Material Science and Metallurgy

Topic:~Iron Iron-Carbide Diagram

(Basic Definitions & States)

Mechanical Department

Definition of structures

- Various phases that appear on the Iron-Carbon equilibrium phase diagram are as under:
  - Austenite
  - Ferrite
  - Pearlite
  - Cementite
  - Martensite
  - Ledeburite

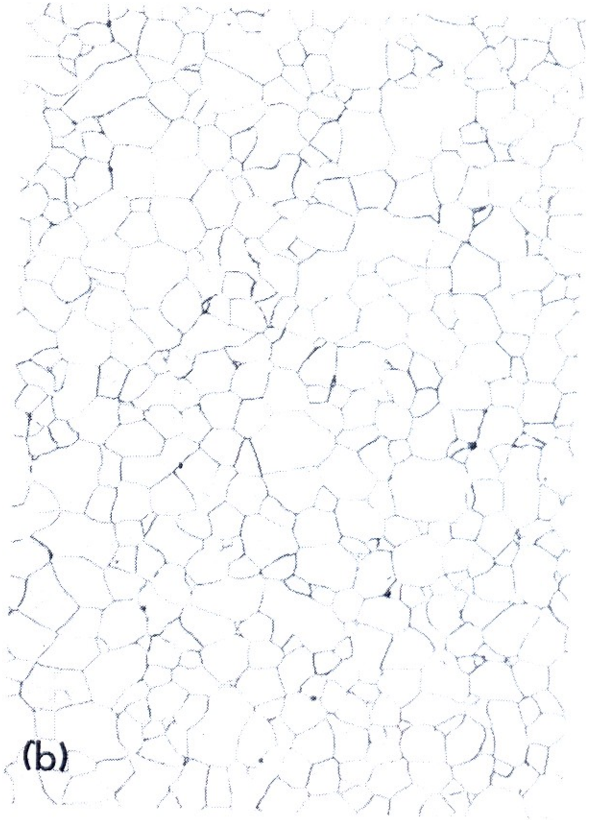
Definition of structures

- **Ferrite** is known as α solid solution.
- It is an interstitial solid solution of a small amount of carbon dissolved in α (BCC) iron.
- stable form of iron below 912 deg.C
- The maximum solubility is 0.025 % C at 723 deg.C and it dissolves only 0.008 % C at room temperature.
- It is the softest structure that appears on the diagram.

Definition of structures

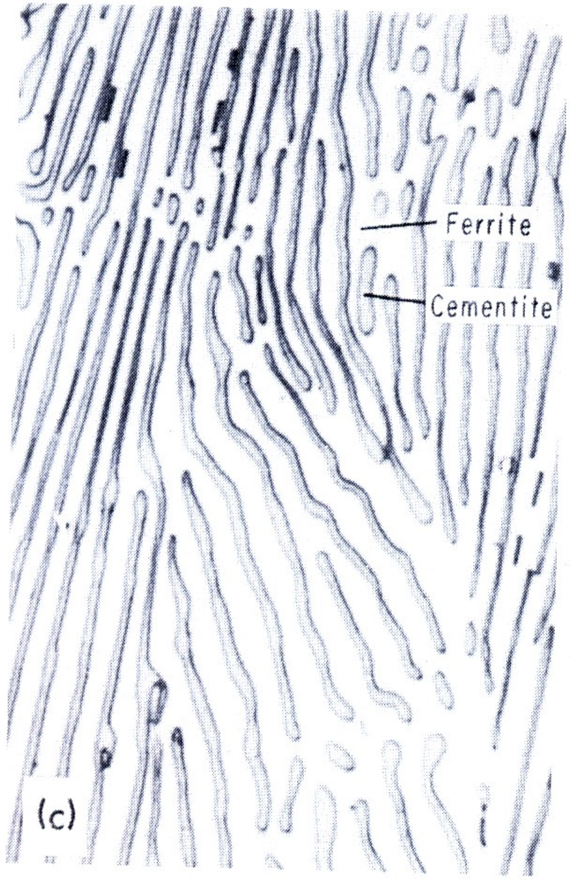
- **Ferrite**

- Average properties are:
  - Tensile strength = 40,000 psi;
  - Elongation = 40 %



Definition of structures

- **Pearlite** is the eutectoid mixture containing 0.80 % C and is formed at 723 deg.C on very slow cooling.
- It is a very fine plate like or lamellar mixture of ferrite and cementite.
- The white ferrite background or matrix contains thin plates of cementite (dark).



