

## **Basic Metallurgy**

Metals are the backbone of the engineering industry being the most important Engineering Materials. In comparison to other engineering materials such as wood, ceramics, fabric and plastics, these are used in

- Largest tonnage,
- Offers very wide range of properties and
- Highest possible strengths.

Engineer is mostly concerned with mechanical properties of the metals which he uses. However compositions, shaping history and heat-treatment have tremendous effect on the ultimate behavior of the alloys. Properties of the metals and alloys are in fact dependent on the internal structure of the metals.

Study of metallurgy helps in co-relating the behavior of the metals and alloys with the internal structure

**Metals are used by industry for either one or combination of the following properties**

- Mechanical strength
- Ductility & toughness
- Hardness
- Fatigue strength
- Corrosion Resistance
- Wear resistance
- Creep resistance
- Resistance to heat and oxidation damage
- Resistance to radiation damage

### **Extractive Metallurgy**

Extractive Metallurgy deals with processing of the natural occurring raw materials for converting those in to useful metals and alloys. It also deals with reaction of metal with slag's and gases.

Thus reflects on the compositional changes in the molten metal before solidification of the weld pool.

### **Physical Metallurgy**

Physical Metallurgy deals with identifying, controlling and varying the properties of the metals and alloys as per requirements of the mankind. It takes into consideration the phase changes with temperature and/or composition. It reflects on the causes of the change in mechanical and physical properties.

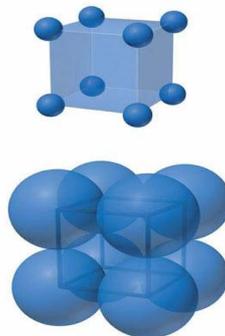
## Crystal Structure

The crystal structure of a material or the arrangement of atoms in a crystal structure can be described in terms of its unit cell. The unit cell is a tiny box containing one or more motifs, a spatial arrangement of atoms. The unit cells stacked in three-dimensional space describe the bulk arrangement of atoms of the crystal. The crystal structure has a three dimensional shape. The unit cell is given by its lattice parameters, the length of the cell edges and the angles between them, while the positions of the atoms inside the unit cell are described by the set of atomic positions  $(x_i, y_i, z_i)$  measured from a lattice point.

### Type of Crystal Structure

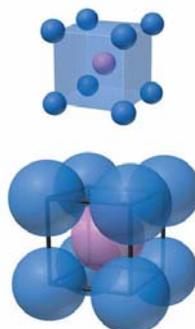
- Cubic
- Hexagonal
- Tetragonal
- Triclinic
- Rhombohedra
- Orthorhombic
- Monoclinic

#### 1. Simple Cubic Structure



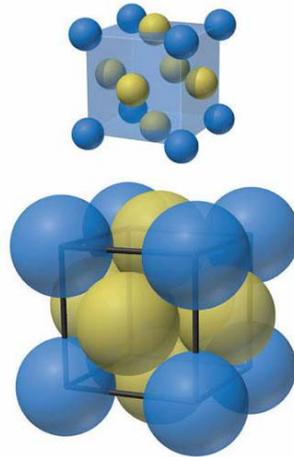
#### 2. BODY CENTERED CUBIC STRUCTURE:

It has 9 atoms, one at each corner of the cube & one at the centre. This is present in such metals as iron, molybdenum, chromium vanadium & tungsten. They have higher strength with low cold working properties.

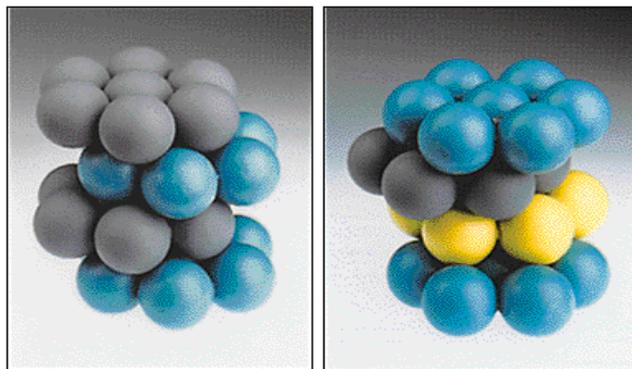


### 3. FACE CENTERED CUBIC STRUCTURE:

It has one atom in the centre & one atom at each face besides one atom at each of the corners, totaling to 14 atoms. This type of structure is present in aluminum, copper, nickel, lead, gold, silver & platinum. They are ductile, plastic & cold workable.



