Iron-Carbon Phase Diagram

Its defined as:-

A map of the temperature at which different phase changes occur on very slow heating and cooling in relation to Carbon content . is Isothermal and continuous cooling transformation diagrams for plain carbon and alloy steels.

Iron- Carbon diagram shows

1- the type of alloys formed under very slow cooling.
2- Proper or (suitable) heat-treatment temperature .
3- the properties of steels and cast irons can be depend on changed by heat-treatment.

In their simplest form, ***steels are alloys of Iron (Fe) and Carbon (C).***

Notes: -

This graph, which is known as iron- carbon equilibrium diagram has the following important points: -

1- The percentage of carbon is between 0% and 6.67%. Because:-

- 6.67 % carbon is maximum ratio of carbon can be dissolved in iron.
- after 6.67 % carbon , all metallic alloys are non-important alloys in engineering applications .

2- Iron contains from (0% to 1.7% C) known as steel.

3- Steel contains below approximately (0% to 0.83 % C) known as ***hypoeutectoid steel*** consist of primary ***ferrite and pearlite phases .***

4- **Eutectoid steel** (carbon content 0.83%) entirely consists of ***pearlite***.

5- steel contains from (0.83% to above 1.7 % C) known as ***hypereutectoid steel*** consist of primary ***cementite and pearlite*** phases .

6- Iron contains carbon more than 1.8 % C known as ***cast iron***.

There are two iron-carbon equilibrium diagrams:

1- stable iron-graphite Fe-Gr.

The stable condition usually takes a very long time to develop.

2- metastable iron-cementite Fe-Fe_3C

While The metastable diagram is of more interest or important .

The Iron–Iron Carbide (Fe–Fe_3C) Phase Diagram

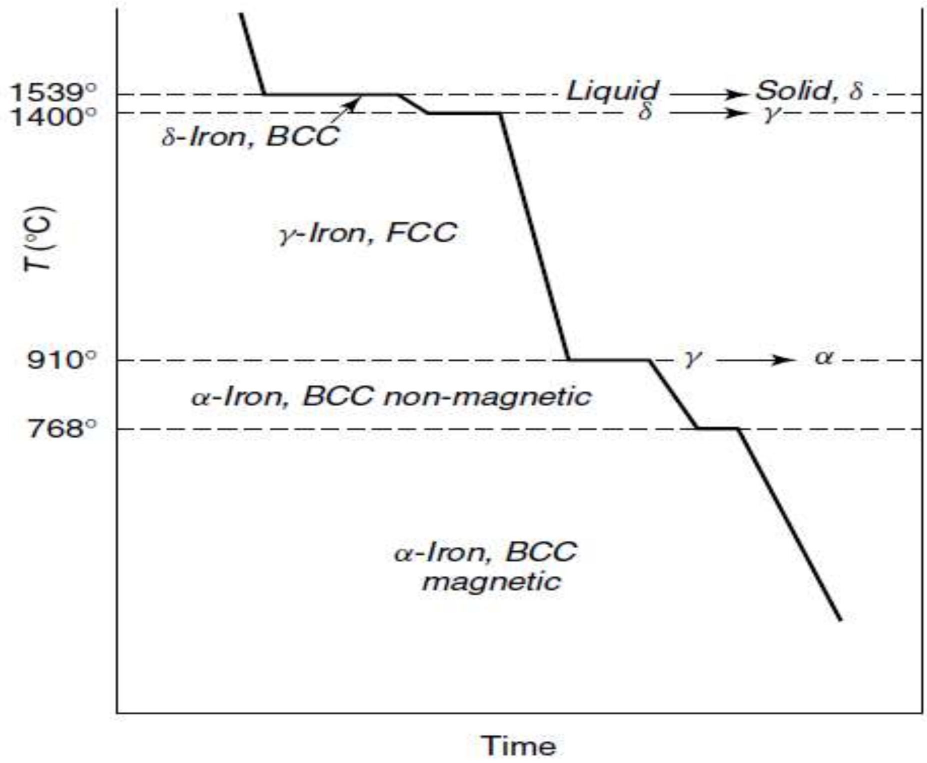
- The iron at room temperature to 912 $\overset{o}{C}$, was stable and called as (Alpha iron) or (α- ferrite), and have a body center cubic structure (BCC) **, is ductile but not very strong.** .

- After 912 C^0 to 1395 C^0 , the structure transform to a face center cubic structure (FCC) and form new phase called as (Camma iron) or (γ-Austenite) .

- From 1395 C^0 to 1539 C^0 , the structure transform to a body center cubic (BCC) and form new phase called as (Delta iron) or (δ-ferrite) .

- 1539 C^0 is melting point of iron , and after this degree the iron transform to liquid phase .