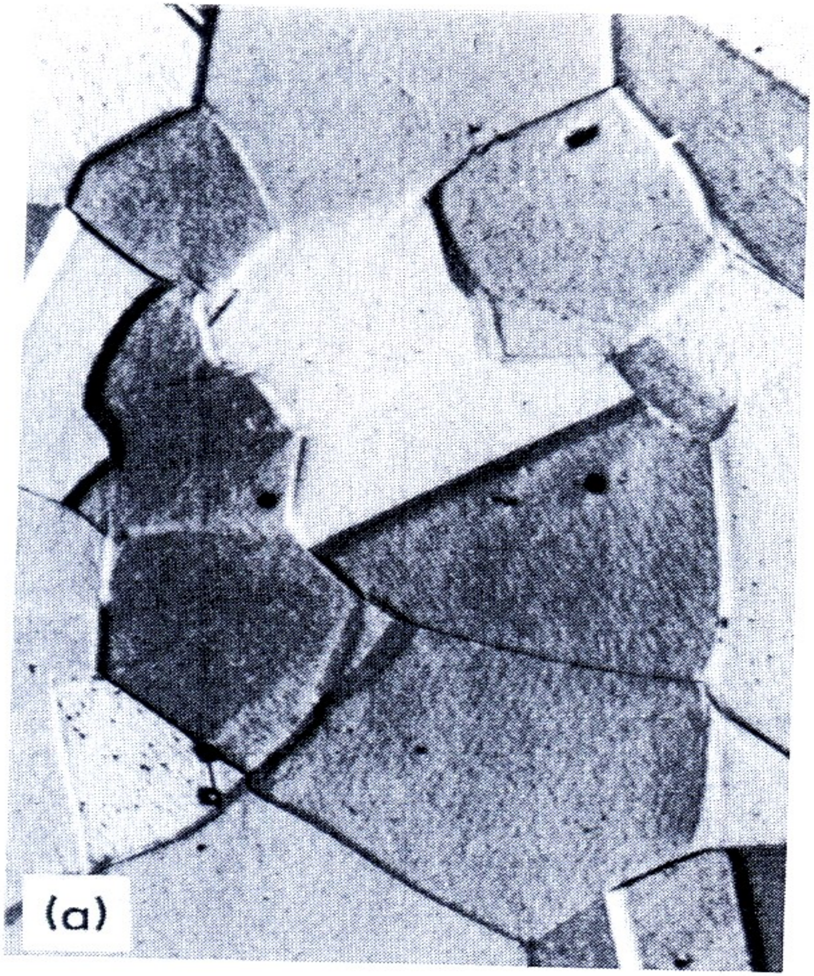
Definition of structures

- **Austenite** is an interstitial solid solution of Carbon dissolved in γ(F.C.C.) iron.
- Maximum solubility is 2.0 % C at 1130 deg.C.
- High formability, most of heat treatments begin with this single phase.
- It is normally not stable at room temperature. But, under certain conditions it is possible to obtain austenite at room temperature.

Definition of structures

Austenite

- Average properties are:
  - Tensile strength =150,000 psi;
  - Elongation = 10%



Definition of structures

- **Cementite** or iron carbide, is very hard, brittle intermetallic compound of iron & carbon, as Fe_3C, contains 6.67 % C.
- It is the hardest structure that appears on the diagram, exact melting point unknown.
- It is has
  - low tensile strength (approx. 5,000 psi), but
  - high compressive strength.

Definition of structures

- **Ledeburite** is the eutectic mixture of austenite and cementite.
- It contains 4.3 percent C and is formed at 1130°C.

