FERROUS METAL

Introduction

- Ferrous metals mean they **do** contain iron.
- Ferrous metals may be pure iron, like wrought iron, or they may be alloys of iron and other elements. Steel, being an alloy of iron and carbon, would therefore be a ferrous metal.
- Non-ferrous metals mean they **do not** contain iron.
- Common non-ferrous metals include aluminum, tin, copper, zinc, and brass, an alloy of copper and zinc. Some precious metals such as silver, gold, and platinum are also non-ferrous.

Ferrous Metals
(Iron and Alloys of Iron)

- The widespread use of ferrous alloys is accounted for by the following three factors:

(1) Iron containing compounds exist in abundant quantities within the earth's crust;

(2) Metallic iron and steel alloys may be produced using relatively economical extraction, refining, alloying and fabrication techniques; and

(3) Ferrous alloys are extremely versatile, in that they may be tailored to have a wide range of mechanical and physical properties.

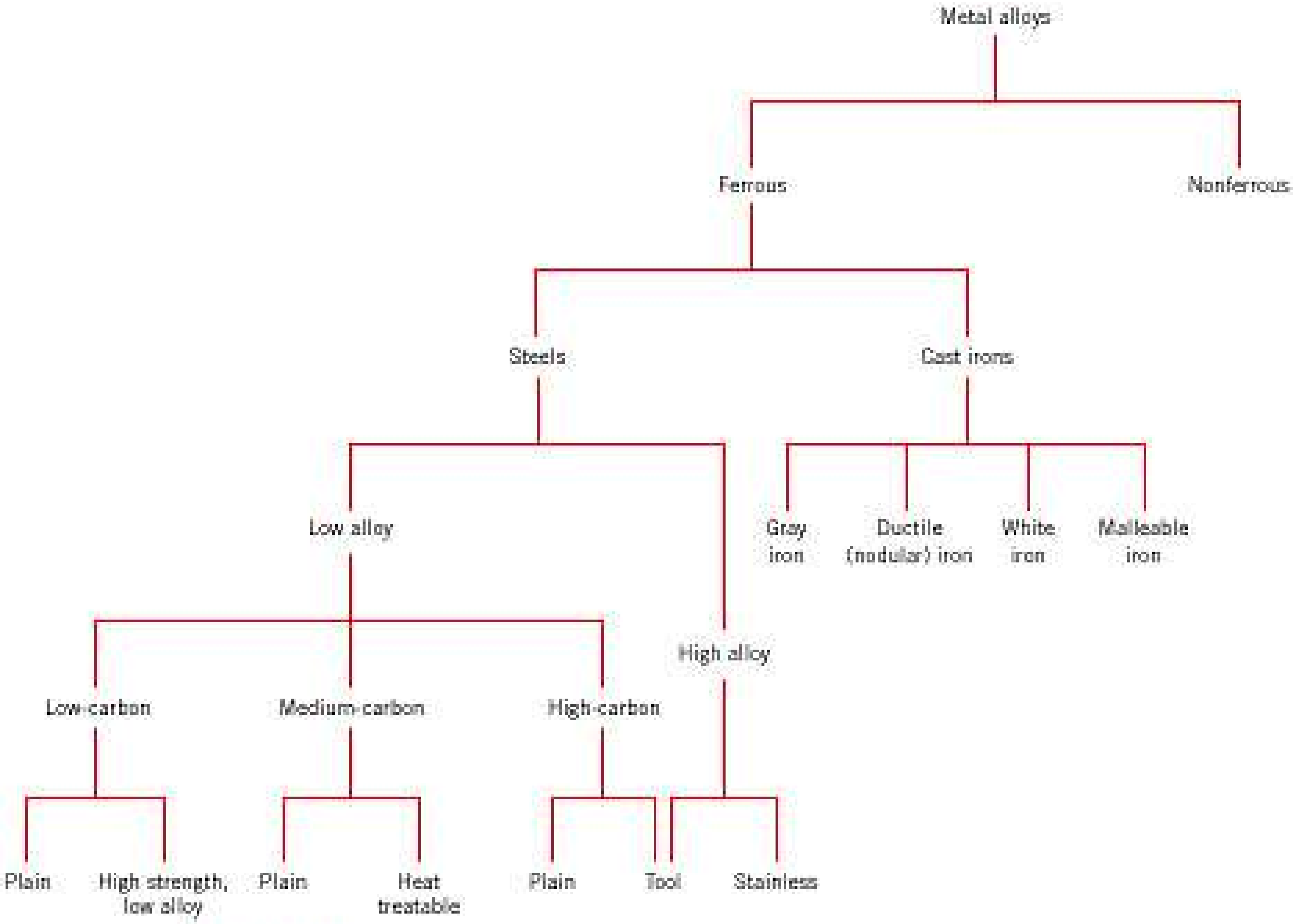


FIGURE 12.4 Classification scheme for the various ferrous alloys.

IRON ORES

- Iron is the most abundant metal in the earth's crust after Aluminium.
- It is found in the form of ores as oxides, carbonates, silicates & sulfides.
- Some of the important / principal iron-ores are …

