Imperial College London

# Materials and Manufacturing

Metals and engineering alloys II

https://www.youtube.com/watch?v=IrdYueB9pY4

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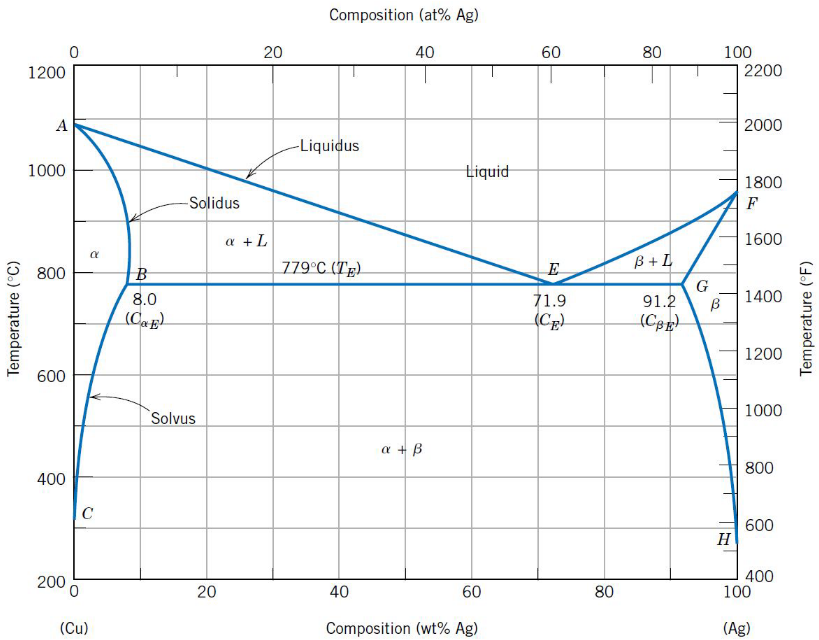
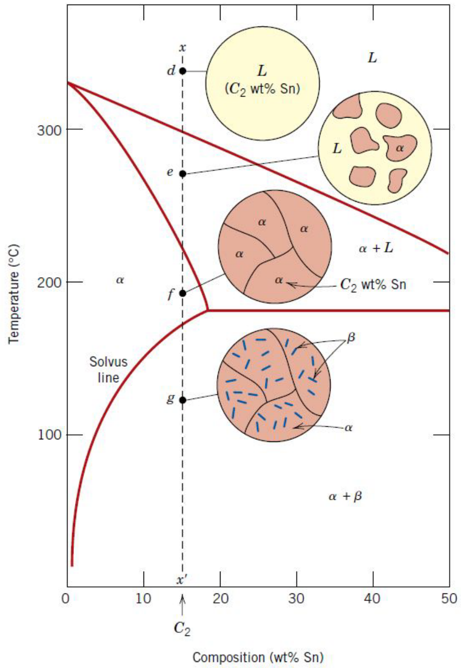
# Last time on M&M…

- Describe why alloys are used and be able to define the terms used for their description
- Evaluate an equilibrium phase diagram and be able to label the various lines and regions present
- Apply the lever rule to determine key characteristics of a phase diagram
- Analyse and describe the microstructural changes which occur when cooling an alloy of given composition from the liquid phase



# Learning objectives

- Evaluate and apply the iron-carbon equilibrium phase diagram
- Describe the concepts around eutectoid, hypo-eutectoid and hyper-eutectoid steel
- Explain how the strength and ductility/toughness vary with carbon content and demonstrate an awareness of how this knowledge is applied

# Why is this important?

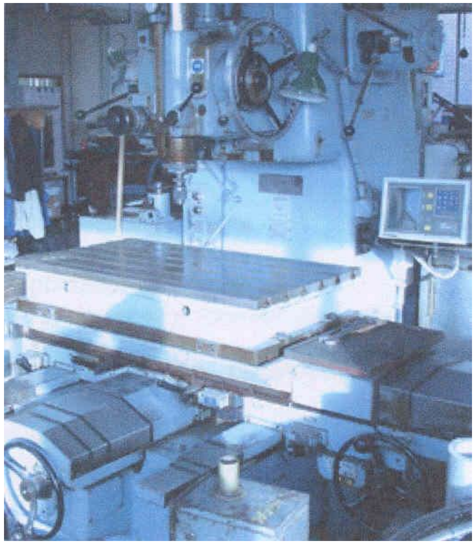
Steels have been (and probably will remain) one of the most important engineering materials used

Therefore, an appreciation of the different forms of steel that can be created, their mechanical properties and the origins of these properties is useful for any engineer.