Cooling Curve of pure iron :-



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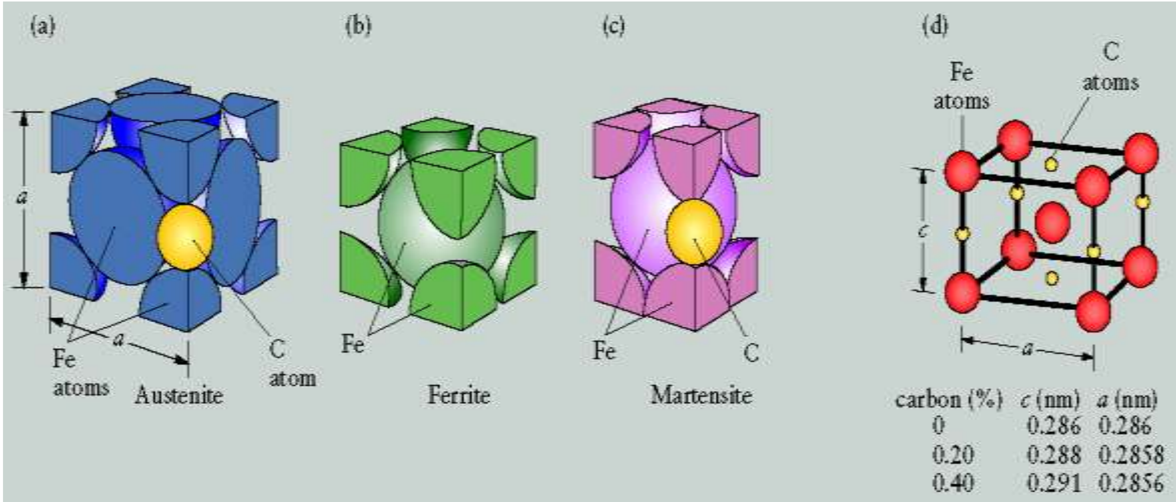
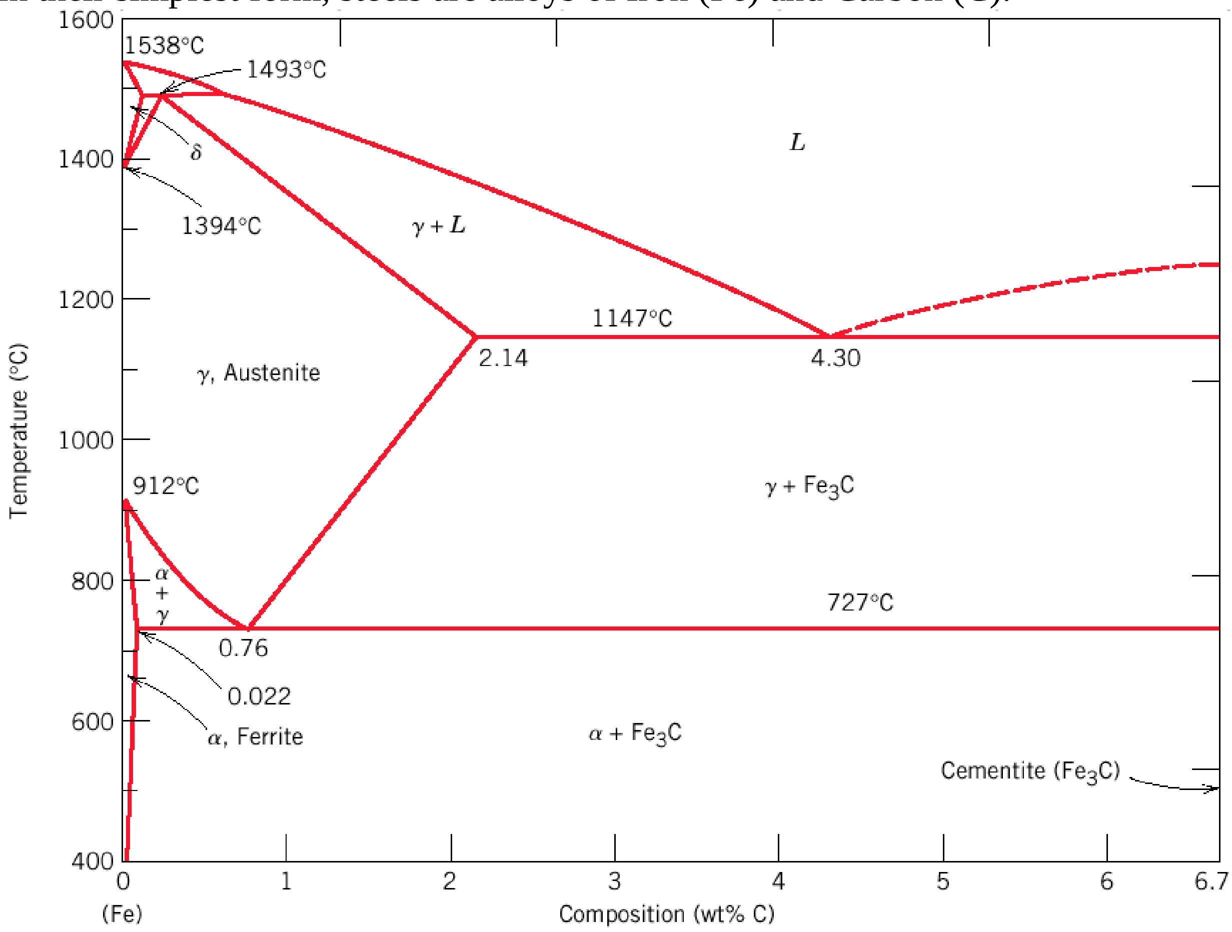


FIGURE - The unit cell for (a) austentite, (b) ferrite, and (c) martensite. The effect of the percentage of carbon (by weight) on the lattice dimensions for martensite is shown in (d). Note the interstitial position of the carbon atoms and the increase in dimension *c* with increasing carbon content. Thus, the unit cell of martensite is in the shape of a rectangular prism.

