MATERIALS
AND
METALLURGY

IV SEMESTER
AUTOMOBILE ENGINEERING

Metals and Non- Metals

Concepts

(i) Classification of elements (ii) Physical properties of metals (iii) Chemical properties of metals (iv) Physical properties of non-metals) (v) Chemical properties of non-metals

Classification of elements

Today, some 117 chemical elements are known but only 103 out of them are well characterized in terms of their properties. The systematic classification of these 103 elements reveals that 90 elements are solids, 2 are liquids and 11 are gases. Further, 79 of them are metals, 17 are non-metals and 7 are metalloids. Metals differ from non-metals in many respects. In fact, metals and non-metals are two extremes as regards their properties.

Metals occupy the bulk of the periodic table, while non-metallic elements can only be found on the right-hand-side of the Periodic Table. A diagonal line, drawn from boron (B) to polonium (Po), separates the metals from the non-metals. Most elements on this line are metalloids, sometimes called semiconductors. This is because these elements exhibit electrical properties intermediate to both, conductors and insulators. Elements to the lower left of this division - line are called metals, while elements to the upper right of the division - line are called non-metals.

On the basis of their general physical and chemical properties, every element in the periodic table can be termed either a metal or a non-metal. (A few elements with intermediate properties are referred to as metalloids).

Physical properties of metals

Metals show following general physical properties.

1) Physical state - Metals are solids at room temperature e.g. sodium, aluminium, potassium, magnesium. There is exception to this. Mercury and gallium are metals but they are in liquid state at room temperature.

1) **Lustre** – Metals have a shining surface called lustre when freshly prepared. They have a quality of reflecting light from their surface and they can be polished e.g. metals like gold, silver, copper show this property.

2) **Malleability** - Metals can be beaten into thin sheets. This property is called malleability. Due to this property, metals can be rolled into sheets e.g. aluminium, copper, zinc can be beaten into sheets.

2) **Ductility** - Metals can be drawn into thin wires. This property is called ductility. For example, 100 grams of silver can be drawn into a thin wire about 200

meters long.

3) **Hardness** – Metals are generally hard e.g. iron, cobalt, nickel. There are few exceptions to this. Sodium and potassium are soft and they can be cut with a knife.

4) **Conduction** – Generally, metals are good conductors of heat and electricity because they have free electrons. Silver and copper are the two best conductors. Relatively, lead and bismuth are poor conductors of heat and electricity.

5) **Density** - Metals generally have high density and they are heavy. Iridium and osmium have the highest densities while lithium has the lowest density.

6) **Melting and boiling point** – Metals usually have high melting point and boiling point. For example, iron, cobalt and nickel have high melting and boiling point. Tungsten has the highest melting point. There are some exceptions to this. For example, most of the alkali metals have low melting and boiling point.

7) **Tensile strength** – Most of the metals possess high tensile strength i.e. tenacity. For example, iron, titanium, some alloys have high tensile strength. However, elements like sodium, potassium and mercury do not possess tenacity.

Chemical properties of metals

Metals show following general chemical properties.

1) **Electron configuration** – Metals usually have 1 to 3 electrons in the outermost shell of their atom. For example, sodium, magnesium and aluminium have 1, 2 and 3 electrons respectively in the outermost shell of their atom.

2) **Valency** - Metal atoms can lose 1 to 3 electrons in their outermost shell and show valencies1 to 3.

3) **Electrochemical nature** - Metal atoms have tendency to lose electrons and form cations. . This tendency is called the electropositive nature. Metals generally have moderate to high electropositive nature. For example, Na, Mg and Al have high electropositive character while Zn, Cd, Sn and Pb have moderate electropositive nature.

4) **Electronegativity** - Metals generally have low electronegativity i.e. tendency to attract electrons in the state of molecule. For example, metals like Ca, Mg, Al, and Zn have low electronegativity.

5) **Formation of oxides** – Metals form oxides which are generally ionic and basic in nature. If this basic oxide dissolves in water, it forms an alkali. For example, oxides of Na, K and Ca viz. Na_2O, K_2O and CaO are highly basic in nature and when dissolved in water, they form alkalies NaOH, KOH and $Ca(OH)_2$. The

oxides react with acids to form salts. Oxides of metals like Pb, Zn, Al and Sn viz. PbO_2, ZnO, Al_2O_3 and SnO_2 are moderately basic and they react with acids as well as alkalies to form salt. So such oxides are called amphoteric oxides. The oxides Sb_2O_3 and Cr_2O_3 are exceptions and they are acidic in nature.

6) **Reducing agent** - All metals act as reducing agents. Strongly electropositive metals like Mg, Al and Cr act as strong reducing agents while moderately electropositive elements like Zn, Cd and Sn act as moderate reducing agents.

7) **Reaction with water** - Strongly electropositive metals like Na and K react even with cold water to produce their hydroxides and they evolve hydrogen gas. The heat evolved is not sufficient for the hydrogen to catch fire. Metals like Mg do not react with cold water . They react only with hot water to form hydroxide evolving hydrogen. The elements less electropositive than Na, K and Mg like Al, Fe and Zn do not react with cold or hot water. These hot metals react only with steam to form their oxides and hydrogen .However, metals like Cu, Ag and Au which are below hydrogen in the activity series do not react with water at all.

8) **Reaction with acids** - Highly reactive metals like Na, Mg and K react with dilute mineral acids like HCl or H_2SO_4 to form salt and hydrogen gas. These reactions are displacement reactions. If nitric acid is used, the hydrogen evolved gets oxidized to water and hence no hydrogen gas is evolved. Metals like Cu, Ag and Au which are below hydrogen in the reactivity series do not react with dilute mineral acids and do not evolve H_2 .

9) **Reaction with non-metals** - Metals like Mg, Ca, Al etc. react with non-metals like H, S, Cl, Br and I under different conditions of temperature to form their respective salts. However, all metals are not equally reactive so they require different conditions to react with non-metals.

Physical properties of non-metals

Non- metals show properties opposite to that of metals. Non-metals show following general physical properties

1) **Physical state –** Non-metals can exist in solid or liquid or gaseous state at room temperature. . For example, carbon, sulphur, phosphorus, iodine are in solid state, bromine is in liquid state while oxygen, nitrogen, chlorine are in gaseous state at room temperature.

2) **Luster** – Non-metals do not have luster. They do not reflect light from their surface. (exception – diamond and iodine) Non-metals have dull appearance. For example, sulphur, phosphorus and carbon show this property.

3) **Malleability** - Non-metals are non-malleable. If solids, they are brittle i.e. they break or shatter on hammering. For example, coal, sulphur, phosphorus are brittle.

4) **Ductility** – Non-metals can not be drawn into thin wires. So they are not ductile.

5) Hardness – Non-metals are usually not hard. They are soft. For example, coal, sulphur and phosphorus are soft. Diamond is exception to this. It is the hardest substance known.

6) Conduction - Non- metals are usually poor conductors of heat and electricity. However, carbon in the form of gas carbon and graphite is exception to this. These forms of carbon are good conductors of electricity.

7) Density – Non- metals which are gases have low density. Solid non-metals have low to moderate density. They are medium light. For example, sulphur, phosphorus and boron have densities 1.82, 2.07 and 2.34 respectively. . However, diamond has high density which is about 3.5.

8) Melting and boiling point – Non-metals usually have low melting and boiling points. For example, phosphorus, sulphur, and iodine have melting points 44^0, 115^0 and 114^0 C respectively and boiling points 280^0, 445^0 and 184^0C respectively. . However, carbon, silicon and boron possess very high melting and boiling points.