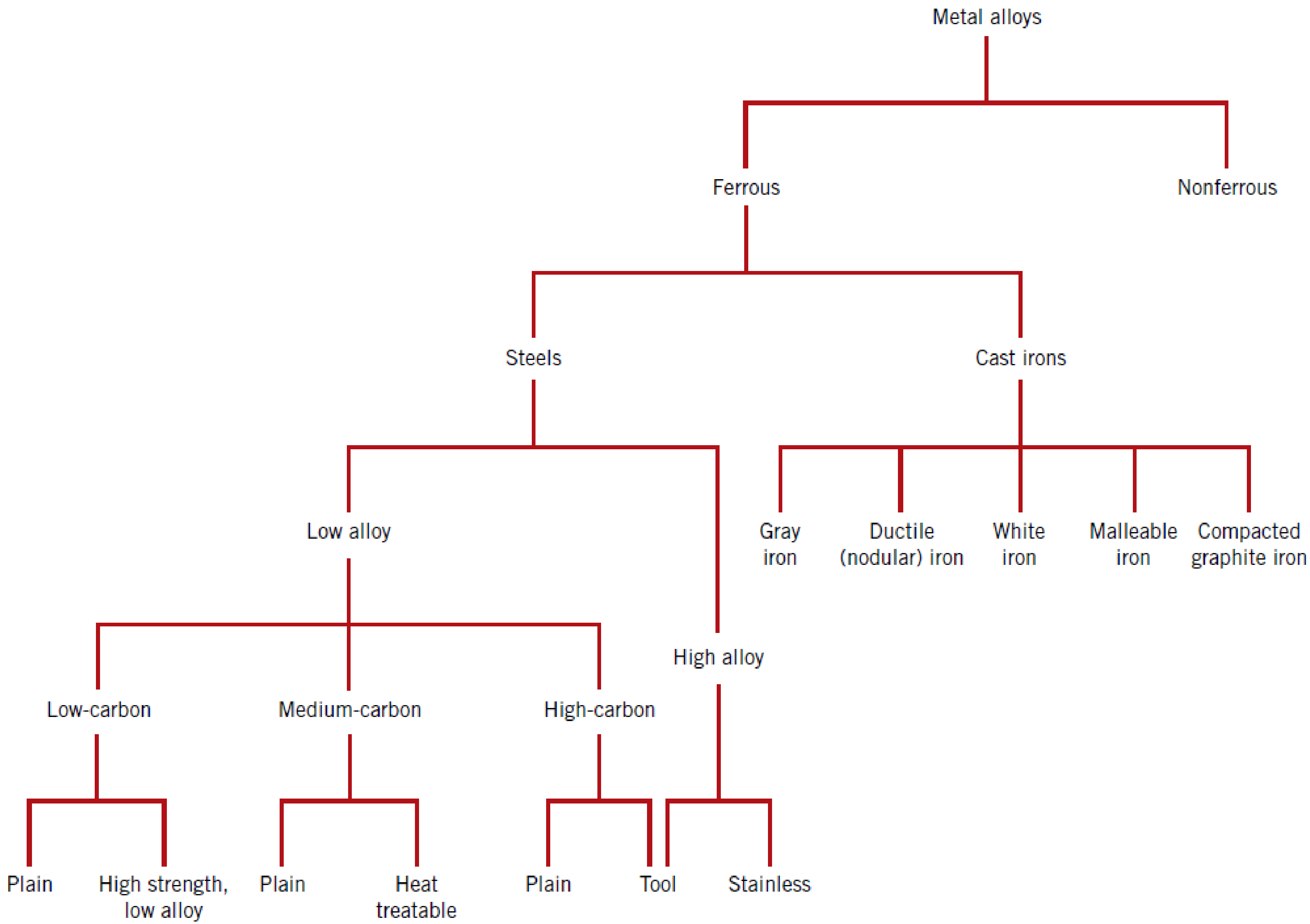
**Low carbon steels**

**High carbon steels**

**Grey cast iron**



# Ferrous alloys



# Steels

**Steel**: 0.04-1.7% carbon

**Cast iron**: >1.7 carbon

**Low alloy steel** (carbon steel): Carbon being the main alloying element

**Alloy steel**: When other alloying elements are present (e.g. Stainless 18% Cr and 8% Ni)

**Low carbon steel**
(mild steel)
0.04-0.3 wt%

- Cheap
- Machinable
- Weldable
- 'Low strength'

