Lecture 2:
Introduction - Steel

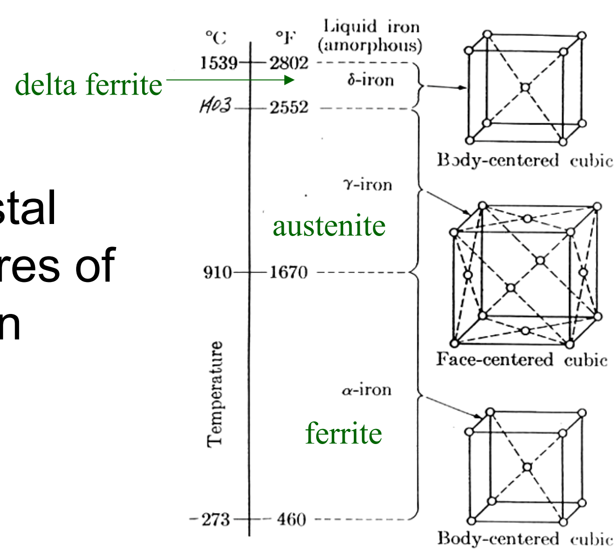
MMat 380

Lecture outline

- Crystal structures of Iron
- Fe-Fe_3C phase diagram
  - Four solid phases
  - Three invariant reactions in Fe-Fe_3C phase diagram
  - Critical temperatures

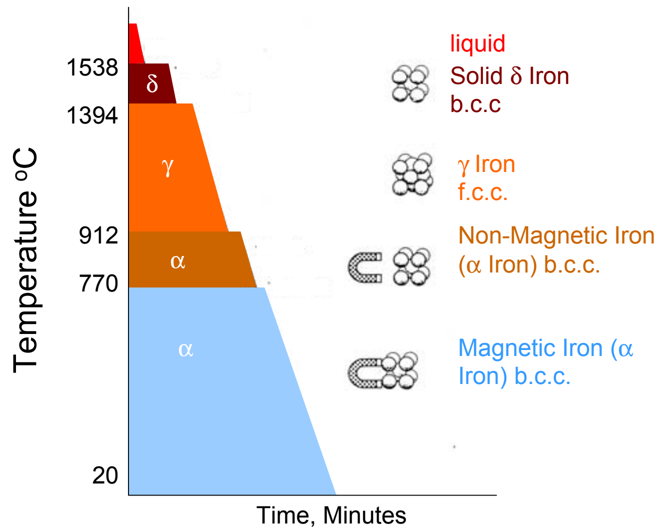
3. Slow cooling of plain carbon steels
    - Eutectoid alloy (Fe-0.77%C)
    - Hypoeutectoid alloy (Fe-< 0.77%C)
    - Hypereutectoid alloy (Fe-> 0.77%C)

Crystal structures of iron



The temperature ranges in which the allotropic forms of iron exist under :quilibrium conditions.

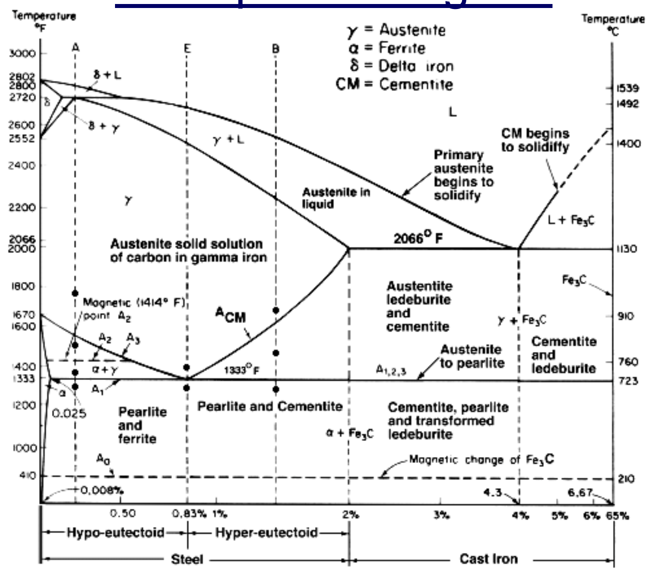
Crystal structures of iron



Introduction to
Fe-C phase diagram

- Regions:
  - Steels 0 <wt%C <2
  - Cast iron 2 <wt%C <4 1 <wt%Si <3
- Phases:
  - Ferrite
  - Austenite
  - Cementite

