Asst.Lecturer: Hiba Mohsin AL- bawi
E-mail: hiba.mohsin.abd@uomus.edu.iq

The Iron-Carbon Phase Equilibrium Diagram

Pure iron is a relatively soft, ductile low strength metal with few practical engineering applications. The addition of Carbon to pure iron increases strength and hardenability to useful levels. However it decreases ductility. The addition of Carbon influences the allotropic changes discussed previously. Since mechanical behavior is directly related to the phases present, it is important to study these phases and how they are influenced by temperature. A study of the Iron-Carbon phase diagram is used for this purpose. An Iron-Carbon phase diagram showing the phases present in any alloy containing up to **6%** Carbon is shown in figure 1.

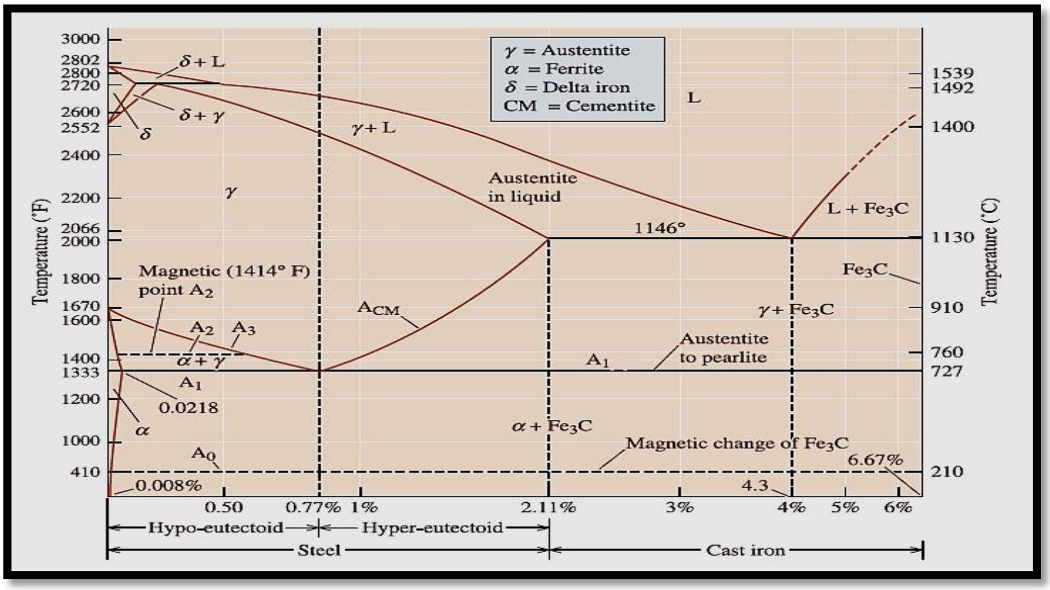


Figure 1. Iron-Carbon Equilibrium Diagram.

This phase diagram tells us the various phases a particular alloy of Iron and Carbon will go through when allowed cooling down to room temperature. In general iron carbon alloys up to **2%** are known as steels while from **2%** upwards the alloys are identified as cast iron. Our study mainly deals with the alloys up to **2%** carbon i.e. the steels part of the diagram, so we will move on to look at this section of the diagram.

The Steel Section of the Iron - Carbon Diagram

Shown here is the steel part of the iron carbon diagram containing up to **2%** Carbon. At the eutectoid point **0.83%** Carbon, Austenite which is in a solid solution changes directly into a solid known as Pearlite which is a layered structure consisting of layers of Ferrite and Cementite.