Applications

- Car body panels
- Reinforcements in concretes

**Medium carbon steel**
0.3-0.7 wt%

- Harder than low carbon steels
- Weldable
- More expensive

Applications

- Gears
- Cutting tools

**High carbon steel**
0.7-1.7 wt%

- Very hard
- Difficult to weld

Applications

- Railway tracks

**Cast iron**
1.7-4.0 wt%

- Extremely hard
- Extremely brittle

Applications

- Pots
- Workshop machinery

# Pure forms of iron

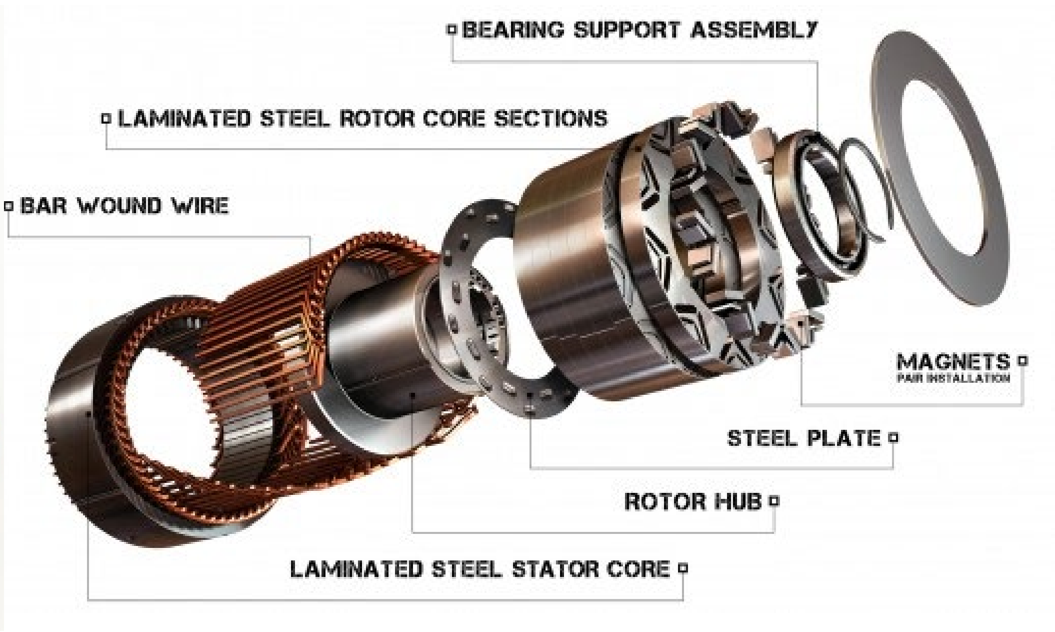
For practical purposes lets define pure iron as containing < 0.03 wt% C

Depending on temperature iron can exist in **3 different forms**

**Ferrite** (α-Fe) – BCC crystal structure, exists at < 910°C – Magnetic

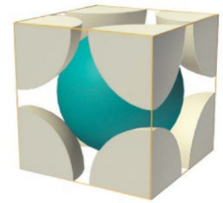
**Austenite** (γ-Fe) – FCC crystal structure, 910°C<T<1391 °C – Non-magnetic

δ-Fe – BCC crystal structure, 1391°C<T<1536°C – Not that relevant

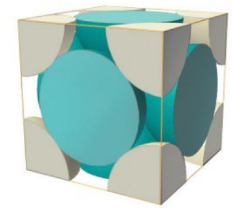


# Iron-carbon alloys

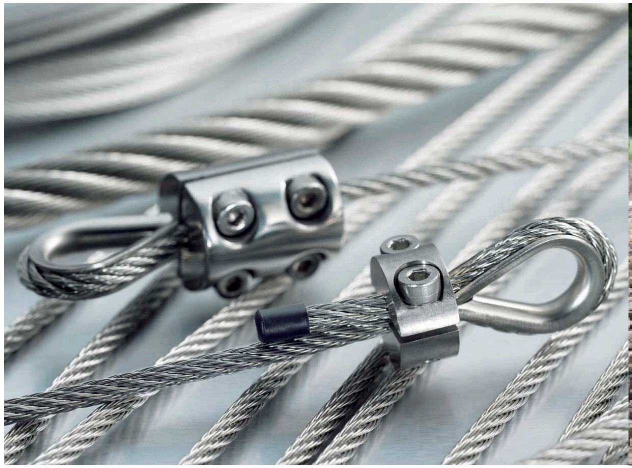
- α and γ are used to describe interstitial solid solutions of C in Fe but are now not pure forms of iron
- Names are retained due to crystal structure
- **Ferrite** – BCC
- **Austenite** – FCC
- In addition to ferrite and austenite a 3rd phase might form known as **Cementite** ($Fe_3C$) which has a fixed carbon content of 6.7% C wt%.
- Cementite is very hard and brittle
- Mechanical properties of steels largely depend on the amount of cementite



