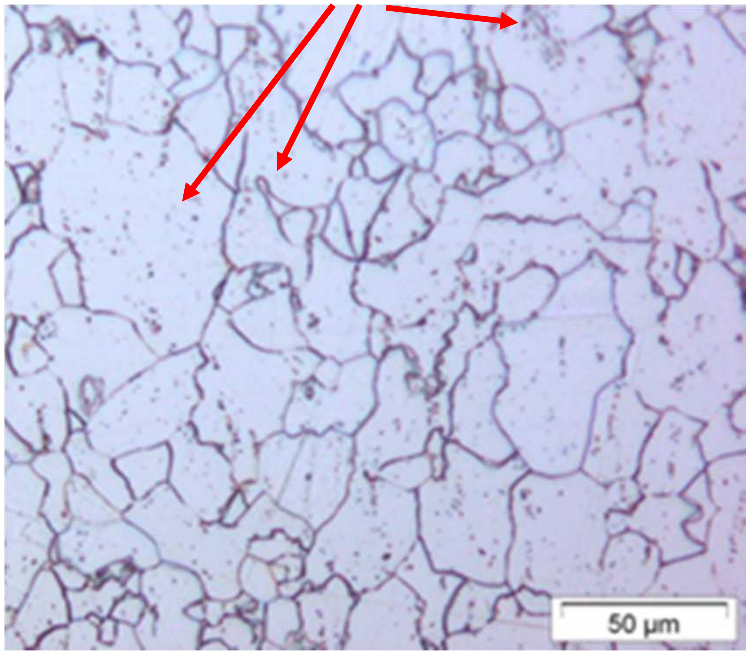
[http://deuns.chez.com/sciences/cristallo/cristallo2.html]

Solutions vs compounds (4)

- [alloying element] > solubility limit

➡ Excess precipitates forming a new intermetallic compound

- Solubility limit of C in BCC Fe at R.T.: 10^{-5} mass %
- Excess C forms cementite (Fe_3C)



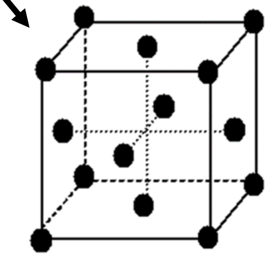
[A. Mertens, ULg]

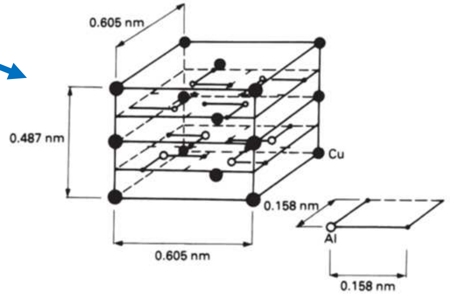
Phases (1)

Phase = region of a material that has uniform physical and chemical properties

Phases (2)

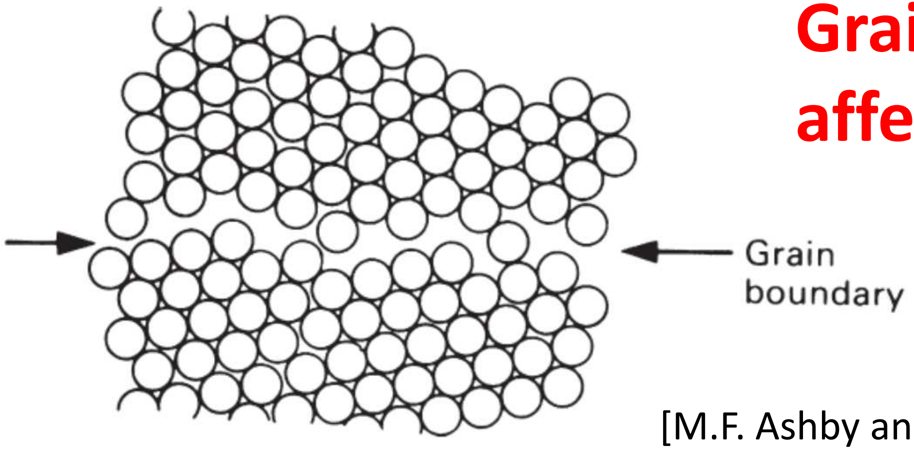
- Liquid water = one phase
  Ice = one phase
  Liquid water + ice = two phases
- Cu fully dissolved in Al
  = one solid solution
  = one phase
- [Cu] > solubility limit in Al
  = Al (solid solution) + $CuAl_2$ (precipitates)
  = two phases





Grain and phase boundaries (1)

- A pure metal or a solid solution are single-phase systems...
- ... but they are usually made of many crystals (with the same crystalline structure and chemical composition)
- Individual small crystal = **grain**

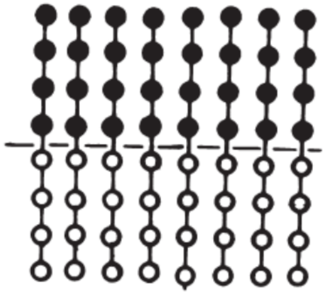


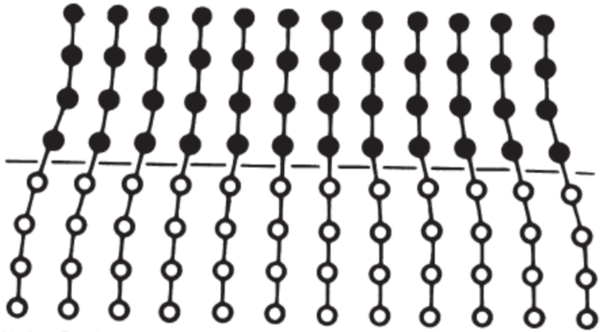
Grains size and shape may affect material properties!

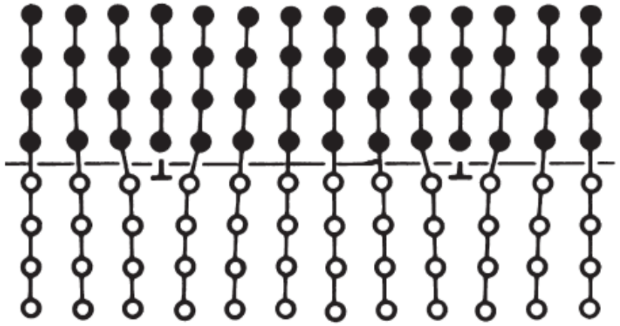
[M.F. Ashby and D.R.H. Jones, Engineering Materials, vol. 2]

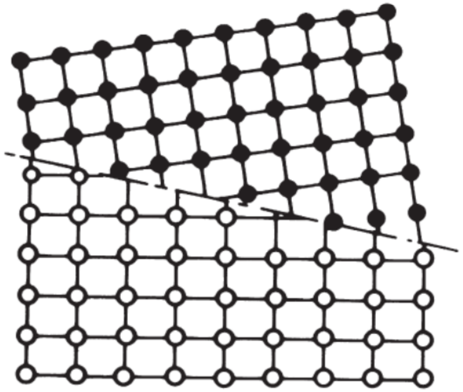
Grain and phase boundaries (2)

- Two-phases metallic materials are also made from many grains of each of the phases
- Interphase boundaries: ≠ types