In their simplest form, steels are alloys of Iron (Fe) and Carbon (C).



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

1-First horizontal line is about at 1493 °C, where ***peritectic reaction*** takes place:

Liquid + δ ↔ austenite

2-Second horizontal line is at about (1130°C to 1147C) , where ***eutectic reaction*** takes place:

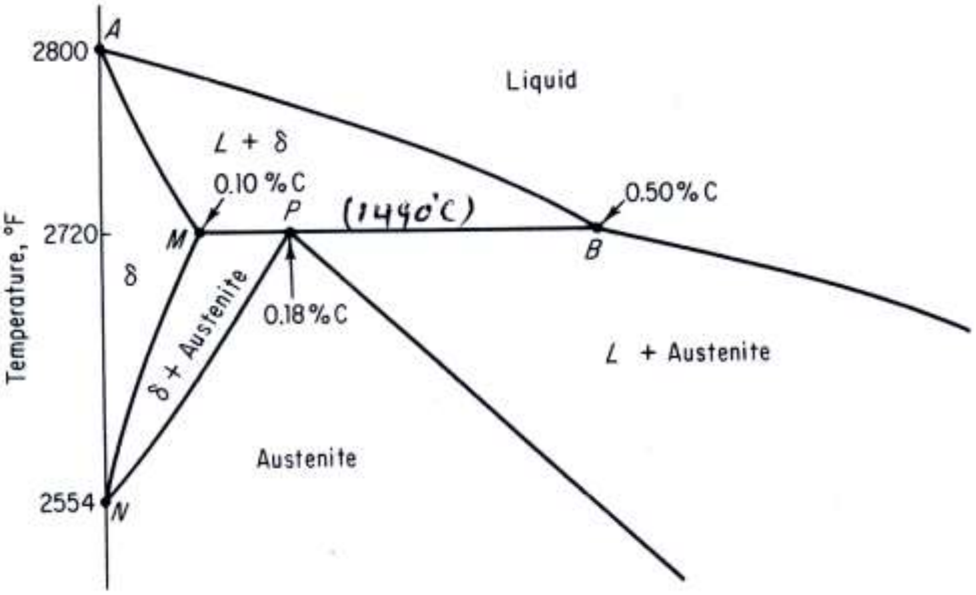
liquid ↔ austenite + cementite

3-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

Liquid + δ ↔ austenite



Phases in Iron Carbon Phase Diagram

1- α-**ferrite**

- ***interstitial*** solid solution of Carbon in BCC iron (Fe).
- Stable form of iron at room temperature to 912 C.
- The maximum solubility of Carbon is 0.022 wt% at 727°C .
- Transforms to FCC γ-austenite phase at 912 °C.
- it dissolves only 0.008 % C at room temperature..

Properties it is ductile, highly magnetic and it has a low tensile strength of approximately 2800 Kg/cm^2. Its soft phase.

2- γ-**austenite**

- ***interstitial*** solid solution of Carbon in FCC Fe.
- The maximum solubility of Carbon is 2.14 wt % at 1147°C .
- Transforms to BCC δ-ferrite at 1395 °C.
- Is not stable below the eutectic temperature (727 ° C) unless cooled rapidly.
- It is stable above 727°C .
- This phase plays an important role in the phase transformations of steels.
- 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**.**
- FCC structure

Properties it is generally soft, ductile, non- magnetic and it is denser than ferrite.

Summary of austenite transformations

1- Austenite…… slow cooling ………… Pearlite (α + Fe_3C) .
2- Austenite…… moderate cooling……. Bainite (α + Fe_3C).
3- Austenite ……rapid quenching………martensite (BCT phase).

3- δ-**ferrite**

- **solid solution of Carbon in BCC Fe**
- The same structure as α-ferrite.
- Stable only at high Temperature , above 1395 °C.
- Melts at 1539 °C.
- Maximum carbon solubility: 0.09-0.10 wt.%.
- BCC structure
- Paramagnetic

4- *Cementite(Fe_3C)*

- This intermetallic compound is metastable,
- It is a product which contains 6.67% carbon and 93.33% iron by weight.
- It is found in steel containing over 0.8% carbon when it cools .
- The amount of cementite increase with increasing the percentage of carbon in iron.
- is very hard, brittle intermetallic compound of iron & carbon , can strengthen steels , with chemical formula **Fe_3C .**
- as Fe_3C, contains 6.67 % C.

- It is the hardest structure that appears on the diagram, exact melting point unknown.
- Its crystal structure is orthorhombic.
- It is has
  - low tensile strength (approx. 5,000 psi), but
  - high compressive strength.

5- ***Pearlite***

- is a structure (i.e. consists of two phases) consists of alternate layers of ***ferrite and cementite*** in the proportion 87:13 by weight.
- formed from austenite at eutectoid temperature (A_1) 727°C upon slow cooling**.**
- Pearlite is the eutectoid mixture containing 0.80 % C and is formed at 723°C on very slow cooling.
- It is a very fine plate like or lamellar mixture of ferrite and cementite.