Body centred cubic

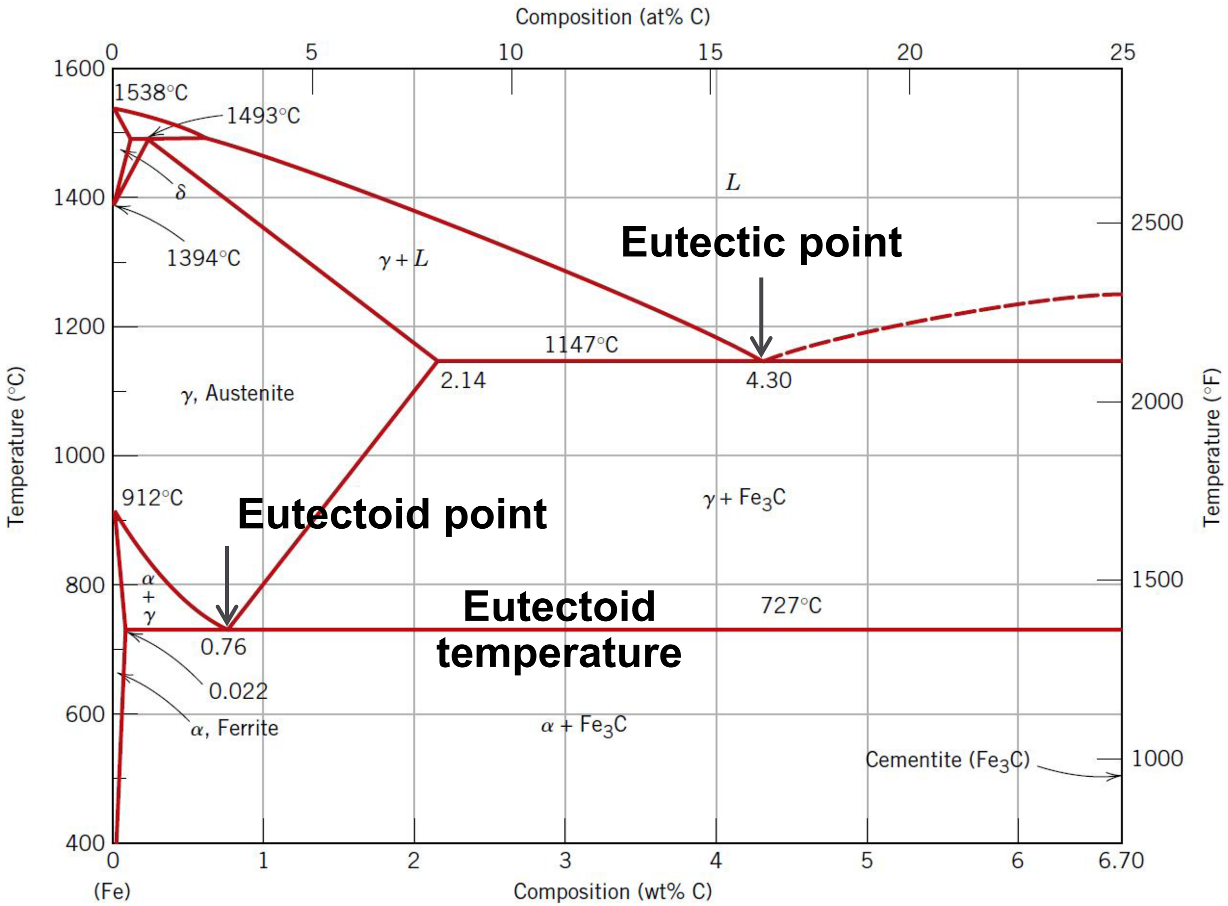


Face centred cubic



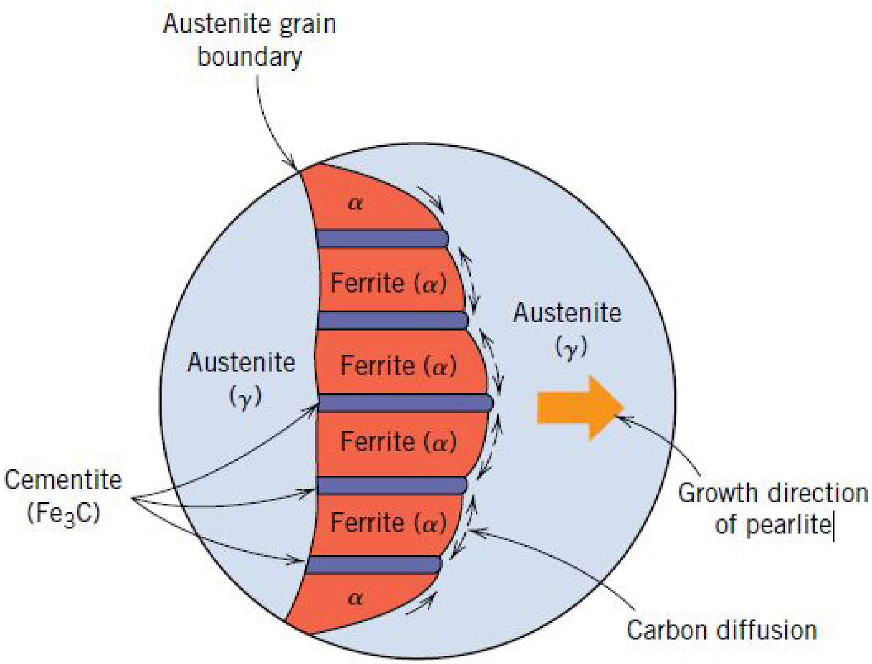
# Iron-carbon phase diagram

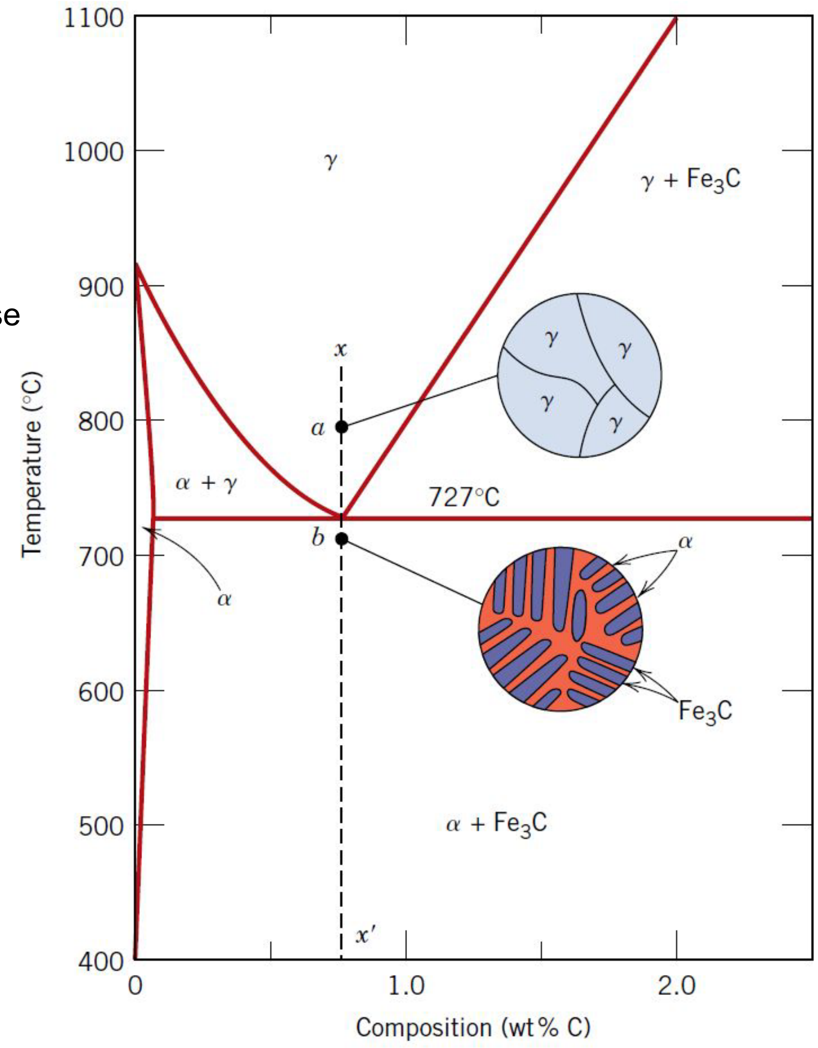
- **Eutectic point** – Corresponds to the composition and temperature of lowest melting point – 4.3 wt% C – Very brittle!
- Most of the useful stuff is 0.04 wt%<C<1.7 wt%
- **Eutectoid point** – The point in a phase diagram indicating a solid is in equilibrium with two other solid phases



