Iron and steel

Applications:

Cutting tools, pressure vessels, bolts, hammers, gears, cutlery, jet engine parts, car bodies, screws, concrete reinforcement, 'tin' cans, bridges…

Why?

• Ore is cheap and abundant

• Processing techniques are economical (extraction, refining, alloying, fabrication)

• High strength

• Very versatile metallurgy – a wide range of mechanical and physical properties can be achieved, and these can be tailored to the application

Disadvantages:

• Low corrosion resistance (use e.g. titanium, brass instead)

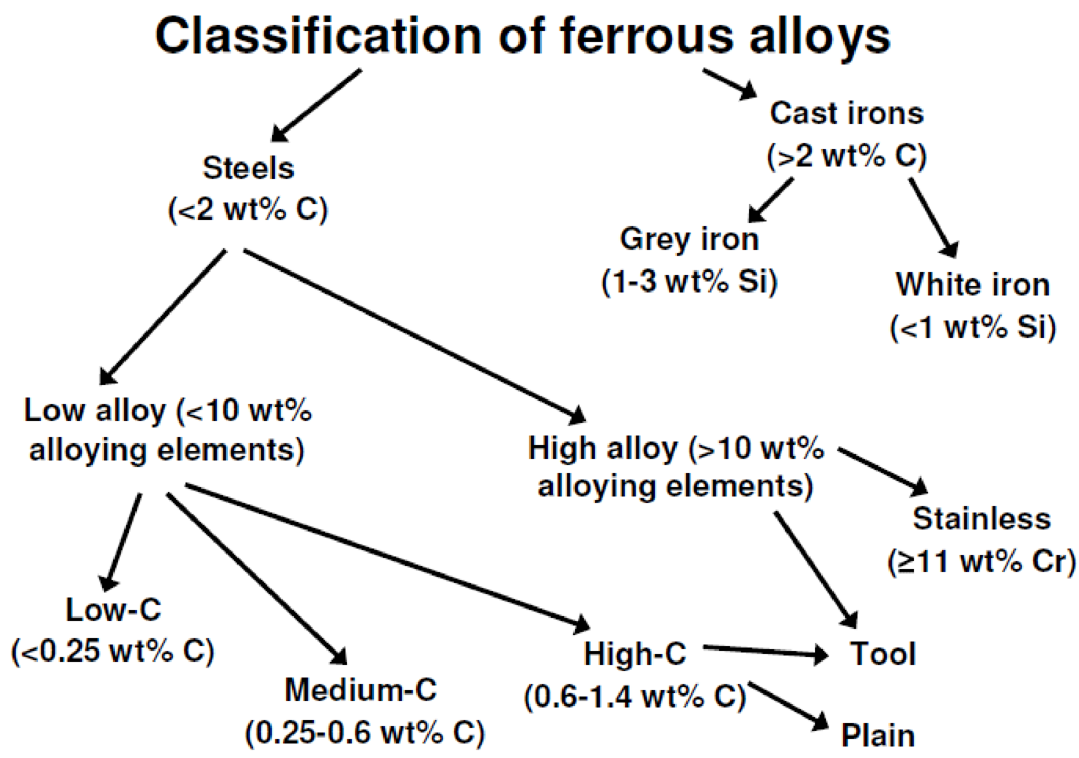
• High density: 7.9 g cm-3 (use e.g. aluminium, magnesium instead)

• High temperature strength could be better (use nickel instead)

Basic distinction between ferrous and nonferrous alloys:

• Ferrous metals are 'all-purpose' alloys

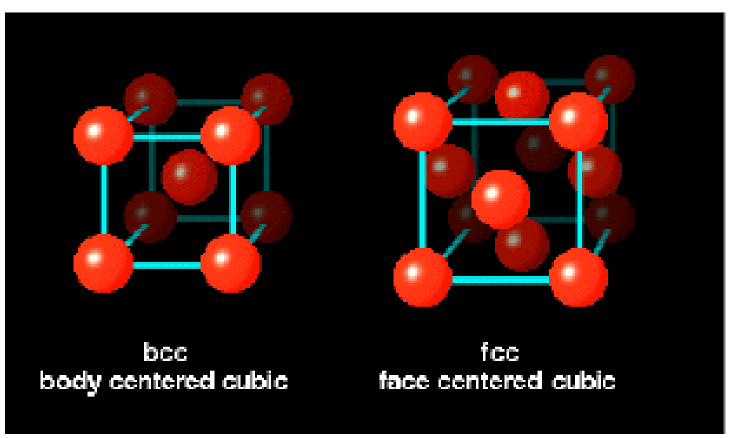
• Non-ferrous metals used for niche applications, where properties of ferrous metals are inadequate



Steel metallurgy

Iron is allotropic / polymorphic i.e. exhibits different crystal structures at different temperatures

Most importantly: bcc ↔ fcc transformation at 912°C (for pure iron)