Properties it is strong metal phase, may be cut reasonably well with cutting tool and it has tensile strength of 8750 Kg/cm^2.

6-Ledeburite

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

7-***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 (growth less).

Note :-

- Steel with 0.8% carbon is wholly pearlite phase only.

- steel contains less than 0.8% carbon containing ferrite + pearlite which is hard.
- Steel contains more than 0.8% carbon and (pearlite + cementite).

Reactions in Iron Carbon Phase Diagram

There are ***Three*** Phase Reactions:-

1- Eutectoid reactions **:**

0.76 wt% Carbon , at 727 °C

γ(0.76 wt% C) $\leftrightarrow$ α (0.022 wt% C) + Fe_3C

in Eutectoid reaction , the two-phase mixture (ferrite & cementite). They are steels.

2- ***Eutectic reactions*** **:**

4.30 wt% Carbon , at 1147 °C

L $\leftrightarrow$ γ + Fe_3C
In Eutectic reaction , alloys called cast irons.

Eutectic and ***eutectoid*** reactions are very important in heat treatment of steels.

3- Peritectic
L + δ = γ

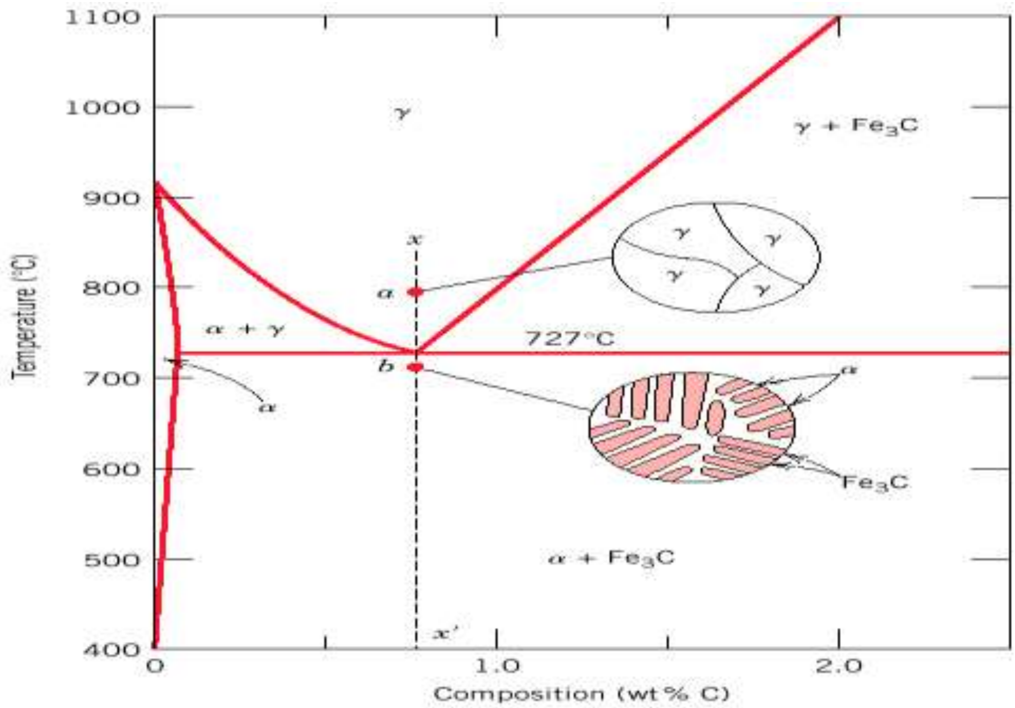
Peritectic reaction , at 1493 deg.C, with low wt% C alloys (almost no engineering importance).

Development of Microstructure in Iron - Carbon alloys

Microstructure depends on ***composition (carbon content)*** **and** ***heat treatment***. In the discussion below we consider slow cooling in which equilibrium is maintained.

