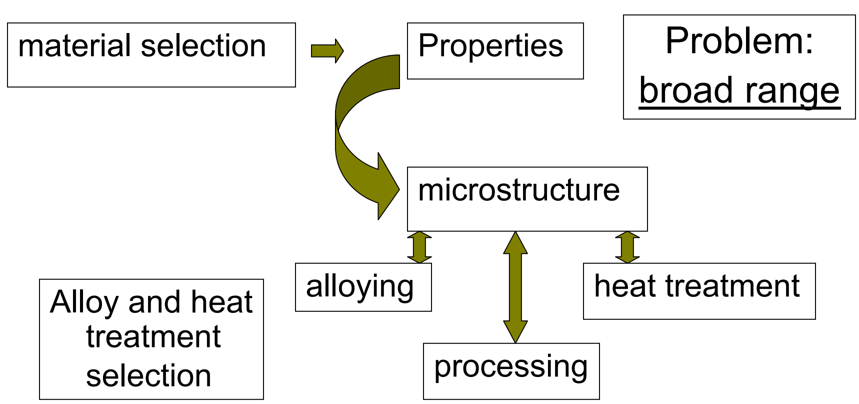
Lecture 1: Introduction

MMat 380

Structure and Properties of Metals

Why take this course?



Range of properties/cost

Metal	Yield Strength (MPa)	Density (Mg/m^3)	Cost (US$/tonne)
High-carbon steel	350-1600	7.8	200
Low-alloy steels	290-1600	7.8	230-330
High-alloy steels	170-1600	7.8	1400-1800
Cast irons	50-400	7.4	160
Aluminum 2000 series	200-500	2.8	1430
Titanium	170	4.5	6020
Copper	75	8.9	1330
Superalloys	800	7.9	6500

Table 1: from Ashby, M. F. ; Jones, D.R.H "Engineering Materials 2" Butterworth-Heinman, Table 1.6, p10

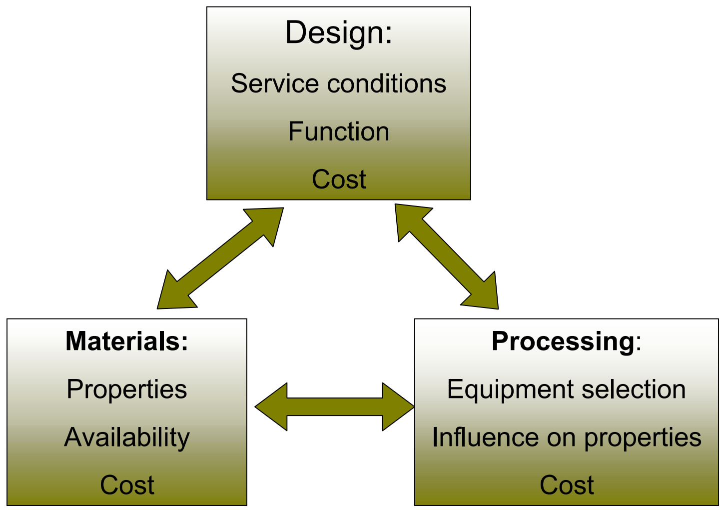
Introduction

- ~50 metallic elements – however only a few produced and used in large quantities in engineering practice
- Most important?
- Most important is iron used to make steels and cast irons
- For structural use order of importance of metals is:
  - Fe, Al, Cu, Ni and Ti

- Nickel-based alloys - heat resisting and corrosion applications ($$$ therefore applications are restricted)
- Ti - aerospace industry (high strength and low density)
- Cu and Al - conductivity and electricity
- Tin (Sn) and Zn - corrosion resistance (tin plated steel and galvanized steel)

Design criteria for materials

- Strength-stiffness
- Toughness (area under the σ–ε curve) and fracture toughness
- Formability
- Joinability
- Corrosion resistance
- Cost
- Operating temperature
- Coefficient of thermal expansion
- Recyclability



Why take this course?
1. Strength of Materials

Theoretically: $\sigma_y = E/10$

– based on bonding and force atomic distance relationship

Example: For Fe: σ_y = 200 GPa/10 = 20 000 MPa

(which is much too high)

Practically for pure metals: $\sigma_y = E/100\text{-}10000$

i.e. for Fe 20-2000 MPa

Yield strength of real metals is ~100-1000x smaller then theoretical predictions for very pure metals

Why take this course?
1. Strength of Materials

For normal/commercial purity metals: σ_y = E/2000

for Al: σ_y = 70 GPa/2000 = 35 MPa

Question – How do you go from E/2000 to E/100 i.e. 20x increase in strength?