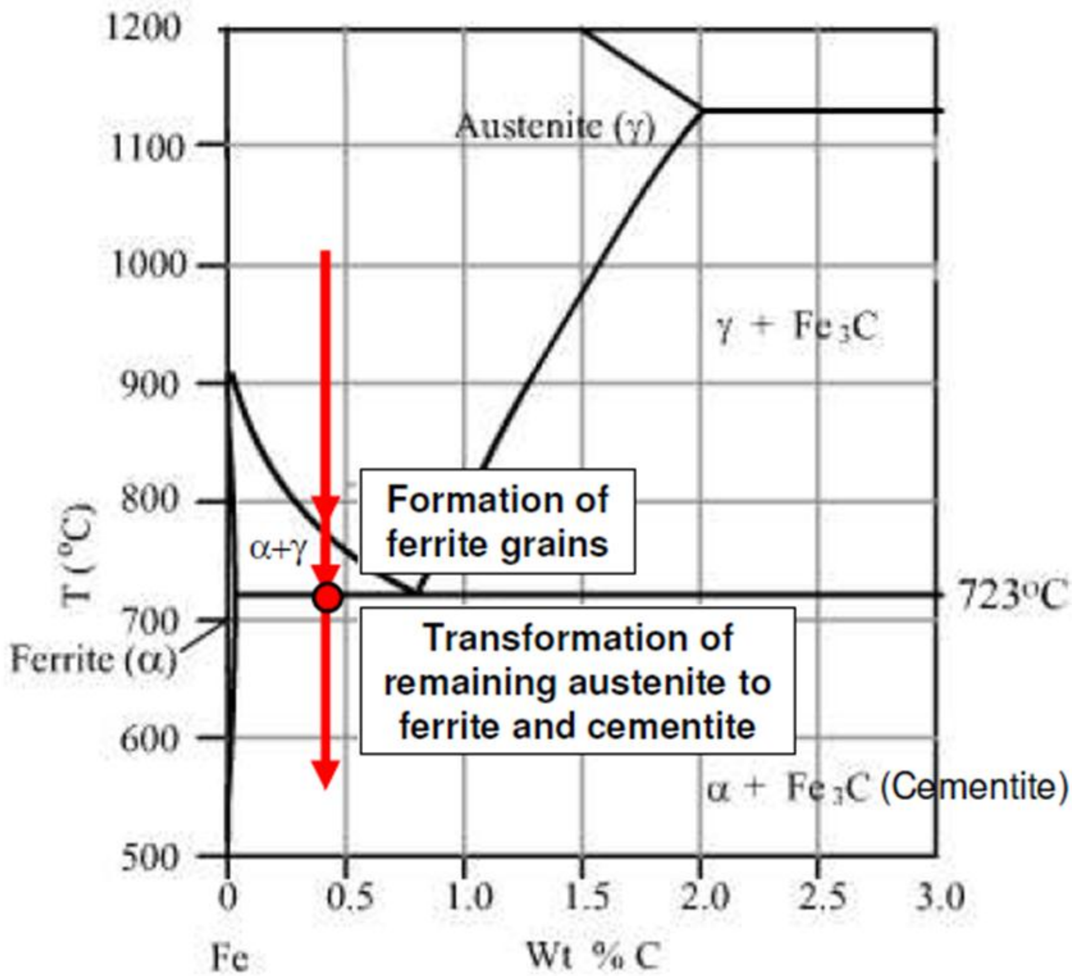


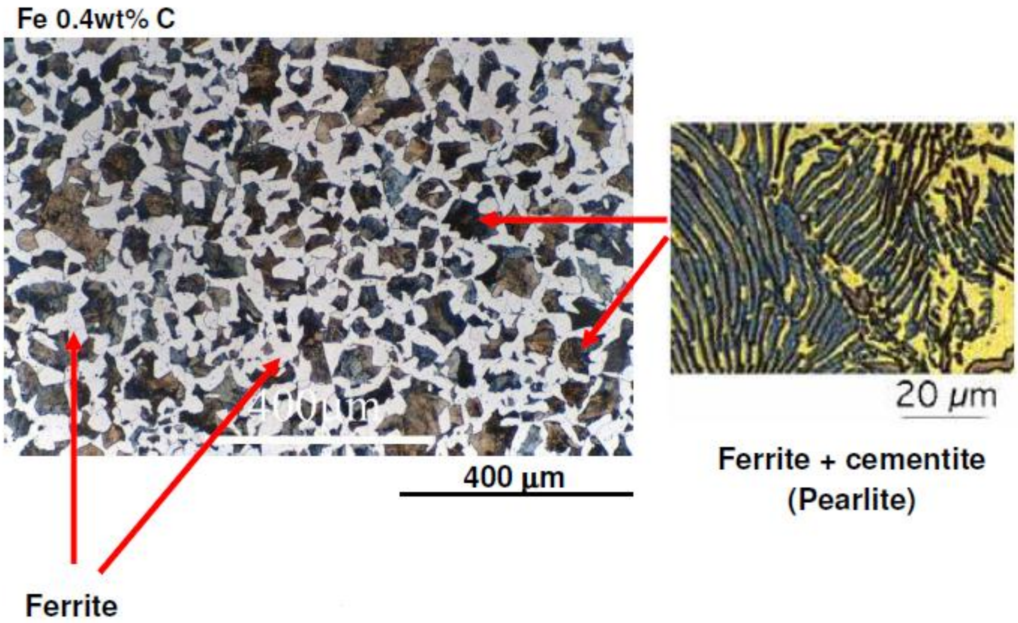
Solubility of carbon in ferrite (α-iron, bcc): 0.02 wt%

austenite (γ-iron, fcc): 2.1 wt%

What happens to carbon when crystal structure transforms from fcc to bcc?

