# Iron – Carbon System

iron–carbon phase diagram is presented in Figure 1. Pure iron, upon heating, experiences two changes in crystal structure before it melts. At room temperature the stable form, called **ferrite,** or iron, has a BCC crystal structure. Ferrite experiences a polymorphic transformation to FCC **austenite,** or iron, at (912 °C). This austenite persists to (1394 °C), at which temperature the FCC austenite reverts back to a BCC phase known as d ferrite, which finally melts at (1538 °C). All these changes are apparent along the left vertical axis of the phase diagram.

Regions of Fe-C phase diagram

1- **Iron:** less than 0.008 wt % C in $\alpha -$ferrite at room T
2- **Steels:** 0.008 - 2.14 wt % C (usually < 1 wt % )
3- **Cast iron:** 2.14 - 6.7 wt % (usually < 4.5 wt %)

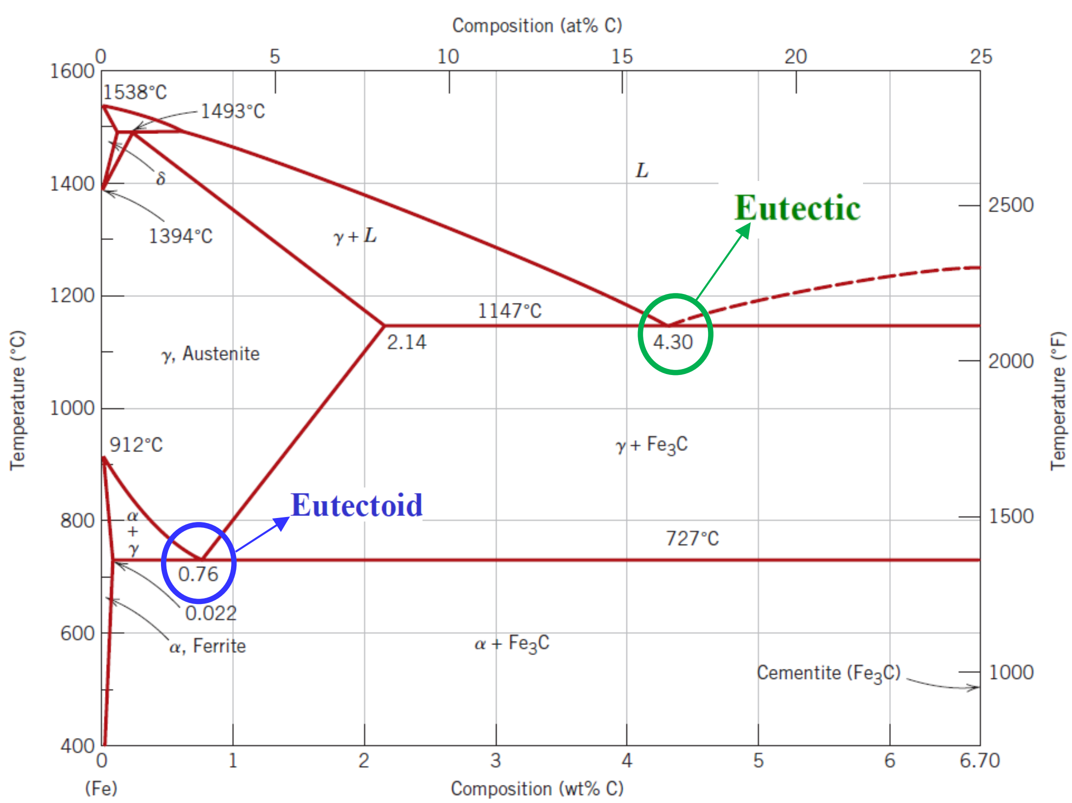
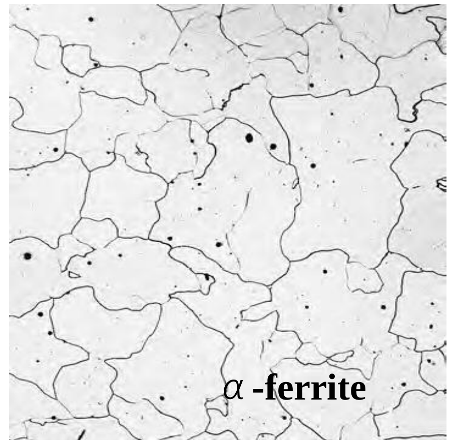
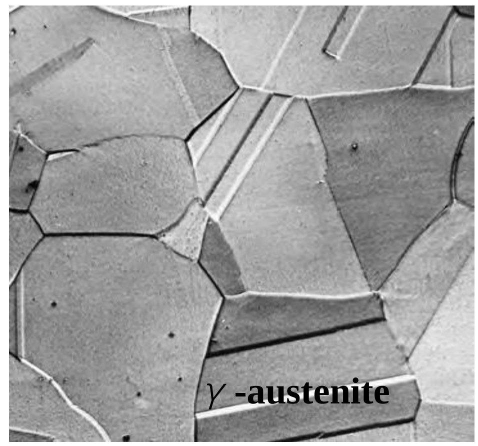