Plain Carbon Steel	*% of Carbon*
Dead Mild Steel(Low Carbon Steel)	0.05 - 0.15 % carbon
Mild Steel	0.10 - 0.30 % carbon
Medium Carbon Steel	0.30 – 0.50 % carbon
High Carbon Steel	0.50 - 0.90 % carbon
High carbon Steel (Tool Steel)	0.90 – 1.50 % carbon

Mechanical Properties and Application of Carbon Steel						
Type of steel	% carbon	BHN No.	Tensile Strength	Yield Strength	% elongation	% Reduction in area
Dead mild Steel	0.05-0.15	100-110	390	260	40	60
Uses: Chains, stampings, rivets, nails, seamwelded pipe, tin plates, automobile body. Steel and material subject to drawing and pressing.						
Mild Steel	0.10-0.30	120-150	420-555	355-480	36-21	66-55
Uses: Structural steels, universal beams, screw, drop forging,case hardening steel, gears free cutting steel, shaft.						
Medium Steel	0.30-0.50	150-350	700-770	550-580	18-20	51-53
Uses: Conecting rods, shafting, axles, crankhooks, forging, Gears, Dies, Rotors, Tyres, Wheels.						
High carbon	0.50-0.90	350-600	1200-665	750-645	10-12	35-33
Uses: Loco Tyres, rails, wire ropes, Drop Hammer Dies, Saws, Screw Drivers, Band Saw, Hammers, Laminated Springs, Cable wire, Large Dies for cold press, drills.						
Tool Steel	0.90-1.10	550-600	580	415	13	26
Uses:Axes kinves, drill, tapes, screws ring dies.						
High Carbon	1.10-1.50	600-750	500	375	13	20
Uses: Ball Bearing, files, broaches, boring and finishing tools, machine parts where resistance to were is essential.						

In order to fully understand the changes that occur in these different alloys of steels we will look at individual microstructures of common steel alloys. Here we see the various microstructures that exist in phases up to **2%** Carbon content.

Phases in Fe-Fe_3C Phase Diagram

A. α-Ferrite - Solid Solution of C in BCC Fe.

(**1**) Stable form of iron at room temperature, (**2**) The maximum solubility of **C** is (**0.022wt%**), (**3**) Transforms to FCC γ - austenite at (**912°C**).

B. γ- Austenite - Solid Solution of C in FCC Fe.

(**1**) The maximum solubility of C is (**2.14 wt %**), (**2**) Transforms to BCC δ - ferrite at (**1395°C**), (**3)** Is not stable below the eutectic temperature (**727°C**) unless cooled rapidly.

C. δ-Ferrite - Solid Solution of C in BCC Fe.

(**1**) The same structure as α - ferrite, (**2**) Stable only at high T, above (**1394°C**), (**3**) Melts at (**1538°C**).

D. Fe_3C (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**.

E. Fe-C Liquid Solution.

A few comments on Fe-Fe_3C system **C** is an interstitial impurity in Fe. It forms a solid solution with α, γ, **δ** phases of iron.

Maximum solubility in BCC α-ferrite is limited (max. **0.022 wt%** at **727°C**) - BCC has relatively small interstitial positions.

Maximum solubility in FCC austenite is (**2.14 wt%**) at (**1147°C**) FCC has larger interstitial positions.
Mechanical Properties: Cementite is very hard and brittle - can strengthen steels. Mechanical properties also depend on the microstructure, that is, how ferrite and cementite are mixed.

Magnetic Properties: α -ferrite is magnetic below (**768°C**), austenite (γ) is non-magnetic.

Classification of Ferrous Alloys

1. Iron: less than 0.008 wt % C in α-ferrite at room T.
2. Steels: (0.008 - 2.14) wt % C (usually < 1 wt %) α-ferrite + Fe_3C at room T.
3. Cast Iron: (2.14 - 6.7) wt % (usually < 4.5 wt %).

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.

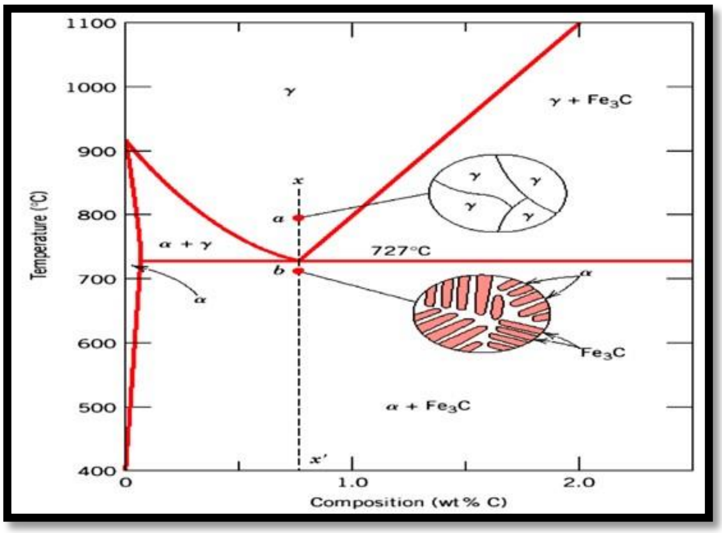


Figure 2. Microstructure depends on carbon content.