Fundamental issue in metallurgy of low alloy steels

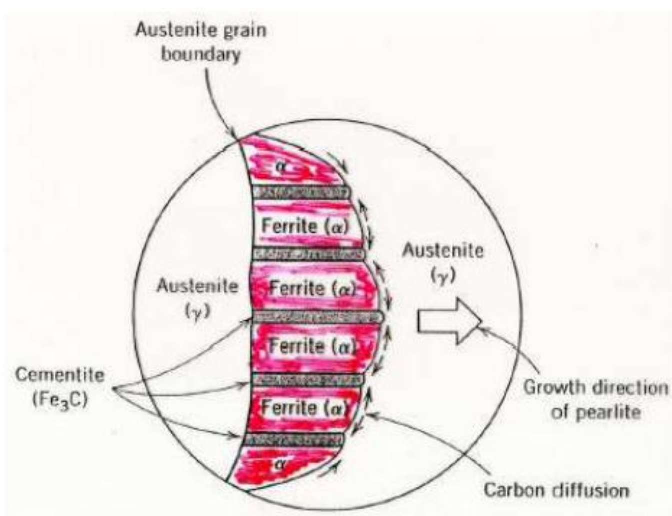


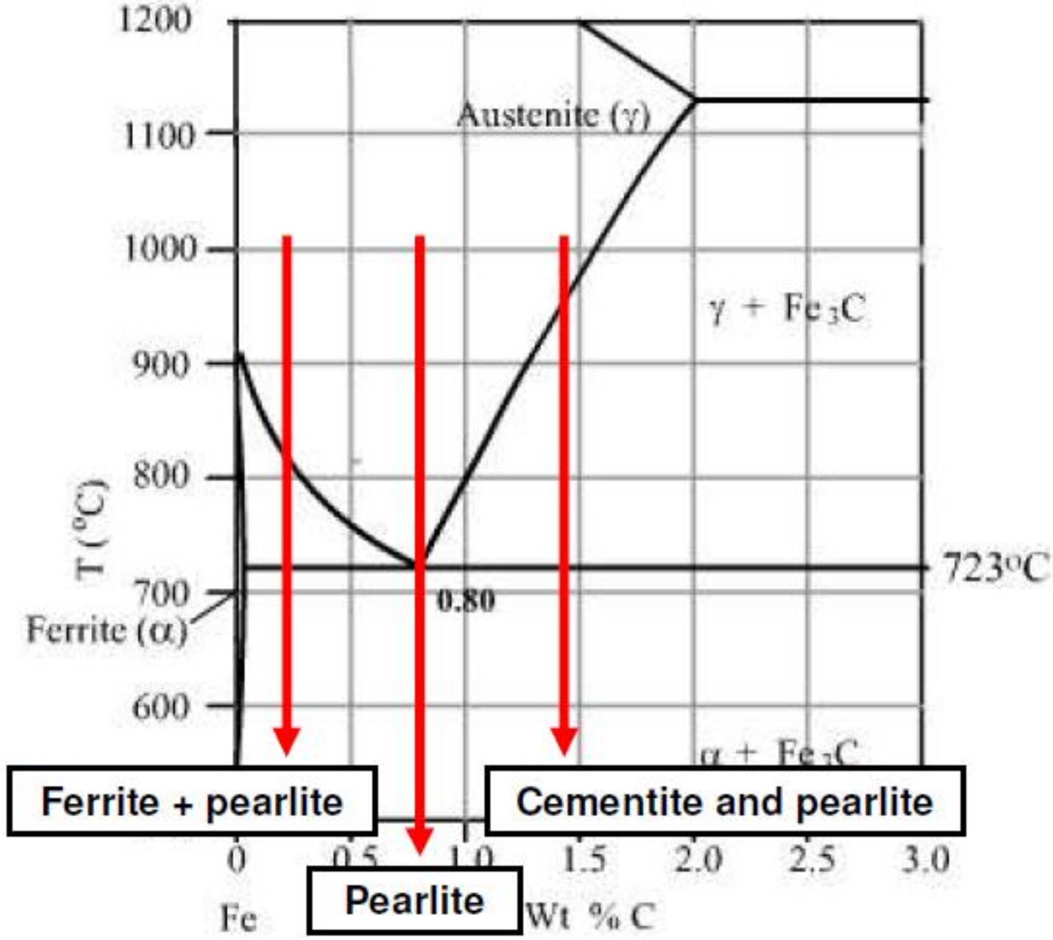


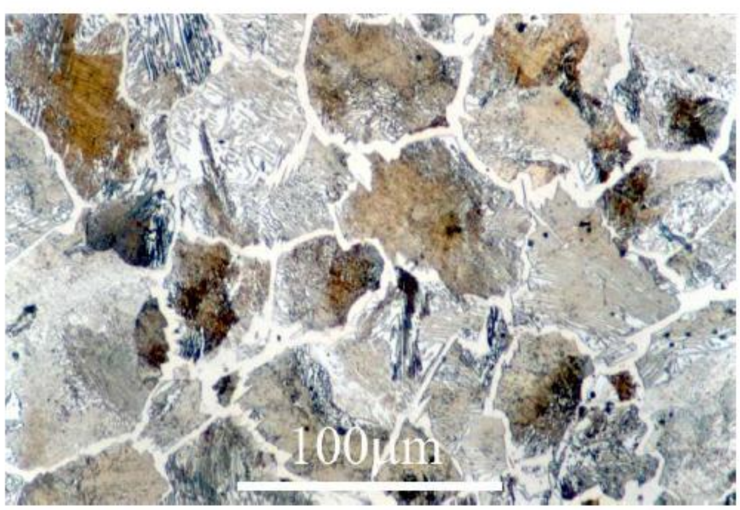
Pearlite

NB Pearlite is a MIXTURE of phases (on a very fine scale)