Definition of structures

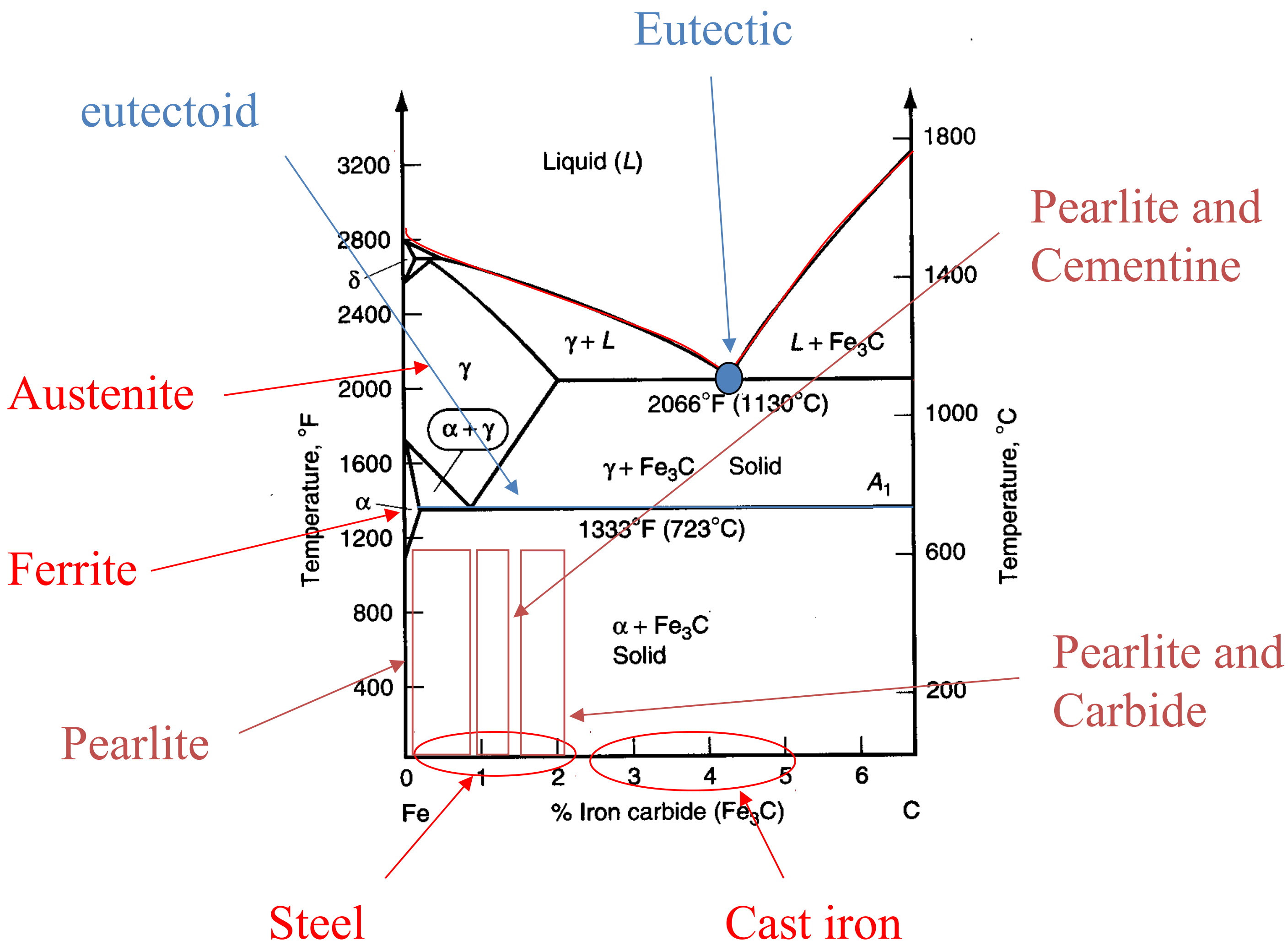
- **Martensite** - a super-saturated solid solution of carbon in ferrite.
- It is formed when steel is cooled so rapidly that the change from austenite to pearlite is suppressed.

Iron Iron-Carbide Diagram

The Iron-Iron Carbide Diagram

- A map of the temperature at which different phase changes occur on very slow heating and cooling in relation to Carbon, is called Iron- Carbon Diagram.
- Iron- Carbon diagram shows
  - The type of alloys formed under very slow cooling,
  - Proper heat-treatment temperature and
  - How the properties of steels and cast irons can be radically changed by heat-treatment.

How to read the Fe-C phase diagram



Various Features of Fe-C diagram

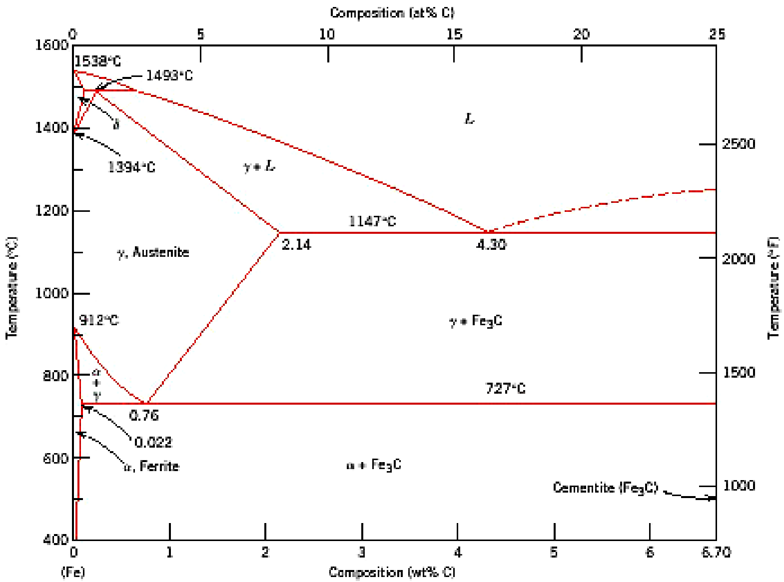


Figure 9.22 The iron–iron carbide phase diagram. (Adapted from *Binary Alloy Phase Diagrams*, 2nd edition, Vol. 1, T. B. Massalski, Editor-in-Chief, 1990. Reprinted by permission of ASM International, Materials Park, OH.)