(a) Coherent


(b) Coherency strain

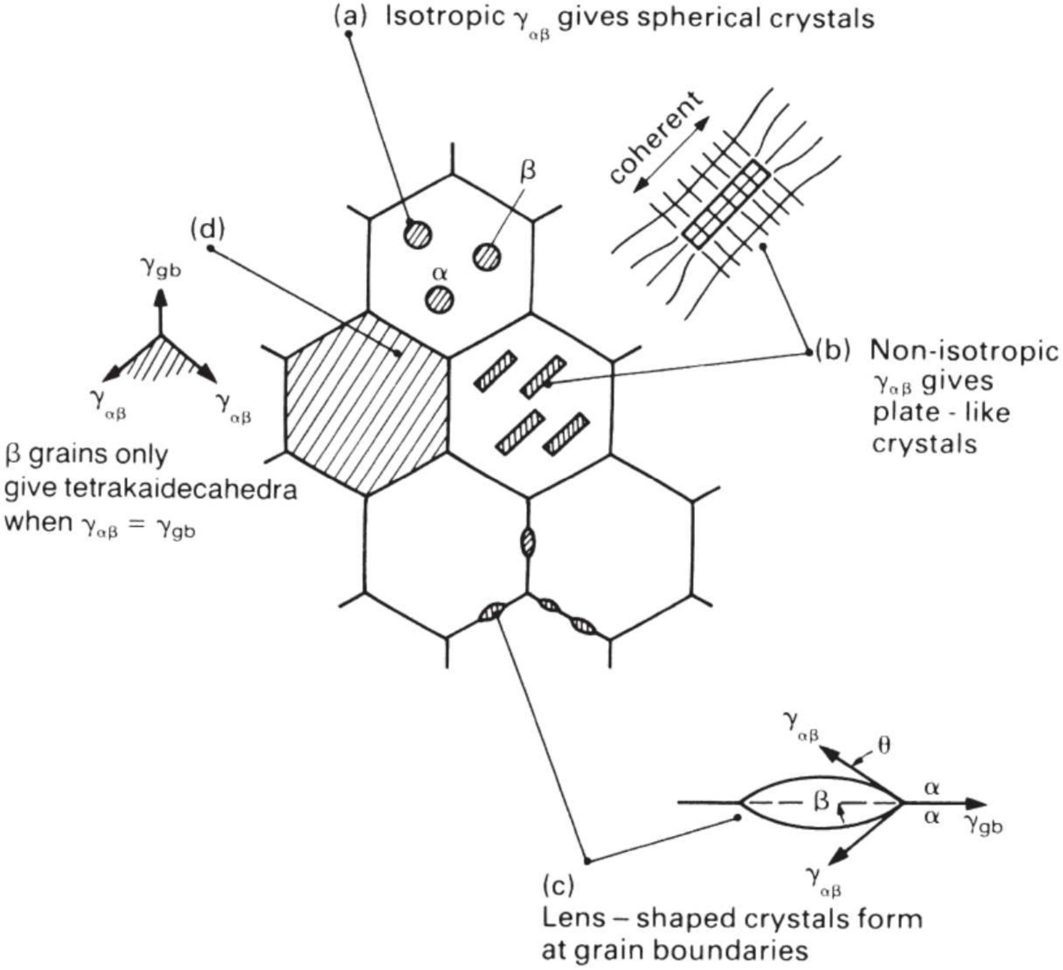

(c) Semi-coherent


(d) Incoherent

Nature of interphase boundaries may affect material properties!

Grain and phase boundaries (3)

- Precipitates may take ≠ shape/morphology



[M.F. Ashby and D.R.H. Jones, Engineering Materials, vol. 2]

Partial summary (2)

- Some properties (e.g.: yield strength) are influenced by the **structure** of the material.
  - Crystalline (or amorphous) structure
  - Phases (solid solution, intermetallic compounds...)
  - Size and shape of grains
  - Interphase boundaries
- Structure is determined by
  - Chemical composition
  - Processing method (deformation, heat treatments...)

Outline

- Introduction
- Metal structures

How can we understand/control the structure of a metallic material?

Today

  - Influence of chemical composition?
- Equilibrium constitution and phase diagrams
- Case studies in phase diagrams

  - Influence of processing method?

Next week

Equilibrium constitution and phase diagrams

How do we describe the influence of the chemical composition and external conditions (T,p) on the structure of a metallic materials?

Equilibrium (1)

Intuitively:

A system is in equilibrium when it exhibits no further tendency to change with time

Equilibrium (2)

Intuitively:

A system is in equilibrium when it exhibits no further tendency to change with time

Thermodynamics:

A system is in equilibrium when its energy is minimized

Equilibrium (2)

Intuitively:

A system is in equilibrium when it exhibits no further tendency to change with time

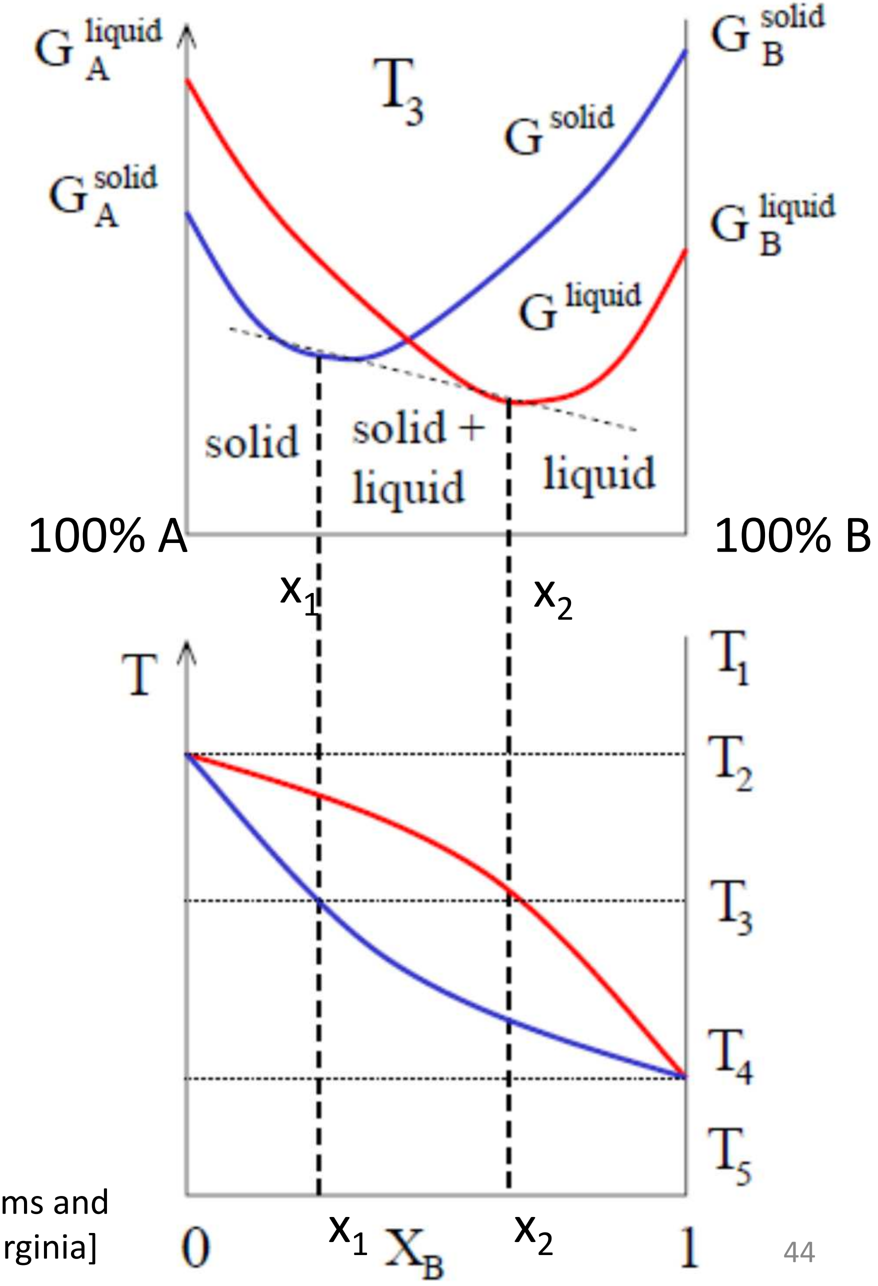
Thermodynamics:

A system is in equilibrium when its energy is minimized

Equilibrium = G minimum with G: enthalpy

Phase diagrams

- x_B : fraction of element B
  $1-x_B$: fraction of element A
- Atmospheric pressure
- Equilibrium = G minimum
- Equilibrium state of a binary system (A,B) at T_3
  - 2 phases are present (liquid, solid)
  - Compositions of each phase
  - Fractions of each phase



[L. Zhigilei, Phase diagrams and Kinetics, University of Virginia]

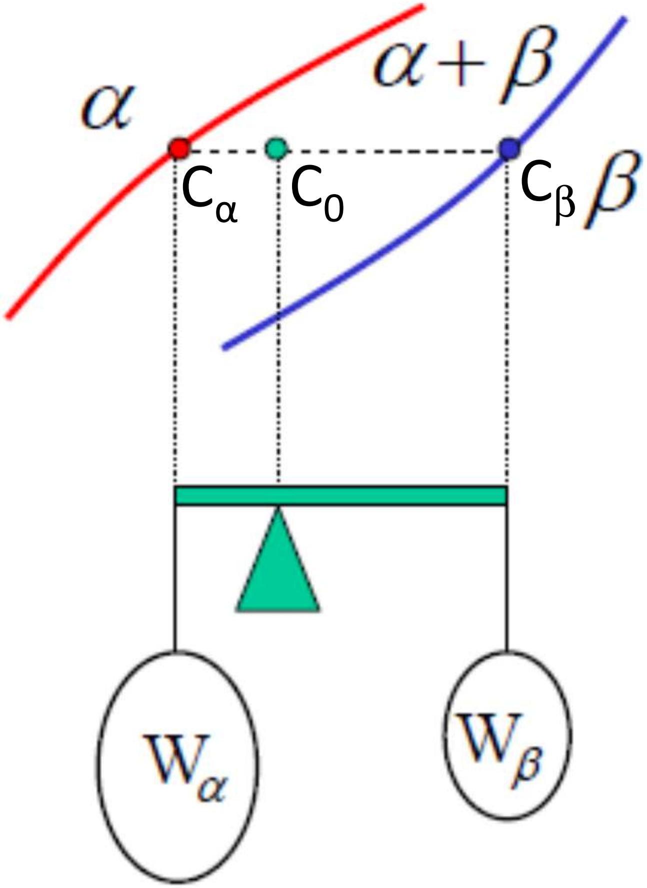
Reading phase diagrams: The Lever Rule

- Binary system with 2 phases (α, β)

- Relative fractions of each phase

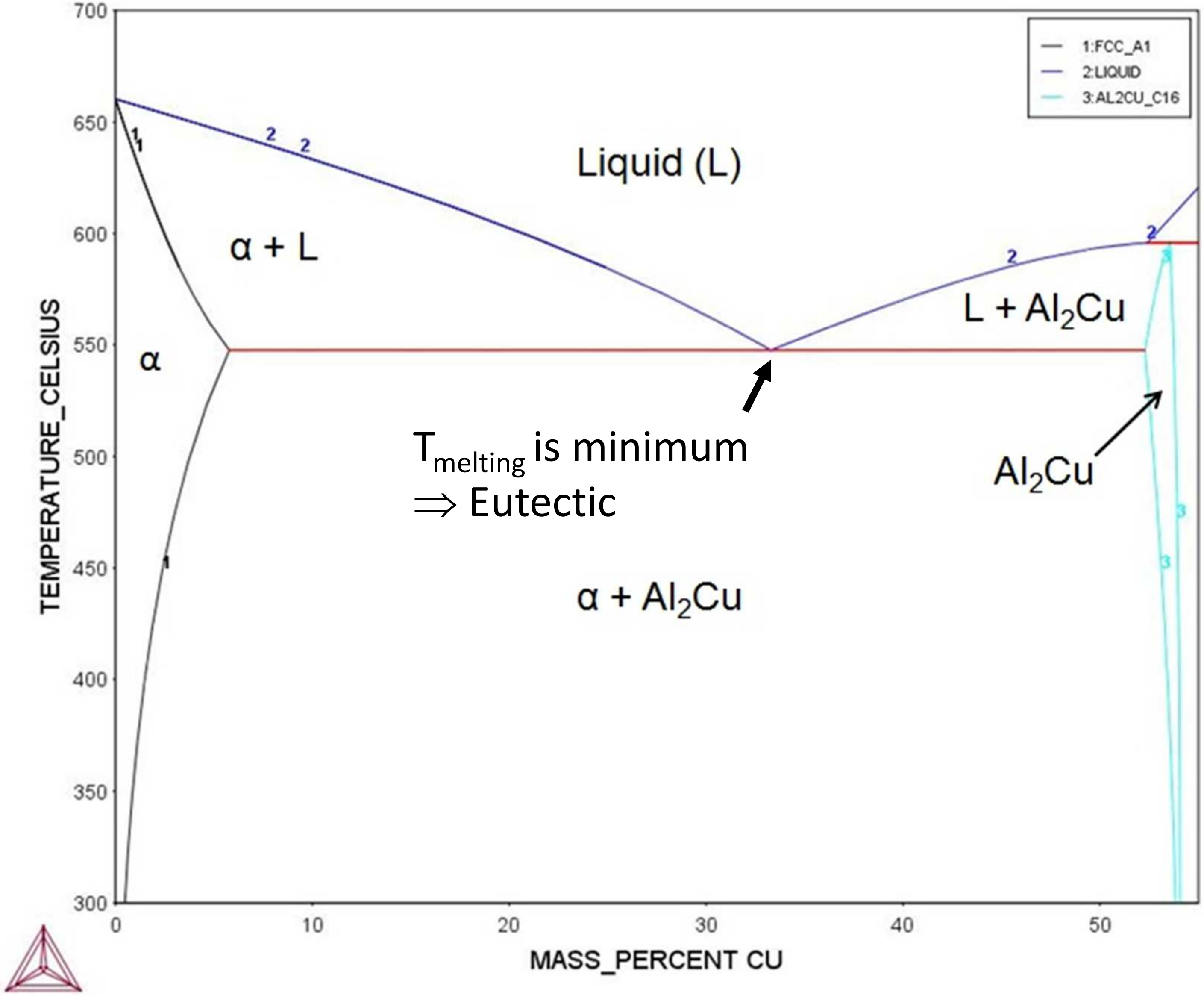
$W_\alpha = (C_\beta - C_0)/(C_\beta - C_\alpha)$

$W_\beta = (C_0 - C_\alpha)/(C_\beta - C_\alpha)$



[L. Zhigilei, Phase diagrams and Kinetics, University of Virginia]