# The eutectoid composition

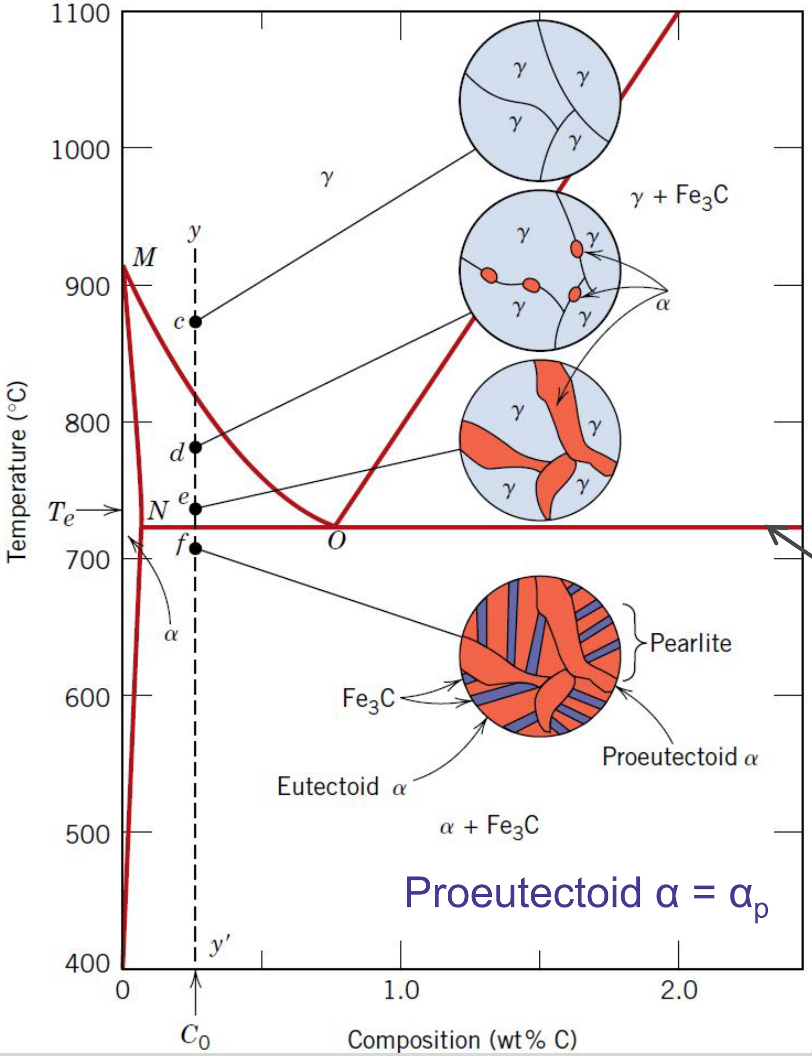
- **Cementite** ($Fe_3C$) – Hard and brittle
- **Ferrite** (α) – Soft and ductile
- **Pearlite** – Eutectoid structure
  - Alternating layers of cementite and ferrite (lamellar)
  - Pearlite forms by the simultaneous precipitation of α + $Fe_3C$
  - Not a single phase but rather an arrangement of 2 phase



