STUDY 1: IRON AND STEEL METALLURGY

1.0 INTRODUCTION

A metal may be described as a material which is solid at room temperature has relatively high density, high melting temperature, low specific heat, good electrical and thermal conductivity, strength and hardness.

A metal can exist in the solid, liquid or gaseous state depending upon the temperature and pressure exerted on the metal. Some of the common metals and alloys are iron, copper, aluminum, nickel, tin, brass and bronze etc.

The non-metals in the solid state are mostly brittle and are poor electrical and thermal conductors. They do not form alloy but combined chemically to form compounds. Ex: Glass, wood, plastic and concrete.

Hence, in accordance to their properties the materials are broadly divided into two groups i.e., METAL and NON-METAL.

1.1 CLASSIFICATION OF METALS

All the metals are classified into two groups: FERROUS and NON-FERROUS. Ferrous Metals are those which contain iron.The latin words of iron is **ferrum**. Ferrous metals are Pig iron, Cast iron, Wrought iron, Carbon Steel, Alloy Steel.

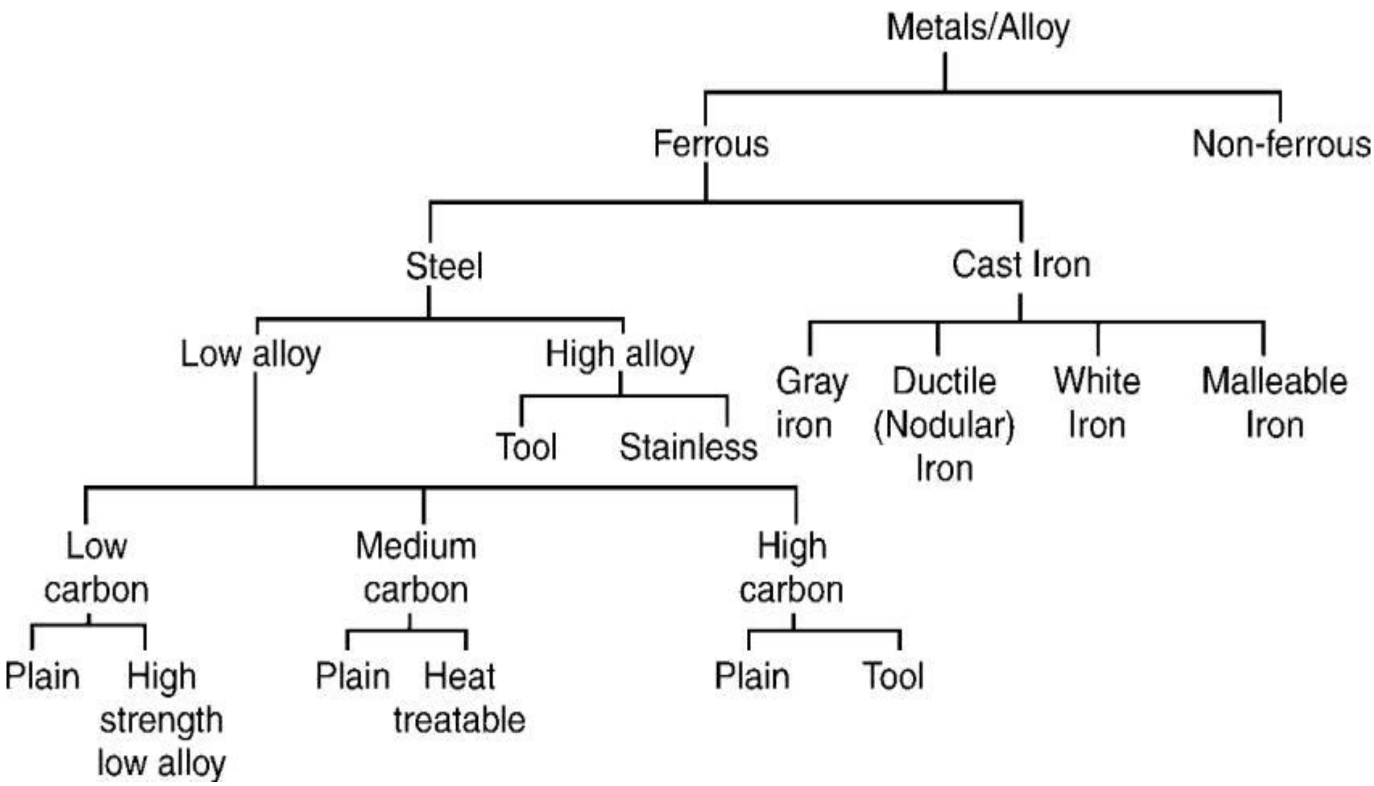


Fig. 1: Ferrous Materials

1.2 FERROUS METALS

Non-ferrous metals are those which do not contain iron. Ex: Lead, Copper, Zinc, and tin. Non-ferrous metals are more costly as compared to ferrous metals, but they are good conductivity of heat and electricity lightness in weight, good machinability, high resistance to corrosion and the property of being anti-magnetic.

PIG IRON

All iron and steel products are derived originally from pig iron. This is the raw material obtained from the chemical reduction of iron ore in a blast furnace. The process of reduction of iron ore to pig iron is known as **SMELTING**. Pig Iron partly refined in a coupla furnace produces various grades of Cast Iron. By puddling or shotting processes, wrought iron is produced from pig iron. Steel is produced from pig iron by various steel making processes, such as Bessemer Converter, Open-hearth Furnace, Oxygen Processes, Electric and Spray steel making furnace

The main raw materials required for pig iron are:

I. Iron ore
II. Fuel
III. Flux

Iron Ore