9) Tensile strength – Non-metals have low tensile strength i.e. they have no tenacity.

Chemical properties of non - metals

Non – metals show following general chemical properties

1) Electron configuration – Non -metals usually have 4 to 8 electrons in their outermost shell. For example, C, N, O, F and Ne have 4, 5, 6, 7 and 8 electrons in their outermost shell.

2) Valency - Non - metals can gain or share 1 to 4 electrons in their outermost shell and show valencies 1 to 4 . Sometimes, they show valency 5 to 7. For example, P shows valency 5 in P_2O_5 , S shows valency 6 in SO_3 and Cl shows valency 7 in $HClO_4$,

3) Electrochemical nature - Non – metal atoms have tendency to gain electrons and form anions or share electrons with other non-metals to form covalent bonds. Non - metals generally have moderate to high electronegative nature. For example, Cl, O and N have high electronegative nature while Si, P, S and I have moderate electronegative nature.

4) Electronegativity - Non - metals generally have high electronegativity i.e. tendency to attract electrons in the state of molecule. Foe example, non - metals like F, Cl, O and N have high electronegativity.

5) Formation of oxides – Non- metals form oxides which are generally covalent and acidic in nature. If this acidic oxide dissolves in water, it forms an oxyacid. For example, oxides of Cl, P and S viz. Cl_2O_7 , P_2O_5 and SO_3 are highly acidic in nature and when dissolved in water, they form acids like $HClO_4$,.H_3PO_4 and H_2SO_4 . These oxides react with alkalies to form salts. Oxides of non- metals like C, H and N i.e. CO, H_2O and NO are neutral.

6) Oxidizing agent - All non - metals (except carbon) act as oxidizing agents. Strongly electronegative elements such as F, Cl and O act as strong oxidizing agents while moderately electronegative elements like sulphur, bromine and iodine act as moderate oxidizing agents. Carbon sometimes acts as a reducing agent.

7) Reaction with water - Non-metals do not react with water . Whether the water is in the form of cold water, hot water or steam, all non-metals remain unresponsive to water. The reason for this is that non-metals are electronegative and are unable to break the bond between H and O in water.

8) Reaction with acids: Most non-metals do not react with non-oxidizing acids. They are not capable of replacing hydrogen from the acids and forming a salt. For example, C, S or P do not react with dilute and concentrated HCl or dilute H_2SO_4 to give off hydrogen. Concentrated nitric acid, dilute nitric acid and concentrated sulphuric acid act as oxidizing agents and react with non – metals to form their oxides or acids. Non-metals like N, O, Si, halogens and noble gases are exception to this and they do not react with these acids. Usually solid non-metals react with these oxidizing acids.

$C + 4\,\underset{\text{Conc.}}{HNO_3} \rightarrow CO_2 + 4\,NO_2 + 2H_2O$; $3C + 4\,\underset{\text{Dilute}}{HNO_3} \rightarrow 3CO_2 + 4\,NO + 2\,H_2O$

$C + 2\,\underset{\text{Conc.}}{H_2SO_4} \rightarrow CO_2 + 2\,H_2O + SO_2$; $S + 2\,\underset{\text{Conc.}}{H_2SO_4} \rightarrow 3\,SO_2 + 2\,H_2O$

$2\,P + 5\,\underset{\text{Conc.}}{H_2SO_4} \rightarrow 2\,H_3PO_4 + 2\,H_2O + SO_2$

9) Reaction with metals - Metals like Mg, Ca, Al etc. react with non-metals like H, S, Cl, Br and I on heating to form their respective salts. However, all non - metals are not equally reactive so they require different conditions like high temperature to react with metals.

10) Reaction with non-metals – Non-metals can react with each other. For example, carbon can react with non-metals like H, O, Cl at different temperatures to form the corresponding compounds like CH_4 , CO_2 and CCl_4. Non – metals react with each other under different conditions.

No.	**Metals**	**Non – metals**
1)	Metals are solids at room temperature	Non – metals may be solids, liquids or
	(Exceptions – Hg, Ga)	gases at room temperature.
2)	Metals have luster. They reflect light	Non-metals do not have luster.
	from polished or freshly cut surface.	(Exceptions – Diamond and Iodine)
3)	Metals generally have high density.	Non-metals generally have low density.
4)	They are good conductors of heat and	They are usually bad conductors of heat
	electricity.	and electricity. (exception – carbon in the
		form of gas carbon and graphite)
5)	Metals are malleable and ductile.	Non-metals are not malleable and ductile.
	They can be beaten into sheets and	They are brittle when solid. They can be
	drawn into wires.	crushed into powder.
6)	They have a three dimensional	They have different types of structures
	crystal structure with metallic bonds	with covalent and van-der-Walls’ bonds
7)	Metals are generally hard.	Non- metals are generally soft (Exception: Diamond)
8)	Metals usually have high tensile	Non- metals usually have low tensile
	strength	Strength
9)	Metals generally have 1 to 3 electrons	Non-metals generally have 4 to 8
	in their outermost shell of the atom	electrons in outermost shell of their atoms
10)	They show valency 1 to 4	They show valency 1 to 7
11)	They are electropositive in nature.	They are electronegative in nature.
12)	They generally form basic oxides.	They generally form acidic oxides.
13)	They act as reducing agents.	They act as oxidizing agents.
14)	Only active metals react with cold or	Non-metals usually do not react with
	hot water.	cold and hot water.
15)	Only active metals react with non-	Solid non-metals react with oxidizing
	oxidizing acids to form hydrogen gas	acids to form their oxides or oxyacids
16)	They react with non-metals under	They react with metals as well as non-
	different conditions to form salts	metals under different conditions to
		form salts

Ferrous Materials and Non-Ferrous Metals and Alloys

Ferrous materials/metals may be defined as those metals whose main constituent is iron such as pig iron, wrought iron, cast iron, steel and their alloys. The principal raw materials for ferrous metals are pig iron. Ferrous materials are usually stronger and harder and are used in daily life products. Ferrous material possesses a special property that their characteristics can be altered by heat treatment processes or by addition of small quantity of alloying elements. Ferrous metals possess different physical properties according to their carbon content.

IRON AND STEEL

The ferrous metals are iron base metals which include all varieties of iron and steel. Most common engineering materials are ferrous materials which are alloys of iron. Ferrous means iron. Iron is the name given to pure ferrite Fe, as well as to fused mixtures of this ferrite with large amount of carbon (may be 1.8%), these mixtures are known as pig iron and cast iron. Primarily pig iron is produced from the iron ore in the blast furnace from which cast iron, wrought iron and steel can be produced.

CLASSIFICATION OF CARBON STEELS

Plain carbon steel is that steel in which alloying element is carbon. Practically besides iron and carbon four other alloying elements are always present but their content is very small that they do not affect physical properties. These are sulphur, phosphorus, silicon and manganese. Although the effect of sulphur and phosphorus on properties of steel is detrimental, but their percentage is very small. Sulphur exists in steel as iron sulphide which produces red shortness or manganese sulphide which does affect its properties.

forging dies. Likewise for production of cold chisels, punches and dies. Springs, broaches and reamers can be produced for steel containing carbon. As the percentage of carbon further increases, it can be used for production of milling cutters, anvils, taps, drills, files, razors, metal cutting tools for lathes, shapers, planner and drawing dies.