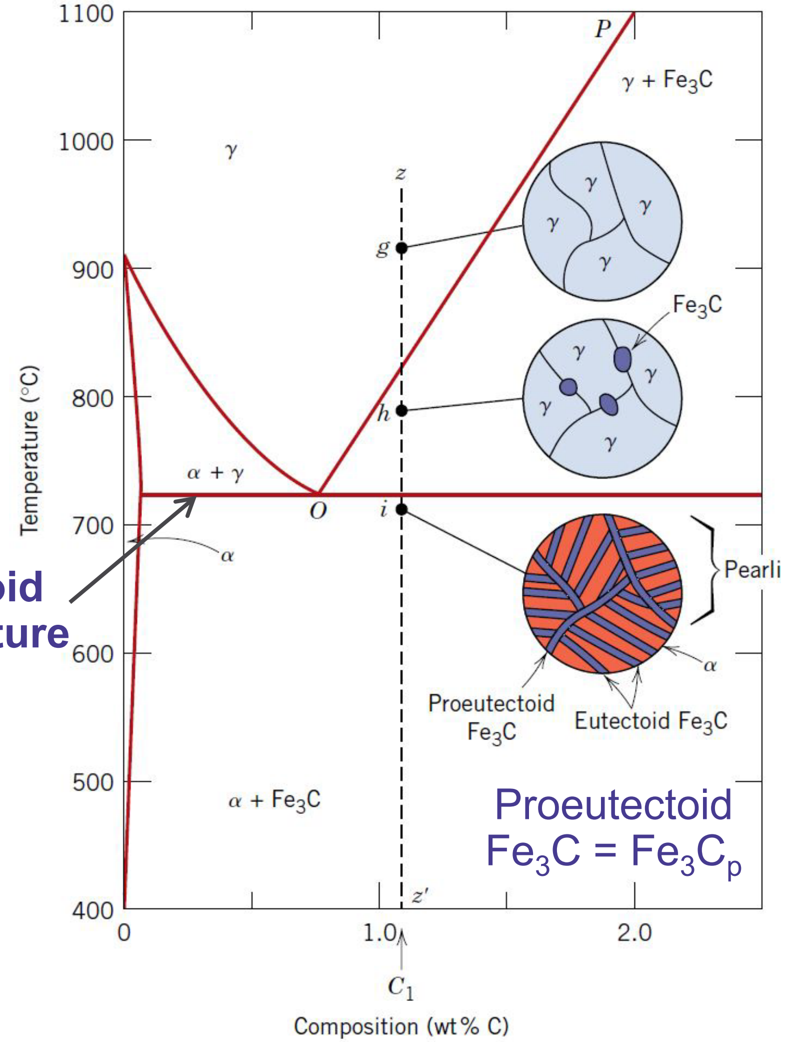
# Hypo/hyper-eutectoid composition

## Hypo-eutectoid



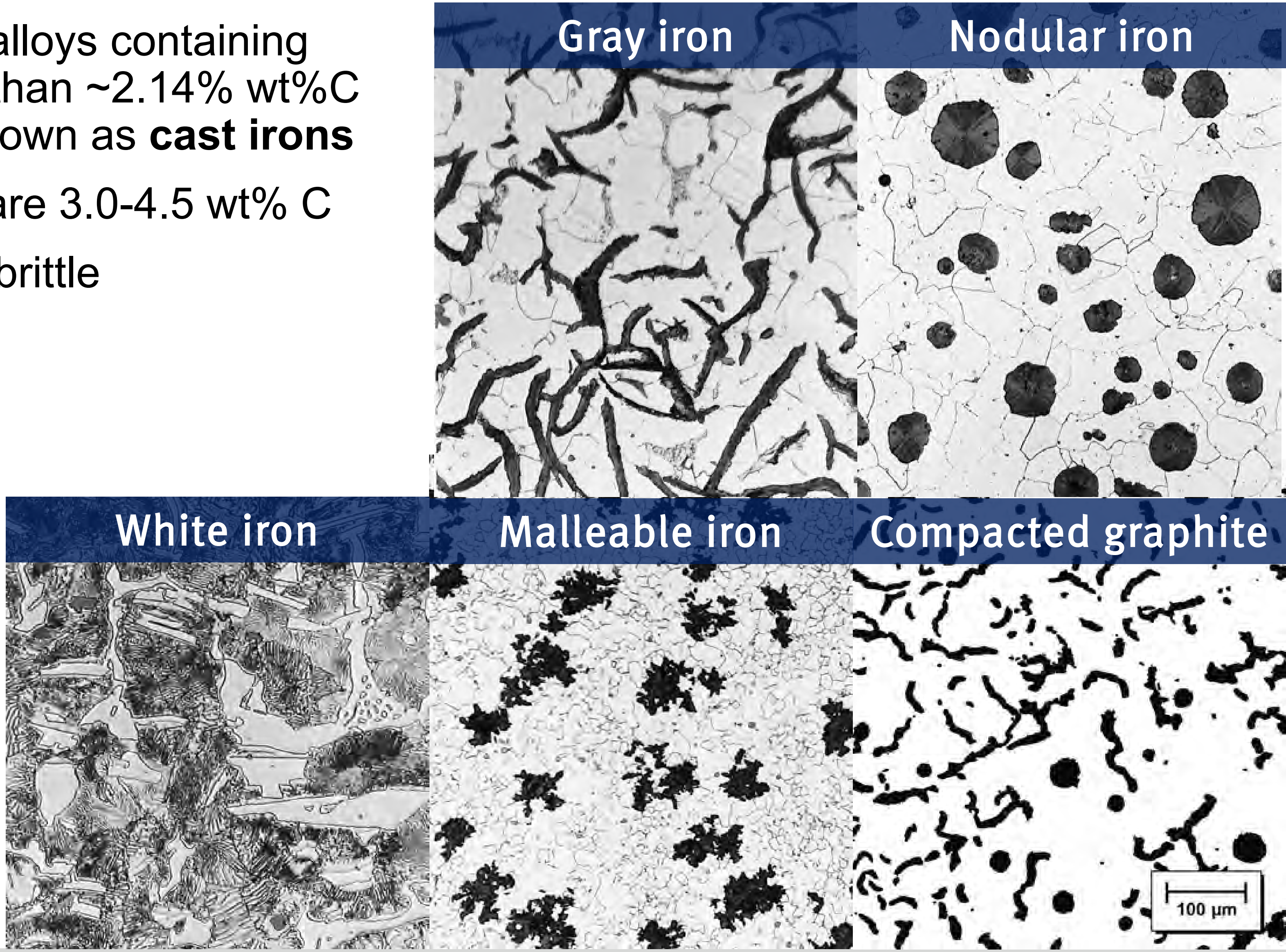

Eutectoid temperature

## Hyper-eutectoid



# Cast irons

- Fe-C alloys containing more than ~2.14% wt%C are known as **cast irons**
- Most are 3.0-4.5 wt% C
- Quite brittle



# Non-ferrous alloys

Problems with steel

- Relatively high density, low electrical conductivity, low corrosion resistance

| Copper | Aluminium | Magnesium | Superalloys |
|---|---|---|---|
| • High corrosion resistance<br>Brasses (Zn)<br>• Musical instruments<br>Bronzes (Sn, Al, Si, Ni)<br>• Good tensile properties | • Low density<br>• High thermal conductivity<br>• High electrical conductivity<br>• Corrosion resistant<br>• High ductility<br>• Car frames, planes | • Extremely low density<br>• Susceptible to corrosion<br>• Car frames, planes | • Extremely good mechanical properties<br>• Extremely good corrosion resistance<br>• Turbines |