Iron ore are generally carbonates, hydrates or oxides of the metals. These iron ores are found in India in several states—namely, Bihar, Orissa, MP, AP, Mysore, Tamil Nadu. Following are the common varieties of iron ores:

ORE	***Composition***	***Form***	***% of Metal***
Red hematite	Fe_2O_3	Oxide	60-70
Magnetite	Fe_3O_4	Oxide	62-72
Limonite	$Fe_3O_3H_2O$	Oxide	40-60
Iron Pyrite	FeS_2	Sulphide	30-40
Iron Stone(Siderite)	$FeCO_3$	Carbonate	35-50

Fuel

Hard coke is commonly used as a fuel in blast furnace. This coke has two functions, one is to provide the required heat for melting and the other to combine with the oxygen of the ore in order to reduce the same. It is desirable that the fuel used should be hard enough to withstand the heavy weight of the charge without being crushed. It should possess, high calorific value, low ash content, high density and good porosity.

Flux

Flux is a mineral substance that is charged into a blast furnace to lower the milting point of the ore and to promote the removal of the ash, sulphur and the residues of the burnt fuel. **Lime stone** is the most commonly used flux in blast furnace.

1.3 BLAST FURNACE AND ITS CHEMISTRY

BLAST FURNACE

The blast furnace is a vertical furnace designed for the continuous operation. The smelting room of the blast furnace comprises a throat, stack, body, bosh and hearth. It consist of a tall steel structure supported on a strong foundation and heavy columns all around. The outer shell is made of mild steel plates and the inner surface is lined throughout by the refractory materials (called fire bricks). It's structure is divided into two parts, upper parts is known as **stack or shaft** and lower parts is known as **bosh.**

The upper part is tapered upwords and the lower one downwords.Two tapping holes are provided near the bottom for removing the metal and slag resp.

The raw materials known as the charge are taken to the top of the furnace by a specially designed bucket called **"skip"** running along an incline(or by the conveyor). The charge is then introduced into the throat of the furnace by means of a cup and cone hopper arrangement to prevent the escape of blast furnace gas which is used as a fuel. The proportion of raw materials are approximately 1/2 iron ore, 1/3 fuel and 1/6 flux.

