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Prosthetics and orthotics Materials Science

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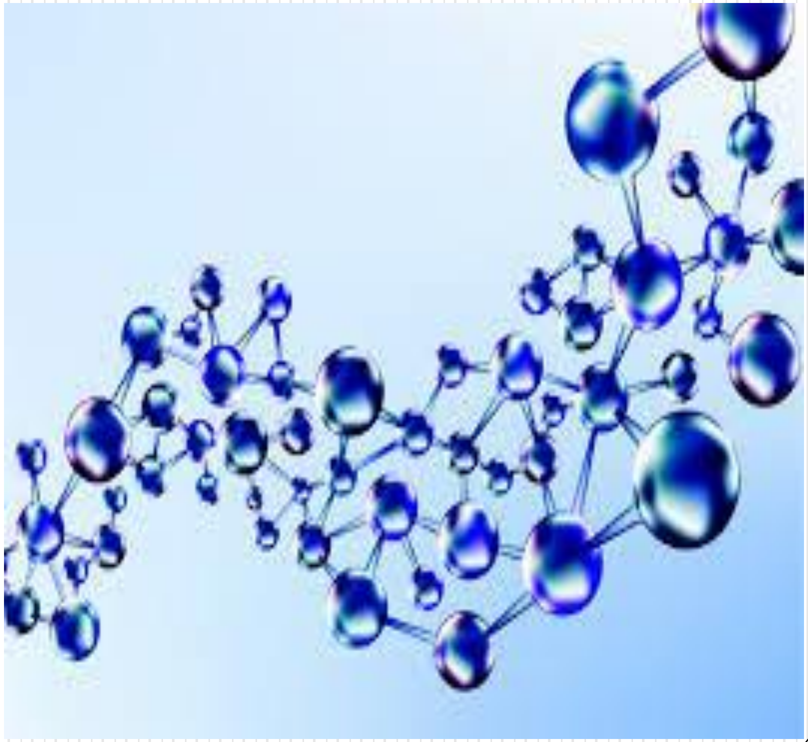


Materials Science

Phase Diagrams

“Iron-carbon diagram”

Topics

- Introduction
- Cooling curve for pure iron
- Iron-Carbon equilibrium phase diagram
- Phases in Fe-Fe_3C diagram
- Reactions occur in Fe-Fe_3C diagram
- Fe-C alloy classification

Introduction

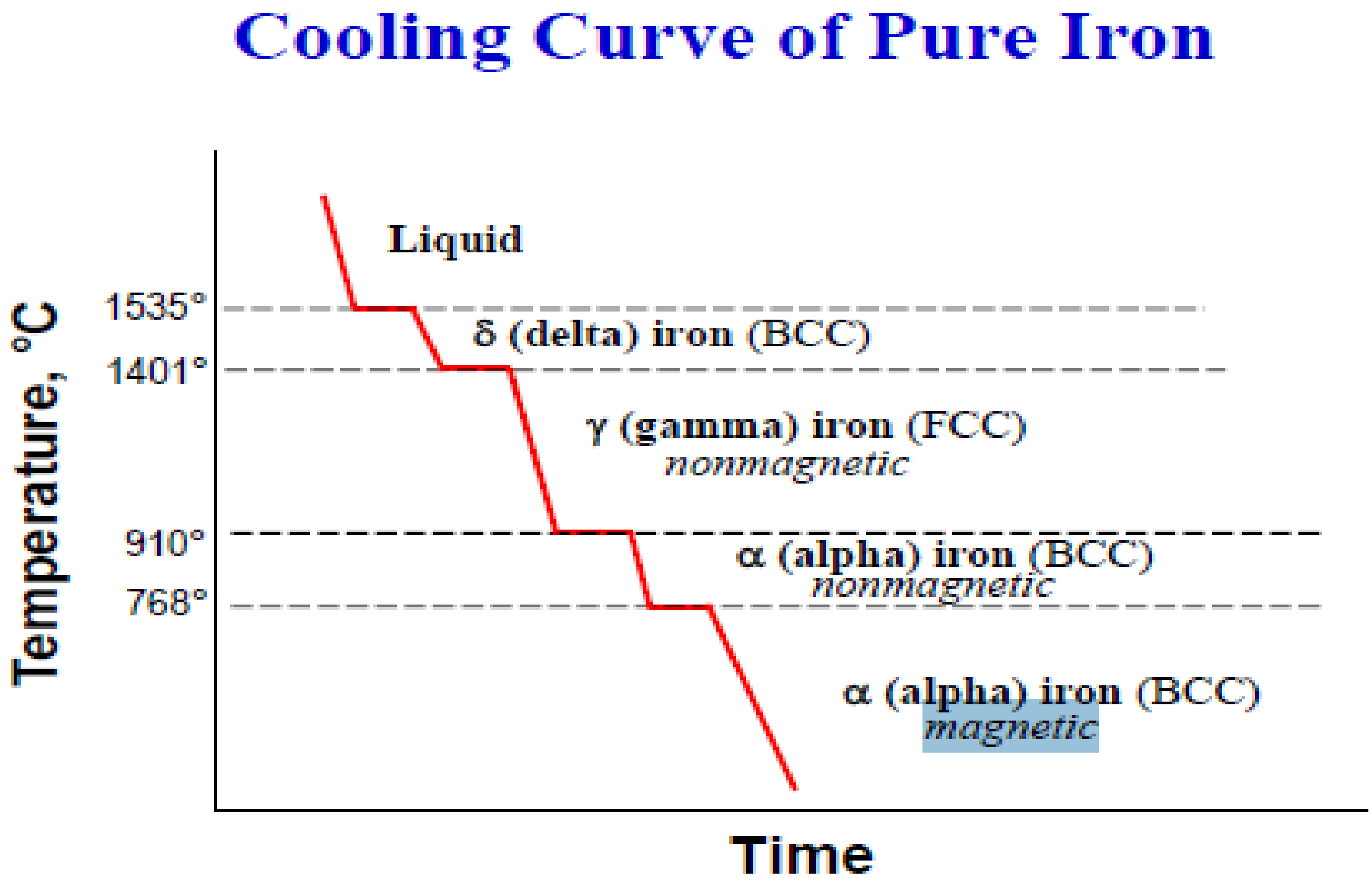
- ❑ Of all binary alloy systems, the one that is possibly the most important is that for **iron and carbon.**

- ❑ Both **steels** and **cast irons**, primary structural materials in every technologically advanced culture, are essentially iron–carbon alloys.

- ❑This section is devoted to a study of the phase diagram for this system and the development of several of the possible microstructures.

Cooling curve for pure iron

❑ Allotropy of iron:



Iron-Carbon equilibrium phase diagram

- ***Iron-Carbon diagram*** is a map of the temperature at which different phase changes occur on very slow heating and cooling in relation to Carbon.

- **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 changed by heat-treatment.

Iron-Carbon equilibrium phase diagram

- Carbon (C) forms an interstitial solid solution with α, γ, δ phases of iron (Fe).

- In the iron-carbon system, the composition axis in Fig. extends only to **6.67 wt% C**; at this concentration the intermediate (intermetallic) compound iron carbide which called cementite (Fe_3C), is formed.

- Cementite (Fe_3C) is represented by a vertical line on the phase diagram. Thus, the iron-carbon system may be divided into two parts: an iron-rich portion (as in Fig.) and the other (not shown) for compositions between 6.67 and 100 wt% C.