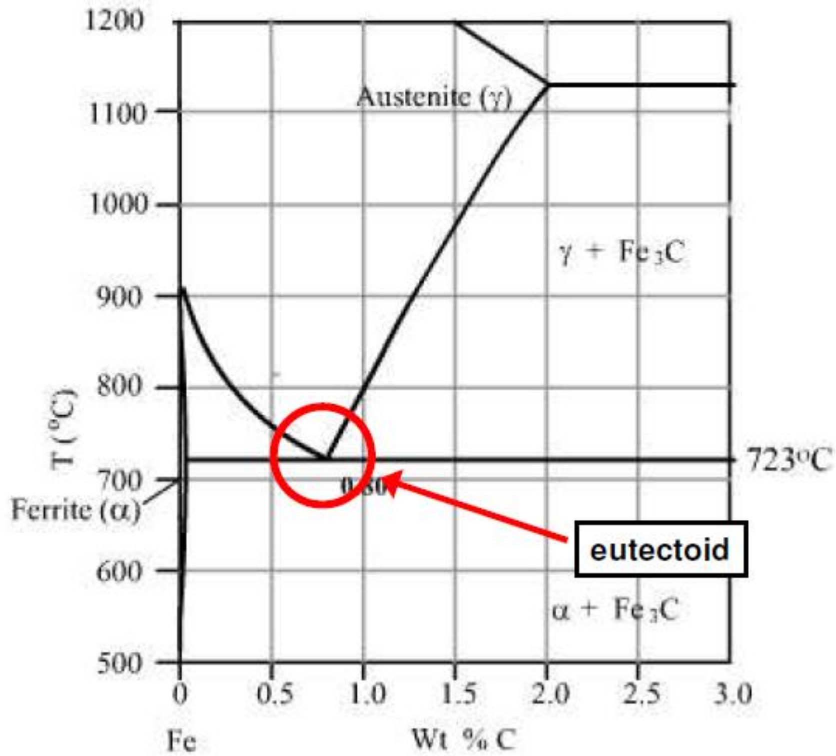
Alternating layers of ferrite and cementite formed simultaneously from the remaining austenite when temperature reaches 723°C