Iron ore	*Chemical formula*	*Colour*	*Iron content (%)*
Magnetite	Fe_2O_3	Black	72
Haematite	Fe_3O_4	Red	70
Limonite	$FeCO_3$	Brown	60–65
Siderite	$Fe_2O_3\ (H_2O)$	Brown	48

- The iron ore contains impurities, mainly silica (silicon dioxide).
- Since iron is below carbon in the reactivity series, iron in the ore is reduced to iron metal by heating with carbon (coke).

Some Terms – Lets Have a Look

Minerals: A solid element or compound which **occurs naturally** in the Earth's crust is called a mineral.

Ore: A mineral from which **metals can be extracted profitably** is called a metal ore. Profitable extraction means that the cost of getting the metal out of the ore is sufficiently less than the amount of money made by selling the metal. So ***All Ores Are Minerals But All Minerals Are Not Ores.***

Metals are obtained from their ores by **reduction**.

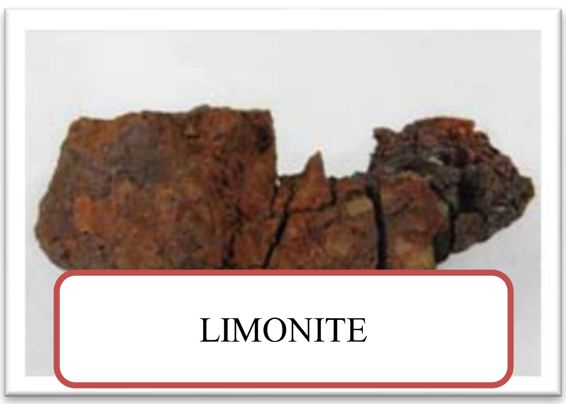
PHYSICAL PROPERTIES OF IRON

- ✓Iron is a lustrous, ductile, malleable, silver-gray metal.
- ✓It is known to exist in four distinct crystalline forms.
- ✓Iron rusts in damp air, but not in dry air and dissolves readily in dilute acids.
- ✓It has a very high tensile strength.
- ✓Boiling point : 3000 °C(5,400 °F)
- ✓Melting point : 1,536 °C (2,797 °F)

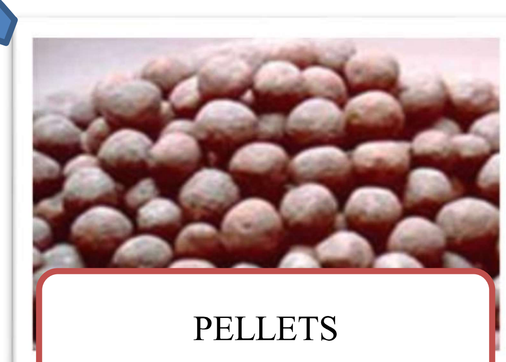
- **Iron Ores Required in Iron-making.**