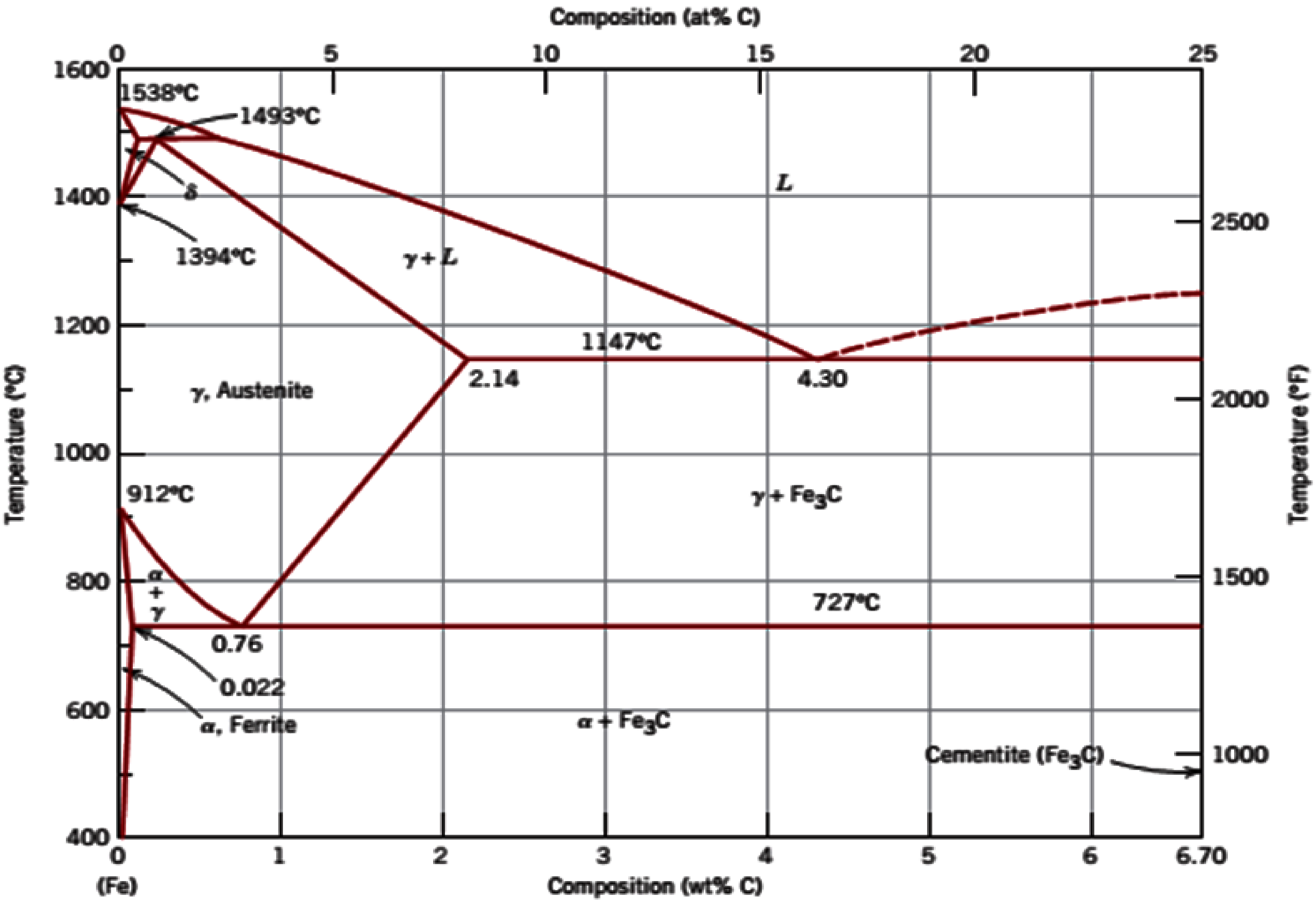
Iron-Carbon equilibrium phase diagram

- In practice, all steels and cast irons have carbon contents less than 6.67 wt% C; therefore, we consider only the iron-iron carbide system.

- Therefore, Fig. would be more appropriately labeled the Fe-Fe_3C phase diagram, because Fe_3C is now considered to be a *component*.

- The composition still be expressed in “wt% C” rather than “wt% Fe_3C”; 6.67 wt% C corresponds to 100 wt% Fe_3C.

Iron-Iron carbide phase diagram



Phases in Fe-Fe_3C diagram

- Phases in Fe-Fe_3C diagram are:

1. Liquid Phase (L):

- liquid solution of carbon (C) in iron (Fe).

2. δ-ferrite (delta):

- Solid solution of C in BCC Fe.
- BCC crystal structure
- Paramagnetic
- It is stable only at T >1400 °C
- Max. solubility of C in δ-ferrite = 0.15% at 1493°C.
- Because the δ-ferrite is stable only at relatively high temperatures, it is of no technological importance.

Phases in Fe-Fe_3C diagram

3. γ (Austenite):

- Is an interstitial solid solution of carbon in FCC iron.
- FCC crystal structure
- Non -magnetic
- Ductile
- Max. solubility of C in austenite=2.14% at 1147 °C.

4. α-ferrite:

- Is an interstitial solid solution of a small amount of carbon dissolved in BCC iron.
- BCC crystal structure
- Ferromagnetic
- The softest structure that appears on the diagram.
- Stable form of iron at room temperature
- Max. solubility of C in ferrite = 0.022% at 727 °C and it dissolves only 0.008 % C at room temperature.

Phases in Fe-Fe_3C diagram

5. Fe_3C (Cementite- Intermetallic Compound)

- Its crystal structure is orthorhombic.
- Hard
- Brittle
- It is a metastable phase, it decomposes (very slowly, within several years) into α-Fe and C (graphite) at 650 -700 °C.

Reactions occur in Fe-Fe_3C diagram

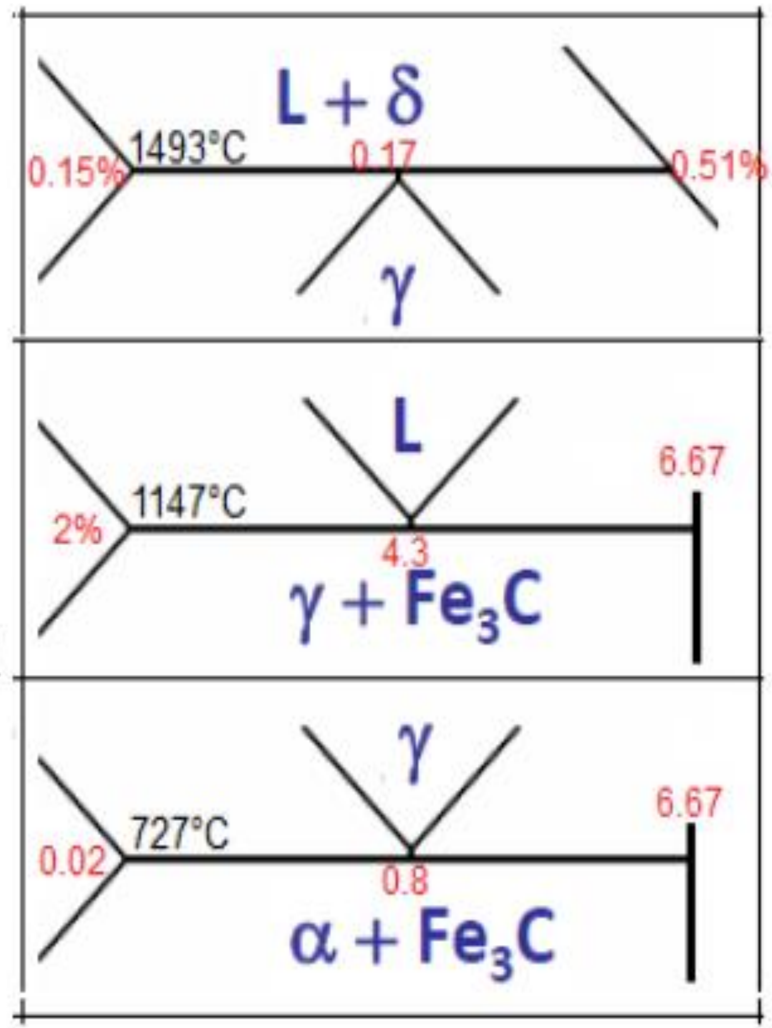
❑ Reactions occur in Fe-Fe_3C diagram are:

1. Peritectic Reaction

Liquid + $\text{Solid}_1 \leftrightarrow \text{Solid}_2$

$$L_{(0.51\%C)} + \delta_{(0.15\%C)} \rightarrow \gamma_{(0.17\%C)}$$

➢Occurs at 1493°C by **δ-solid solution, containing 0.15% carbon , reacting** with liquid containing **0. 51% C to form a new solid solution, austenite, containing 0. 17% C.**



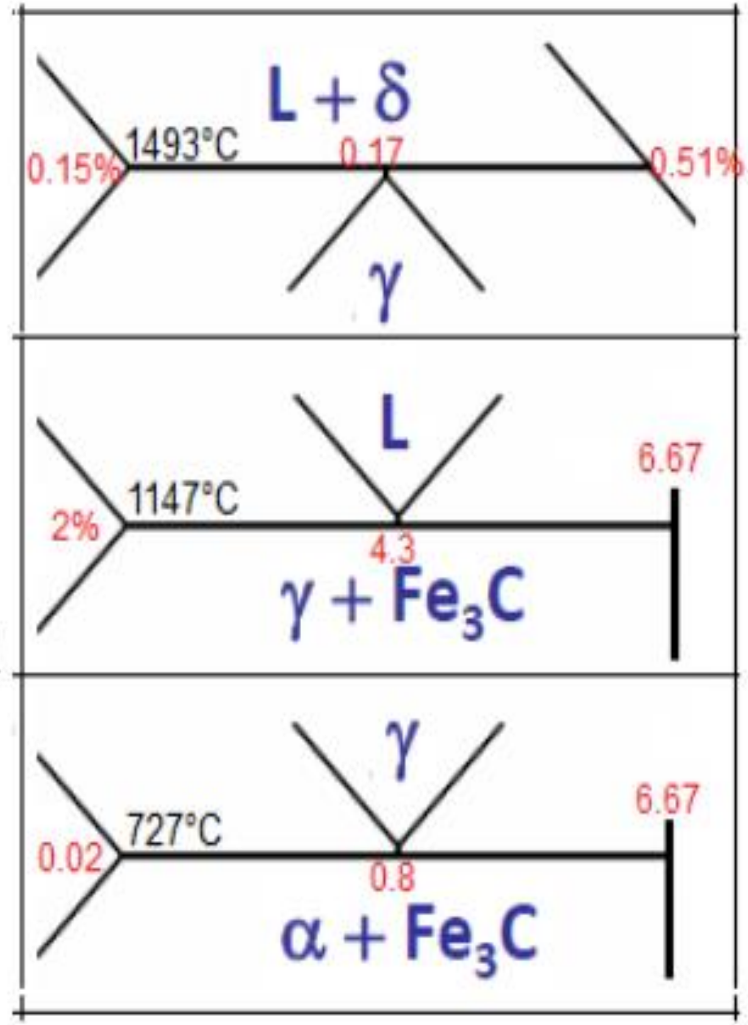
Reactions occur in Fe-Fe_3C diagram

Reactions occur in Fe-Fe_3C diagram are:

2. Eutectic Reaction

$$\text{Liquid} \leftrightarrow \text{Solid}_1 + \text{Solid}_2$$

$$\mathbf{L_{(4.3\ \%C)} \rightarrow \gamma_{(2\%C)} + Fe_3C_{(6.67\%C)}}$$



- Occurs at 1147°C when liquid **containing 4.3 % carbon solidifies to form mixture of austenite and cementite.**
- Eutectic mixture of austenite and cementite is called ***ledeburite.***

Reactions occur in Fe-Fe_3C diagram

- Reactions occur in Fe-Fe_3C diagram are:

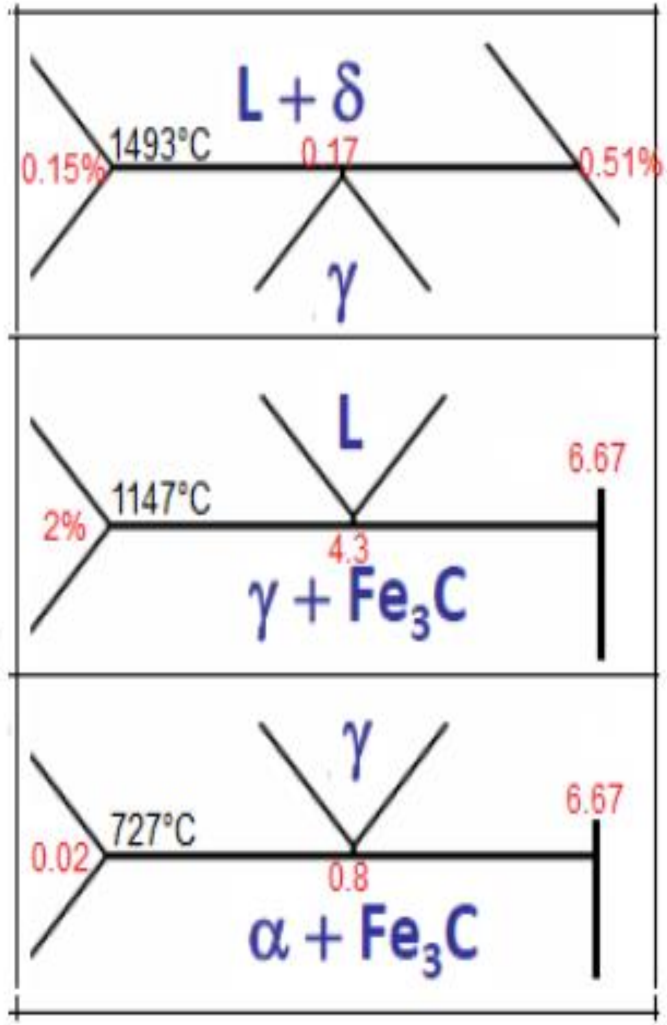
3. Eutectoid Reaction

$$\text{Solid}_1 \leftrightarrow \text{Solid}_2 + \text{Solid}_3$$

$$\gamma_{(0.8\%C)} \rightarrow \alpha_{(0.02\ \%C)} + Fe_3C_{(6.67\%C)}$$

- Occurs at 727°C when austenite containing 0.8 % carbon decomposes to form a structure consisting of alternate layers of ferrite and cementite.