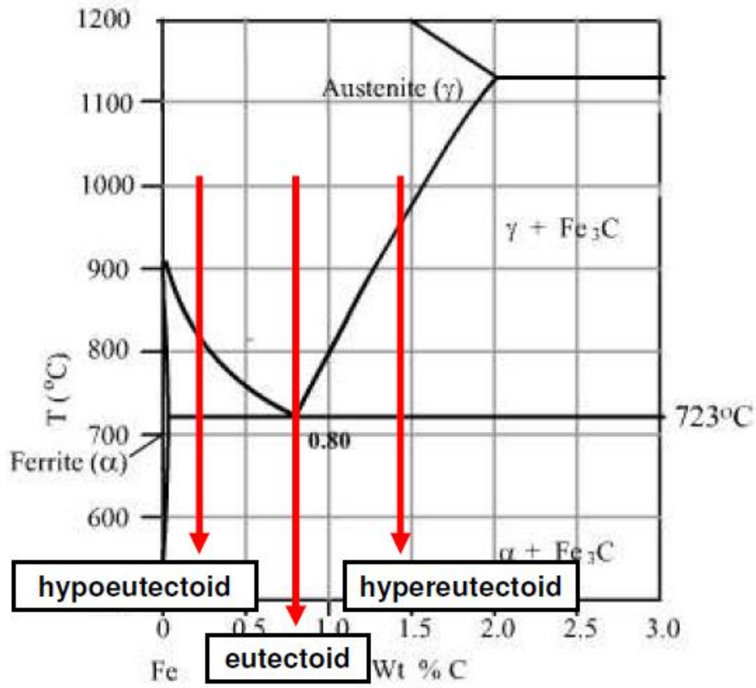






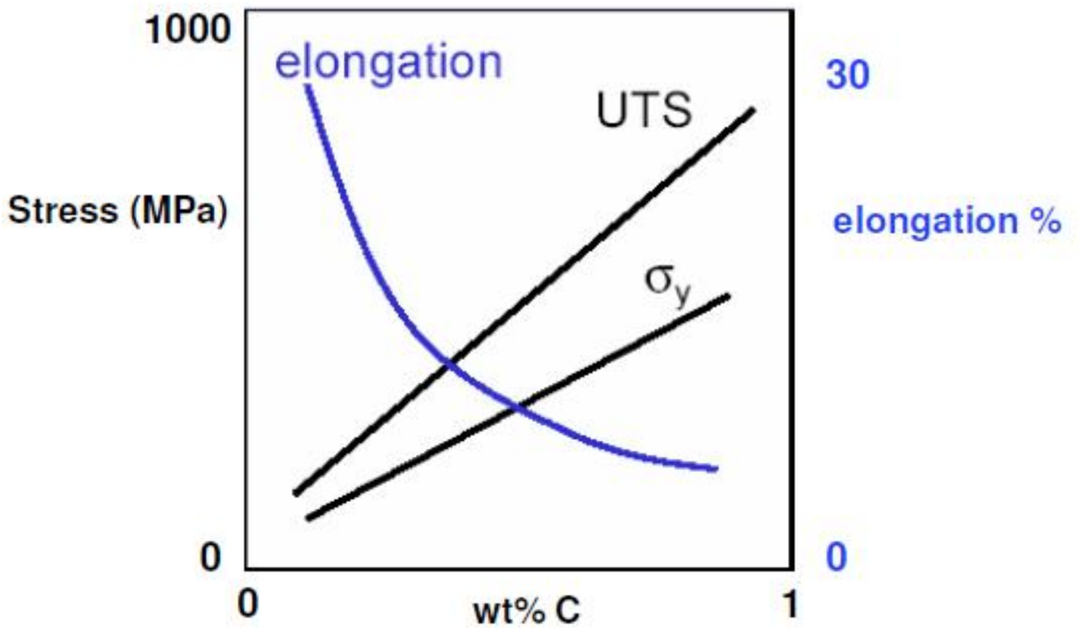
Fe 1.3 wt% C: Cementite precipitates at austenite grain boundaries, remaining austenite is transformed into pearlite


1200
1100
1000
900
800
700
600
500
T (°C)
Ferrite (α)
Austenite (γ)
γ + Fe3C
α + Fe3C
723°C
0.80
eutectoid
0
0.5
1.0
1.5
2.0
2.5
3.0
Fe
Wt % C


1200
1100
1000
900
800
700
600
T (°C)
Ferrite (α)
Austenite (γ)
γ + Fe3C
α + Fe3C
723°C
0.80
hypoeutectoid
hypereutectoid
eutectoid
0
0.5
1.0
1.5
2.0
2.5
3.0
Fe
Wt % C

Mechanical properties

Ferrite: soft and ductile Cementite: hard and brittle



What happens during rapid cooling?

• Phase diagrams only show stable phases that are formed during slow cooling

• If cooling is rapid, the phase diagram becomes invalid and metastable phases may form

• In the case of steel, the formation of ferrite and cementite requires the diffusion of carbon out of the ferrite phase. What happens if cooling is too rapid to allow this? The crystal lattice tries to switch from fcc (austenite) to bcc (ferrite). Excess carbon → distorted body centred lattice → MARTENSITE

Martensite (α')

• Distorted bcc lattice

• Non-equilibrium carbon content

• Forms plate-like or needle-shaped grains

Fe, C 2, Mn 0.7 (wt%)

Martensite

• Hard and brittle

• Applications: crankshafts, spanners, high-tension bolts

• In general too brittle to be useful, BUT if tempered can be used to produce optimum steel microstructure