HEMATITE

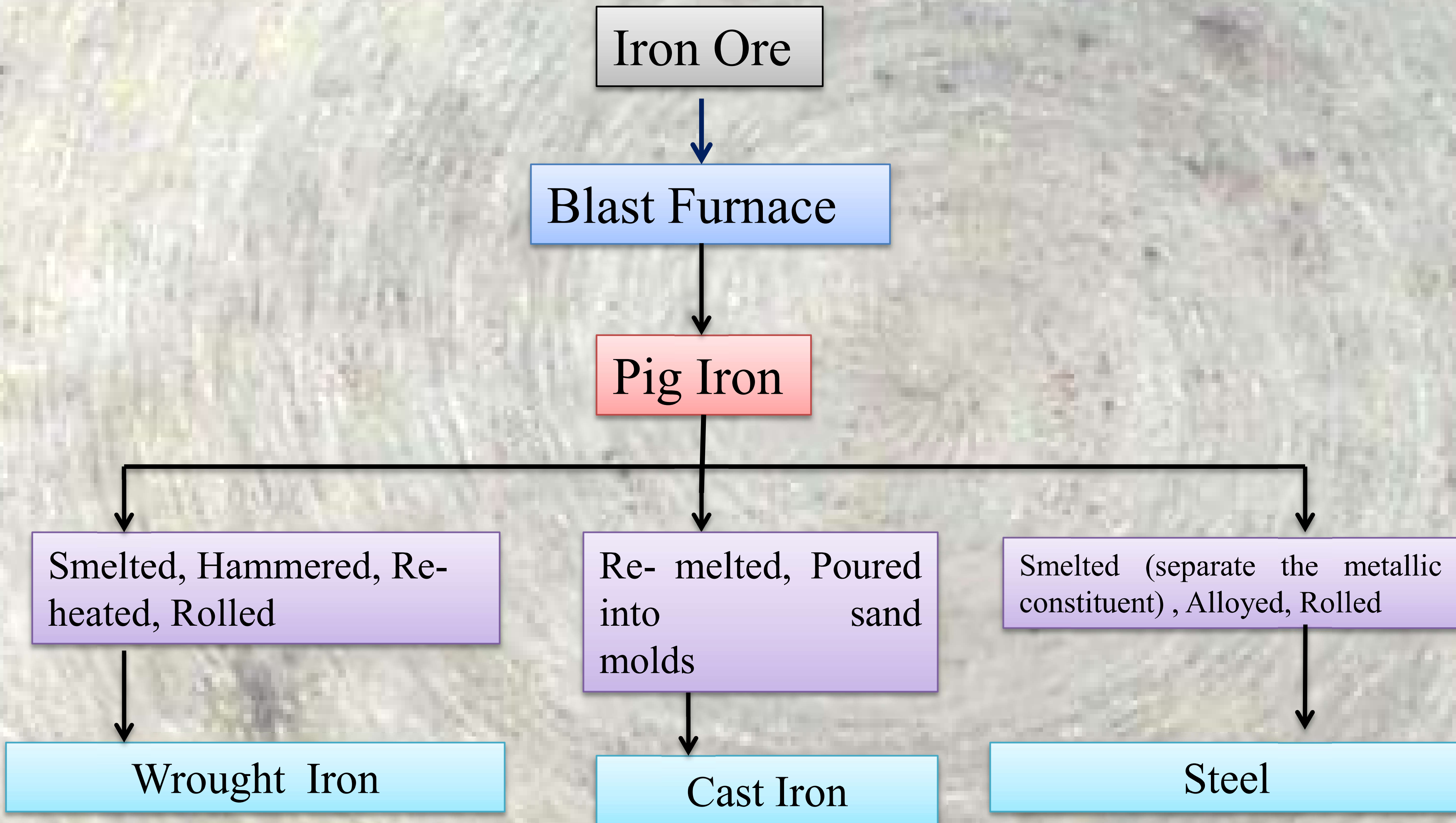
MAGNETITE



LIMONITE



PELLETS


Iron Ore
Blast Furnace
Pig Iron
Smelted, Hammered, Re-heated, Rolled
Re- melted, Poured into sand molds
Smelted (separate the metallic constituent) , Alloyed, Rolled
Wrought Iron
Cast Iron
Steel

PIG IRON

- PIG IRON is the principal raw material for all ferrous products like iron and steel.
- It is obtained by chemical reduction of iron ore in a blast furnace. This process is known as smelting.
- The product obtained from the blast furnace is crude and impure iron.
- Typical Chemical Composition of Pig Iron is as under
- Pig iron has a very high carbon content, typically 3.5 - 4.5%, which makes it very brittle and not useful directly as a material except for limited applications

C%	Si%	Mn%	P%	S%
3.00-4.00	0.50-3.00	0.10-1.00	0.02-0.10	0.03-2.00

Raw Materials for Pig Iron Production

- Iron Ore

- Limestone ----------→

- Coke

Why coke is used…?