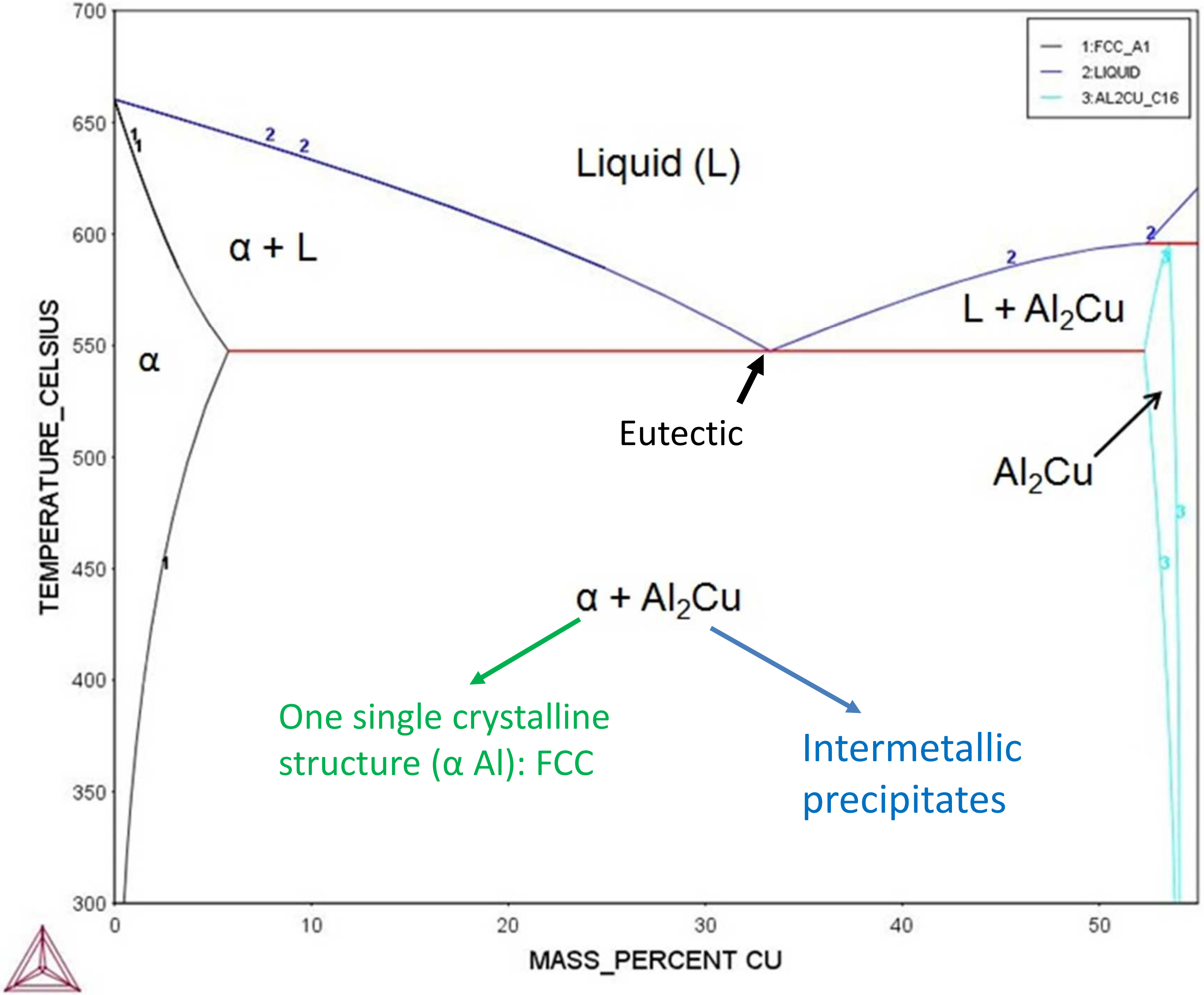
Example: Al-Cu alloys (1)



$T_{melting}$ is minimum

⇒ Eutectic

Example: Al-Cu alloys (2)



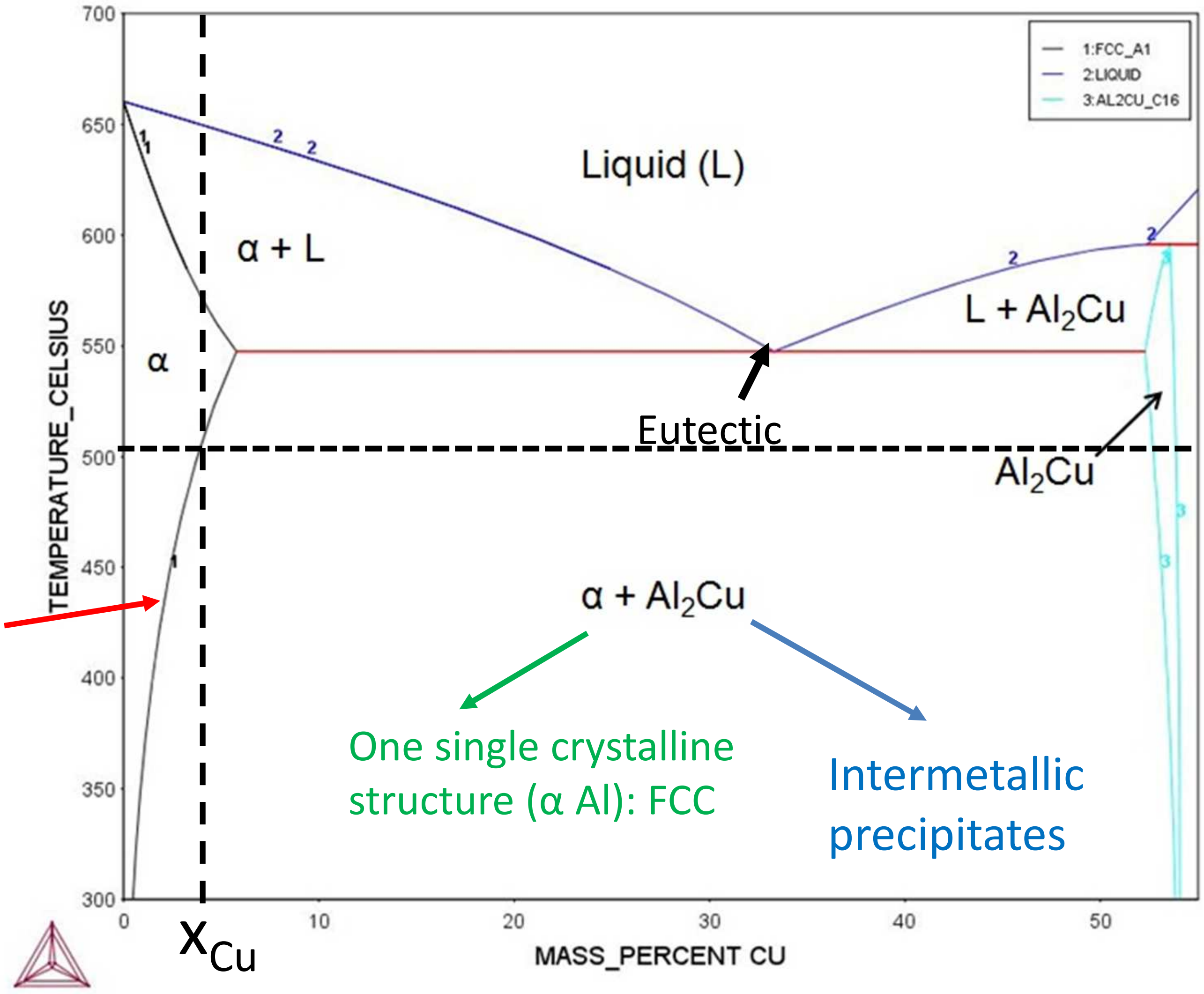
Eutectic

Al_2Cu

One single crystalline structure (α Al): FCC

Intermetallic precipitates

Example: Al-Cu alloys (3)