Phases present

L

α ferrite
BCC structure
Ferromagnetic
Fairly ductile

δ
BCC structure
Paramagnetic

γ austenite
FCC structure
Non-magnetic
ductile

Fe_3C cementite
Orthorhombic
Hard
brittle

Reactions

Peritectic $L + \delta = \gamma$

Eutectic $L = \gamma + Fe_3C$

Eutectoid $\gamma = \alpha + Fe_3C$

Max. solubility of C in ferrite=0.022%

Max. solubility of C in austenite=2.11%

Three Phase Reactions

- Peritectic, at 1490 deg.C, with low wt% C alloys (almost no engineering importance).
- Eutectic, at 1130 deg.C, with 4.3wt% C, alloys called cast irons.
- Eutectoid, at 723 deg.C with eutectoid composition of 0.8wt% C, two-phase mixture (ferrite & cementite). They are steels.

The Iron-Iron Carbide Diagram

The diagram shows three horizontal lines which indicate isothermal reactions (on cooling / heating):

- First horizontal line is at 1490°C, where peritectic reaction takes place:

  Liquid + δ ↔ austenite

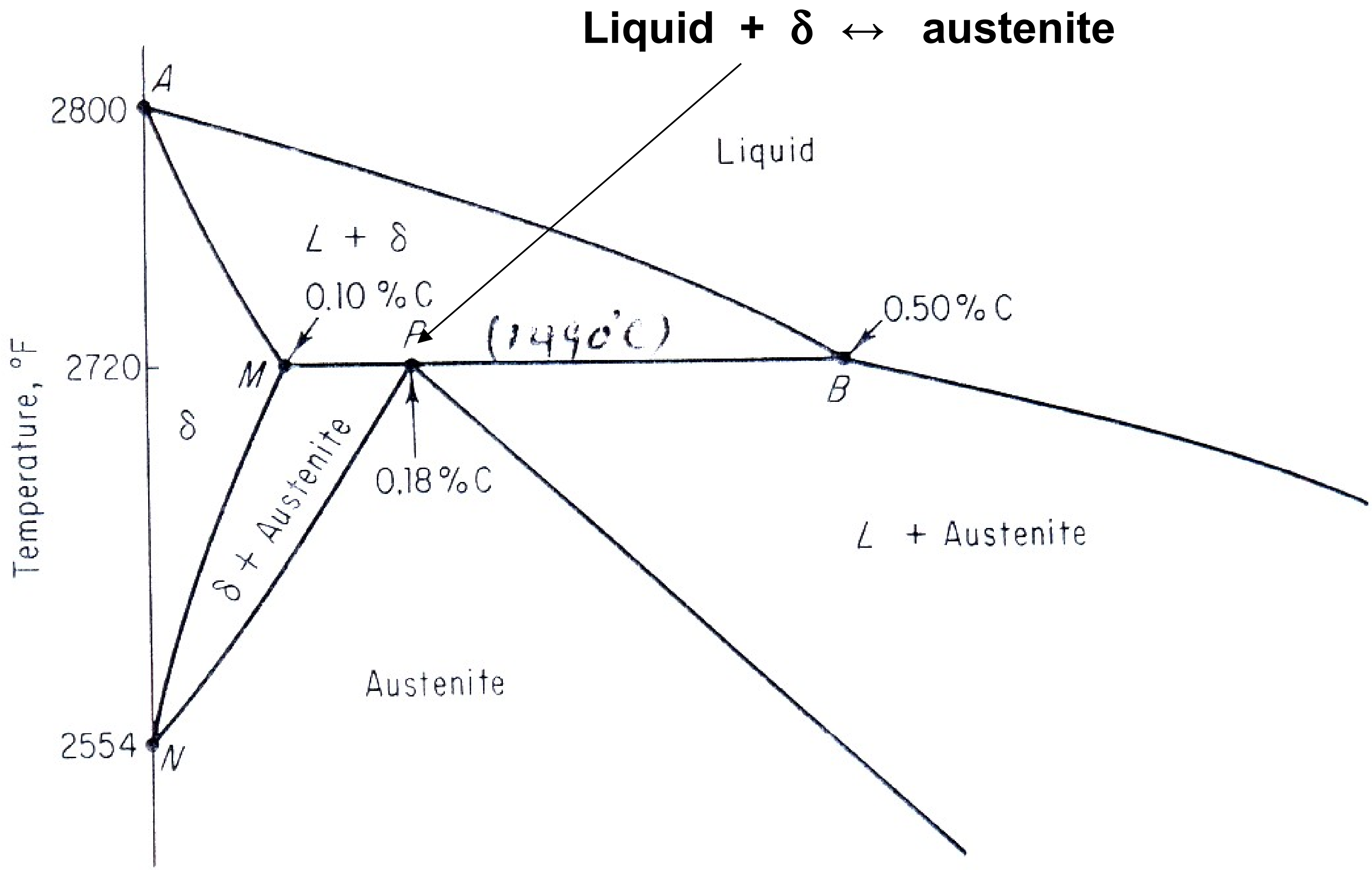
- Second horizontal line is at 1130°C, where eutectic reaction takes place:

  liquid ↔ austenite + cementite

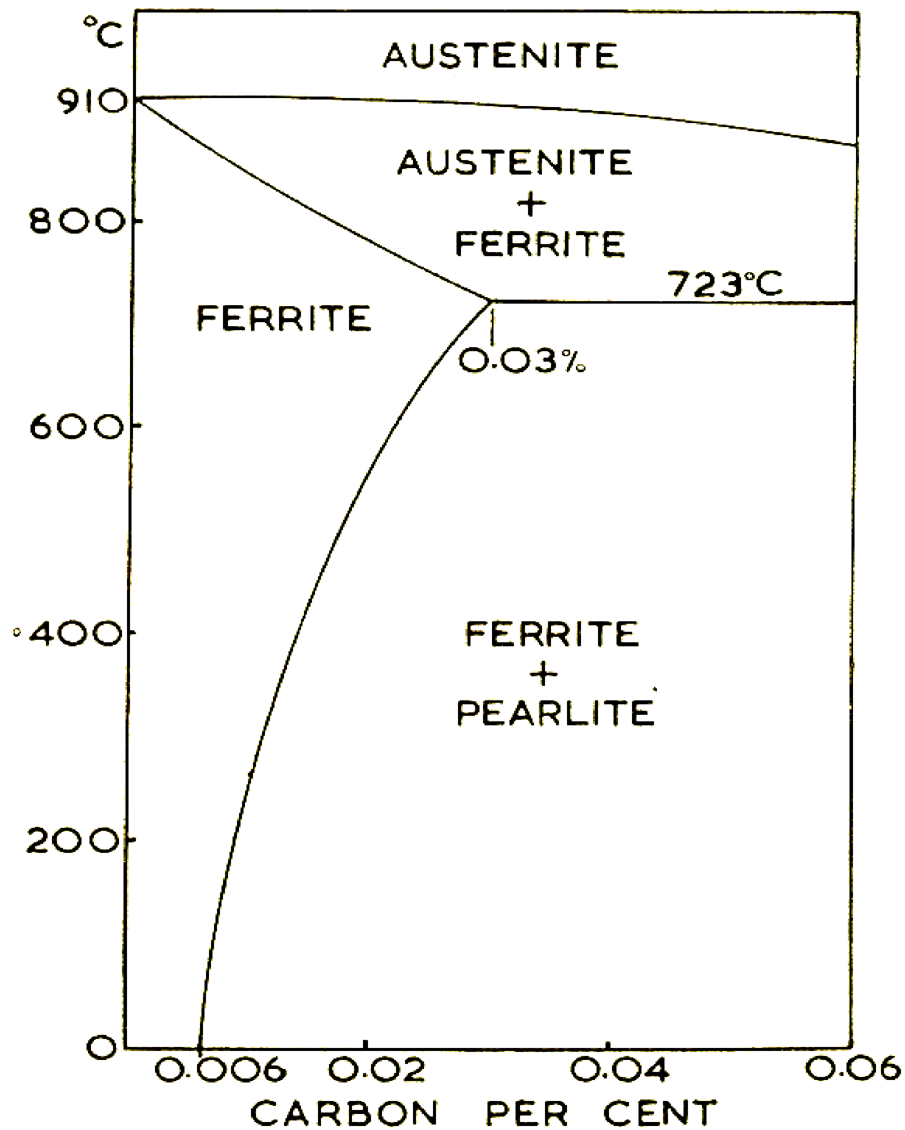
- Third horizontal line is at 723°C, where eutectoid reaction takes place:

  austenite ↔ pearlite (mixture of ferrite & cementite)

Delta region of Fe-Fe carbide diagram



Ferrite region of Fe-Fe Carbide diagram



2.—The "Ferrite Area" of the Iron–Carbon Equilibrium Diagram, Showing the Extent to Which Carbon is Soluble in α Iron.