1. Generates high heat, needed in order for chemical reactions in iron making to take place.
2. Produces CO (carbon monoxide) which reduces iron-oxide to Iron.

Limestone (calcium carbonate) is used to remove impurities.

✓When the metal is melted, limestone combines with impurities and floats to the top of the metal, forming slag. The slag can then be removed, purifying the iron.

✓Slag is lighter than molten iron so it floats over molten iron and protects it from oxidising back into its oxides.

Preparation of Pig Iron

Step1: Concentration

The ore is crushed in crushers and is broken to small pieces. It is concentrated with **gravity separation** process in which it is washed with water to **remove clay, sand**, etc.

Step1: Concentration

Step2: Calcination

The ore is then **heated in absence of air (calcined).** This results in decomposition of carbonates into oxides and then ferrous oxide is converted into Ferric Oxide.

$$FeCO_3 \rightarrow FeO + CO_2$$

$$4FeO + O_2 \rightarrow 2Fe_2O_3$$

Steps of Extraction

Step1: Concentration

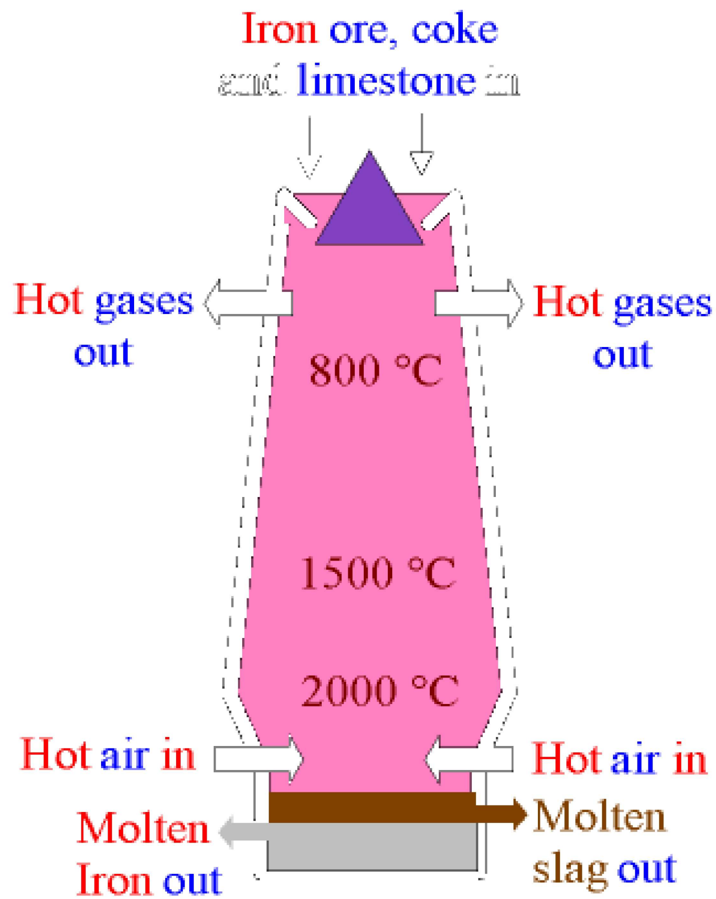
Step2: Calcination

Step3: Smelting

The concentrated ore is **mixed with** calculated quantity of **coke, limestone** and the mixture is put in the **Blast Furnace** from top.

Blast Furnace

- It is a **tall cylindrical** furnace made of **steel.**
- It is lined inside with **fire bricks.**
- It is **narrow at the top** and has an arrangement for the introduction of ore and outlet for waste gases.
- Heated with help of **Hot Gases.**



Chemical Reactions

Following Chemical Reactions Take Place in a Blast Furnace

i) Formation of Carbon Monoxide:

Near the bottom of the furnace, coke burns in air to form Carbon Dioxide and a lot of heat is produced. We get a temperature of about 1875 K.