- This mixture of ferrite and cementite is called ***Pearlite.***



Development of microstructure in steel alloys

- Various microstructures can be produced in steel alloys. The developed microstructure depends on both the carbon content and heat treatment.

Eutectoid steels:

- Consider an alloy of eutectoid composition (0.76wt% C) as it is cooled from a temperature within the phase region, say 800°C, that is, beginning at *point (a)* in Fig. and moving down the vertical *line xx'.*

- Initially, the alloy is composed entirely of the austenite phase having a composition of 0.76wt.%C and corresponding microstructure, also indicated in Fig.

Development of microstructure in steel alloys

Eutectoid steels:

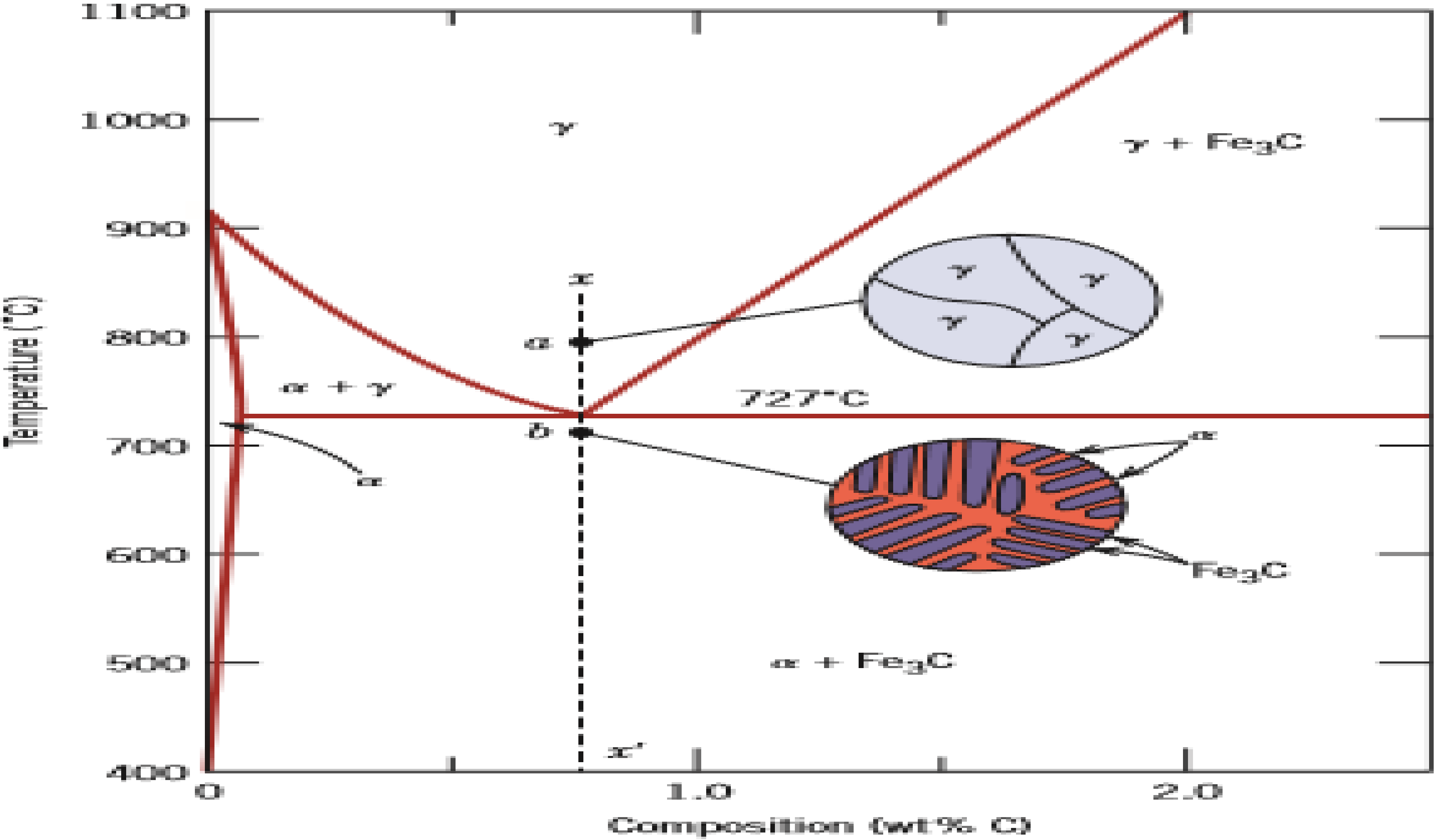
- As the alloy is cooled, no changes will occur until the eutectoid temperature (727°C) is reached. Upon crossing this temperature to point (b), the austenite transforms to pearlite according to the eutectoid reaction equation.

- Subsequent cooling of the pearlite from point (b) will produce insignificant microstructural changes.

$$\gamma(0.76\ \text{wt\%}\ \text{C}) \underset{\text{heating}}{\overset{\text{cooling}}{\rightleftharpoons}} \alpha(0.022\ \text{wt\%}\ \text{C}) + \text{Fe}_3\text{C}\ (6.7\ \text{wt\%}\ \text{C})$$

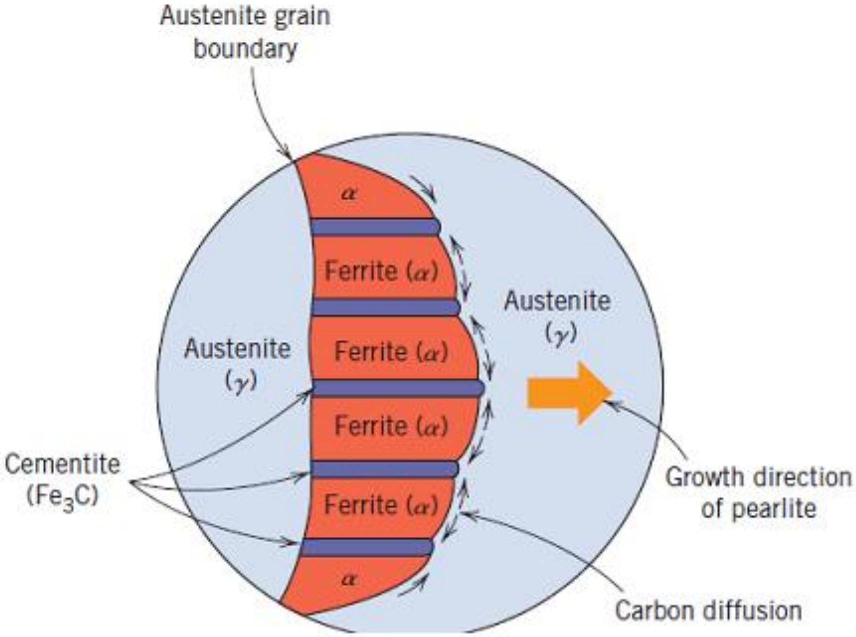
Development of microstructure in steel alloys