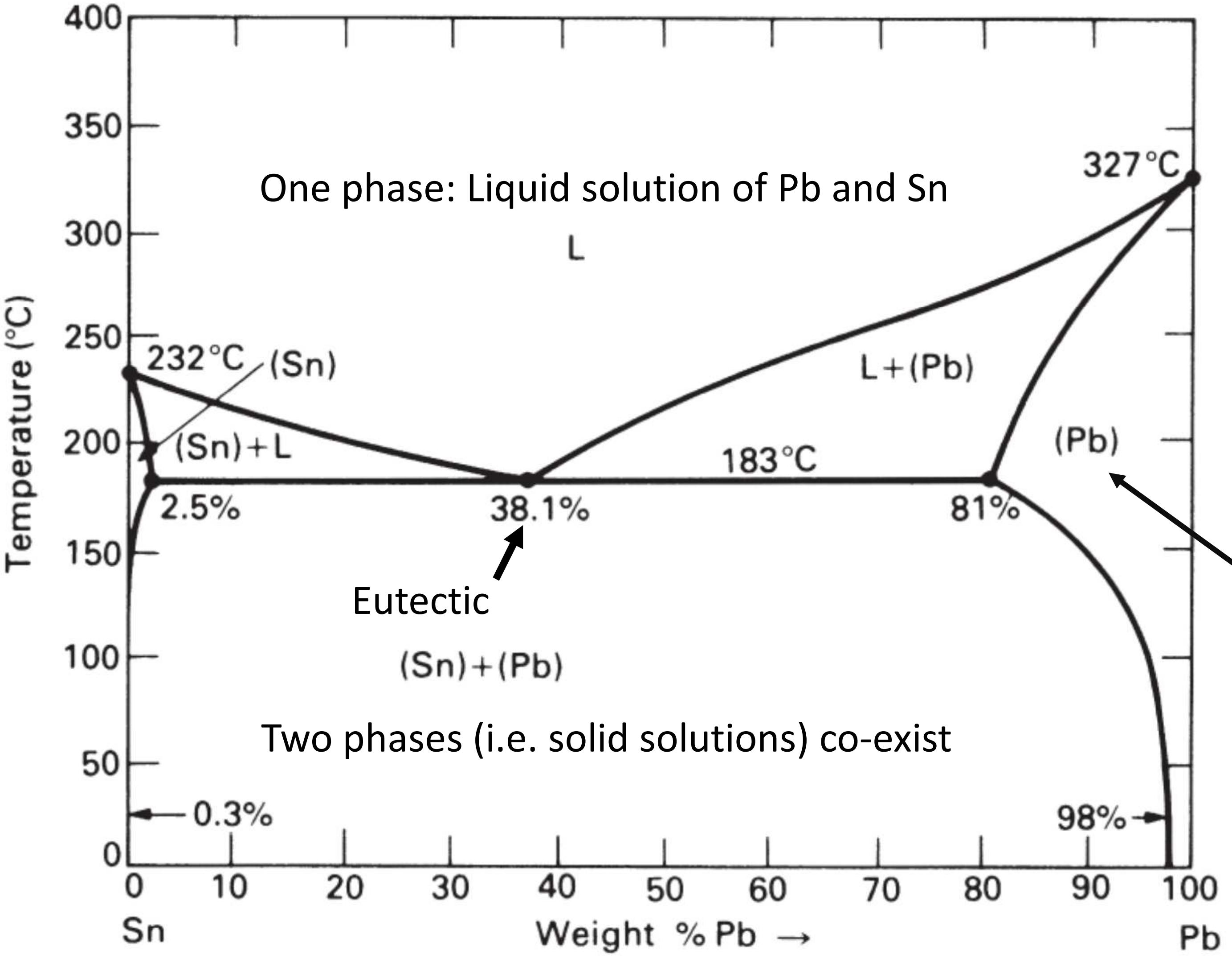
Miscibility gap - Solubility of Cu in Al decreases with T

One single crystalline structure (α Al): FCC

Intermetallic precipitates

Example: Pb-Sn alloys (1)

Common alloys for solder



One phase: Liquid solution of Pb and Sn

Eutectic

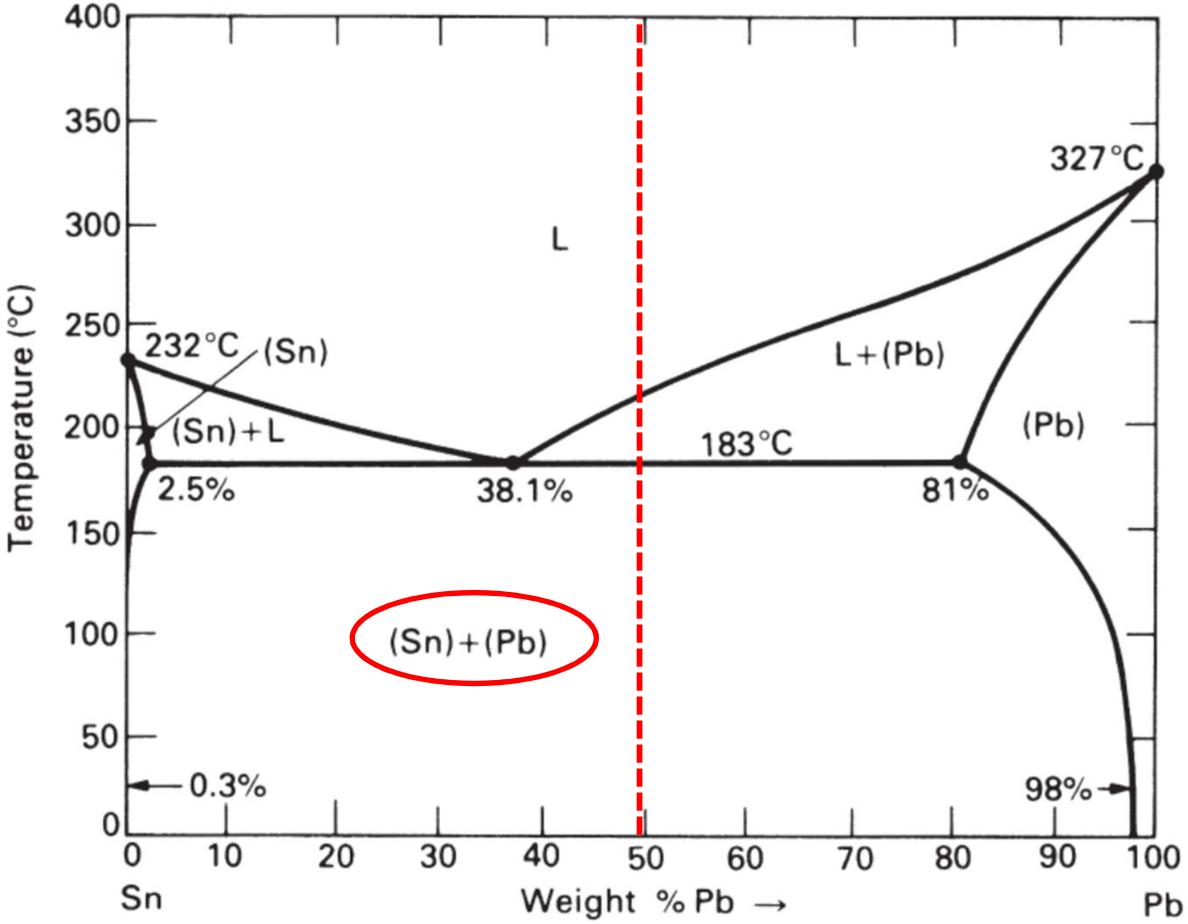
Two phases (i.e. solid solutions) co-exist

Solid solution of Sn in Pb

[M.F. Ashby and D.R.H. Jones, Engineering Materials, vol. 2]