**Figure 1** The iron–iron carbide phase diagram.

# Phases in Fe–$Fe_3C$ Phase Diagram




### 1- α -ferrite - solid solution of C in BCC Fe

- Stable form of iron at room temperature.
- The maximum solubility of C is 0.022 wt%
- Transforms to FCC γ -austenite at 912 ° C

### 2- γ -austenite - solid solution of C in FCC Fe

- The maximum solubility of C is 2.14 wt %.
- Transforms to BCC δ -ferrite at 1395 ° C
- Is not stable below the eutectoid temperature (727 ° C) unless cooled rapidly (Chapter 10)

### 3- δ -ferrite solid solution of C in BCC Fe

- The same structure as α -ferrite
- Stable only at high T, above 1394 ° C
- Melts at 1538 ° C

### 4- Fe3C (iron carbide or cementite)

- This intermetallic compound is metastable, it remains as a compound indefinitely at room T, but decomposes (very slowly, within several years) into α -Fe and C (graphite) at 650 - 700 ° C

# Three invariant reaction in Fe -Fe3C phase diagram

- Peritectic reaction:

$$S + L \rightarrow S_1$$

- Eutectic reaction:

$$L \rightarrow S_1 + S_2 \qquad L \leftrightarrow \gamma + Fe_3C$$

- Eutectoid reaction:

$$S \rightarrow S_1 + S_2 \qquad \gamma \leftrightarrow \alpha + Fe_3C$$

## **Development of microstructure in iron–carbon alloys**.

Microstructure depends on composition (carbon content) and heat treatment.