The Austenite to ferrite / cementite transformation in relation to Fe-C diagram

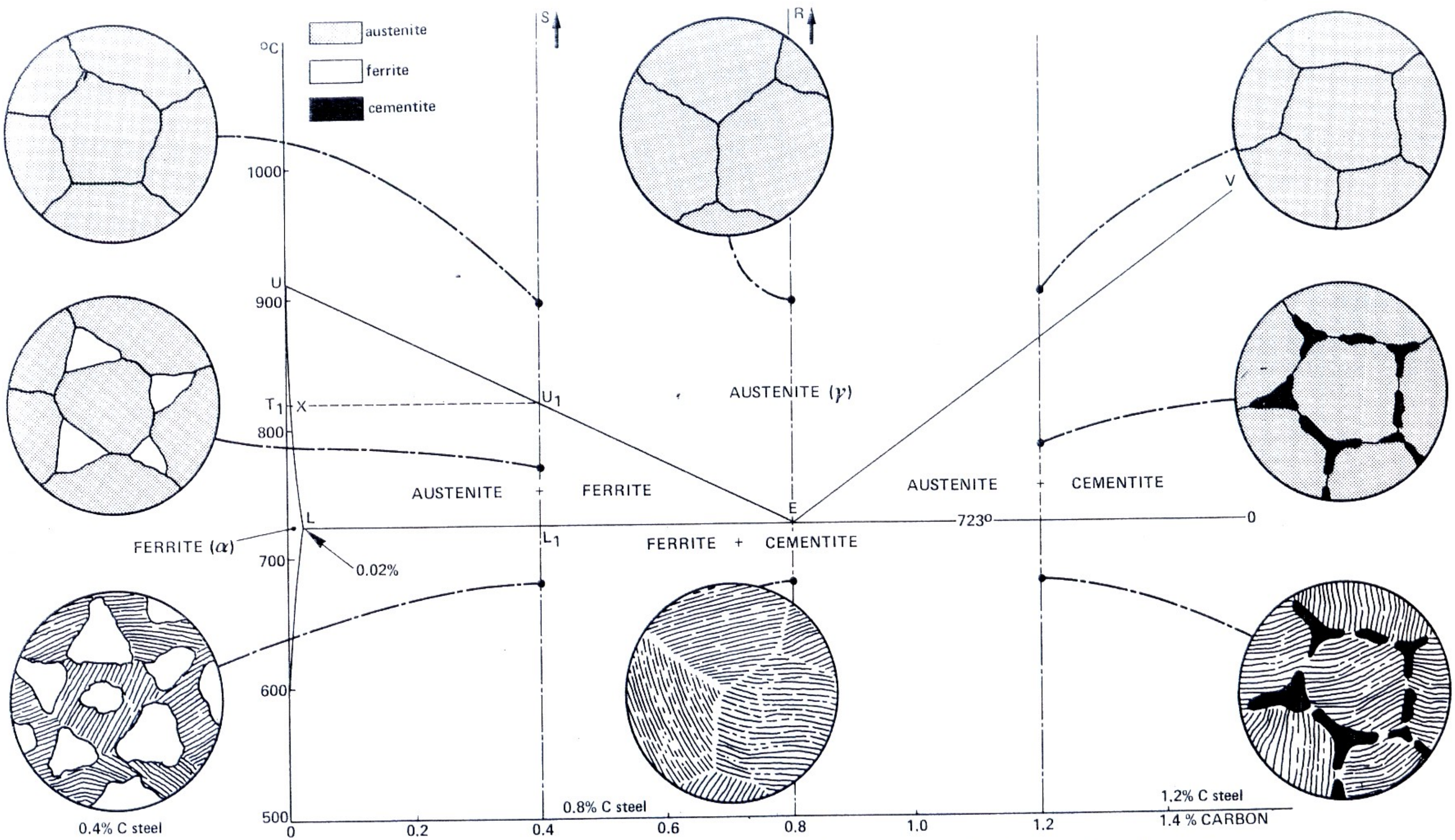


Fig. 9.3—The austenite → ferrite/cementite transformation in relation to the iron–carbon diagram.