WROUGHT IRON

The meaning of “wrought” is that metal which possesses sufficient ductility in order to permit hot and/or cold deformation. Wrought iron is the purest iron with a small amount of slag forged out into fibres. The typical composition indicates 99 per cent of iron and traces of carbon, phosphorus, manganese, silicon, sulphur and slag. During the production process, first all elements in iron (may be C, S, Mn, Si and P) are eliminated leaving almost pure iron molten slag. In order to remove the excess slag, the final mix is then squeezed in a press and reduced to billets by rolling milling. The resulting material would consist of pure iron separated by thin layers of slag material. The slag characteristic of wrought iron is beneficial in blacksmithy/forging operations and provides the material its peculiar fibrous structure. Further, the non-corrosive slag constituent makes wrought iron resistant to progressive corrosion and also helps in reducing effect of fatigue caused by shocks and vibrations.

Wrought iron is tough, malleable and ductile and possesses ultimate tensile strength of 350 N/mm^2. Its melting point is 1530°C. It can neither be hardened nor tempered like steel. The billets of wrought iron can be reheated to form bars, plates, boiler tubing, forgings, crane hook, railway coupling, bolts and nuts, chains, barbed wire, coal handling equipment and cooling towers, etc.

CAST IRON

It is primarily an alloy of iron and carbon. The carbon content in cast iron varies from 1.5 to 4 per cent. Small amounts of silicon, manganese, sulphur and phosphorus are also present in it. Carbon in cast iron is present either in free state like graphite or in combined state as cementite. Cast iron contains so much carbon or its equivalent that it is not malleable. One characteristic (except white cast iron) is that much of carbon content is present in free form as graphite. Largely the properties of cast iron are determined by this fact.

Melting point of cast iron is much lower than that of steel. Most of the castings produced in a cast iron foundry are of grey cast iron. These are cheap and widely used.

The characteristics of cast iron which make it a valuable material for engineering applications are:

- Very good casting characteristics.
- Low cost
- High compressive strength
- Good wear resistance
- Excellent machinability

The main limitation of this metal is brittleness and low tensile strength and thus cannot be used in those components subjected to shocks.

The varieties of cast iron in common use are:

- Grey cast iron
- White cast iron
- Malleable cast iron
- Nodular cast iron
- Chilled cast iron
- Alloy cast iron

Grey Cast Iron

It is the iron which is most commonly used in foundry work. If this iron is machined or broken, its fractured section shows the greyish colour, hence the name "grey" cast iron. The grey colour is due to the fact that carbon is present in the form of free graphite. A very good characteristic of grey cast iron is that the free graphite in its structure acts as a lubricant. This is suitable for those components/products where sliding action is desired. The other properties are good machinability, high compressive strength, low tensile strength and no ductility.

In view of its low cost, it is preferred in all fields where ductility and high strength are not required. The grey cast iron castings are widely utilized in machine tool bodies, automobile cylinder blocks and flywheels, etc.

2.5.2 White Cast Iron

It is so called due to the whitish colour shown by its fracture. White cast iron contains carbon exclusively in the form of iron carbide Fe_3C (cementite). From engineering point of view, white cast iron has limited applications. This is because of poor machinability and possessing, in general, relatively poor mechanical properties. It is used for inferior castings and places where hard coating is required as in outer surface of car wheels. Only crushing rolls are made of white cast iron. But it is used as raw material for production of malleable cast iron.

Malleable Cast Iron

Malleable cast iron is produced from white cast iron. The white cast iron is brittle and hard. It is, therefore, unsuitable for articles which are thin, light and subjected to shock and vibrations or for small castings used in various machine components. The malleable cast iron is produced from white cast iron by suitable heat treatment, i.e., annealing. This process separates the combined carbon of the white cast iron into noddles of free graphite.

The malleable cast iron is ductile and may be bent without rupture or breaking the section. Its tensile strength is usually higher than that of grey cast iron and has excellent machining qualities. Malleable cast iron components are mainly utilized in place of forged steel or parts where intricate shape of these parts creates forging problem. This material is principally employed in rail, road automotive and pipe fittings etc.

Nodular Cast Iron

It is also known as “spheroidal graphite iron” or Ductile iron or High strength “Cast iron”. This nodular cast iron is obtained by adding magnesium to the molten cast iron. The magnesium converts the graphite of cast iron from flake to spheroidal or nodular form. In this manner, the mechanical properties are considerably improved. The strength increases, yield point improves and brittleness is reduced. Such castings can even replace steel components.

Outstanding characteristics of nodular cast iron are high fluidity which allows the castings of intricate shape. This cast iron is widely used in castings where density as well as pressure tightness is a highly desirable quality. The applications include hydraulic cylinders, valves, pipes and pipe fittings, cylinder head for compressors, diesel engines, etc.

Chilled Cast Iron

Quick cooling is generally known as chilling and the iron so produced is “chilled iron". The outer surface of all castings always gets chilled to a limited depth about (1 to 2 mm) during pouring and solidification of molten metal after coming in contact with cool sand of mould. Sometimes the casting is chilled intentionally and some becomes chilled accidentally to a small depth.

Chills are employed on any faces of castings which are required to be hard to withstand wear and friction. Chilled castings are used in producing stamping dies and crushing rolls railway, wheels cam followers, and so on.

Alloy Cast Iron

Alloying elements are added to cast iron to overcome inherent deficiencies in ordinary cast iron to provide requisite characteristics for special purposes. The alloy cast iron is extremely tough, wear resistant and non-magnetic steel about 12 to 14 per cent manganese should be added.

- **Nickel:** It may be termed as one of the most important alloying elements. It improves tensile strength, ductility, toughness and corrosion resistance.
- **Chromium:** Its addition to steel improves toughness, hardness and corrosion resistance.

- **Boron:** It increases hardenability and is therefore very useful when alloyed with low carbon steels.
- **Cobalt:** It is added to high speed steels to improve hardness, toughness, tensile strength, thermal resistance and magnetic properties. It acts as a grain purifier.
- **Tungsten:** Tungsten improves hardness, toughness, wear resistance, shock resistance, magnetic reluctance and ability to retain hardness at elevated temperatures. It provides hardness and abrasion resistance properties to steel.
- **Molybdenum:** It improves wear resistance, hardness, thermal resistance, ability to retain mechanical properties at elevated temperatures and helps to inhibit temper brittleness.

- **Vanadium:** It increases tensile strength, elastic limit, ductility, shock resistance and also acts as a degaser when added to molten steel. It provides improvement to hardenability of steel.
- It is a very good deoxidizer and promotes grain growth. It is the strongest carbide former. Titanium is used to fix carbon in stainless steel and thus

prevents the precipitation of chromium-carbide.

- **Niobium:** It improves ductility, decreases hardenability and substantially improves the impact strength. It also promotes fine grain growth.

STAINLESS STEELS

The only material known to engineers which possesses a combination of various properties such as: wide range of strength and hardness, high ductility and formability, high corrosion resistance, good creep resistance, good thermal conductivity, good machinability, high hot & cold workability and excellent surface finish is stainless steel. Alloy steels have been developed for a specific purpose. We shall study them as follows:

They are known as stainless since they do not corrode or rust easily in most of environment and media. Stainless steels can be further divided into the following three categories:

(1) Ferritic stainless steel: It is that steel when properly heat treated and finished, resists oxidation and corrosive attacks from corrosive media. Ferritic stainless steels contain 12–18% chromium, 0.15 to 0.2% carbon besides iron and usual amounts of manganese and silicon. The steels are stainless and relatively cheap. They are magnetic in nature. Structure of these steels consist of ferrite phase which cannot be hardened by heat raptures. They are normally used in forming and machining of metals. So the requirements in a tool steel are that it should be capable of becoming very hard and further that it should be able to retain its hardness at high temperatures normally developed during cutting of materials. This property is known as "red hardness". Further, tool steel should not be brittle for smooth working. treatment. These steels are actually iron-chromium alloys and cannot be hardened by heat treatment. Such type of steel is utilized in manufacture of dairy equipment food processing plants, etc.