## Microstructure of eutectoid Alloys

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

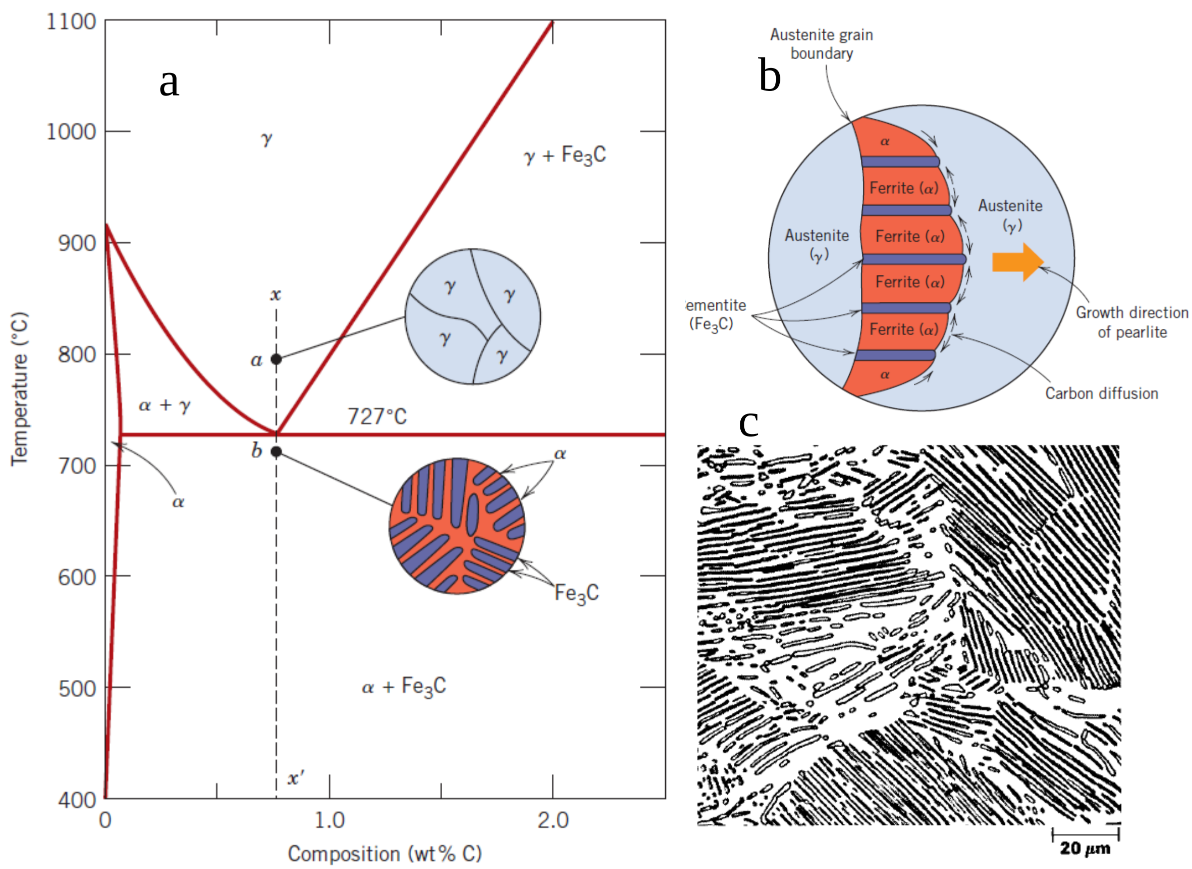



**Figure 2 (a)** Schematic representations of the microstructures for an iron–carbon alloy of eutectoid composition (0.76 wt% C) above and below the eutectoid temperature. (b) Schematic representation of the formation of pearlite from austenite (c) pearlite microstructure