Example: Pb-Sn alloys (2)

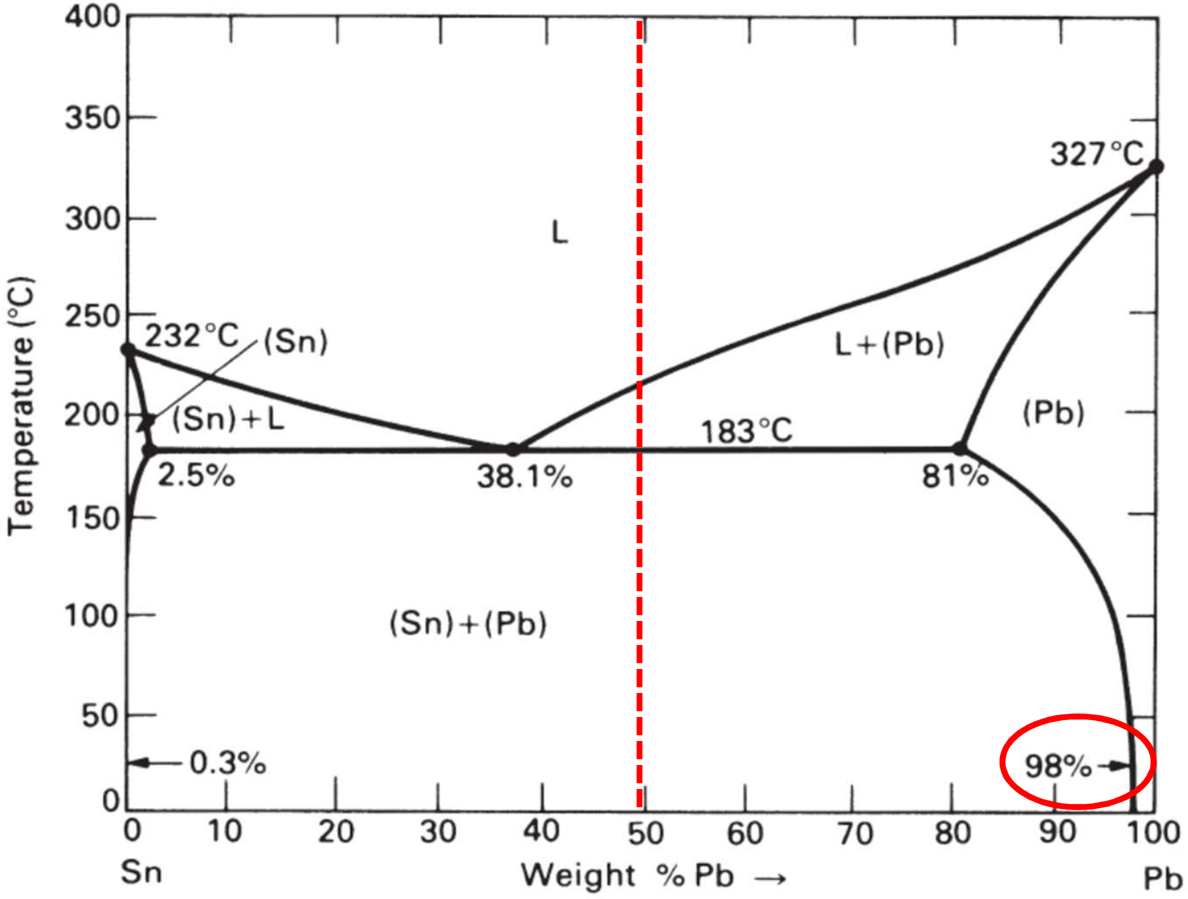
- Consider an alloy with 50% Pb and 50% Sn
- Number of phases at R.T.: 2 (Sn) and (Pb)



[M.F. Ashby and D.R.H. Jones, Engineering Materials, vol. 2]

Example: Pb-Sn alloys (3)

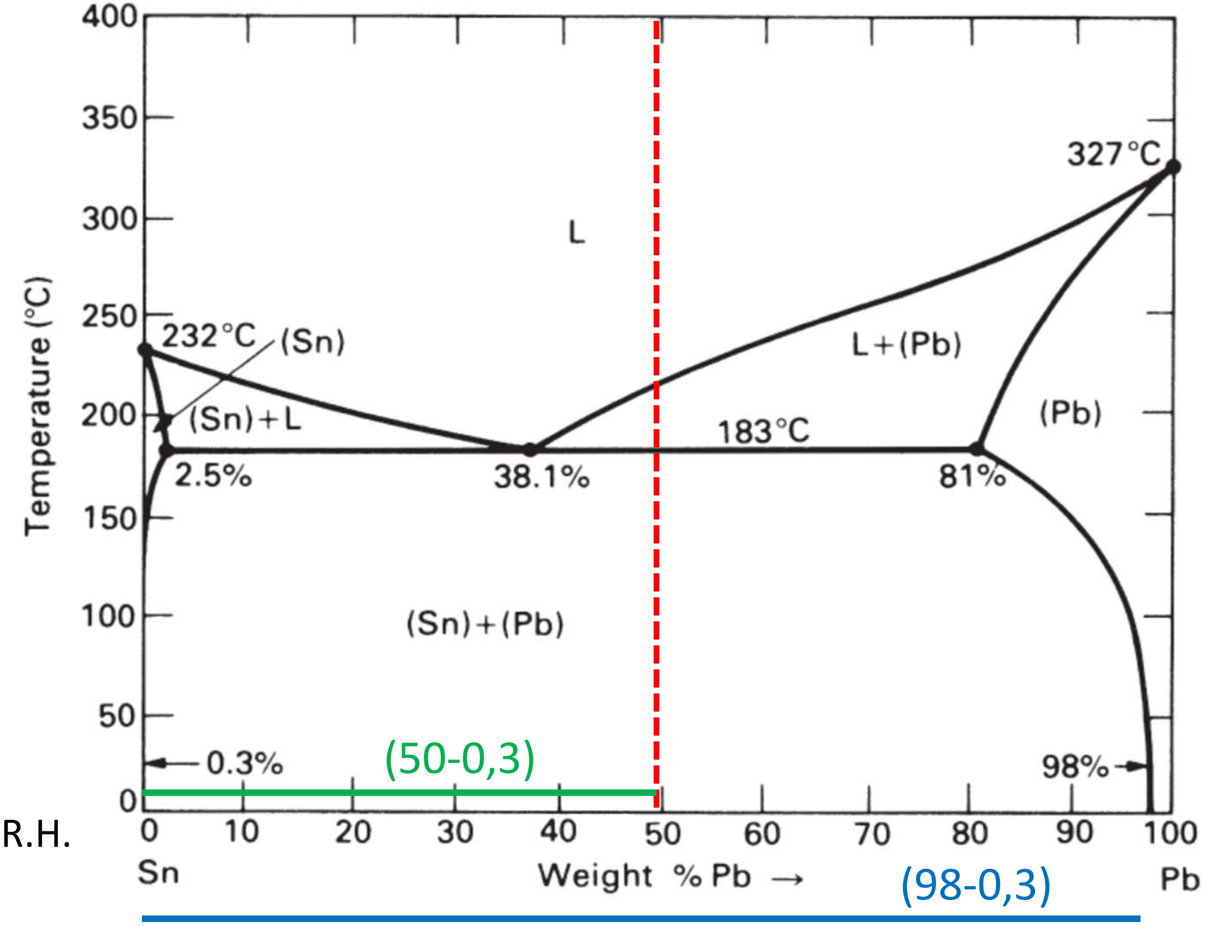
- Consider an alloy with 50% Pb and 50% Sn
- Composition of (Pb) at R.T.: 2 wt% Sn.