Al: σ_y 35 – 650 MPa

Fe: σ_y 100 – 2000 MPa

Why take this course:
1. Strength of Materials

Question: What about effect of strength on other properties i.e.: Joinability, cost, corrosion resistance, fabricability ?

Best commercial alloys

Al (7xxx) σ_y = 650 Mpa (i.e. E/100)

Steel σ_y =2000 Mpa (i.e. E/100)

E – modulus, is a structure insensitive property

Can't make high strength material from low E material

Elastic modulus for various materials

Metal	E (GPa)	Metal	E (GPa)
Pb	14	Ni	207
Mg	45	Be	300
Al	70	Al_2O_3	400
Zn	105	B	400
Ti	120	BeO	400
Cu	130	SiN	400
Fe	205	SiC	500
Co	207	C	700

Fe as a base material

Advantages

- High melting point – 1540°C = $0.4T_M$
- Retains strength to high temperatures
  - T_H = 450°C
- Highest E of the common metals
  - E = 205 GPa
- Common – thousands of years supply
- Cheap: easy to make:
  - $Fe_2O_3 + 3CO = 2Fe + 2CO_2$
- Easy to recycle – Over 50% recycled
- Ductile – easy to hot or cold form by rolling, forging, extrusion (BCC or FCC)
- Can be cast (Fe and Steel)
- Easy to weld
- Heat treatable to a wide range of strengths and toughness values
- Easy to alloy
  - dissolve large amounts of Cr, Ni, Co, Cu
  - Stainless alloys; abrasion-resistance alloys

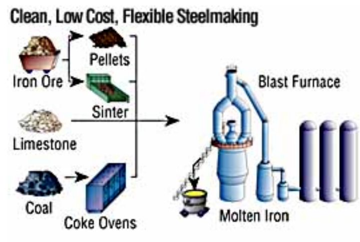
Disadvantages

- BCC phase has a ductile-to-brittle transition: brittle at low temperatures
- High specific gravity 7.8 gm/cm^3

Modern Steelmaking

Ore dressing

Blast furnace ironmaking



- Reduction of iron compounds (iron oxides) to molten iron (pig iron)

Blast furnace: coke (C) acts as reduction agent

$Fe_2O_3 + 3CO = 2Fe + 2CO_2$

Fe contains 3-4 %C

Modern Steelmaking

Ore dressing

Blast furnace ironmaking

Blast oxygen furnace steelmaking

Ladle furnace

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Continuous casting

- Process steelmaking:

  Excess C in steel is reduced by controlled oxidation

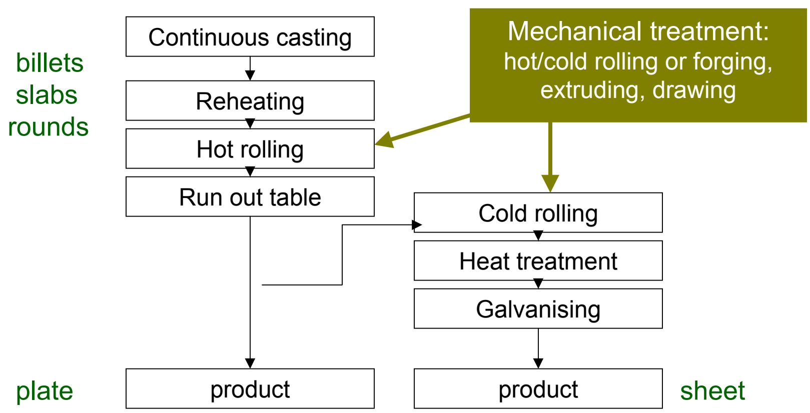
- Fine tune deoxidation

  Alloy addition

  Temperature control

- Flotation of nonmetallics from deoxidation

Modern Steelmaking



Good interactive explanatory site:
http://www.metsoc.org/virtualtour/processes/steel.asp

http://www.slater.com/atlasstainless/info.html