### 4. HEXAGONAL CLOSE PACKED LATTICE STRUCTURE:



This structure is more closely packed & is present in metals like titanium, cobalt, zinc, bismuth, cadmium & magnesium. In pure metals these crystals will start to form at many centres called nuclei throughout cooling. This dendritic structure rapidly builds up & grows in all directions with twigs & branches. As the temperature continues to fall the dendrite increases in size till it comes in contact with other similar structures. Growth stops at this point in this direction & solidification starts & continues until the crystal is formed. If any impurities are present or the metal is cooled rapidly which may cause shrinkage cavities. In large ingots the crystal (grains) may vary in size considerably from outer edges to the centre. When the first metal starts cooling with a chilling effect & the small grains are the result. As the mould warms up cooling will slow down & extremely elongated columnar crystals are formed. The metal in the centre cools very slowly & equiaxed crystals with their own nuclei are formed.

## Metals and Alloys

Metals are elementally pure substances such as Iron, Copper, Nickel, Aluminum, Titanium, gold, silver etc.

Alloys are consisting of two or more elements with major element being metal. Pure metals normally do not impart the highest possible properties therefore are generally alloyed with other metallic or non-metallic elements

**Periodic Table of Elements**

1	2																	3	4	5	6	7	8	9	10														
1	2																	3	4	5	6	7	8	9	10														
3	4																	5	6	7	8	9	10																
11	12	13	14	15	16	17	18																	13	14	15	16	17	18										
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36																	31	32	33	34	35	36
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54																	49	50	51	52	53	54
55	56	57	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86																	81	82	83	84	85	86
87	88	89	104	105	106	107	108	109	110																	87	88	89	104	105	106	107	108	109	110				

* Lanthanide Series	58	59	60	61	62	63	64	65	66	67	68	69	70	71
	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
+ Actinide Series	90	91	92	93	94	95	96	97	98	99	100	101	102	103
	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

Legend - click to find out more...

<b>H - gas</b>	<b>Li - solid</b>	<b>Br - liquid</b>	<b>Tc - synthetic</b>
 Non-Metals	 Transition Metals	 Rare Earth Metals	 Halogens
 Alkali Metals	 Alkali Earth Metals	 Other Metals	 Inert Elements

## Metallurgy of a Weld in Iron

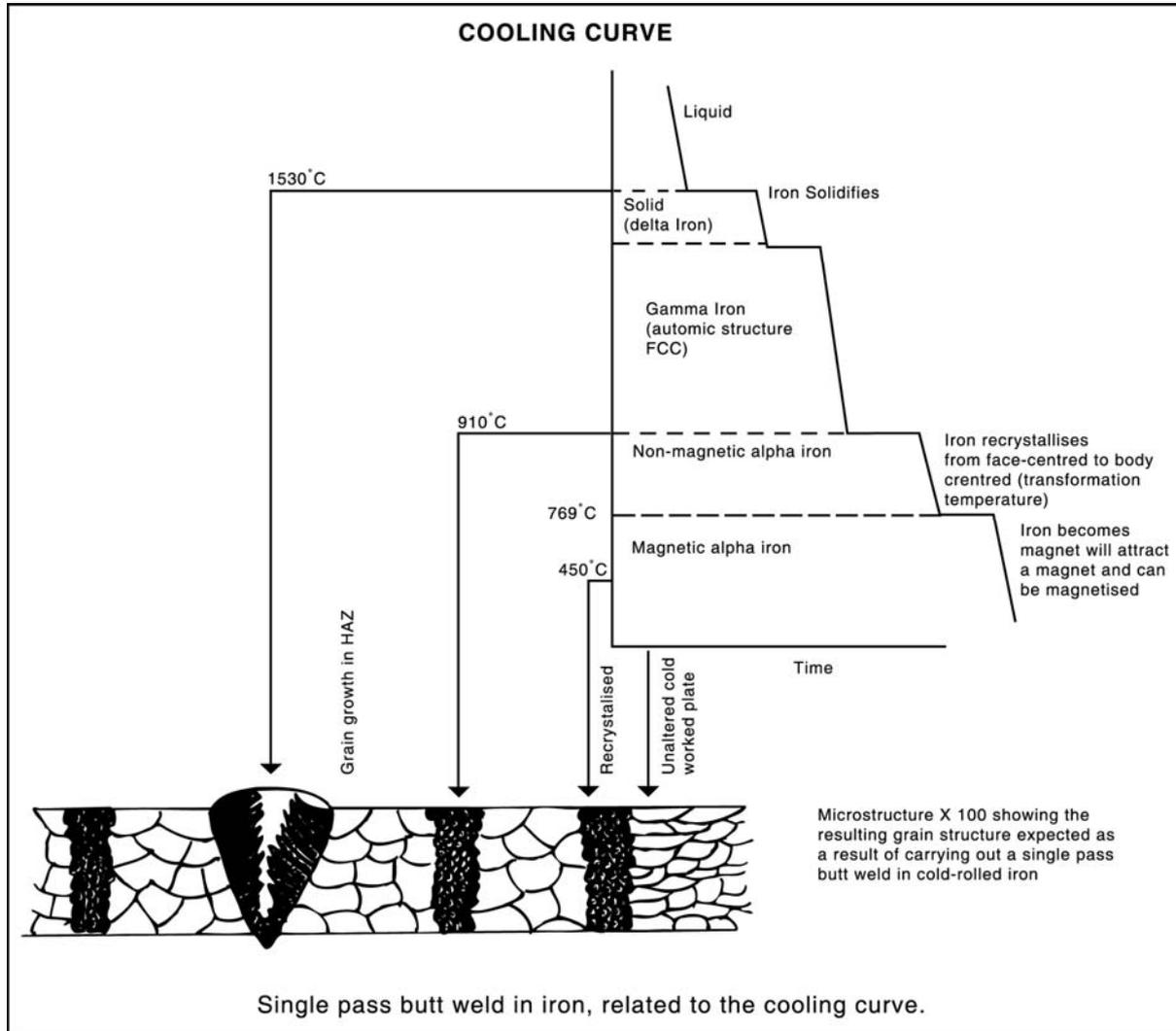
Iron has a distinction of existing in different forms at different temperatures. This property gives rise to many different alloys and unique ability to alter properties of iron alloys by heating and cooling at different rates. Heating and cooling of various metals and alloys for attaining the desired mechanical properties is known as “Heat Treatment”