Fe-C phase diagram



Four solid phases

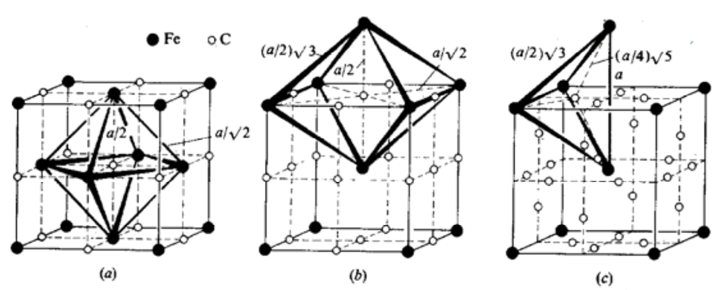
- **α-ferrite**
  - solid solution of carbon in a iron,
  - BCC structure
  - carbon only slightly soluble in the matrix
    - maximum solubility of 0.02%C at 723°C to about 0.008%C at room temperature.
- **Austenite (γ)**
  - solid solution of carbon in γ–iron
  - FCC structure: can accommodate more carbon than ferrite
    - maximum of 2.08%C at 1148°C, decreases to 0.8%C at 723°C
    - difference in C solid solubility between γ and α is the basis for **hardening** of most steels.

δ-ferrite

- solid solution of carbon in δ–iron
- BCC crystal structure
  - maximum solubility of ferrite being 0.09%C at 1495°C

- **Cementite (Fe_3C)**
  - intermetallic Fe-C compound
    - Fe_3C : 6.67%C and 93.3%Fe.
  - orthorhombic crystal structure: hard and brittle

Solubility of carbon:



- γ fcc- iron: higher C solubility (a)
- α bcc-iron: lower C solubility (b, c)

Three invariant reactions in Fe-Fe_3C phase diagram

- Peritectic reaction:

$$S + L \rightarrow S_1$$

- Eutectic reaction:

$$L \rightarrow S_1 + S_2$$

- Eutectoid reaction:

$$S \rightarrow S_1 + S_2$$

Critical temperatures

A = Thermal arrest

- A_1 line: eutectoid transformation
- A_3 line: γ transformation to α
- A_{cm} line: γ transformation to Fe_3C
- Cooling vs heating (A_r and A_c)

Plain carbon steels

Fe-C steel alloys containing:

– from a trace to ~1.2%C

– minor amounts of other elements

(Mn, Si, S, P, O, N)

Slow cooling of plain carbon steels

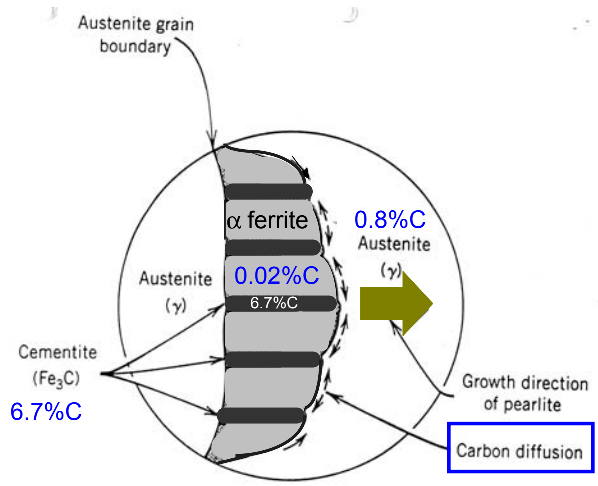
Eutectoid alloy (Fe-0.77%C)

Austenite → Pearlite @727°C

- Microstructure: pearlite
  - lamellar eutectoid product alternates plates of α and Fe_3C
  - two phases grow simultaneously.