The Austenite to ferrite / cementite transformation in relation to Fe-C diagram

In order to understand the transformation processes, consider a steel of the eutectoid composition. 0.8% carbon, being slow cooled along line *x-x'*.

- At the upper temperatures, only austenite is present, with the 0.8% carbon being dissolved in solid solution within the FCC. When the steel cools through 723°C, several changes occur simultaneously.

The Austenite to ferrite / cementite transformation in relation to Fe-C diagram

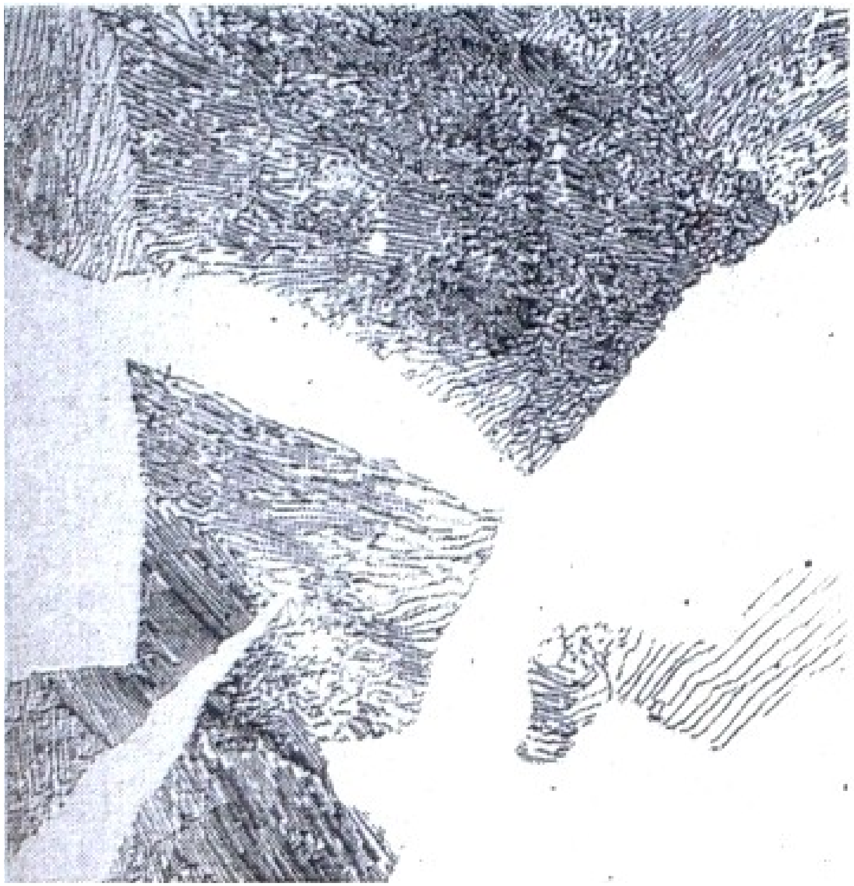
- The iron wants to change crystal structure from the FCC austenite to the BCC ferrite, but the ferrite can only contain 0.02% carbon in solid solution.
- The excess carbon is rejected and forms the carbon-rich intermetallic known as cementite.

The Austenite to ferrite / cementite transformation in relation to Fe-C diagram

- **Hypo-eutectoid steels:** Steels having less than 0.8% carbon are called *hypo-eutectoid steels (hypo* means "less than").
- Consider the cooling of a typical hypo-eutectoid alloy along line *y-y'.*
- At high temperatures the material is entirely austenite.
- Upon cooling it enters a region where the stable phases are ferrite and austenite.
- The low-carbon ferrite nucleates and grows, leaving the remaining austenite richer in carbon.

The Austenite to ferrite / cementite transformation in relation to Fe-C diagram

- **Hypo-eutectoid steels-** At *723°C*, the remaining austenite will have assumed the eutectoid composition *(0.8%* carbon), and further cooling transforms it to pearlite.
- The resulting structure, is a mixture of *primary or pro-eutectoid ferrite* (ferrite that forms before the eutectoid reaction) and regions of pearlite.