Iron is allotropic because it exists in many forms. At approx. 1530°C the molten iron weld pool begins to freeze. The temp. Will remain constant until all the iron solidifies. At about 1400°C an insignificant change will take place and temperature falls steadily till 910°C which will remain constant for some time. Here the atoms rearrange themselves from face centered cubic lattice structure in to body centered cubic lattice form. Iron above 910°C is called gamma iron & below 910°C is called alpha iron.

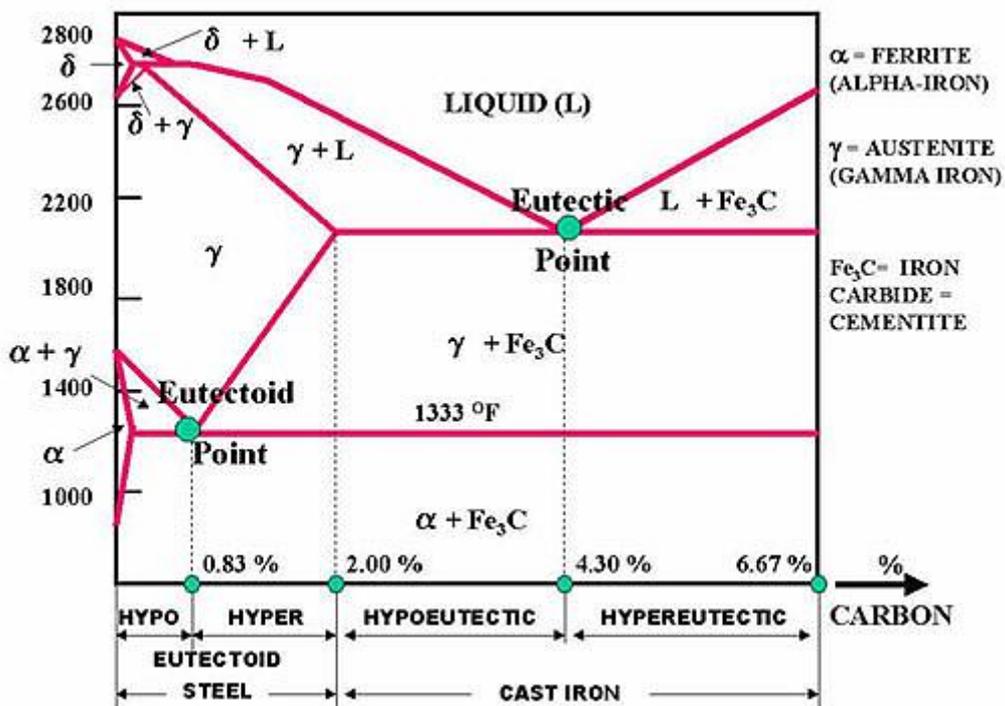
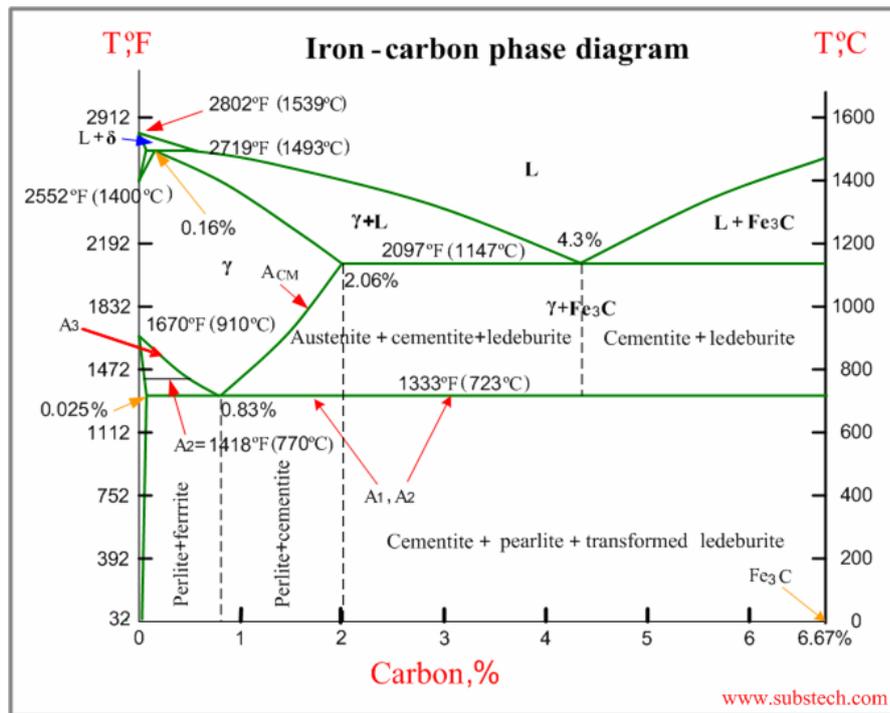
The temperature at which such a change in crystalline structure takes place is known as transformation temperature. On cooling further to 769°C the iron regains its magnetic properties & this point is called curie point. The parent material that has been heated above 910°C will have undergone the crystalline structure change in to increase in size of grains but the parent metal that has not reached 910°C will have no atomic change but if the parent metal has been cold worked prior to welding which is the case with repair & maintenance welding then re crystallization will take place till 450°C.