1- Microstructure of eutectoid steel

0.76 wt%C, 727 °C
γ(0.76 wt% C) $\leftrightarrow$ α (0.022 wt% C) + Fe_3C

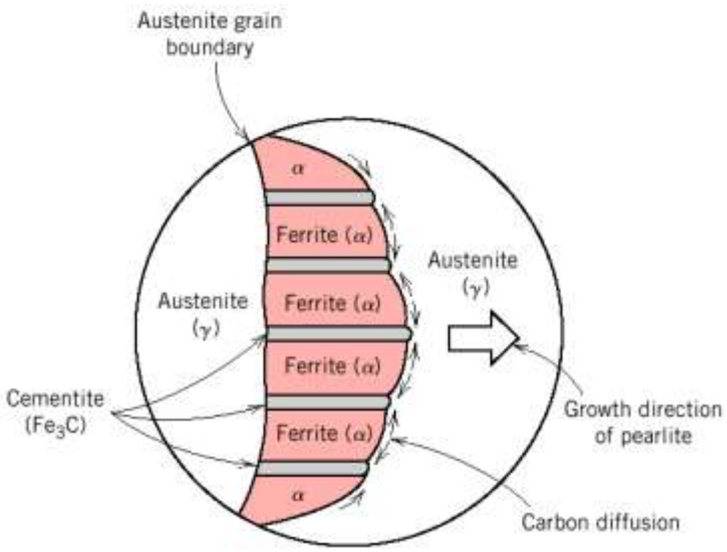


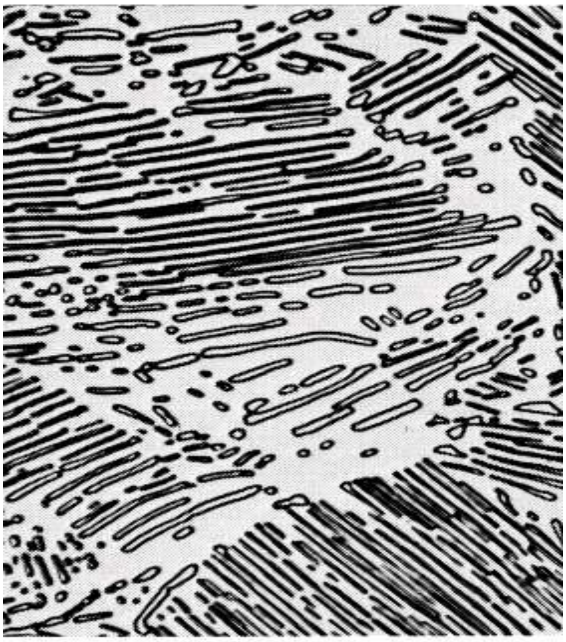
When alloy of eutectoid composition (0.76 wt % C) is cooled slowly it forms ***perlite***, a lamellar or layered structure of two phases: ***α-ferrite and cementite (Fe_3C).***

The layers of alternating phases in pearlite are formed for the same reason as layered structure of eutectic structures: ***redistribution C atoms between ferrite (0.022 wt%) and cementite (6.7 wt%) by atomic diffusion.***

Mechanically, pearlite has properties intermediate to soft, ductile ferrite and hard, brittle cementite.

In the micrograph, the ***grey areas are Fe_3C layers, the red phase is α-Ferrite***

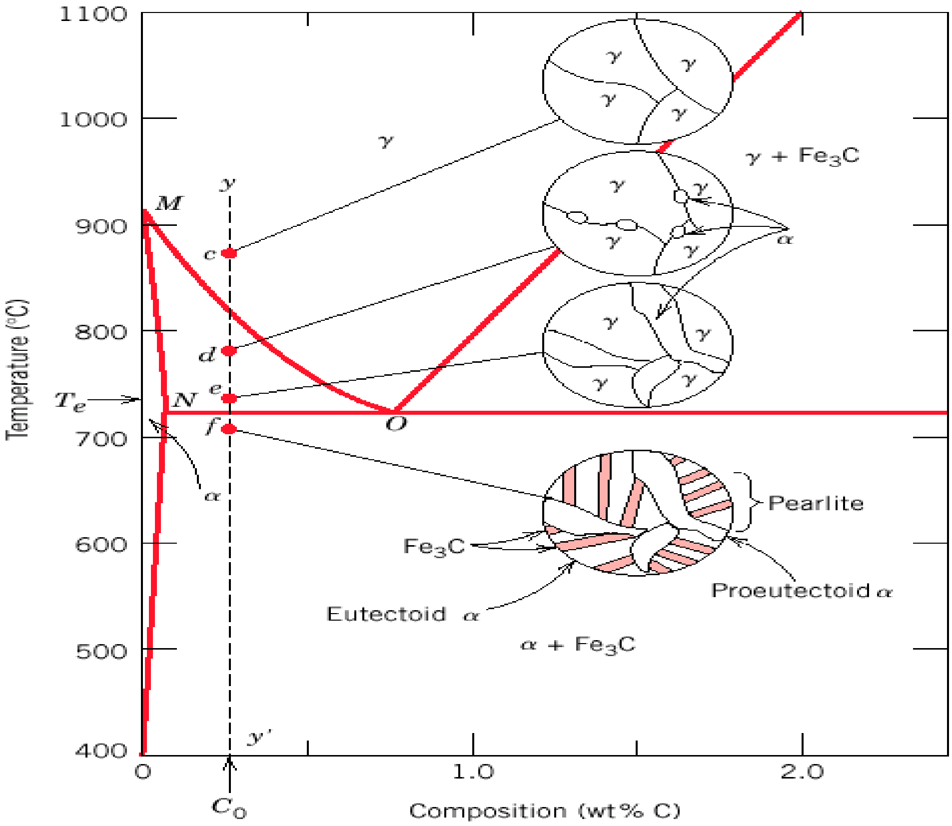




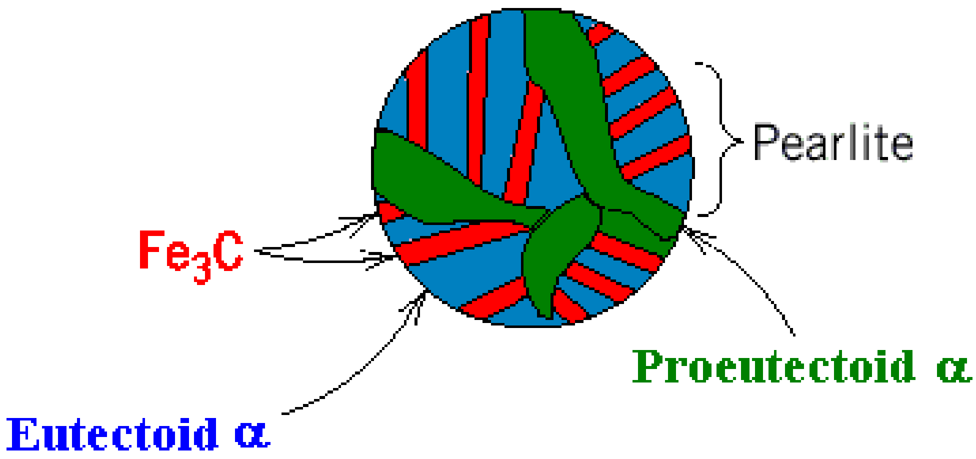
2- Microstructure of hypoeutectoid steel

Compositions to the left of eutectoid (0.022 - 0.76 wt % C)
hypoeutectoid (*less than eutectoid*) alloys.