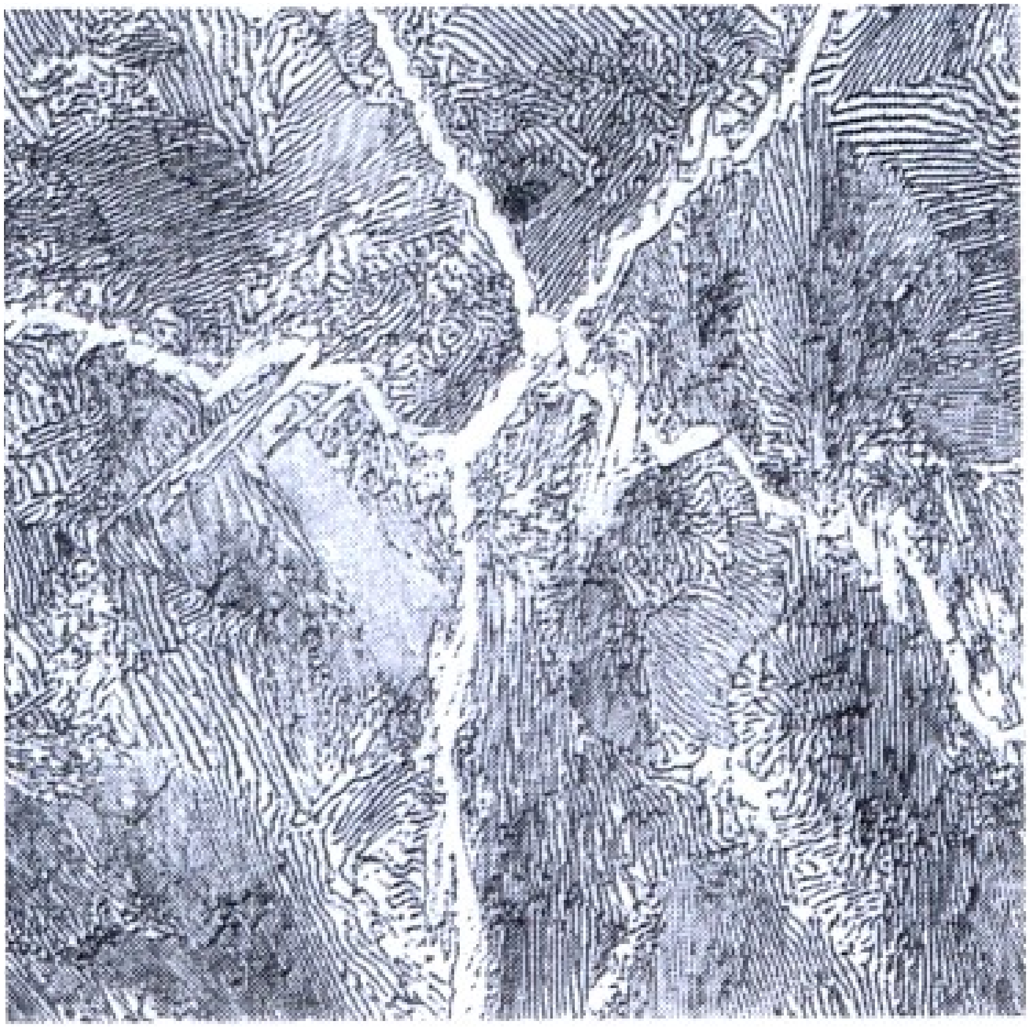
The Austenite to ferrite / cementite transformation in relation to Fe-C diagram

- **Hyper-eutectoid steels** (*hyper* means "greater than") are those that contain more than the eutectoid amount of Carbon.
- When such a steel cools, as along line *z-z'* , the process is similar to the hypo-eutectoid steel, except that the primary or pro-eutectoid phase is now cementite instead of ferrite.

The Austenite to ferrite / cementite transformation in relation to Fe-C diagram

- As the carbon-rich phase nucleates and grows, the remaining austenite decreases in carbon content, again reaching the eutectoid composition at 723°C.
- This austenite transforms to pearlite upon slow cooling through the eutectoid temperature.
- The resulting structure consists of primary cementite and pearlite.
- The continuous network of primary cementite will cause the material to be extremely brittle.

The Austenite to ferrite / cementite transformation in relation to Fe-C diagram



Hypo-eutectoid steel showing primary cementite along grain boundaries pearlite

The Austenite to ferrite / cementite transformation in relation to Fe-C diagram

- When the alloys are cooled rapidly, entirely different results are obtained, since sufficient time may not be provided for the normal phase reactions to occur.
- In these cases, the equilibrium phase diagram is no longer a valid tool for engineering analysis.
- Rapid-cool processes are important in the heat treatment of steels and other metals (to be discussed later in H/T of steels).

Principal phases of steel and their Characteristics

Phase	Crystal structure	Characteristics
Ferrite	BCC	Soft, ductile, magnetic
Austenite	FCC	Soft, moderate strength, non-magnetic
Cementite	Compound of Iron & Carbon Fe_3C	Hard &brittle

Thank You.!