(2) Martensitic stainless steel: These steels contain 12–18% chromium and 0.1 to 1.8% carbon. These steels can be hardened by heat treatment but their corrosion resistance is decreased. Steels with 12 to 14% chromium and 0.3% carbon are widely used for table cutlery, tools and equipment. Steel with little less carbon percentage and higher percentage of chromium are used as springs, ball bearings and instruments under high temperature and corrective conditions.

(3) Austentic stainless steels: These are the most costliest among all stainless steels. In these steels besides chromium, nickel is also added. Nickel is a very strong austenitic stabilizer and therefore the microstructure of these steels is austentic at room temperature. These steels contain 12 to 21% chromium and 8 to 15% nickel and carbon less than 0.2%. The most familiar alloy of this group is known as 18:8 stainless steel i.e. 18% chromium and 8% nickel plus other. Other elements like carbon, manganese and silicon in very small quantities.

TOOL STEELS

Tool steels are specially alloyed steels designed for high strength, impact toughness and wear resistance at room and elevated temperature.

High Speed Steel (H.S.S.)

It is the name given to the most common tool steel. As the name implies, it can cut steel at high cutting speeds. These steels are high in alloy content, have excellent hardenability, maintain their hardness at elevated temperatures around 650°C, are quite resistant to wear and contain relatively large amounts of tungsten or molybdenum, together with chromium, cobalt or vanadium. They are used to produce cutting tools to be operated for various machining operations such as turning, drilling, milling, etc. A typical composition of H.S.S. is tungsten 18%, chromium 4% and vanadium 1%, carbon 0.75 to 0.9% and rest iron.

Molybdenum High Speed Steel

This steel contains 6% tungsten, 6% molybdenum, 4% chromium and 2% vanadium and have excellent toughness and cutting ability. The molybdenum high speed steel are better and cheaper than other types of steel. It is particularly utilized in drilling and tapping operations.

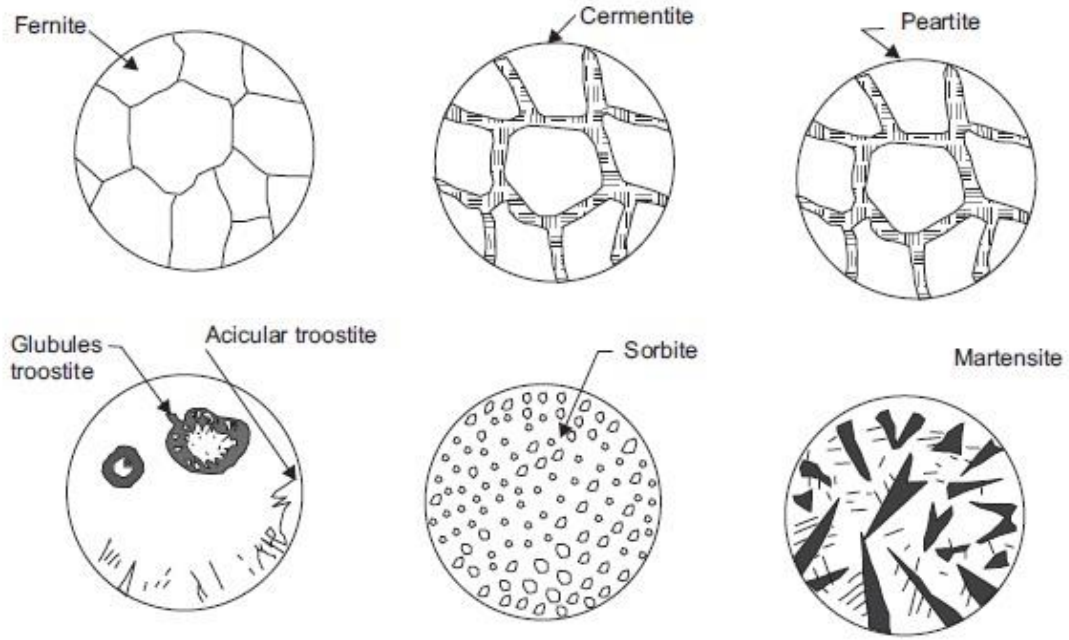


Fig. 2.2: Steel microstructure in heat treatment process

Full annealing: During this process, heating phase results in fine grained austenite and thus, fine grained structure is obtained on cooling. This results in improvement in mechanical properties, high ductility and high toughness. It is the process where hypoeutectoid steel is heated 30–50°C above the critical temperature, holding it for some time at that temperature which heats the metal thoroughly and phase transformation takes place throughout. This is followed by slow cooling in furnace.

Heating rate is usually 100°C/hr and holding time is 1 hr/ton of metal, cooling rate is kept from 10°C–100°C for alloy steels and can be 200°C/hr for carbon steels.

Partial annealing: It is a process where steel is heated slightly above lower critical temperature and this annealing is applied for hypereutectoid steels only. It is also applied to hypoeutectoid steels where hardness is to be reduced while improving machinability**.** In this operation, pearlite is transformed to austenite and ferrite is partially deformed into austenite. Heating and holding period is followed by slow cooling.

Isothermal Annealing: Steel is heated in the same way as it is treated in full annealing and then it is rapidly cooled from 500°C to 100°C below critical temperature. This is followed by keeping steel at this temperature for a long period which results in complete decomposition of iron. Then this is cooled in air.

The isothermal annealing results in improved machinability and more homogenous structure throughout the section.

Normalizing

It is the process of heating the steel to the temperature 50°C or more above the critical temperature 723°C. Then the steel is held at this temperature for a considerable period which results in complete transformation. This is followed by air cooling of steel. In normalizing, complete phase recrystallization takes place and fine grained structure is obtained.

Here in cooling, rate of cooling is faster than furnace cooling. During air cooling, austenite transforms into finer and more abundant pearlite structure in comparison to annealing. Properties obtained by normalizing depend on the size and composition of steel. As the smaller pieces cool more rapidly because of more exposure area, fine pearlite is formed and thus they are harder than larger pieces.

The object of normalizing is to refine the structure of steel and remove strains which may have been caused by cold working. When steel is cold worked the crystal structure is distorted and the metal may be brittle and unrealistic.

Quenching

We have observed that to transform the austenite to martensite efficiently, the cooling must be so rapid that the temperature of transformation is from about 750° to 300°C. This involves very rapid cooling and invites trouble of cracking and distortion. The factors which tend to cause the metal to warp and crack are:

(1) When a metal cooled it generally undergoes a contraction which is normally not uniform, but occurs at the outside surfaces and specially in thin sections of products.

(2) When steel cools through the critical range an expansion occurs.

Now if we would arrange to cool the whole volume of metal suddenly at the same instant, we should not experience much problem with change in volume, etc. but unfortunately this is not possible. When we suddenly plunge the metal into water from furnace at annealing temperature, the outer portion of the metal comes in contact with water and is immediately cooled and undergoes its critical range expansion leading to hard and rigid skin of metal. The inner portion of the metal, however, has not yet felt the quenching effect and is still red hot. When the quenching effect is transferred to outer portion through critical range the outer layer does not crack.