This CO_2 further reacts with more coke and is reduced to CO.

$$C + O_2 \rightarrow CO_2 + Heat$$

$$C + CO_2 \rightarrow 2CO$$

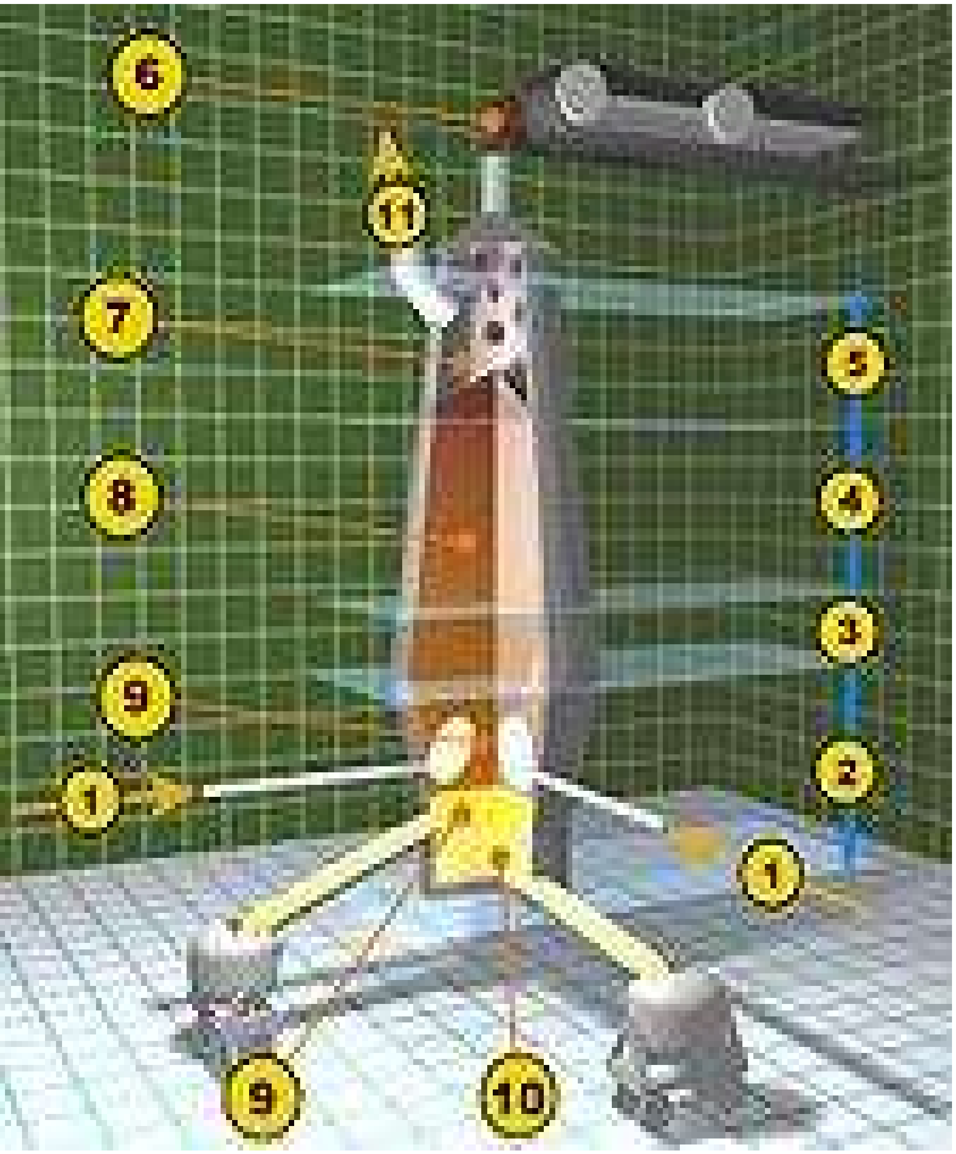
Chemical Reactions

ii) Reduction of Hematite to Iron:

In the **upper part** of the furnace, the temperature is between **975K to 1075K**. Here Haematite is **reduced to Iron** by CO. This **molten Iron** is collected at the **bottom of the furnace**.