$\gamma \rightarrow \alpha + \gamma \rightarrow \alpha + \boldsymbol{Fe_3C}$



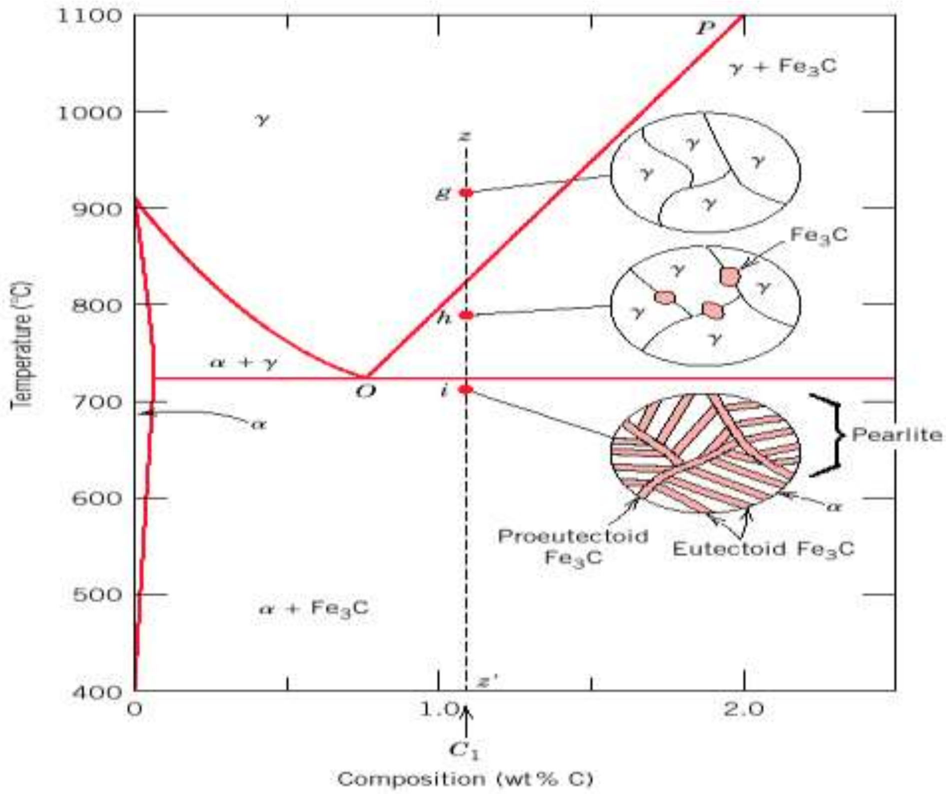
Hypoeutectoid alloys contain proeutectoid ferrite (formed above the eutectoid temperature) plus the eutectoid perlite that contain eutectoid ferrite and cementite.



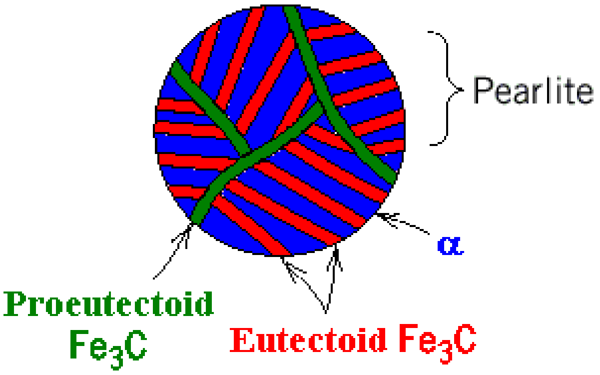
<u>3- Microstructure of hypereutectoid steel</u>

Compositions to the right of eutectoid (0.76 - 2.14 wt % C)
Hypereutectoid (*more than eutectoid*) alloys.