The quenching rate, size and shape of the article affects hardening and elimination of distortion and cracks. A special technique of immersing into the quenching media (may be oil, brine solution or water) is adopted, as described below:

(1) Long articles are immersed with their axis normal to the bath surface.
(2) Thin and flat articles are immersed with their edges first into the bath.
(3) The curved article's curved portion is kept upward during the immersion.
(4) Heavy articles are kept stationary with the quenching media stirred around them.

Very rough surface articles do not respond to uniform hardening, therefore this factor should be taken into account before performing the quenching operation.

Tempering

Martensitic structures formed by direct quenching of high carbon steel are hard and strong but also brittle. They contain internal stresses which are severe and unequally distributed to cause cracks or even fracture of hardened steel. The tempering is carried out to obtain one or more of the following objectives:

(1) To reduce internal stresses produced during heat treatment operations.
(2) To stabilize the structure of metal.
(3) To make steel tough to resist shock and fatigue.
(4) To reduce hardness and improve ductility.

NON-FERROUS METALS AND ALLOYS

Non-ferrous metals are those which do not contain significant quantity of iron or iron as base metal. These metals possess low strength at high temperatures, generally suffer from hot shortness and have more shrinkage than ferrous metals. They are utilized in industry due to following advantages:

1. High corrosion resistance
2. Easy to fabricate, i.e., machining, casting, welding, forging and rolling
3. Possess very good thermal and electrical conductivity
4. Attractive colour and low density

The various non-metals used in industry are: copper, aluminium, tin, lead, zinc, and nickel, etc., and their alloys.

Copper

The crude form of copper extracted from its ores through series of processes contains 68% purity known as Blister copper. By electrolytic refining process, highly pure (99.9%) copper which is remelted and casted into suitable shapes. Copper is a corrosion resistant metal of an attractive reddish brown colour.

Properties and Uses

(1) High Thermal Conductivity: Used in heat exchangers, heating vessels and appliances, etc.

(2) High Electrical Conductivity: Used as electrical conductor in various shapes and forms for various applications.

(3) Good Corrosion Resistance: Used for providing coating on steel prior to nickel and chromium plating

(4) High Ductility: Can be easily cold worked, folded and spun. Requires annealing after cold working as it loses its ductility.

Aluminium

Aluminium is white metal which is produced by electrical processes from clayey mineral known as bauxite. However, this aluminium ore bauxite is available in India in plenty and we have a thriving aluminium industry.

Properties and Uses

(1) Like copper it is also corrosion resistant.

(2) It is very good conductor of heat and electricity although not as good as copper.

(3) Possesses high ductility and light weight so widely utilized in aircraft industry.

(4) Needs frequent annealing if cold worked since it becomes hard after cold working.

(5) In view of its ductility and malleability it has replaced copper in electrical transmission and appliances to some extent.

(6) It is used in manufacturing of household utensils including pressure cookers.

Lead

Lead is the heaviest of the common metal. Lead is extracted from its ore known as **galena**. It is bluish grey in colour and dull lusture which goes very dull on exposure to air.

Properties and Uses

(1) Its specific gravity is 7.1 and melting point is 360°C.
(2) It is resistant to corrosion and many chemicals do not react with it (even acids).
(3) It is soft, heavy and malleable, can be easily worked and shaped.
(4) Lead is utilized as alloying element in producing solders and plumber's solders.
(5) It is alloyed with brass as well as steel to improve their machinability.
(6) It is utilized in manufacturing of water pipes, coating for electrical cables, acid tanks and roof covering etc.

Tin

It is a brilliant white metal with yellowish tinge. Melting point of tin is 240°C

Properties and Uses

(1) Tin is malleable and ductile, it can be rolled into very thin sheets.
(2) It is used for tinning of copper and brass utensils and copper wire before its conversion into cables.
(3) It is useful as a protective coating for iron and steel since it does corrode in dry or wet atmosphere.
(4) It is utilized for making important alloys such as fine solder and moisture proof packing with thin tin sheets.

Zinc

The chief ores of zinc are **blende** (ZnS) and **calamine** ($ZnCO_3$). Zinc is a fairly heavy, bluish-white metal principally utilized in view of its low cost, corrosion resistance and alloying characteristics. Melting point of zinc is 420°C and it boils at 940°C.

Properties and Uses

(1) **High corrosion resistance:** Widely used as protective coating on iron and steel. Coating may be provided by dip galvanizing or electroplating.
(2) **High fluidity and low melting point:** Most suitable metal for pressure die casting generally in the form of alloy.
(3) **When rolled into sheets**, zinc is utilized for roof covering and for providing a damp proof non-corrosive lining to containers.
(4) **The galvanized wires, nails, etc.** are produced by galvanizing technique and zinc is also used in manufacture of brasses.

Nickel

About at least 85% of all nickel production is obtained from sulphide ores.

Properties and Uses

1. Pure nickel is tough, silver coloured metal, harder than copper having some but less ductility but of about same strength.
2. It is plated on steel to provide a corrosion resistance surface or layer.
3. Widely used as an alloying element with steel. Higher proportions are advantageously added in the production of steel such as monel or in conel.
4. It possesses good resistance to both acids and alkalis regarding corrosion so widely utilized in food processing equipment.

Magnesium

Principal ores of magnesium are **magnesite**, **carnallite** and **dolomite**. Magnesium is extracted by electrolytic process. It is a brilliant white metal with yellowish tinge.

Melting point of tin is 240°C.

Properties and Uses:

(1) It is the lightest of all metals weighing around two-thirds of aluminium.
(2) The tensile strength of cast metal is the same as that of ordinary cast aluminium, i.e., 90 MPa.
(3) The tensile strength of rolled annealed magnesium is same as that of good quality cast iron.
(4) Magnesium can be easily formed, drawn forged and machined with high accuracy.
(5) In powdered form it is likely to burn, in that situation adequate fire protection measures should be strictly observed.
(6) Its castings are pressure tight and achieve good surface finish. Magnesium castings include motor car gearbox, differential housing and portable tools.

Vanadium

It occurs in conjunction with iron pyrite, free sulphur and carbonaceous matter.

Properties and Uses:

(1) It is silvery white in colour.
(2) Its specific gravity is 5.67.
(3) Its melting point is 1710°C.
(4) When heated to a suitable temperature it can be hammered into any shape or drawn into wires.
(5) It is used in manufacture of alloy steels.
(6) Vanadium forms non-ferrous alloys of copper and aluminium from which excellent castings can be produced.

Antimony

Chief ore of antimony is **stibnite**. To a small extent, antimony is obtained as a by-product in refining of other metals such as lead, copper silver and zinc.

Properties and Uses

(1) It is silvery white, hard, highly crystalline and so brittle that it may be readily powdered.
(2) Its specific gravity is 6.63 and melting point is 630°C.
(3) It is generally used as an alloying element with most of heavy metals.
(4) Lead, tin and copper are the metals which are most commonly alloyed with

antimony.

Cadmium

It is obtained commercially as a by-product in the metallurgy of zinc and to some extent of lead.

Properties and Uses

(1) White metal with bluish tinge, capable of taking a high polish.
(2) Its specific gravity is 8.67 and melts at 321°C.
(3) It is slightly harder than tin but softer than zinc.
(4) It is malleable and ductile and can be readily rolled and drawn into wires.

It is chiefly utilized in antifriction alloys for bearings. It is also used as rust proof coating for iron and steel. Components of automobiles and refrigerator such as nuts, bolts and trimmings, locks and wire products are plated with it.