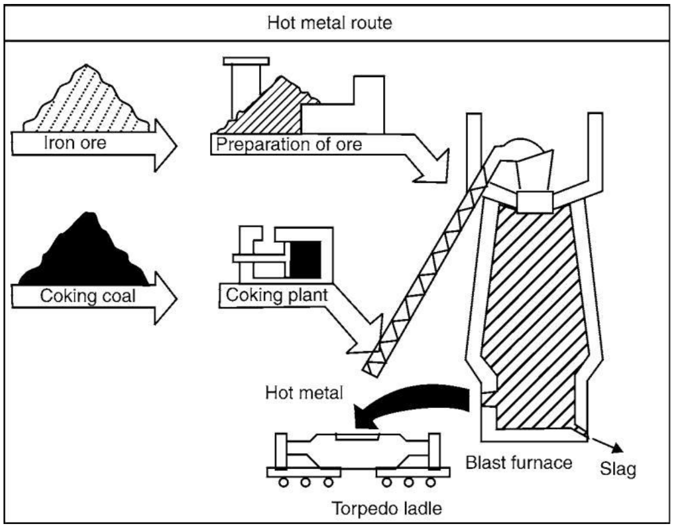


Fig.2: Blast-furnace Process

In addition to the pig iron, slag (60% of pig iron) and gas also produced (500% of pig Iron).A hot blast is forced into the furnace through a number of **nozzle** called **tuyeres**.

The tuyeres are cooled by water circulating between the pipe walls. The air blast is heated to minimise fuel comsumption by passing the cold air blast through the heated checker-work of hot blast stoves.

The temperature of the furnace just above the level of the tuyeres (melting zone) being 1000°C to 1700°C all substance inside the furnace start melting in the heat.The limestone that serves as a flux is combined with the ore to form a molten slag which floats on the top of the molten iron. The slag is tapped off from the furnace through the slag hole. The molten iron is tapped at intervals from 6 to 12 hours through a tapping holes, the blast being turned off meanwhile. The furnace is kept in operation until it gets worn-out.

Charging Operation of Blast Furnace

The mined ore carries a number of earthy impurities and before smelting they are separated from the ore to the extent it is possible. The operation performed for doing so is calcination or roasting. In these preparatory process the mined ore is first crushed into small size and concentrated followed by roasting it in kilns.This enables considerable reduction in moisture content carbondioxide and also to some extent sulphur and arsenic. Ferrous oxide (FeO) is converted into ferric oxide (Fe_2O_3) and ore attains enough porosity which helps in its quicker reduction to iron.

This ore with suitable amount of coke and flux is charged in the blast furnace.These materials are lifted through a hoisting mechanism to the top of the furnace and charged through the double ball arrangement into the throat. The hot air blast enters the furnace through tuyeres and rises upwords. Through the downwards moving charge as the charge is melted, the molten metal is collected as the bottom and the slag floats over its top surface.The normal capacity of this furnace range from 800 to 1200 tonnes of pig iron per 24 hour. This furnace once started can run non-stop fot the years together.

Chemistry of Blast Furnace

Different chemical reaction take place in different parts of the blast furnace. According to the temp in those parts, the highest temp in the furnace is at the bottom and the lowest at the top. According to these temp range, the blast furnace can be divided into following zones.

Preheating Zone (From the top to gas outlet level): Temp range in this zone is 200°C to 350°C which provided only a preheating effect on the charge and helps in evaporating the moisture content from it.

Reduction Zone (from the gas outlet to nearly the max cross-section level): Temp range between 350°C to 1200°C. This is further sub-divided into two zones.

Upper Reduction Zone: (350°C to 700°C)

Here, iron oxide is reduced to metallic iron by reaction with the ascending carbon monoxide. So, this zone is also called iron oxide reduction zone.