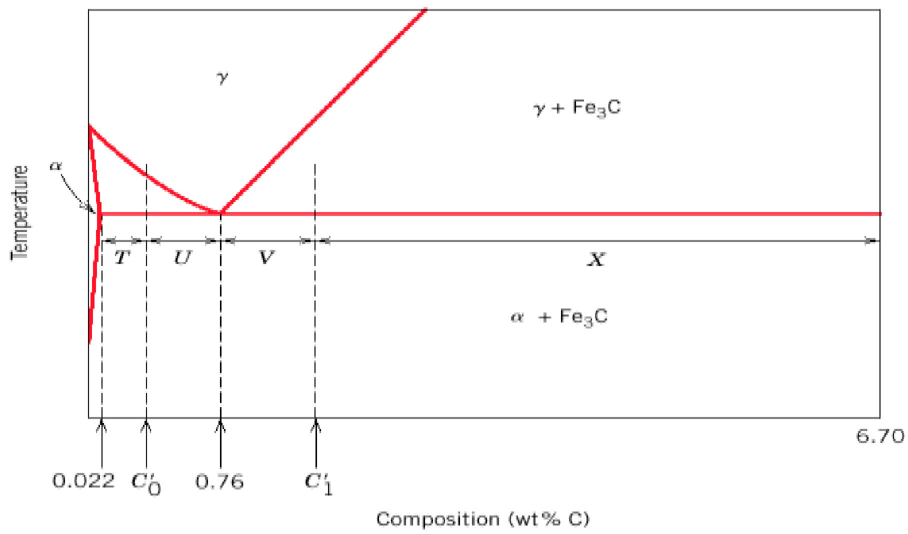
$\gamma \rightarrow \gamma + \mathbf{Fe_3C} \rightarrow \alpha + \mathbf{Fe_3C}$



Hypereutectoid alloys contain proeutectoid cementite (formed above the eutectoid temperature) plus perlite that contain eutectoid ferrite and cementite



<u>How to calculate the relative amounts of eutectoid phase (α or Fe_3C) and pearlite</u>?



Fraction of α phase is determined by application of the lever rule across the entire (α + Fe_3C) phase field:

Example for hypereutectoid alloy with composition C1

<u>Fraction of pearlite (liquid):-</u>

$$W_l = \frac{C_\alpha - C_\circ}{C_\alpha - C_l} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots..(5)$$

W_P = (6.7 – C1) / (6.7 – 0.76)

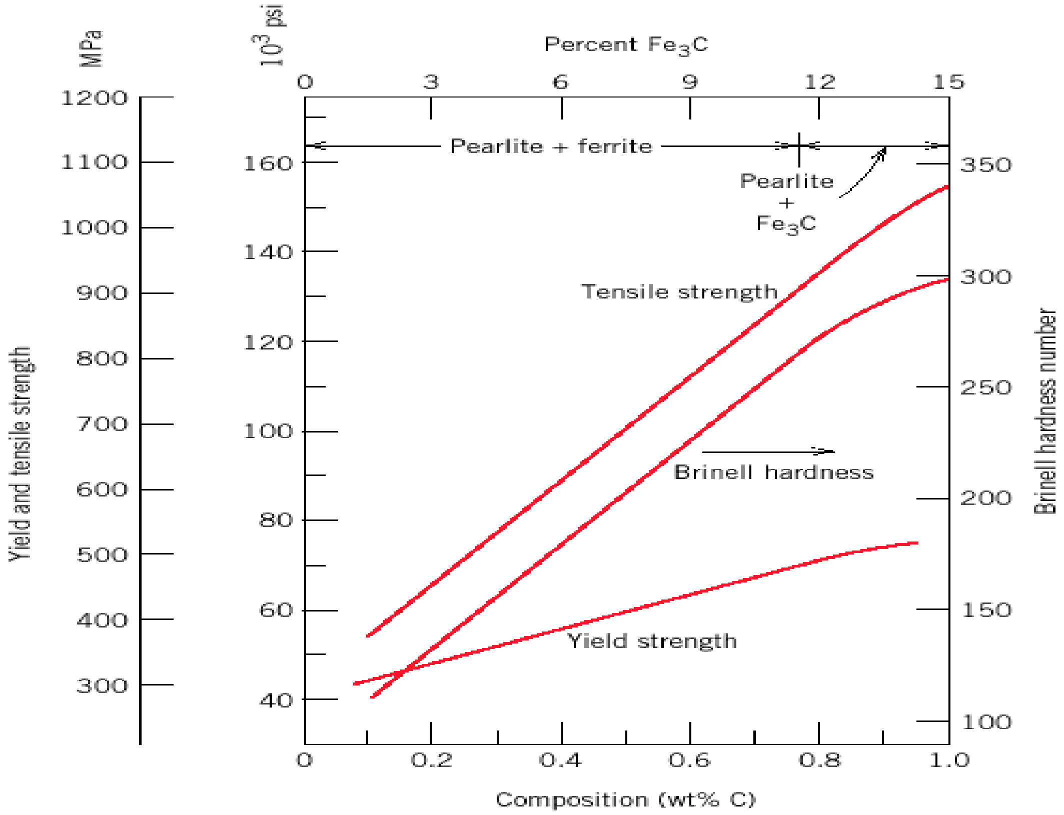
<u>Fraction of proeutectoid cementite:</u>