# Summary

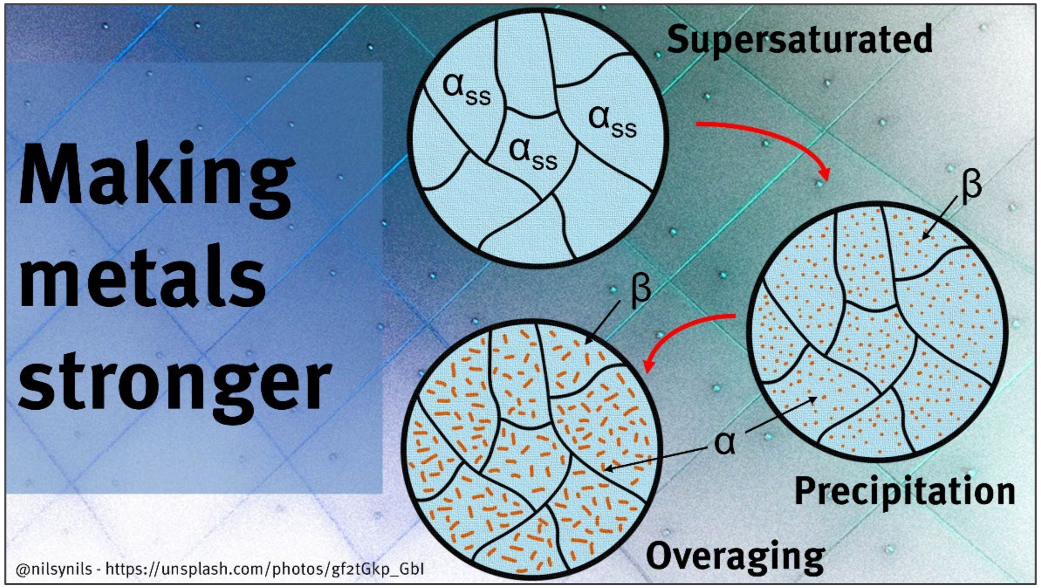
- Evaluate and apply the iron-carbon equilibrium phase diagram
- Describe the concepts around eutectoid, hypo-eutectoid and hyper-eutectoid steel
- Explain how the strength and ductility/toughness vary with carbon content and demonstrate an awareness of how this knowledge is applied

# Keep flipping

Please watch this video on

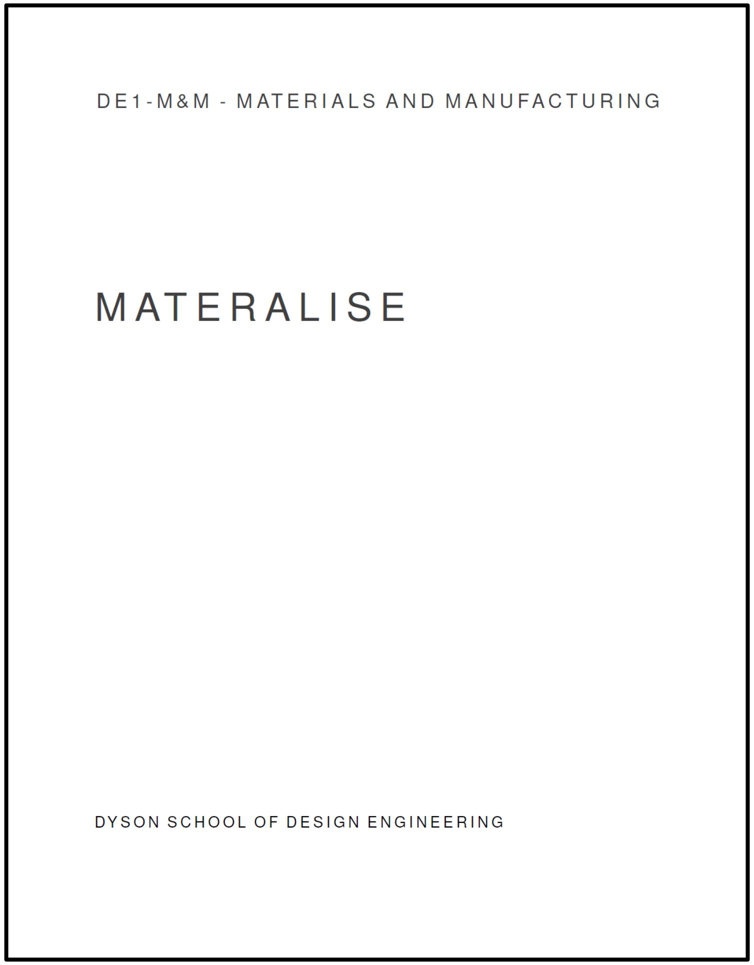
“How to make metal stronger by heat treating, alloying and strain hardening”

https://youtu.be/7IM-Y4XndsE



# DRAW week

- Materialise
- Please access CES EduPack from Imperial softwarehub (It’s free for you)
    - Works on a Window’s operating system
    - If you have a Mac install Bootcamp or have a virtual machine


DE1-M&M - MATERIALS AND MANUFACTURING

MATERALISE

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# Next time on M&M…

## Altering material properties