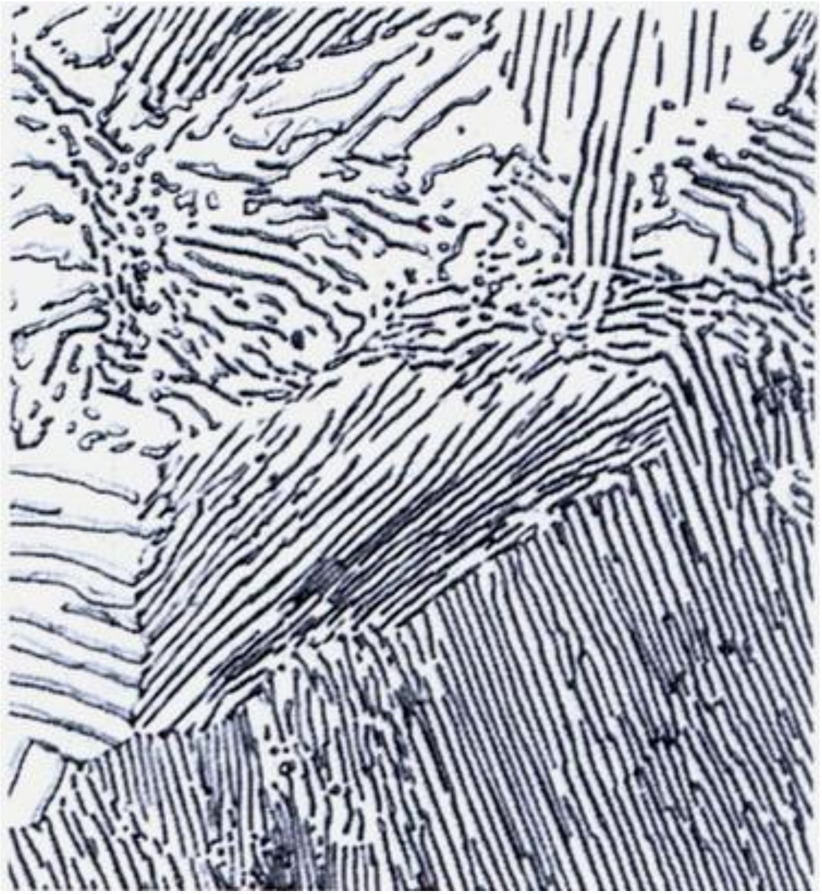
Eutectoid steels:



Development of microstructure in steel alloys

Microstructure of eutectoid steels:





Pearlite (Eutectoid) Structure

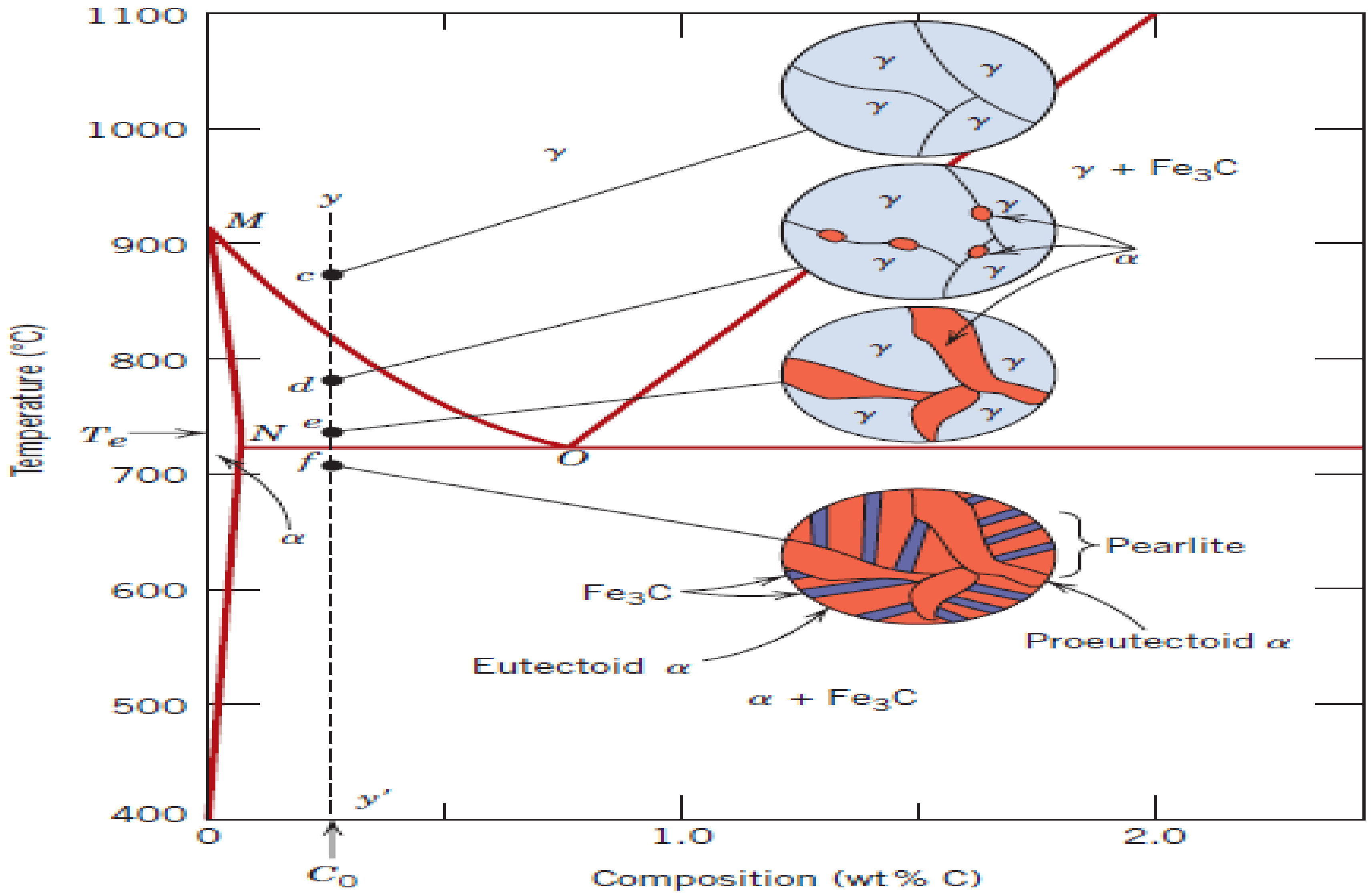
Development of microstructure in steel alloys

Hypo-eutectoid steels:

- Steels having less than 0.76% 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.