EXAMPLE.1

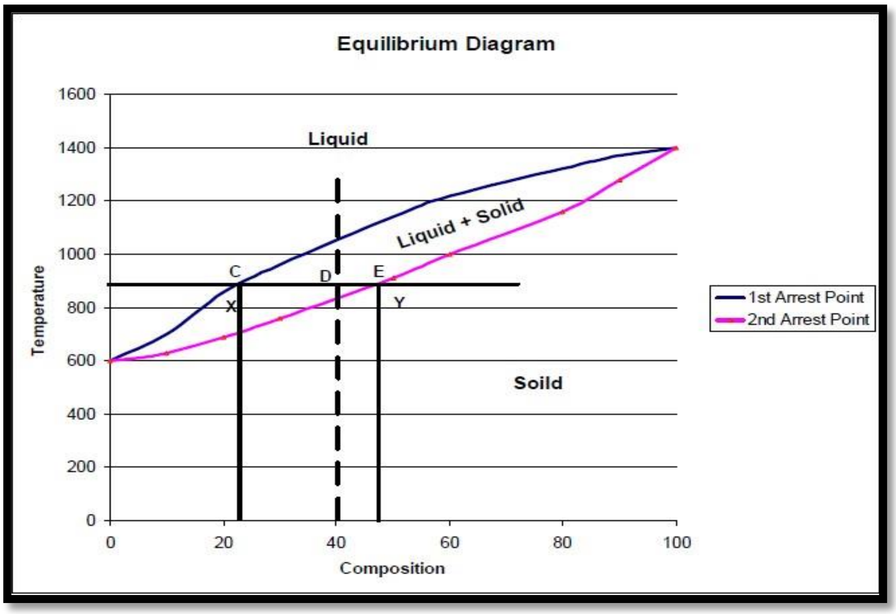
Metal (**A**) melts at (**1400**°C), Metal (**B**) melts at (**600°C**). Thermal arrest data is obtained from cooling curves for the alloy of (**AB**) is shown below.

%A	0	10	20	30	50	60	80	90	100
1st Arrest Point	600	700	860	960	1140	1220	1320	1370	1400
2nd Arrest Point	600	630	690	760	910	1000	1160	1280	1400

1. Plot and label the equilibrium diagram.
2. For an alloy containing (**40%**) **A** and (**60%**) **B** state:
(a) Solidification beginning temperature.
(b) Solidification ending temperature.
(c) Composition of phases at (**900ºC**).
(d) The ratio of phases.

SOLUTION

1.



2.
(a) Solidification beginning at (1060ºC).
(b) Solidification ending at (840ºC).
(c) Composition of phases at (900ºC) = Liquid Point C = 25% A 75% B. Solid point E = 45% A and 65% B (d) Ratio is law of Lever rule.

Solid (S)% = [(40-25) / (48-25)] ×100
= 65.217 %
Liquid (L)% = [(48-40) / (48-25)] ×100
= 34.783 %

EXAMPLE.2

From the cooling curves of the various alloys of **Zinc** and **Cadmium** the following data were obtained,

%A	0	20	40	60	86	90	100
1st Arrest Point	419	392	345	308	266	290	321

2nd Arrest Point		266	266	266		266	

1. Draw and label the equilibrium diagram.
2. With reference to the cooling curve, describe the cooling of an alloy containing 30% cadmium: (a) Composition of the alloy at (**320ºC**).
   (b) Ratio of liquid to solid phase at (**320ºC**).
   (c) The proportion of eutectic in the final structure.

SOLUTION