ALLOYS OF COPPER

Copper alloys are among the best conductors of heat and electricity and they have good corrosion resistance. The common types of copper alloys are brasses and bronzes. The various alloys of copper are discussed as follows:

Brass

All brasses are basically alloys of copper and zinc. Commercially there are two main varieties of brasses:

(1) Alfa brass: Contains upto 36% Zn and rest copper for cold working.
(2) Alfa-Betabrass: Contains 36 to 45% Zn and remainder is copper for hot working.

The tensile strength and ductility of brass both increase with increase in content of Zn upto 30% zinc. With further increase in zinc content beyond 30%, the tensile strength continues to increase upto 45% of Zn, but ductility of brasses drops significantly. β-phase is less ductile than α-phase but it is harder and stronger.
Thus, there are various types of brasses depending upon proportion of copper and zinc. Fundamentally brass is a binary alloy of copper with as much as 50% zinc. Various classes of brasses such as cartridge brass, Muntzmetal leaded brass, Admirality brass, naval brass and nickel brass depending upon the proportion of copper and zinc plus third alloying metal are available for various uses. Suitable type of brasses can undergo the processes of casting, hot forging, cold forging, cold rolling

into sheets, drawing into wires and extrusion for obtaining requisite special cross-section bars. The melting point of brass varies according to its composition but most of the brasses in the common range liquefy between temperatures of 840°C to 960°C. By adding small quantities of other elements, the properties of brass may be greatly affected. For example, addition of 1 to 2% zinc improves the machinability of brass. Brass has a greater strength than that of copper but has a lower thermal and electrical conductivity. Brasses possess very good corrosion resistance and can be easily soldered. Brasses are used in hydraulic fittings, pump linings, utensils, bearings and bushes, etc.

2.12.2 Bronze

The alloy of copper and tin are usually termed **bronzes**. The useful range of composition is 75 to 95% copper and remainder tin. In general, it possesses superior mechanical properties and corrosion resistance to brass. The alloy can be easily cold rolled into wire, rods and sheets. With increase in tin content, the strength of this alloy and its corrosion resistance increases. It is then known as hot working bronze. Bronze is generally utilized in hydraulic fittings, bearings, bushes, utensils, sheets, rods and many other stamped and drawn products.

The generally used bronzes are as follows:

(1) Phosphor bronze: When bronze contains phosphorus, it is known as phosphor bronze. Phosphorus present in such alloy increases the strength, ductility and soundness of castings. Various compositions of this alloy are available for different applications. The composition of the alloy varies according to whether it is to be forged, wrought or cast. A common type of phosphor bronze has the following composition as per Indian standards. Copper = 93.6%, tin = 9%, and phosphorus = 0.1 to 0.3%.

The alloy possesses good wearing qualities and high elasticity. The alloy is resistant to salt water corrosion.

Cast phosphor bronze is utilized for production of bearings and **gears**. Bearings of bronze contain 10% tin and small addition of lead. This is also used in making
gears, nuts, for machine lead screws, springs, pump parts, linings and many other such applications.

(2) Gun metal: Gun metal contains 2% zinc, 10% tin and 88% copper. It is a very famous composition. Sometimes very small amount of lead is also added to improve castability and machinability. The presence of zinc improve its fluidity.

This bronze is used for bearing bushes, glands, pump valves and boiler fittings, etc.

(**3) Silicon bronze:** Silicon bronze has an average composition of 3 per cent silicon, 1 per cent manganese and rest copper. It possesses good general corrosion resistance of copper with higher strength and toughness. It can be cast rolled, stamped, forged and pressed either hot or cold and can be welded by all the usual methods.Silicon bronze is widely utilized for parts of boilers, tanks, stoves or where high strength as well as corrosion resistance is required.

(4) Bell metal: This alloy contains 20 to 21% tin and rest copper. It is hard and resistant to surface wear. It can be readily cast, is generally utilized for casting bells, gongs and utensils, etc.

(**5) Manganese Bronze:** It is an alloy of copper, zinc and manganese. It contains 55 to 60% copper, 40% zinc, with 3.5% manganese. This alloy is highly resistant to corrosion. It is stronger and harder than phosphor bronze. It has poor response to cold working but can be easily hot worked.

It is generally utilized for producing bushes, plungers, feed pumps and rods, etc. Worm gears are frequently made of manganese bronze.

(**6) Muntz Metal:** The composition of this alloy is 60 per cent copper and 40 per cent zinc. Sometimes a small quantity of lead is also added. This alloy is stronger, harder and more ductile than normal brass. While hot working between 700°C to 750, it responds excellently for process but does not respond to cold working.

This alloy is utilized for a wide variety of small components of machines, bolts, rods, tubes, electrical equipment as well as ordinance works. It is widely employed in producing such articles which are required to resist wear.

2.12.3 Alloys of Aluminium

Aluminium may be alloyed with one or more alloying elements such as copper, manganese, magnesium, silicon and nickel. The addition of small quantities of alloying elements converts the soft and weak aluminium into hard and strong metal, while it retains its light weight. The main alloys of aluminium are: Duralumin, Y-alloy, Magnalium and Hindalium which are discussed as follows:

(1) Duralumin: A famous alloy of aluminium containing 4% copper, 0.5% manganese, 0.5% magnesium and a trace of iron with remainder as aluminium is known as duralumnin. It possesses high strength comparable with mild steel and low specific gravity. However, its corrosion resistance is much lower as compared with pure aluminium. The strength of this alloy increases significantly when heat treated and allowed to age for 3 to 4 weeks it will be hardened. The phenomenon is termed age hardening. To improve upon the corrosion resistance of it, a thin film of aluminium is rolled on the duralumin sheets. These sheets are known as Alclad by trade name and are widely used in aircraft industry.

It is widely utilized in wrought conditions for forging, stamping, bars, tubes and rivets. It can be worked in hot condition at 500°C. However, after forging and annealing it could also be cold worked. Due to light weight and high strength this alloy may be used in automobile industry.

(2) **Y-Alloy:** It is also known as copper-aluminium alloy. The addition of copper to pure aluminium improves its strength and machinability. Y-alloy contains 93% aluminium, 2% copper, 1% nickel and magnesium. This alloy is heat treated as well as age hardened just like duralumin. A heat treatment of Y-alloy castings, consisting of quenching in boiling water from 510°C and then aging for 5 days develops very good mechanical characteristics in them. Since Y-alloy has better strength at elevated temperature than duralumin therefore it is much used in aircraft cylinder heads and piston. It is also used in strip and sheet form.

(3) **Magnalium:** It is produced by melting the aluminium 2 to 10% magnesium in a vacuum and then cooling it in vacuum or under a pressure of 100 to 200 atmospheres. About 1.75% copper is also added to it. Due to its light weight and good mechanical characteristics, it is mainly used for aircraft and automobile components.

(4) **Hindalium:** It is an alloy of aluminium and magnesium with small quantity of chromium. It is manufactured as rolled product in 16 gauge mainly used in manufacture of anodized utensils.

Alloys of Nickel

(1) **German silver:** The composition of this alloy is 60% Cu, 30% Ni and 10% zinc. It displays silvery appearance and is very ductile and malleable. It is utilized for electrical contacts, casting of high quality valves, taps and costume jewellery. It is also used in producing electrical wires.

(2) **Monel metal:** It contains 68% Ni, 30% Cu, 1% iron and remainder small additions of Mn and other elements. It is corrosion resistant and possesses good mechanical properties and maintains them at elevated temperatures.