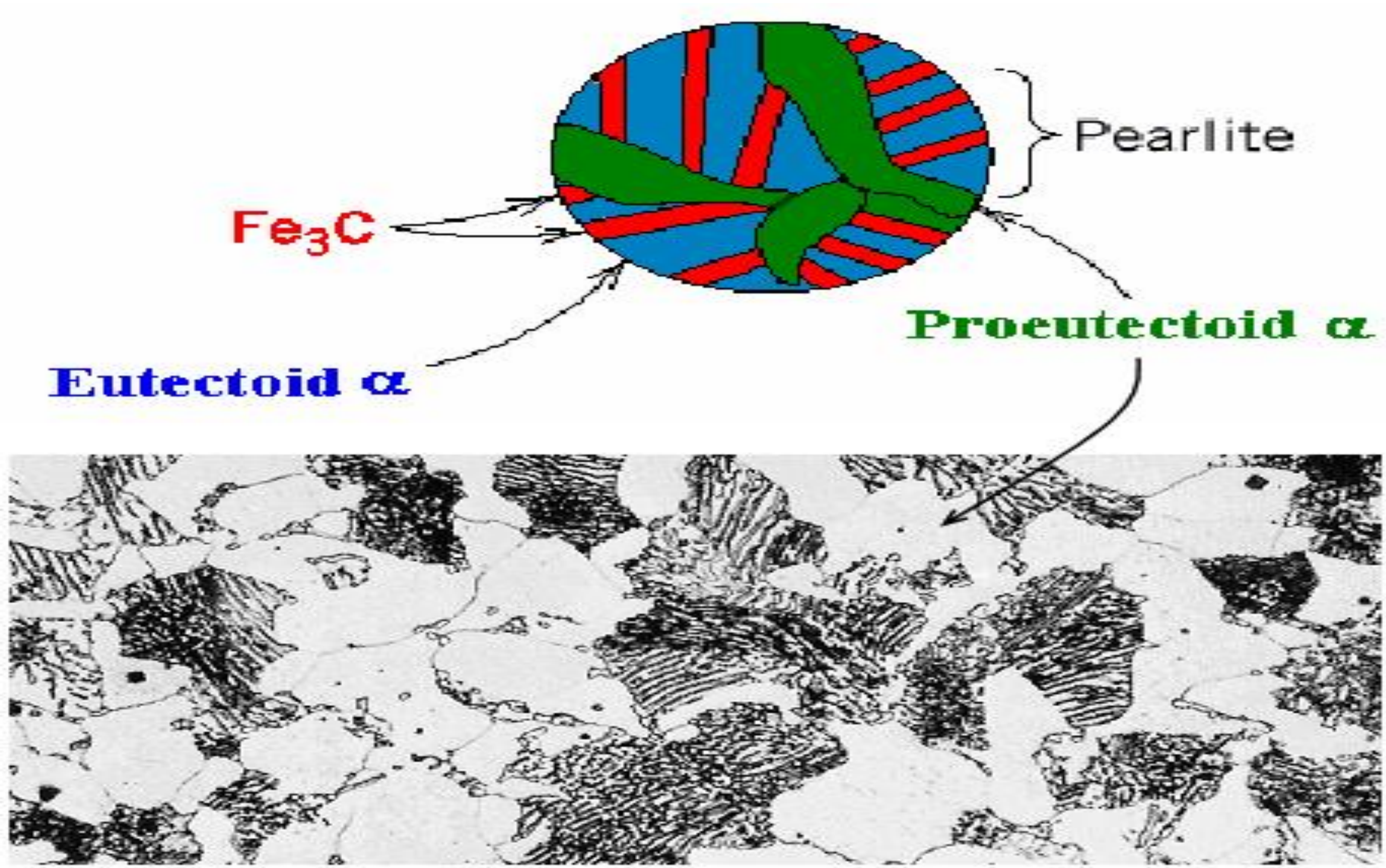
Development of microstructure in steel alloys

Hypo-eutectoid steels:



Development of microstructure in steel alloys

Microstructure of hypo-eutectoid steels:



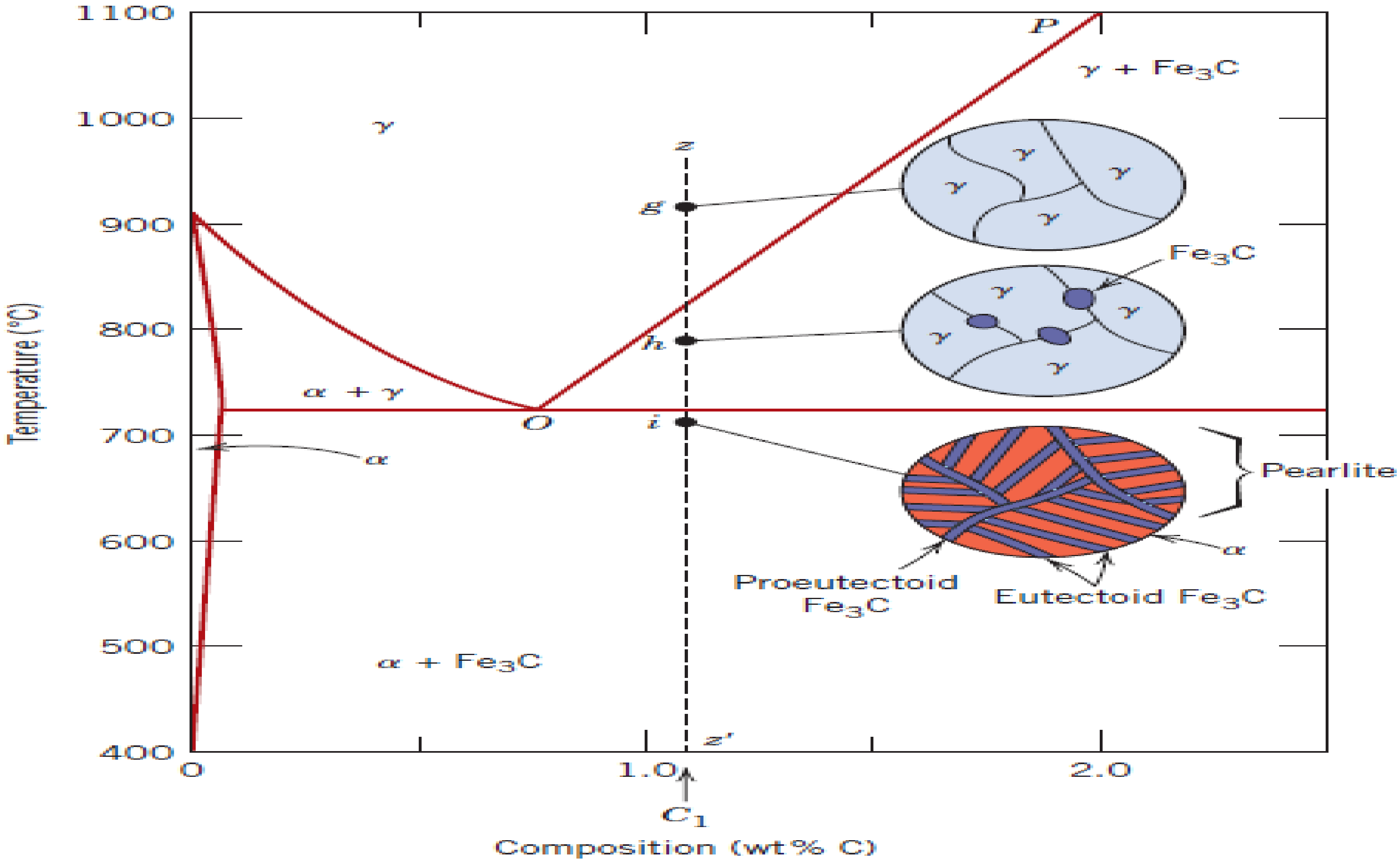
Development of microstructure in steel alloys

Hyper-eutectoid steels:

- 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.**

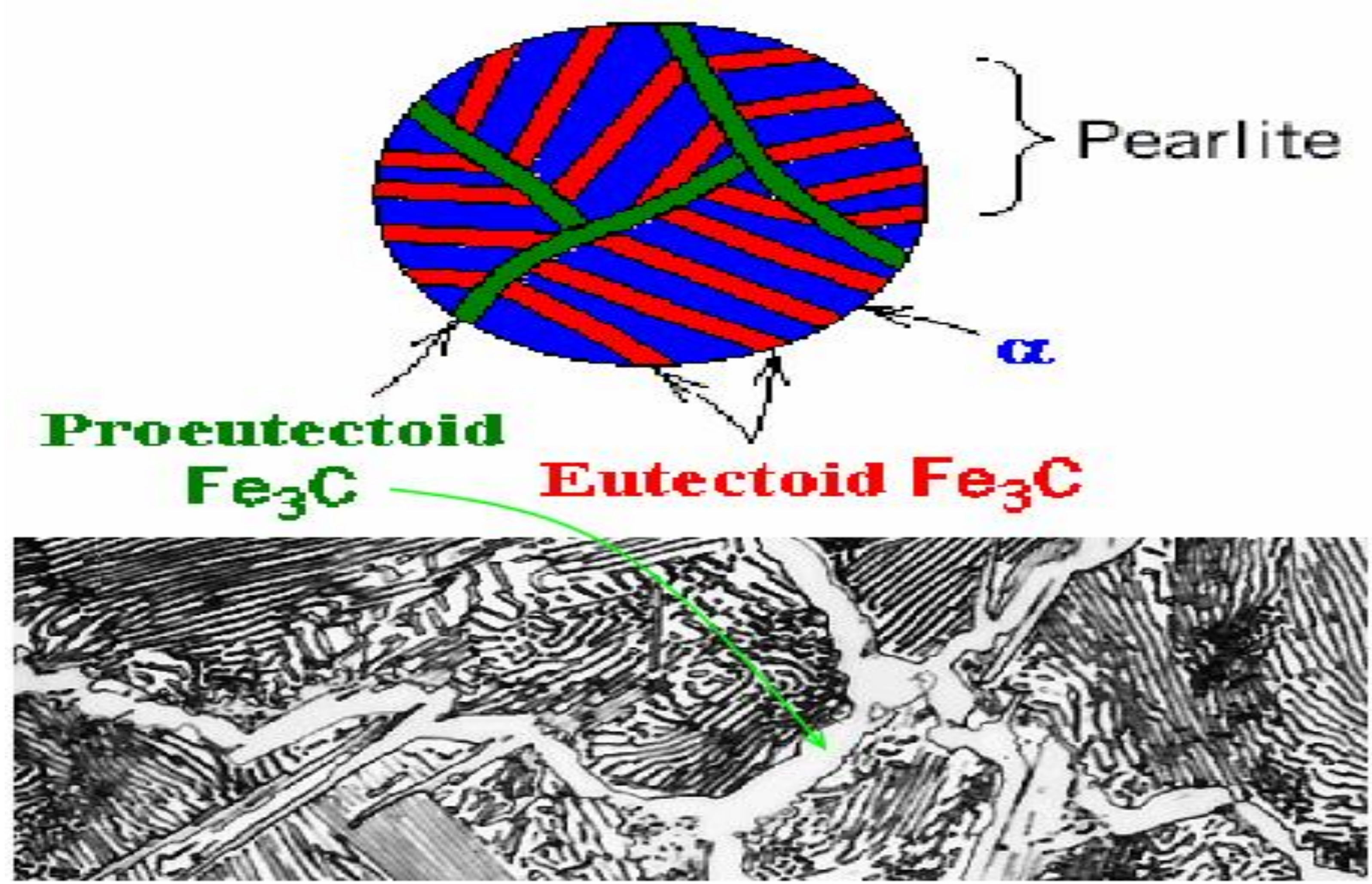
Development of microstructure in steel alloys

Hyper-eutectoid steels:

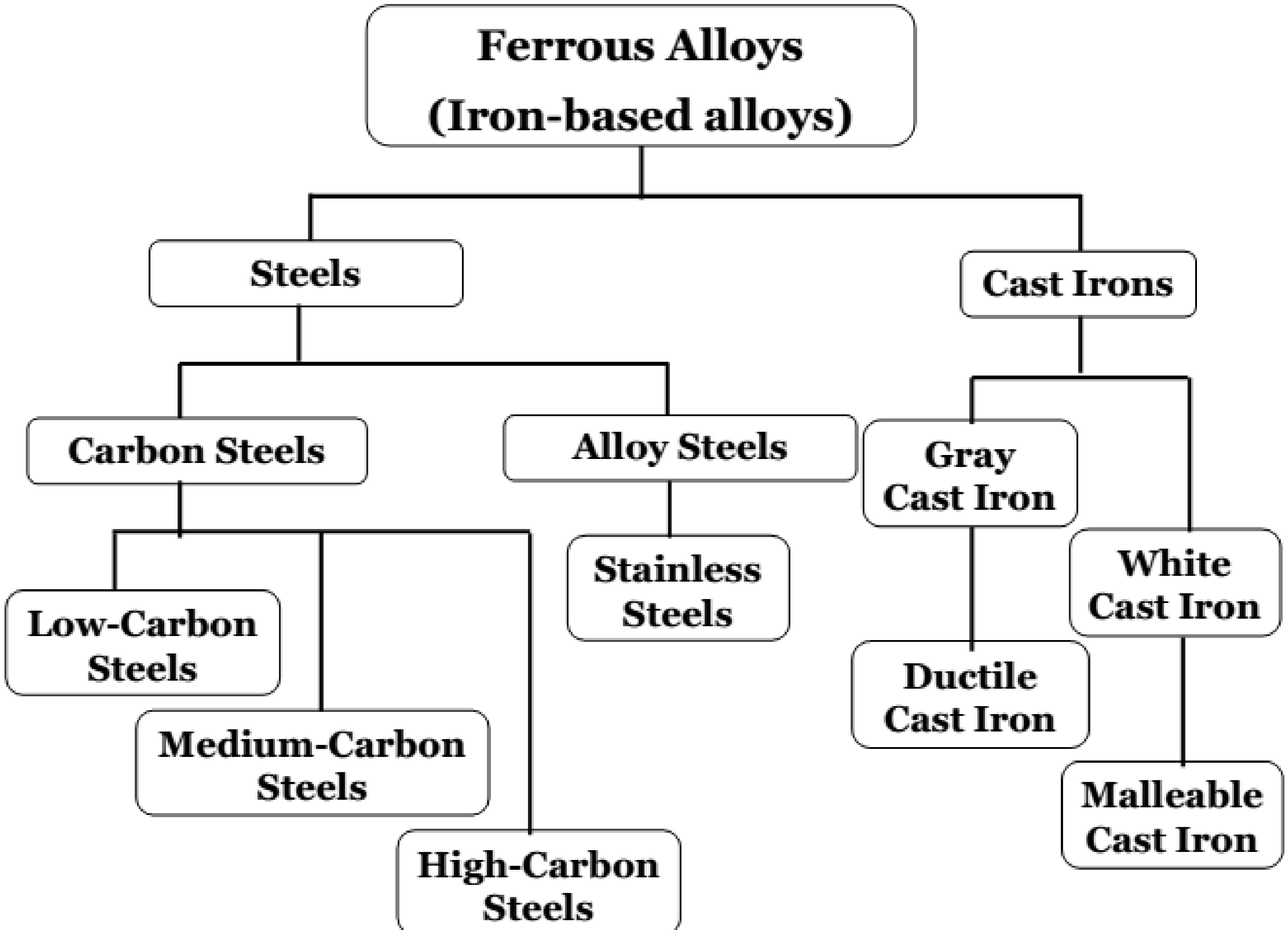


Development of microstructure in steel alloys

Microstructure of hypereutectoid steel:



Fe-C alloys classification



Fe-C alloys classification

I) Carbon steels:

- Carbon steels are classified based on carbon content:

Low-carbon steels

- **Composition:** They have less than 0.3%C.
- **Properties:** Low strength and hardness, high ductility and toughness.
- **Applications:** Structural shapes and sheet plates.
- They cannot be strengthened by heat treatment due to low carbon content; hence these alloys are strengthened by cold work.
- Their microstructure consists of ferrite and pearlite.