## Microstructure of hypoeutectoid Alloys

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

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

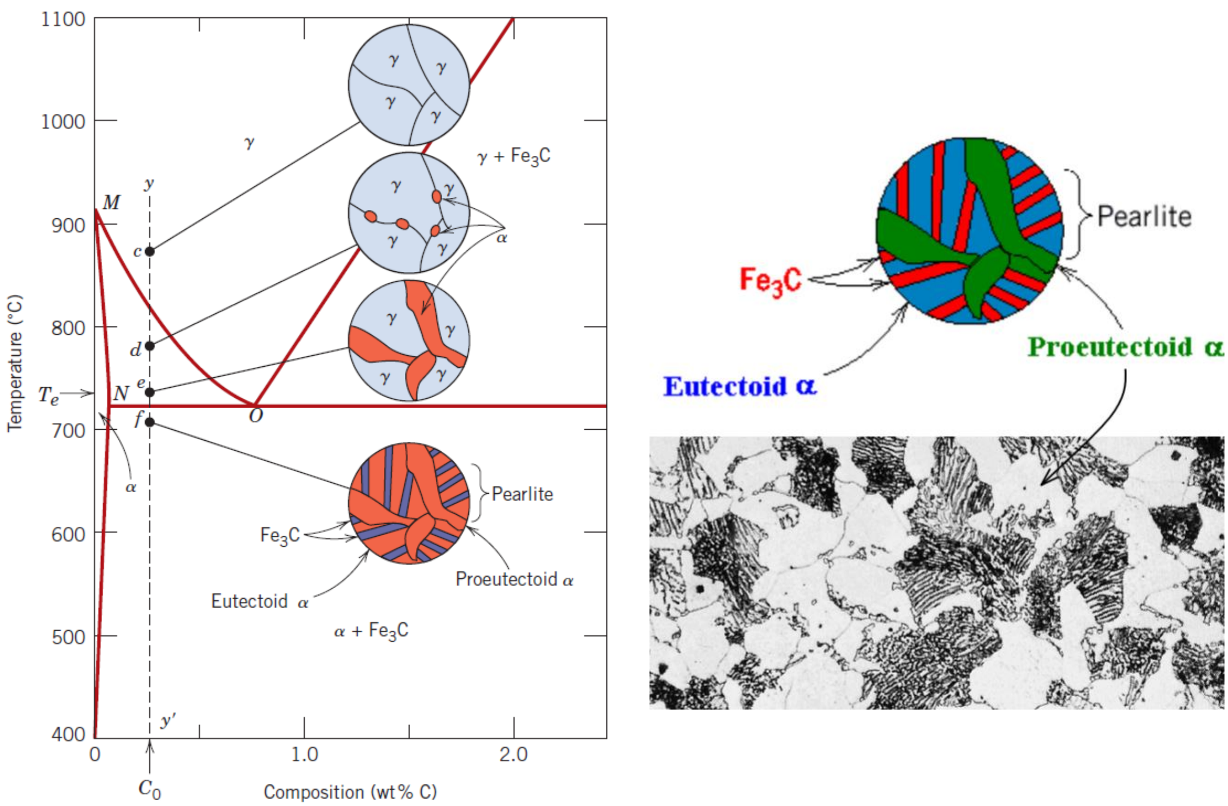



**Figure 3** Schematic representations of the microstructures for an iron–carbon alloy of hypoeutectoid composition (containing less than 0.76 wt% C) with the Photomicrograph of a 0.38 wt% C steel having a microstructure consisting of pearlite and proeutectoid ferrite