$Fe2O3 + 3CO = 2Fe + 3CO2$

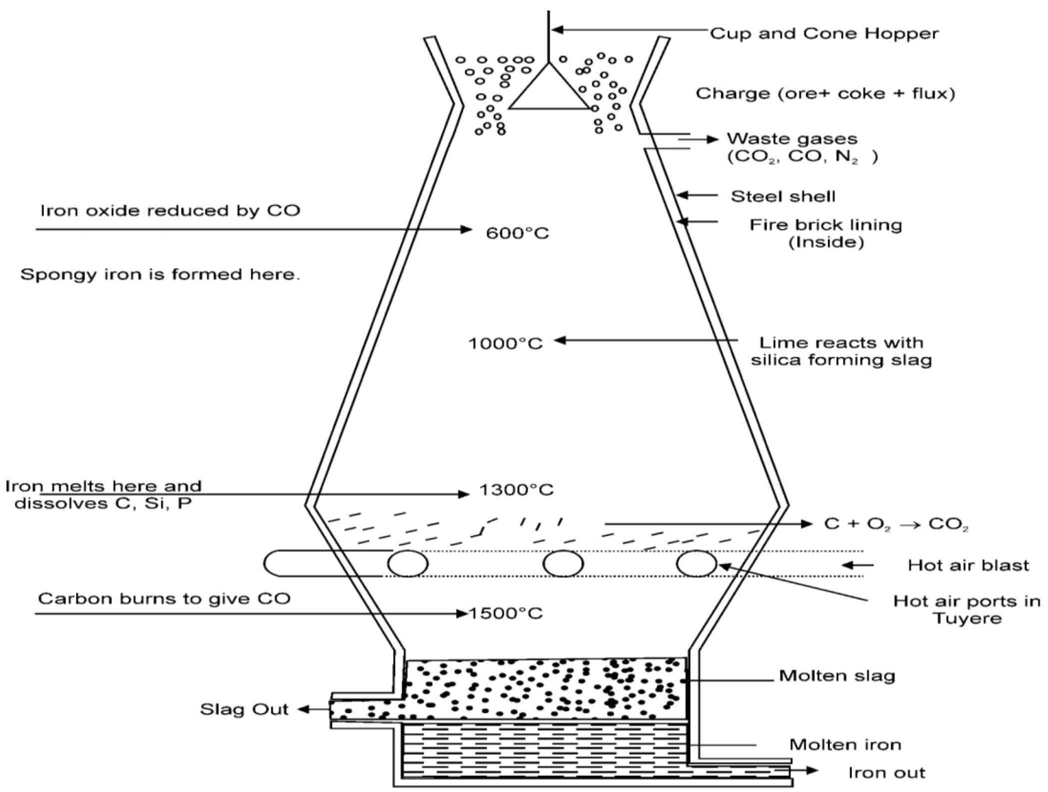
In this zone limestone (flux) also starts dissociating as follows: $CaCO = CaO + CO2$

(b) Lower Reduction Zone (700°C to 1200°C)

Here change becomes hotter as it descends.The decomposition of CaCO3 started earlier is completed at about 850°C. The CO2 formed due to this decomposition recast with the carbon of coke to reduce to CO.

CO2 +C=2CO

Fe2O3 + 3CO 2 → 2Fe + 3CO2



Pre-jeatomg Zone— From top (charge feeding level) to waste gas outlet level.
Reducing Zone — From waste gas outlet level to nearly maximum diameter of the furnace above tuyere.
Fusion Zone — From bottom of reducing zone to a level little below the tuyere.

Fig. 3: Blast Furnace

Reduction of iron oxide is completed here

$$Fe_2O_3 + 3C = 2Fe + 3CO$$

The calcium oxide formed by the decomposition of lime. Stone combines all the impurities like silica and aluminium with it to form the slag. The higher temp of about 1200°C also causes the reduction of other oxides in the ore like P2O5 , MnO2 and SiO2 etc, into respective free element P, Mn and Si. They are absorbed by the metal formed(Fe) as above. As a result of all these, the melting point of iron is lowered and it starts melting at about 1200°C instead of 1530°C (The melting point of pure iron)

Fusion Zone(1200°C to 1600°C): Evidently this parts carries highest temperature and in this region the melting of charge is finally completed. The iron get superheated here.The slag and molten metal are tapped separately from the furnace.The molten metal is poured into the moulds.Where it solidified to form what is known as pig iron.

The product of blast furnace has the following composition (approx)

Composition	*%*
Carbon	3 to 4%
Silicon	1 to 3%
Manganese	0.1 to 1%
Phosphorus	0.3 to 1.7%
Sulphur	Less than 1%

Iron	Remainder

1.4WROUGHT IRON

WROUGHT IRON

It is a highly refined mechanical mixture of very pure iron and a silicate slag.. It is the purest iron which contain at least 99.5% iron but may contain 99.9% iron.