Fe-C alloys classification

2) <u>Medium-carbon steels:</u>

- **Composition:** They have 0.3%-0.6%C.
- **Properties:** Improved strength and hardness than low carbon steel with lower ductility and toughness.
- **Applications:** Gears, crankshafts and railway wheels and tracks.
- These alloys can be heat treated to improve their strength.

3) <u>High-carbon steels</u>

- **Composition:** They have 0.6%-2 % carbon.
- **Properties:** high strength and hardness, low ductility and toughness, high wear resistance .
- **Applications:** Dies, drills and cutting tools.
- These are heat treatable.

Fe-C alloys classification

II) Alloy steels:

➢Steels containing significant amounts of alloying elements (Cr, Ni, V,...) to improve specific properties for specific applications.

1) Stainless steels:

➢The most famous type of high alloy steel.

- **Composition:** It contain more than 12%Cr in addition to Ni, Mo,.
- **Properties:** Characterized by their high corrosion resistance. Stainless refers to the formation of a film of chromium oxide that protects the metal from corrosion.
- **Applications:** Food processing equipment and surgical knives.

Fe-C alloys classification

III) Cast irons:

- **Cast iron** are ferrous alloys, the carbon content in which is higher than 2%C, in addition to other alloying elements, such as silicon.

- Alloying with this high carbon content leads to decreasing the melting temperatures (1150-1300°C), and increase the fluidity than steels. Thus they are easy to cast.

- Cast iron can be classified based on the shape of the carbon present:

- Gray Cast Iron - Ductile (or Nodular) Cast Iron - White Cast Iron - Malleable cast iron

Fe-C alloys classification

III) Cast irons:

1) Gray Cast Iron

➢In which the carbon exists in the form of **graphite flakes**, which are surrounded by either ferrite or pearlite matrix structure, depending on the cooling rate and/or heat treatment.

➢It is called gray cast iron because its fracture surface appears gray because of the presence of graphite flakes.

Fe-C alloys classification

III) Cast irons:

1) Gray Cast Iron

- It is obtained by slow cooling of the liquid alloy.

- Alloying addition of Si (1-3 wt.%) is responsible for decomposition of cementite, and also its high fluidity. Thus castings of intricate shapes can be easily made

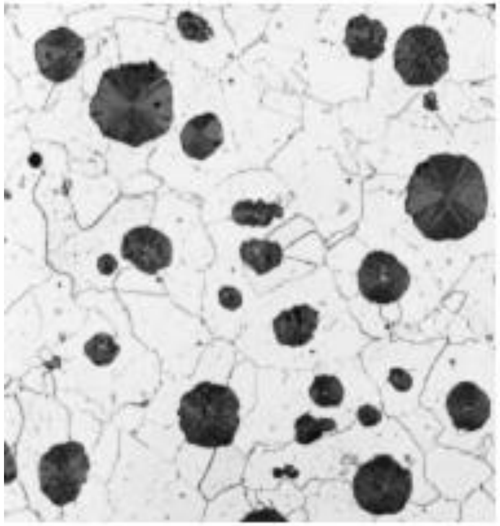
- Due to graphite flakes, **gray cast irons are weak and brittle** in tension. However they possess good damping properties, and thus typical applications include: base structures, bed for heavy machines, etc.

Fe-C alloys classification

III) Cast irons:

2) Ductile (or Nodular) Cast Iron

- This type can be obtained by **alloying the gray cast iron melt with small additions of Mg (0.05 wt.%) before pouring during casting.** This results in graphite to form as nodules or **sphere-like particles** in stead of flakes.
- Matrix surrounding these particles can be either ferrite or pearlite depending on the heat treatment and cooling rate.
- Stronger and ductile than gray cast irons.
- Typical **applications** include: pump bodies, gears, crank shafts, automotive components, etc



Fe-C alloys classification

III) Cast irons:

3) White Cast Iron

- In which the **carbon present in the form of carbide (Fe_3C).** When Si content is low (< 1%) in combination with **faster cooling rates**, there is no time left for cementite to get decomposed, thus most of the cementite retains.

- It is called white cast iron because its fracture surface appears white because of presence of cementite.

Fe-C alloys classification

III) Cast irons:

3) White Cast Iron

- They are very **brittle and extremely difficult to machine.** Hence their use is limited to **wear resistant applications** such as rollers in **rolling mills**.

- Usually white cast iron is heat treated to produce malleable iron

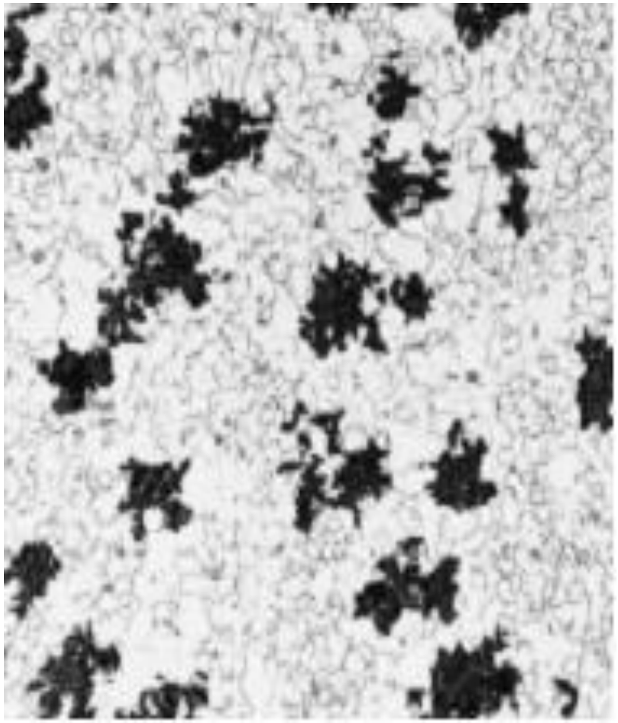
Fe-C alloys classification

III) Cast irons:

4) Malleable cast iron

- This type can be obtained by heat treating of **white cast iron**.

- Heat treatments involve heating the white iron alloy up to 800-900°C, and keep it for long hours, before cooling it to room temperature. This long time at high temperature causes cementite to decompose and form ferrite and graphite **(in the form of rosettes).**



Fe-C alloys classification

III) Cast irons:

4) Malleable cast iron

- The surrounding matrix type depends on the cooling rate after heat treatment. (Fig.)

- Thus these alloys are stronger with appreciable amount of ductility.

- Typical applications include: connecting rods, marine and other heavy-duty services.

Thanks