Fe-C Phase Diagram

Pure Iron

- Upon heating pure Iron experiences two changes in crystal structure.
- At room temperature it exists as ferrite, or α iron.

- When we heat it to 912°C it experiences a polymorphic transformation to austenite, or γ iron

- At 1394°C austenite reverts back to a BCC phase called δ ferrite.
Fe-Fe$_3$C Phase Diagram

- Only part of the phase diagram is shown.
- The left axis is pure iron.
- On the right the phase diagram only extends to 6.70 wt% C.
- At this concentration the intermediate compound iron carbide, or cementite (Fe$_3$C) is formed.

Development of Microstructures in Iron-Carbon Alloys

- Various microstructures can be produced in steel alloys depending on:
  - carbon content
  - heat treatment
- Equilibrium (slow) cooling from the $\gamma$ region through the eutectoid composition of 0.76 wt% C:
  \[ \gamma \Rightarrow \alpha + \text{Fe}_3\text{C} \] (Pearlite)
- $\% \alpha$ and Fe$_3$C in eutectoid pearlite
Formation of Pearlite

- Schematic representation of the formation of pearlite from austenite
- Micrograph of eutectoid steel, showing pearlite microstructure.

Hypo-eutectoid Composition (wt% C <0.76)

- Composition 0.002 and 0.76 wt% C
- Upon cooling enter a two-phase region
  \[ \gamma \Rightarrow \alpha + \gamma \]
- Below 727°C the remaining austenite transforms to pearlite
  \[ \gamma \Rightarrow \alpha + \text{Fe}_3\text{C} \]
Hypo-eutectoid Composition (0.38 wt% C)

White regions: Proeutectoid Ferrite

Dark regions: Pearlite Close-spaced layers Unresolved at this magnification

Pearlite wider-spaced layers

Computing the relative amounts of proeutectoid $\alpha$ and pearlite

- Similar to previous lecture.
- Use the Lever Rule in conjunction with a tie line
- For hypoeutectic composition $C'_0$, fractions of pro-eutectic $\alpha$, and pearlite are:

- $\alpha$ (total) and Fe$_3$C
Computing the relative amounts of proeutectoid $\alpha$ and pearlite

- For hypereutectic composition $C'_1$

- $\alpha$ (total) and Fe$_3$C

Hyper-eutectoid Composition (wt% C >0.76)

- Composition between 0.76 and 2.14 wt% C
- Upon cooling enter a two-phase region $\gamma \Rightarrow \gamma + Fe_3C$
- The pro-eutectoid cementite phase has begun to form along the $\gamma$ grain boundaries
Hyper-eutectoid Composition (1.40 wt% C)

Mechanical Properties of Steels

- The mechanical properties of steel are largely dictated by the phase transformations they undergo upon cooling
- If we heat steel to the **single phase austenite region** and vary the cooling rate we can control the microstructure.
- Understanding phase transformations of metallic alloys
Example: Railway Rails

- Eutectoid composition of 0.76 wt%C
- 100% Pearlite structure
- Pearlite is a natural ‘composite’

- The strength of Pearlite is dictated by its interlaminar spacing, $S$ ($\mu$m)

\[ \sigma_y = 140 + 46.4S^{-1} \]

Pearlite

Coarse Pearlite  Fine Pearlite
Isothermal Transformation Diagrams

- The rate of transformation of the austenite to pearlite is dependent on temperature.
- This temperature dependence can be plotted as % transformation vs. log. time.
- Data was collected for each curve, after rapid cooling of 100% austenite to the temperature indicated.
  - temperature was then kept constant throughout the course of the reaction.

More convenient to represent time-temperature dependence
- Isothermal transformation diagram
- generated from the % transformation-versus-log. times measurements
- Note the eutectoid temperature (727°C)
- Many tests conducted to these construct curves.
Isothermal Transformation Diagrams

Spheroidite

- Hold steel at high temperature
- Large drop in strength occurs
- But ductility is greatly increased

30 µm
Formation of Martensite

- Non-Equilibrium Cooling
- Carbon must diffuse (move) in order to form pearlite

- Diffusion takes time + temperature
- If the sample is “quenched” (plunged into water)

- A supersaturated and unstable structure is formed.

Characteristics of Martensite Transformation

- Occurs by a non-diffusional process
- Transformation occurs extremely fast, i.e. at the speed of sound
- Transformation occurs at temperatures well below eutectoid temperature
- Martensite is very hard (i.e. high $\sigma_y$) but is completely brittle
- Not useful as an engineering material
- Must be “tempered”
Martensite

- Quench
  - Needle shaped
  - White areas austenite
    - quenched too fast
- Tempered
  - 564°C
  - small particles cementite
  - matrix is α ferrite

Effect of Carbon Content on Hardness

Brinell Hardness 0 - 320

Brinell Hardness 0 - 750
Effect of Carbon Content on Yield and Tensile Strength