Chemical Composition

The product has the following chemical composition (approx)

Composition	***%***
Carbon	0.02 to 0.03%
Silicon	0.02 to 0.10%
Sulphur	0.008 to 0.02%
Manganese	Nil to 0.02%
Phosphorus	0.05 to 0.25%

Slag	0.05 to 1.5%
Iron	Balance

Properties

The following are the main properties of wrought Iron.

- It is never cast.
- It is weldable,forgeable,corrosion resistant and shock resistant.
- It is tough, malleable and ductile.
- It cannot be melted.
- It cannot stand sudden and excessive shocks.
- It can neither hardened nor tempered like steel.
- The melting point of wrought iron is 1510°C.
- It is used for bolts, nuts, chains, crane hooks, railway coupling, pipe and pipe fitting, plates, sheets,water pipe.

Manufacture of Wrought Iron

The main point in the manufacture of wrought iron is the oxidation of nearly all the carbon and other elements fron pig iron. The following two processes are commonly used in the manufacture of wrought iron.

PUDDLING PROCESS

Pig iron for this purpose is first subject to a preliminary process of refining, the object of which is to remove silicon as compleltely as possible together with the greater part of the phosphorus, and to convert the graphite into combined carbon and this produces **white iron.**

The next process is to convert the white iron into wrought iron. To do this the slab of white iron are broken into pieces and taken to the puddling furnace which is a coal fired reverberatory furnace.

The term **reverberatory** is applied to furnace in which the charge is not in actual contact with the fire, but receives its heat by reflection from the roof of the shaped furnace.

The products obtained is known as **blooms** having a mass of about 50Kg. The hot metal is then passed through grooved rollers which convert blooms into bars called **muck bars** or **Puddle bars** which have a cross-section of approximately 15 to 100 mm. These bars are cut into short length, fastened together in piles, reheated to a welding temperature and again rolled into bars.

ASTON OR BYERS PROCESS

The large scale production of wrought iron resulted from the work of Dr. James Aston and his associates at the A.M. Byers Co.

In the Aston or Byers process, to produce wrought iron, the pig iron is first melted in a cupola furnace and refining of molten metal is done in a Bessemer converter. At the same time, a quantity of iron silicate slag is prepared in an open heart furnace. The refined iron so made in the Bessemer converter is poured at predetermined rate into a ladle containing the molten slag already prepared.

After the excess slag is poured from the ladle, the remaining mass of iron and slag is taken to a press where some slag is removed. The rectangular block formed in the press is known as **bloom**. The hot bloom as before is immediately passed through rolling mills to produce products of wrought iron of different shapes and sizes.

1.5 CAST IRON

CAST IRON

Cast iron is a general term that describes a series of iron-carbon silicon alloys, which are produced by pouring the molten (sand or metal) alloy into molds.

It is most common material for making castings such as for automobile engine blocks, machine tool structure, frames for electric motor.

It is brittle and gray in colour, So, it cannot be used in those parts which are subjected to shock (due to brittleness).

It contains so much carbon that, as cast, it is not appreciably malleable at any temperature. The main properties are its low cost, good casting characteristics, high compressive strength, wear resistant and excellent machinability, no plasticity, unsuitable for forging works.

Chemical Composition

Composition	*%*
Carbon	2 to 4%
Silicon	1 to 3%
Manganese	0.5 to 1.0%
Phosphorus	1%
Sulphur	0.02 to 0.15%

Production of Cast Iron

It is obtained by remelting pig iron with coke and lime stone in a furnace known as cupola. The limestone and fluxes aid in separating the impurities from the pig iron. The lime stone also acts as a flushing agent to carry off the oxides and ash from the fuel.

CUPOLA FURNACE

The pig iron obtained from blast furnace is most impure and needs refining before using it for making suitable castings. The process involved in refining is remelting of pig iron with coke, limestone (or shell lime) and scrap castings in a cupola. It does not produce metal of uniform quality.

It is very similar to a blast furnace but small size and is much simpler in construction. It consists of a vertical steel cylindrical shell of uniform diameter of about 1 meter and 4 meters high. It is lined with fire bricks and rests on a square bed plate which is supported on four cast iron pillars, above the ground. The square bed plate has a circular opening of the size of the inside dimensions

REFERENCE

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