## Microstructure of hypereutectoid Alloys

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

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

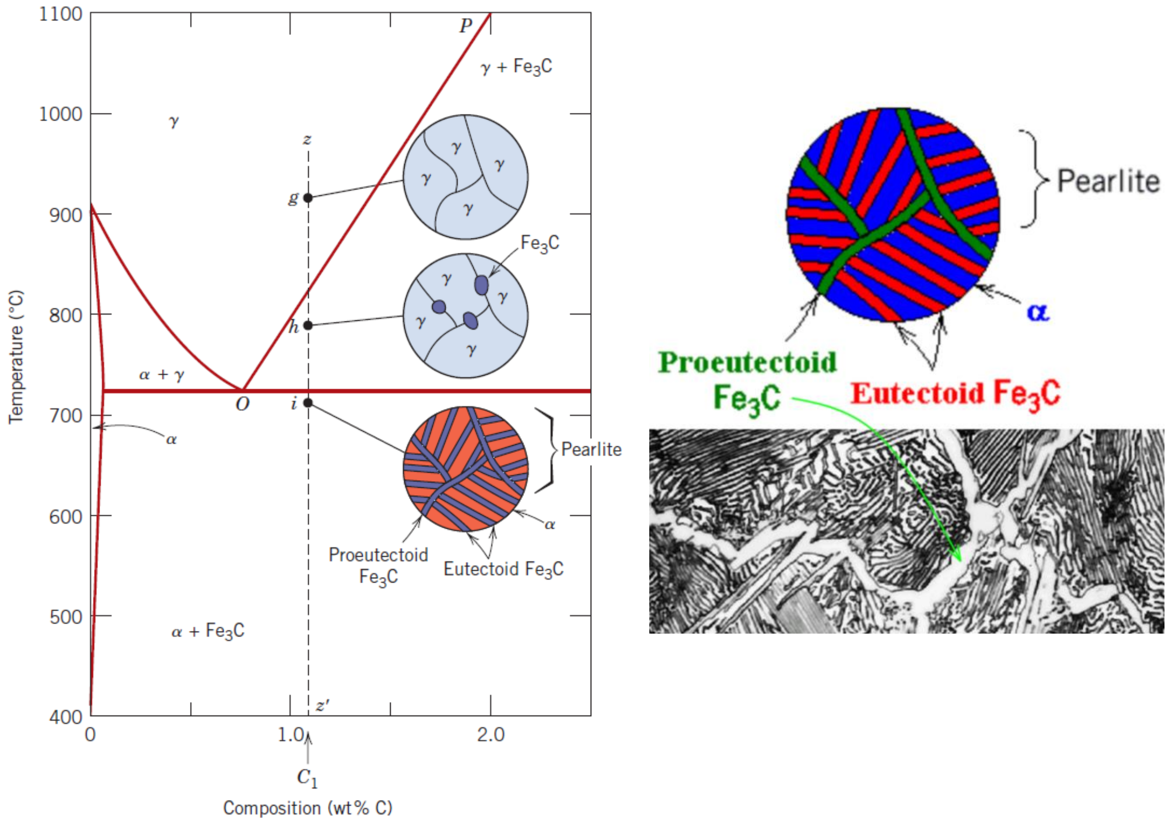



**Figure 4** Schematic representations of the microstructures for an iron–carbon alloy of hypereutectoid composition (containing between 0.76 and 2.14 wt% C) with Photomicrograph of a 1.4 wt% C steel having a microstructure consisting of a white proeutectoid cementite network surrounding the pearlite colonies.

# Steel

## Introduction:-

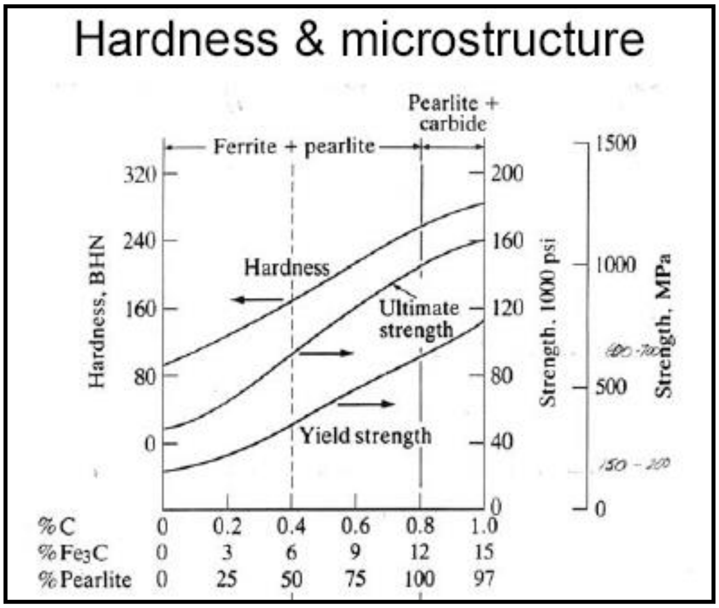
As defined earlier, Steel is an alloy of iron that contains carbon ranging by weight between 0.02% and 2.11% (most steels range between 0.05% and 1.1%C). Steels are very versatile; they can be formed into desired shapes by plastic deformation produced by processes such as rolling and forging; they can be treated to give them a wide range of mechanical properties which enable them to be used for an enormous number of applications.