[M.F. Ashby and D.R.H. Jones, Engineering Materials, vol. 2]

Example: Pb-Sn alloys (4)

- Consider an alloy with 50% Pb and 50% Sn
- Fraction of (Pb) at R.T.: (50-0,3)/(98-0,3)=50,9 %



[M.F. Ashby and D.R.H. Jones, Engineering Materials, vol. 2]

Example: Pb-Sn alloys (5)

- Consider an alloy with 50% Pb and 50% Sn
- Shape and size of (Sn) and (Pb)?
  - Not from phase diagrams
  - Depend on processing method

  ⇒ Deformation, heat treatments (isothermal hold, cooling rate...)
- How can we use phase diagrams for materials selection?

⇒ Case studies in phase diagrams

Outline

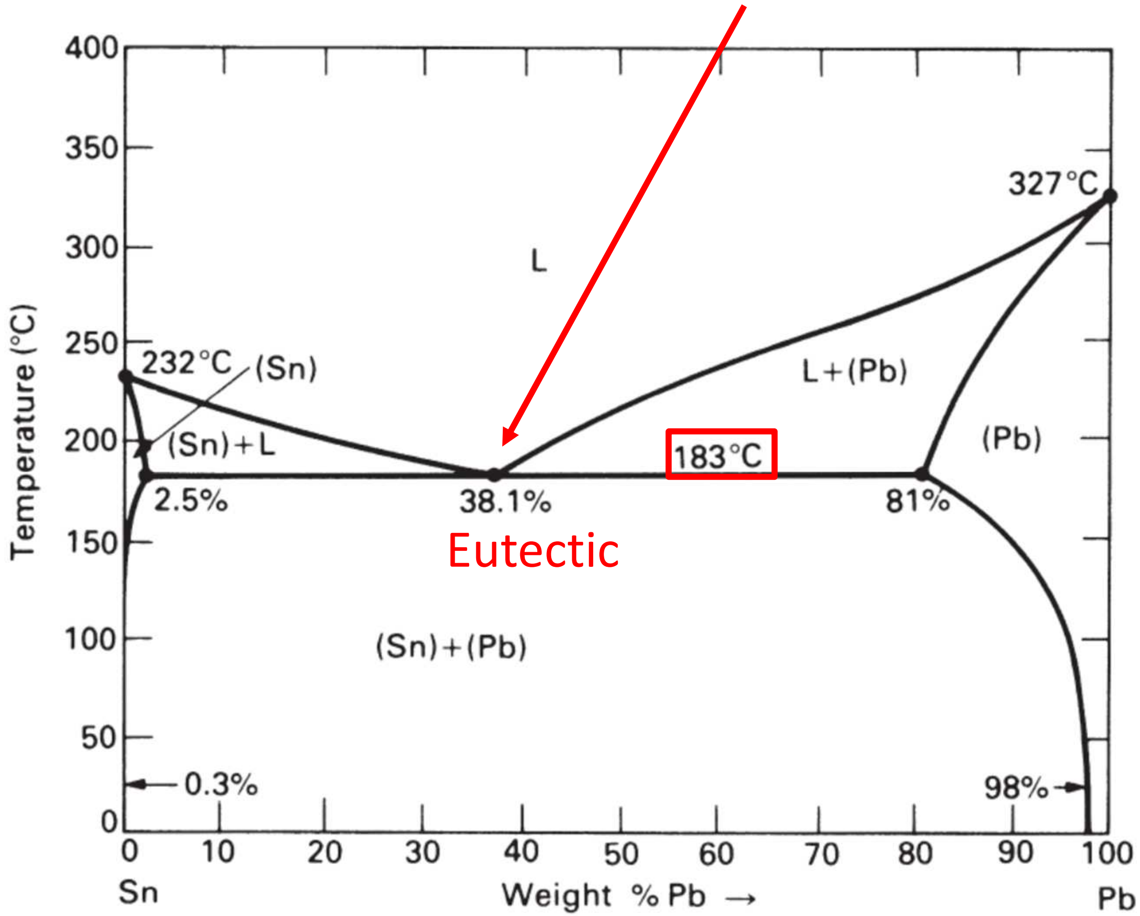
- Introduction
- Metal structures
- Equilibrium constitution and phase diagrams
- Case studies in phase diagrams
  - Materials for soft solders

Case studies in phase diagrams

Selecting a material for soft solders

Solder materials (1)

- Based on the Sn-Pb system
- For electronics: low melting T + easy flow



[M.F. Ashby and D.R.H. Jones, Engineering Materials, vol. 2]

Solder materials (2)

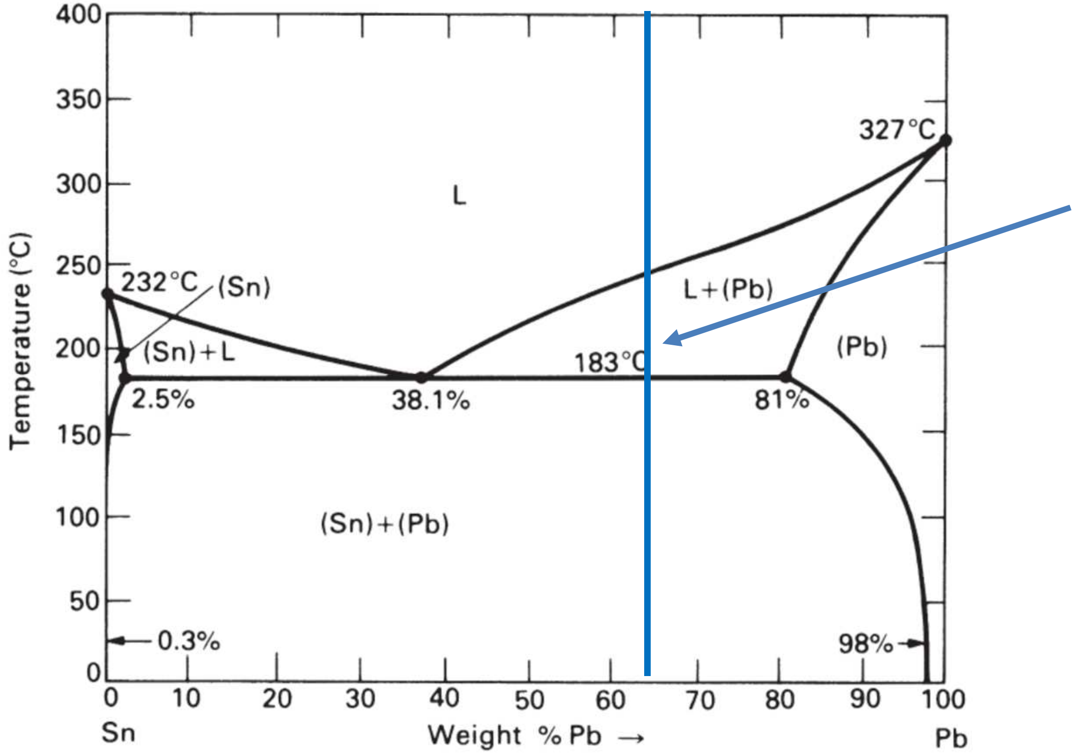
- Based on the Sn-Pb system
- For plumbing:
  Pipes used to be made of Pb
  Solders were built up in thick deposits around joints

⇒ "Pasty" solder

Roman baths, Bath (GB) [A. Mertens]

Solder materials (3)

- Based on the Sn-Pb system
- For plumbing:
  "pasty" solder = solid + liquid mixture