When carbon is added to iron, the iron is called steel. The addition of carbon to steel causes the material to freeze over a temperature range. More the % C added to iron lower the melting point & also the freezing range. In the face centered cubic structure iron can hold large amounts of carbon in solid solution & this solid solution when viewed through a microscope will appear as pure metal with only grain boundaries visible.

Iron with very small amount of carbon ( $\ll 0.006\%C$ ) is known as ferrite. If more than 0.006 % C is added. The changes from body to face centered structure are lowered from 910°C to 723°C, when the carbon content reaches to 0.83%. The changes that occur with various carbon contents can be best understood by referring to iron carbon equilibrium diagram as shown. This diagram has been constructed by plotting a series of curves & noting the changes in internal structure with each percentage of carbon. These change points are then joined up to draw the equilibrium diagram.



## Iron-Carbon Phase Diagram



These changes will occur when cooling takes place slowly. Rapid cooling will not allow steel, time to carry out the internal changes and will give a different structure. At 0-0.006 % of carbon the steel is ferritic in structure. As the carbon level is increased iron carbide is formed with alternative layers of black & white patches called pearlite. They are made up of alternate layers of ferrite & cementite. Carbon will be of 0.83% in pearlite and will be distributed uniformly in the micro structure. It increases tensile strength & hardness of steel but reduces ductility. Steel containing 0.83%C is known as eutectic steel & is formed at the **eutectic point** on the equilibrium diagram.

Increasing the carbon percentage to 1.2% distributes excess cementite around the pearlite grains as only 0.83%C is required to form pearlite. Further increasing the carbon to 1.7% produces an even greater amount of cementite Steels containing less than 0.83%C are called **hypoeutectoid** & steels having more than 0.83%C are called **hypereutectoid**.

## Phases of Iron

- **Pearlite.** Thin, alternating layers of cementite and ferrite forms when austenite cooled slowly, it is known as pearlite. Pearlite is always 0.77 percent carbon
- **Bainite.** Hard with low ductility, bainite is a combination of fine carbon needles in a ferrite matrix. It results when austenite is cooled at a rate lower than what's needed to form martensite.
- **Martensite.** If you take a piece of red-hot steel and quench it in ice water, what you end up with is usually a lot of martensite. Here's why: Martensite results when austenite is quickly cooled to the temperature at which it forms a body-centered tetragonal crystalline structure. If the carbon can't precipitate out of this shear type of structure, which is true for most common steels, it becomes trapped in the body-centered tetragonal lattice—martensite.
- Iron carbon diagram does not give complete picture of the phases forming.
- Under faster cooling rates, more phase forms, these are
  - Martensite,
  - upper bainite ,
  - lower bainite ,
  - side plate ferrite and
  - acicular ferrite