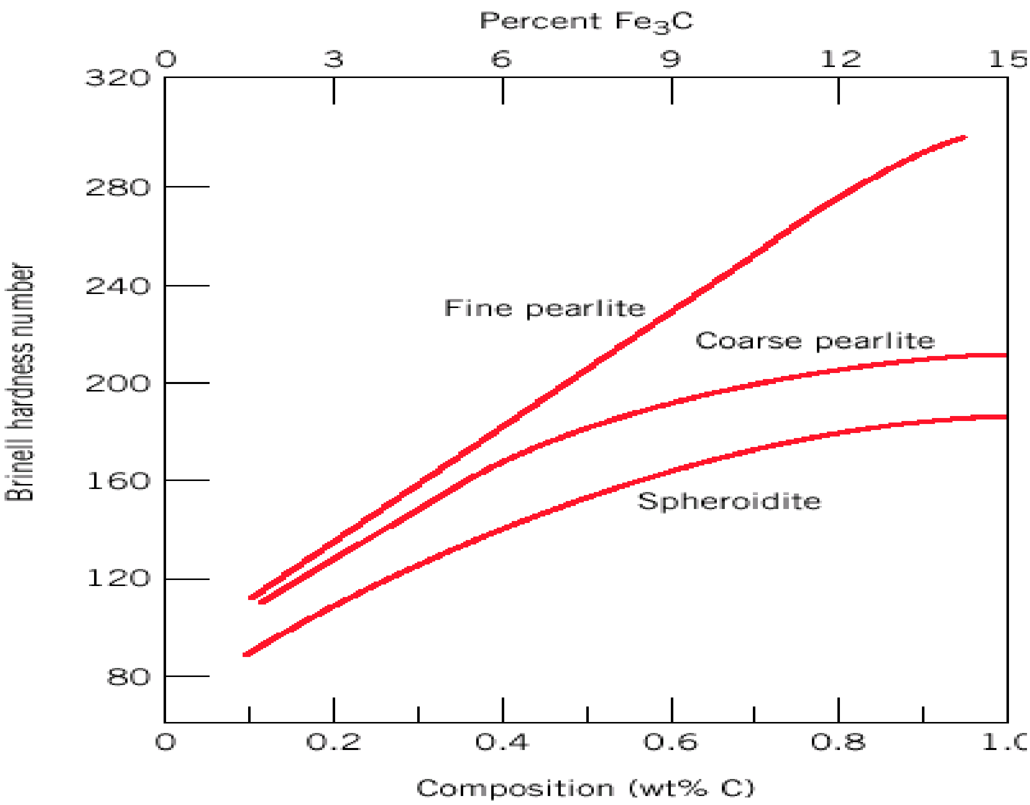
$$W_\alpha = \frac{C_\circ - C_l}{C_\alpha - C_l}$$

W_{Fe3C} = (C1 – 0.76) / (6.7 – 0.76)

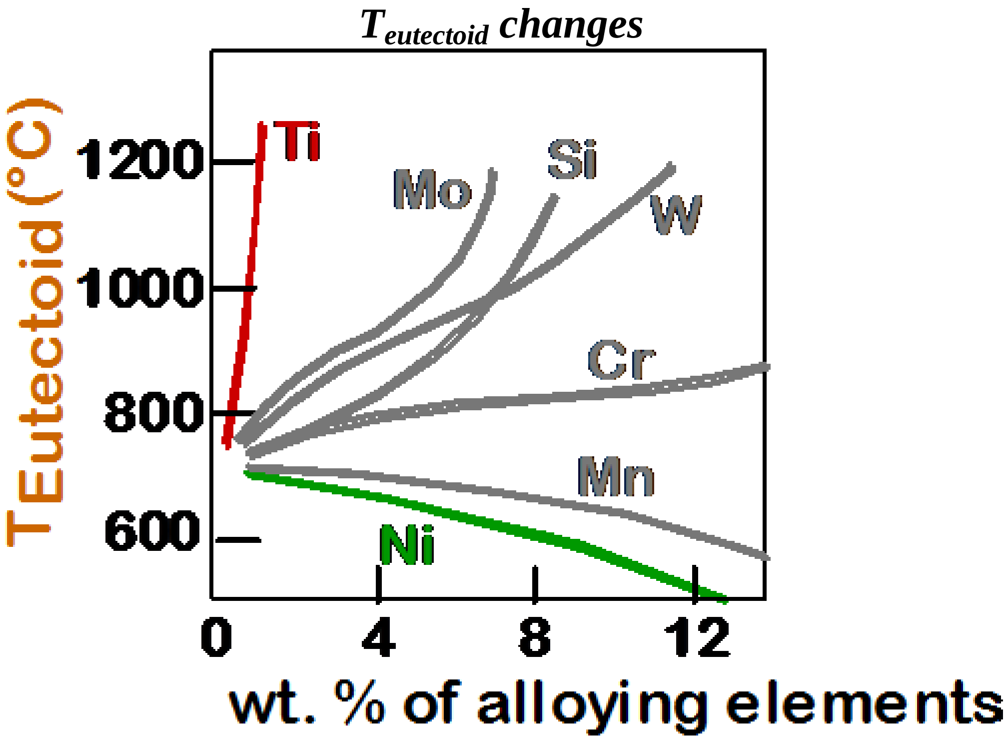
Mechanical Behavior of Fe-C Alloys (I)

Cementite is harder phase and more brittle than ferrite .
increasing cementite fraction therefore makes harder, less ductile material





Effect of Alloying Steel with more Elements:-



Limitations of equilibrium phase diagram

- $Fe\text{-}Fe_3C$ equilibrium / metastable phase diagram.
- Stability of the phases under equilibrium condition only.
- It does not give any information about other metastable phases. i.e. bainite, martensite.
- It does not indicate the possibilities of suppression (reduced) of proeutectoid phase separation.
- No information about kinetics energy.
- No information about size.
- No information on properties.