$$Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$$

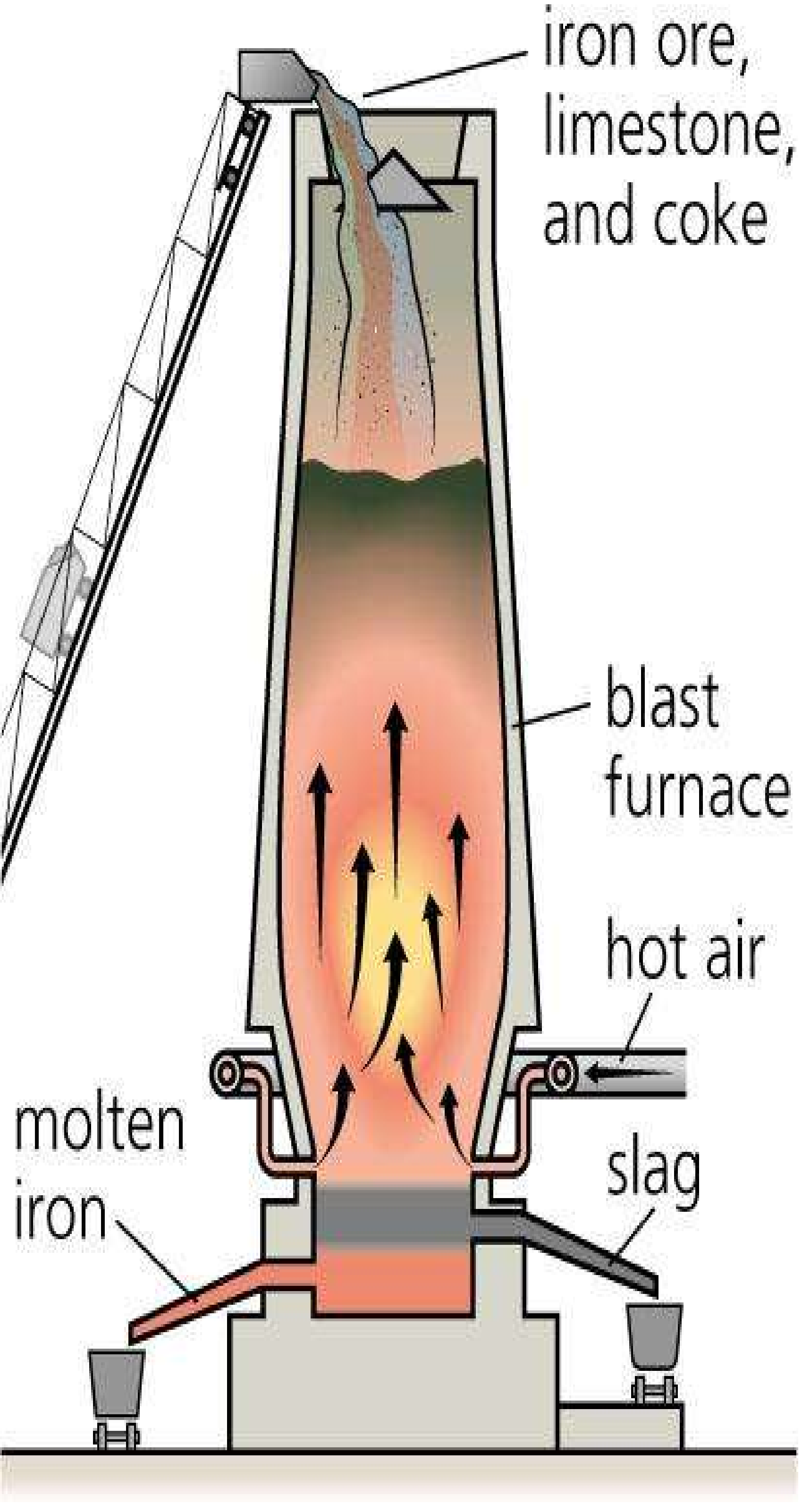
BLAST FURNACE
(FOR MANUFACTURING OF PIG IRON)