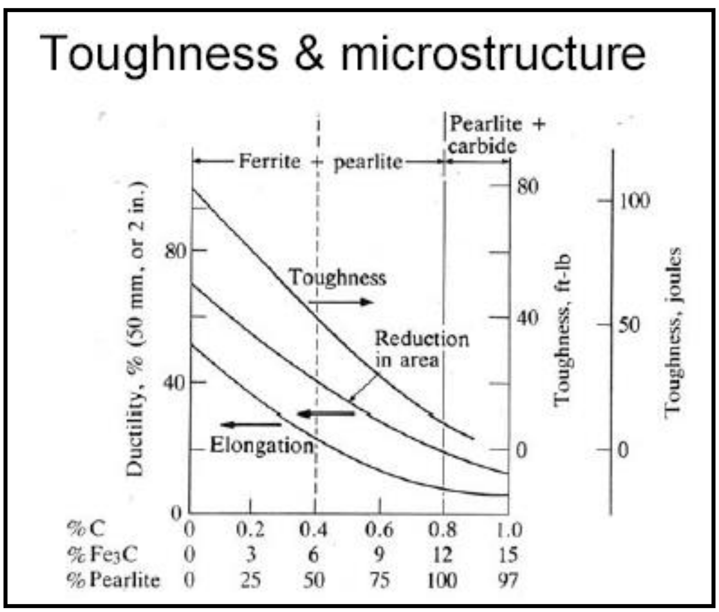
Steels can be divided into two main groups:
1- plain carbon steels
2- alloy steels.

## Plain carbon steels: -

Plain carbon steel is essentially an alloy of iron and carbon, which also contains manganese and a variety of residual elements.
The American Iron and Steel Institute (AISI) has defined a plain carbon steel to be an alloy of iron and carbon which contains specified amounts of Mn below a maximum amount of 1.65 wt. %, less than 0.6 wt. % Si, less than 0.6 wt. % Cu and which does not have any specified **minimum** content of any other deliberately added alloying element. It is usual for **maximum** amounts (e.g. 0.05 wt. %) of S and P to be specified.

Classification of plain carbon steel according to carbon percentage**:**
1- **Low carbon steel** : - %C < 0.3
also called Mild Steel, which used in cold forming to produce strips, rods, tubes, rivets, etc.
2- **Medium carbon steel** : - 0.3 < %C < 0.6
used in manufacturing of shaft, gears, connecting rods, etc.
3- **High carbon steel** : - 0.6 < %C < 1.4
used in manufacturing of small cutting tools (carbon tool steel), dies, railway, etc.


Hardness & microstructure
Pearlite + carbide
Ferrite + pearlite
Hardness, BHN
320
240
160
80
0
Hardness
Ultimate strength
Yield strength
200
160
120
80
40
0
Strength, 1000 psi
1500
1000
500
0
Strength, MPa
%C 0 0.2 0.4 0.6 0.8 1.0
%$Fe_3C$ 0 3 6 9 12 15
%Pearlite 0 25 50 75 100 97


Toughness & microstructure
Pearlite + carbide
Ferrite + pearlite
Ductility, % (50 mm, or 2 in.)
80
40
0
Toughness
Reduction in area
Elongation
80
40
0
Toughness, ft-lb
100
50
0
Toughness, joules
%C 0 0.2 0.4 0.6 0.8 1.0
%$Fe_3C$ 0 3 6 9 12 15
%Pearlite 0 25 50 75 100 97

# Alloy steels

If one or more additional elements are deliberately added to produce specified minimum contents then the product is alloy steel.
Can be classified alloy steels according to important property or on the basis use: -

**1- Structural alloy steel**
steel containing elements such as Mo, W, Si, Cr, Mn which increasing the tensile strength, impact strength, and hardness

**2- Alloy tool steel**
the basic requirement for tool steel are:
- high hardness at service temperature
- wear resistance
- impact strength
- harden ability
- dimensional stability
- oxidation resistance

**3- Stainless Steel**
steels containing more than 12% Cr. This is because a minimum of 12%Cr is required for conferring sufficient corrosion resistance to steels by forming a passive oxide film on the surface.
St. St. are classified into three main groups depending upon their crystal structure at room temperature.
- Ferritic grade
- Martensitic grade
- Austenitic grade

**4- High temperature resistance steel**
steel containing Al and Cr which give the surface oxide prevent the steel from oxidation at high temperature, and this type of steel characteristic by:
- creep resistance
- vibration resistance
- corrosion resistance

**5- Magnetic steel**
- Non- Permanent magnetic steel: - containing Si and used in electric generators
- Permanent magnetic steel: - containing high percentage of C with other elements such as Co, Mo, W (used in some of electrical equipments)