(3) **Nichrome:** It is an alloy of nickel and chromium which is utilized as heat resistant electrical wire in electrical applicances such as furnaces, geysers and electric iron, etc.

(4) **Inconel and incolony:** These alloys principally contain, Ni, Cr, Fe, Mo, Ti and

very small proportions of carbon. These are used as high temperature alloys. Inconel does not respond to heat treatment.

Bearing Materials

A bearing material should possess the following characteristics:

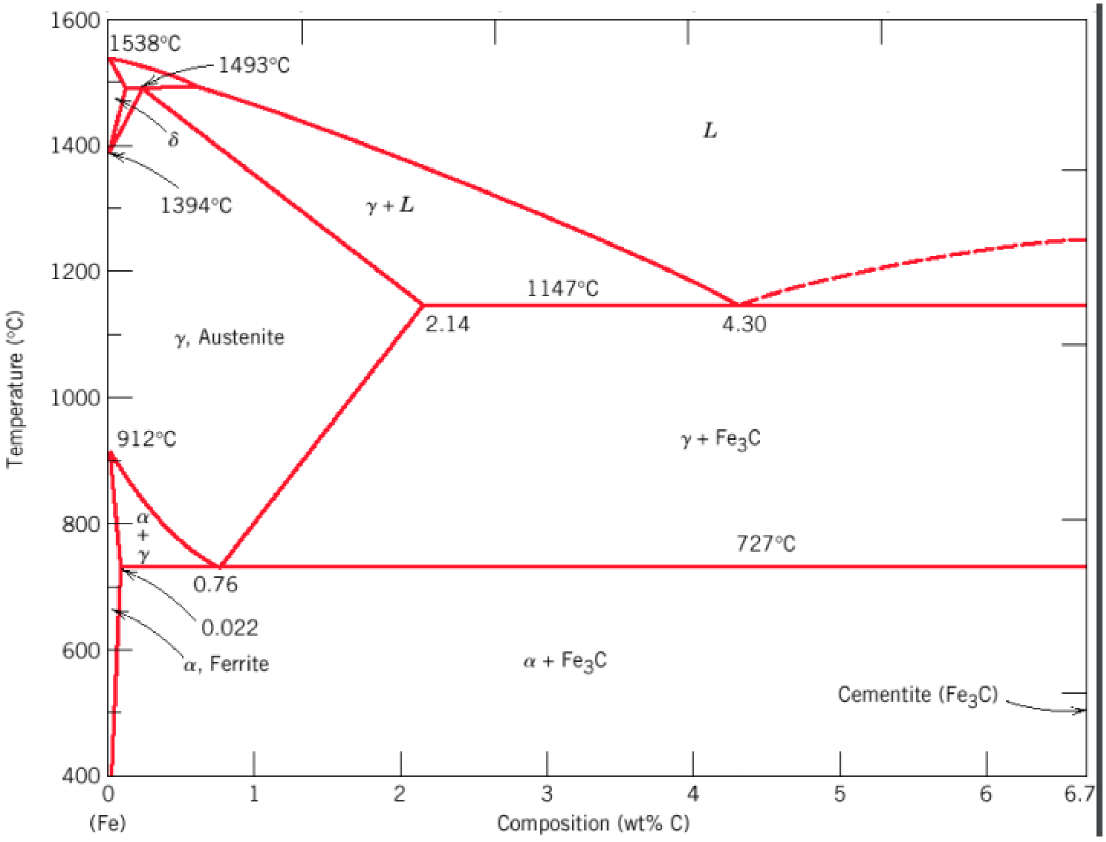
(1) It should possess enough compressive strength to provide adequate load carrying capacity.

(2) It should possess good plasticity to negate small variations in alignment and fitting. Its wear resistance should be adequate to maintain a specified fit.

(3) The coefficient of friction of the bearing material should be low to avoid excessive heating.

The Iron–Iron Carbide (Fe–Fe3C) Phase Diagram

In their simplest form, steels are alloys of Iron (Fe) and Carbon (C). The Fe-C phase diagram is a fairly complex one, but we will only consider the steel part of the diagram, up to around 7% Carbon.



Phases in Fe–Fe_3C Phase Diagram

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

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 eutectic temperature (727 ° C) unless cooled rapidly

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

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

Fe-C liquid solution

- 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 is non-magnetic

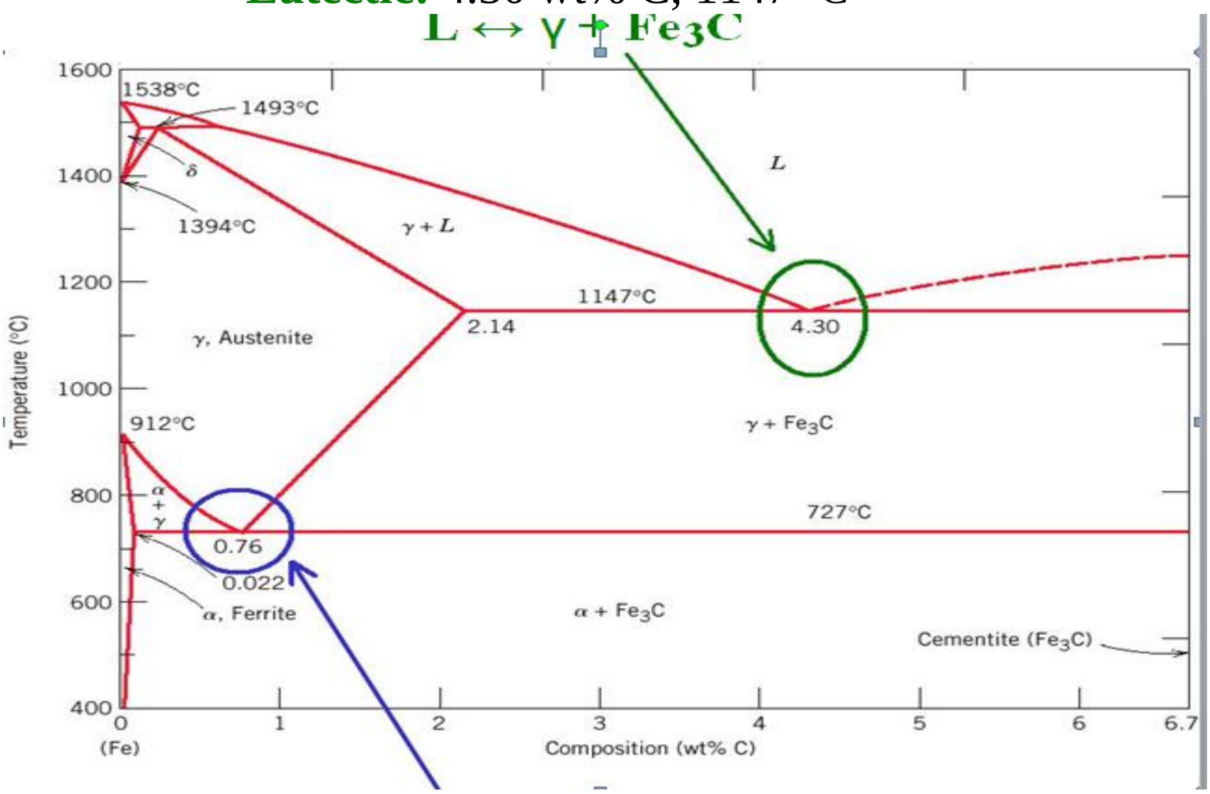
Classification. Three types of ferrous alloys:

- Iron: less than 0.008 wt % C in α−ferrite at room T
- Steels: 0.008 - 2.14 wt % C (usually < 1 wt %)

  α-ferrite + Fe_3C at room T
- Cast iron: 2.14 - 6.7 wt % (usually < 4.5 wt %)

Eutectic and eutectoid reactions in Fe–Fe_3C

Eutectic: 4.30 wt% C, 1147 °C



Eutectoid: 0.76 wt%C, 727 °C

Five individual phases

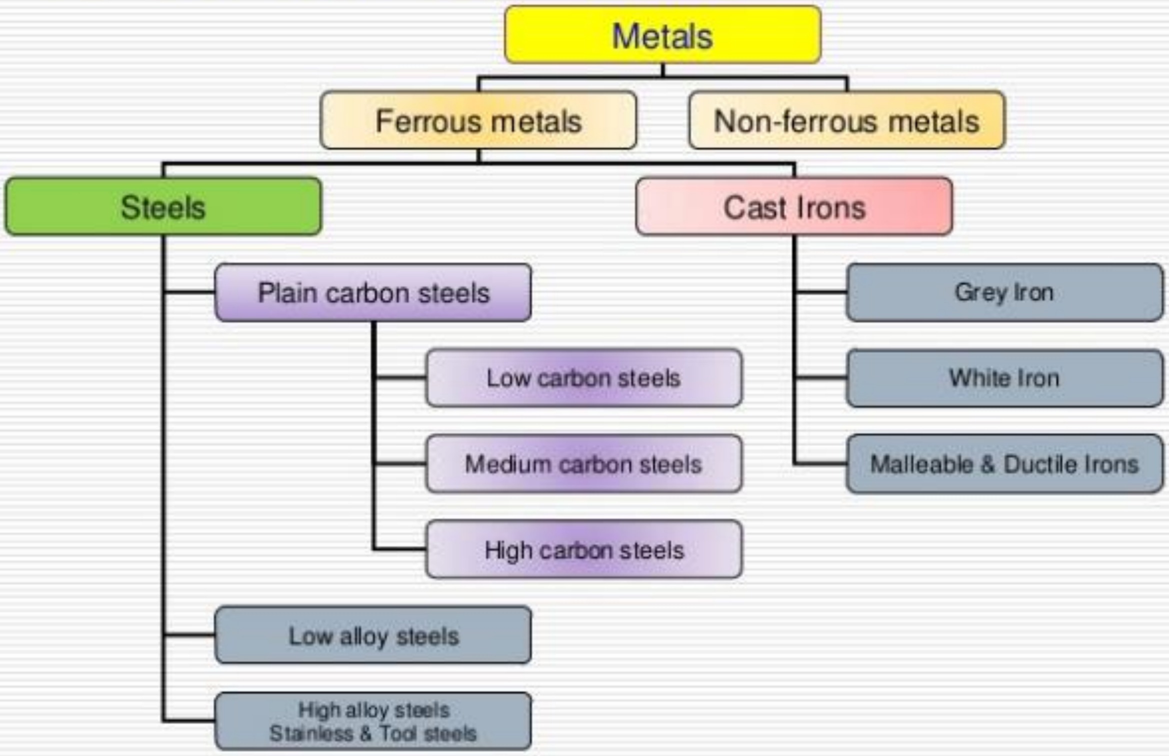
- α–ferrite (BCC) Fe-C solid solution
- γ-austenite (FCC) Fe-C solid solution
- δ-ferrite (BCC) Fe-C solid solution
- Fe_3C (Iron Carbide) *or* cementite – an inter-metallic compound
- Liquid Fe-C solution

Three invariant reactions

A horizontal line always indicates an invariant reaction in binary phase diagrams

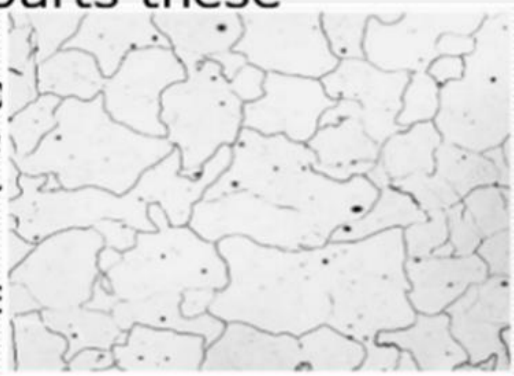
- Peritectic reaction at 1495°C and 0.18%C,
  - δ-ferrite + $L \leftrightarrow \gamma$-iron (austenite)
- Eutectic reaction at 1147°C and 4.3 %C,
  - $L \leftrightarrow \gamma$-iron + Fe_3C (cementite) [ledeburite]
- Eutectoid reaction at 727°C and 0.77%C,
  - γ-iron $\leftrightarrow$ α–ferrite+Fe_3C (cementite) [pearlite]

Fe-C alloy classification



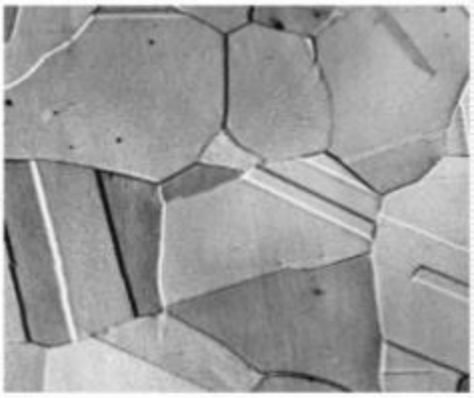
α–Ferrite

- Known as α -iron
- Pure iron at room temperature
- Body-centered cubic structure
- Soft & ductile and imparts these properties to the stee
- Less than 0.01% carb ferrite at room tempe
- High temperature forr the two forms are ide
- Pure ferritic steels are



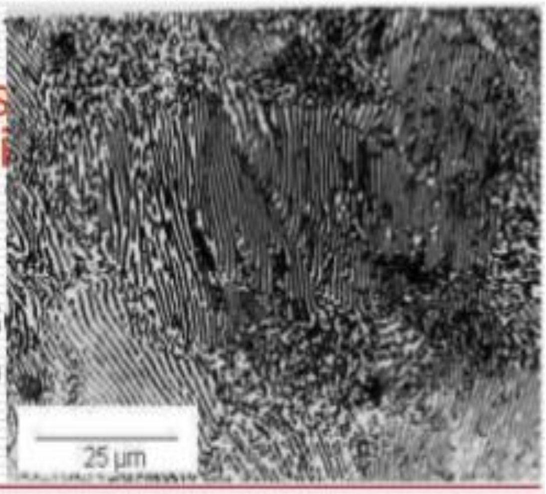
Austenite

- Known as γ -iron
- Face-centered cubic
- Much softer than ferrite
- Not present at room temperatures.
- More easily hot worked



Pearlite

- A laminated structure formed of alternate layers of ferrite and cementite with average composition 0.83% carbon
- Pearly lustre in the microscope
  - Interference of light in its regular layers
- Most common constituen
- It combines the hardness cementite with the ductili key to the wide range of steels.
- The laminar structure als crack movement as in co it toughness



Cementite

- Iron Carbide - an intermetallic compound
- Hard, brittle, white
- melts at 1837 C , density of 7.4 g/cc
- On the phase diagram, cementite corresponds to a vertical line at 6.7%
- Engineers care only abo carbon
- Its presence in steels ca hardness and a reductio toughness