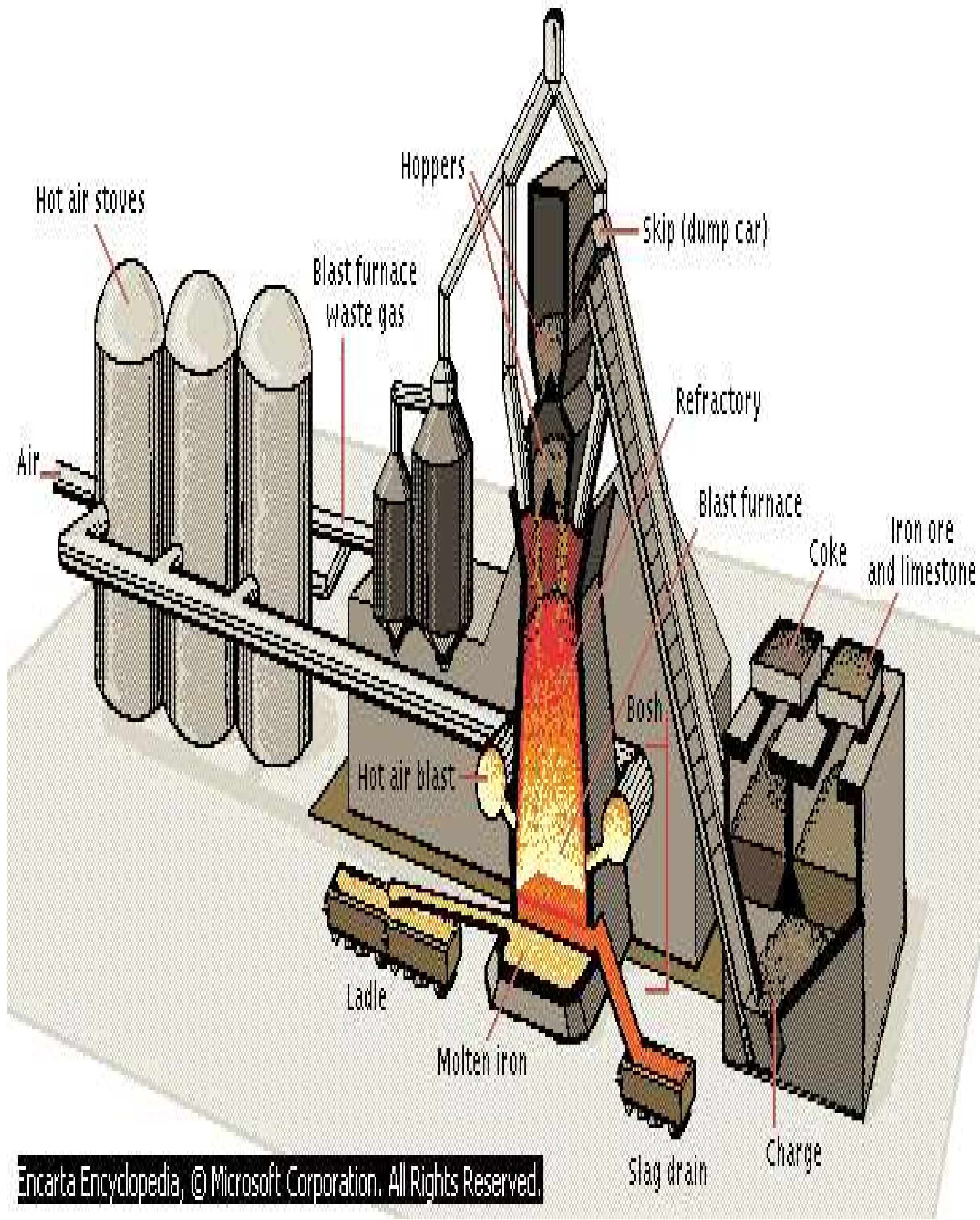


http://www.britishpathe.com/video/blast-furnace

Blast furnace parts …

1. Hot Blast inlet
2. Melting zone (***bosh***)
3. Reduction zone of ferrous oxide (***barrel***)
4. Reduction zone of ferric oxide (***stack***)
5. Pre-heating zone (***throat***)
6. Feed of ore, limestone, and coke
7. Exhaust gases outlet
8. Column of ore, coke and limestone
9. Removal of slag
10. Tapping of molten pig iron
11. Collection of waste gases


iron ore,
limestone,
and coke
blast
furnace
hot air
molten
iron
slag


Hoppers
Hot air stoves
Skip (dump car)
Blast furnace
waste gas
Refractory
Air
Blast furnace
Iron ore
and limestone
Coke
Bosh
Hot air blast
Ladle
Molten iron
Slag drain
Charge