Sn with 65 wt% Pb
Melting range: 183 - 244°C
At 210°C: L + (Pb) slurry
No risk of melting the Pb pipes

[M.F. Ashby and D.R.H. Jones, Engineering Materials, vol. 2]

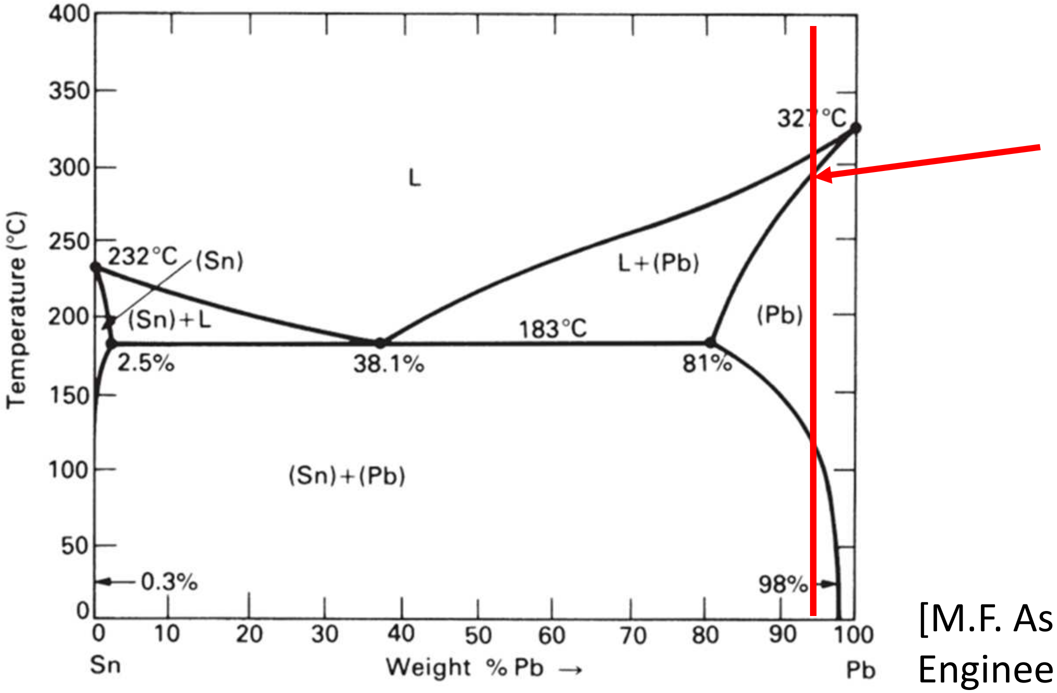
Solder materials (4)

- Boiler in model steam engines

  High service T

  ⇒ Ag-based soft solder ($T_{melting}$ ~600°C)

  ⇒ High Pb-content soft solder



~ $T_{melting}$ pure Pb i.e. 327°C

[M.F. Ashby and D.R.H. Jones, Engineering Materials, vol. 2]

Solder materials (5)

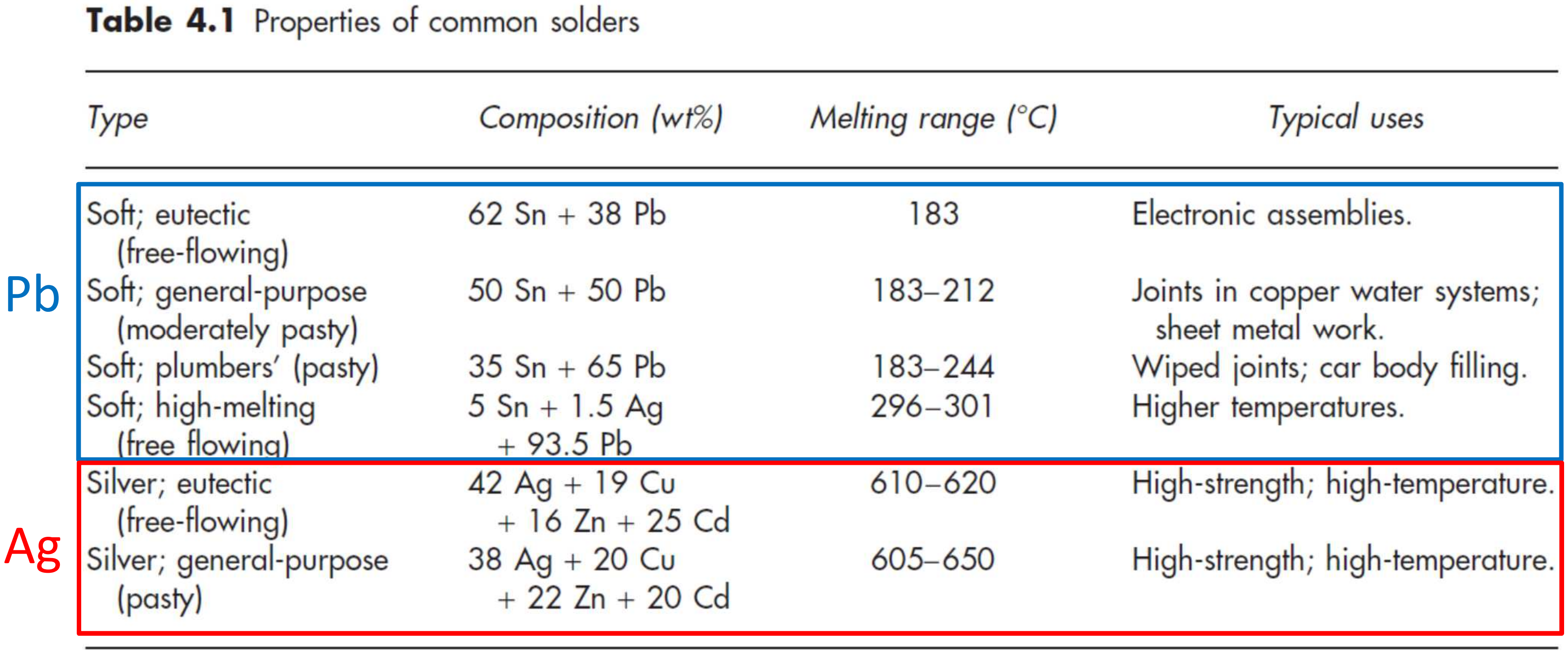


Table 4.1 Properties of common solders

Type	*Composition (wt%)*	*Melting range (°C)*	*Typical uses*
Soft; eutectic (free-flowing)	62 Sn + 38 Pb	183	Electronic assemblies.
Soft; general-purpose (moderately pasty)	50 Sn + 50 Pb	183–212	Joints in copper water systems; sheet metal work.
Soft; plumbers' (pasty)	35 Sn + 65 Pb	183–244	Wiped joints; car body filling.
Soft; high-melting (free flowing)	5 Sn + 1.5 Ag + 93.5 Pb	296–301	Higher temperatures.
Silver; eutectic (free-flowing)	42 Ag + 19 Cu + 16 Zn + 25 Cd	610–620	High-strength; high-temperature.
Silver; general-purpose (pasty)	38 Ag + 20 Cu + 22 Zn + 20 Cd	605–650	High-strength; high-temperature.

[M.F. Ashby and D.R.H. Jones, Engineering Materials, vol. 2]

Summary

- Materials selection $\Rightarrow$ ≠ criteria
  - Properties (physical, mechanical...)
  - Cost
- Some properties are **structure**-sensitive
  - Chemical composition
  - Processing method (deformation, heat treatments...)

$\Rightarrow$ **Understand/describe the structure of a material**

  - Equilibrium (phase diagram) - today
  - Out-of-equilibrium - next week