- Composition: lever rule

Pearlite formation



Slow cooling of plain carbon steels

Hypoeutectoid alloy (Fe-<0.77%C)

$\gamma \Rightarrow$ Proeutectoid α + γ^{I} $\Rightarrow$ Proeutectoid α + pearlite

- Microstructure: **Pearlite with ferrite along g.b's**
- Composition: lever rule
  - Ferrite grows by rejecting C to adjacent austenite
  - C diffuses down gradient in γ to obtain a homogeneous composition

Slow cooling of plain carbon steels

Hypereutectoid alloy (Fe>0.77%C)

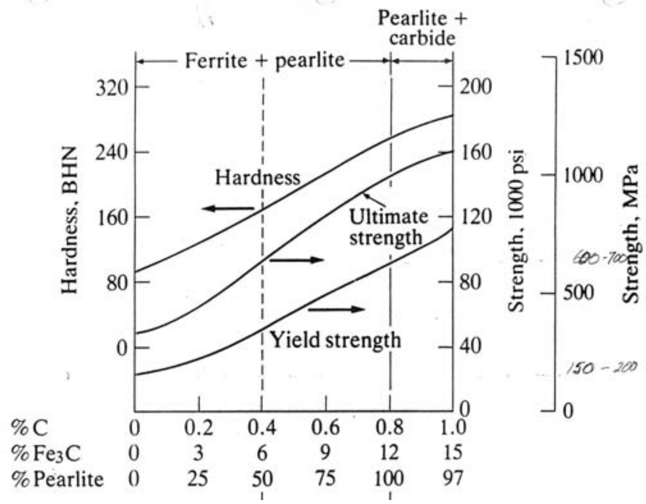
$\gamma \Rightarrow$ Proeutectoid $Fe_3C + \gamma^{l} \Rightarrow$ Proeutectoid Fe_3C + pearlite

- Microstructure: **Pearlite with cementite along the g.b's**
- Composition: lever rule

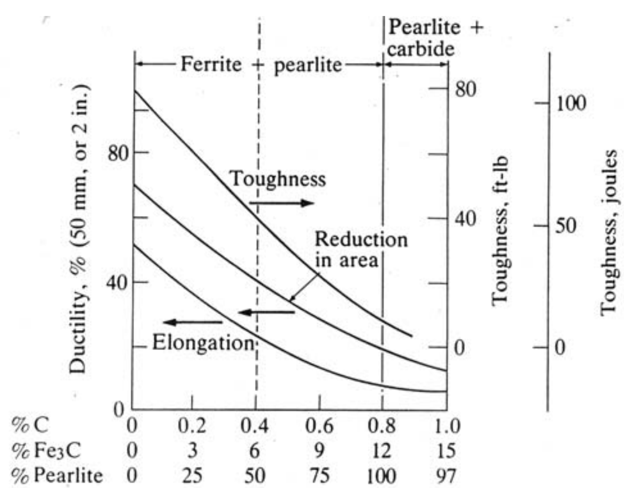
Summary

%C	Microstructure	Phase	Properties
0.8		100% P	Y.S. = 600 MPa
0		100% α	Y.S. = 200 MPa
0.4		50% P 50% α	Mixture of 2 phases: α = soft ductile ferrite with <0.03C P = $\alpha + Fe_3C$ where Fe_3C hard & brittle
0.2		25% P 75% α	

Hardness & microstructure



Toughness & microstructure



Applications

100% α

- sheet steel
- car panels
- roofing
- cans

100% P

- rails
- (cold worked to give high strength)
- cable
- prestressed tendons for concrete