Properties:

- It is hard and brittle as such it is neither ductile nor malleable.
- It is difficult to bend.
- It melts easily. The fusion temperature is 1200°C.
- It can be magnetized.
- It has very high compressive strength but very weak in tension.
- It cannot be welded.

USES:

- cast iron, wrought iron and mild steel are obtained by refining the pig iron.
- Because of its high compressive strength it is used in columns, base plates, door brackets , wheel and pipe work.

EFFECTS OF IMPURITIES ON IRON

SILICON

- Increase the fluidity of metal.
- Induce softness in the iron.
- Produces casting which are free from blow holes

PHOSPHORUS

Give rise to cold shortness (Brittleness at ordinary temperature)

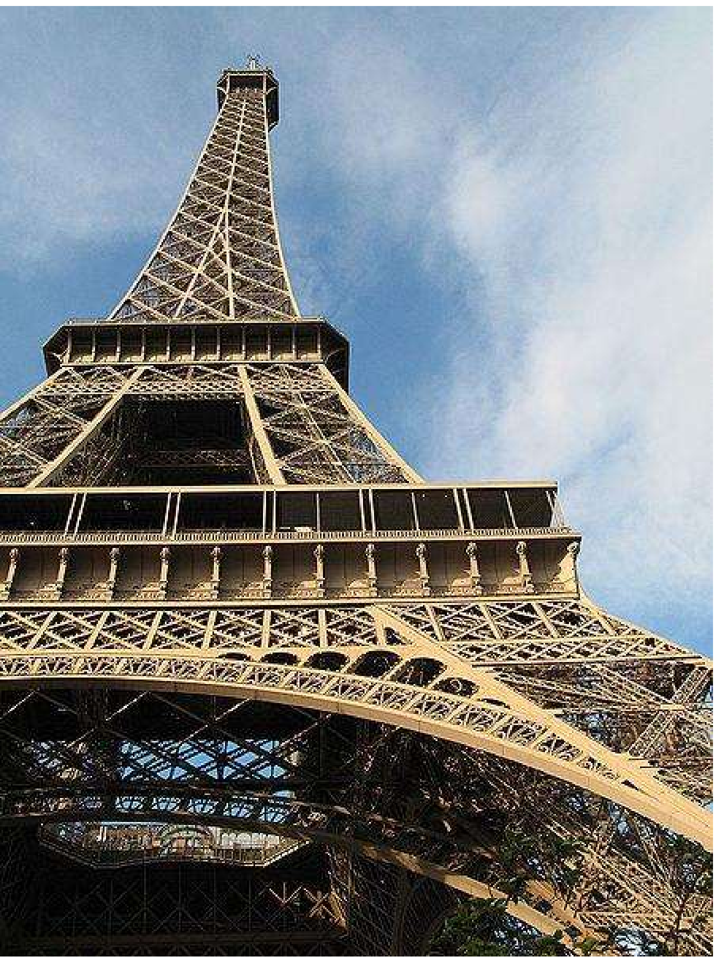
SULPHUR

Give rise to hot shortness (Brittleness at High temperature)

MANGANESE

- Increase Hardness and brittleness
- Reduce the bad effect of sulphur by forming MnS.

02-WROUGHT IRON



WROUGHT IRON

- If all the carbon and other elements in pig iron are oxidized and may be left with 0.25 percent of carbon then we obtain wrought iron.
- It is by far the purest form of iron in which the total impurities do not exceed 0.5%.

PROPERTIES:

- Its structure is fibrous and has silky luster.
- It is ductile and malleable.
- It is tough and can withstand shocks and impact better than cast iron.
- It can be forged and welded.
- It can not rusts easily
- It is unaffected by saline water.
- It cannot be permanently magnetized.

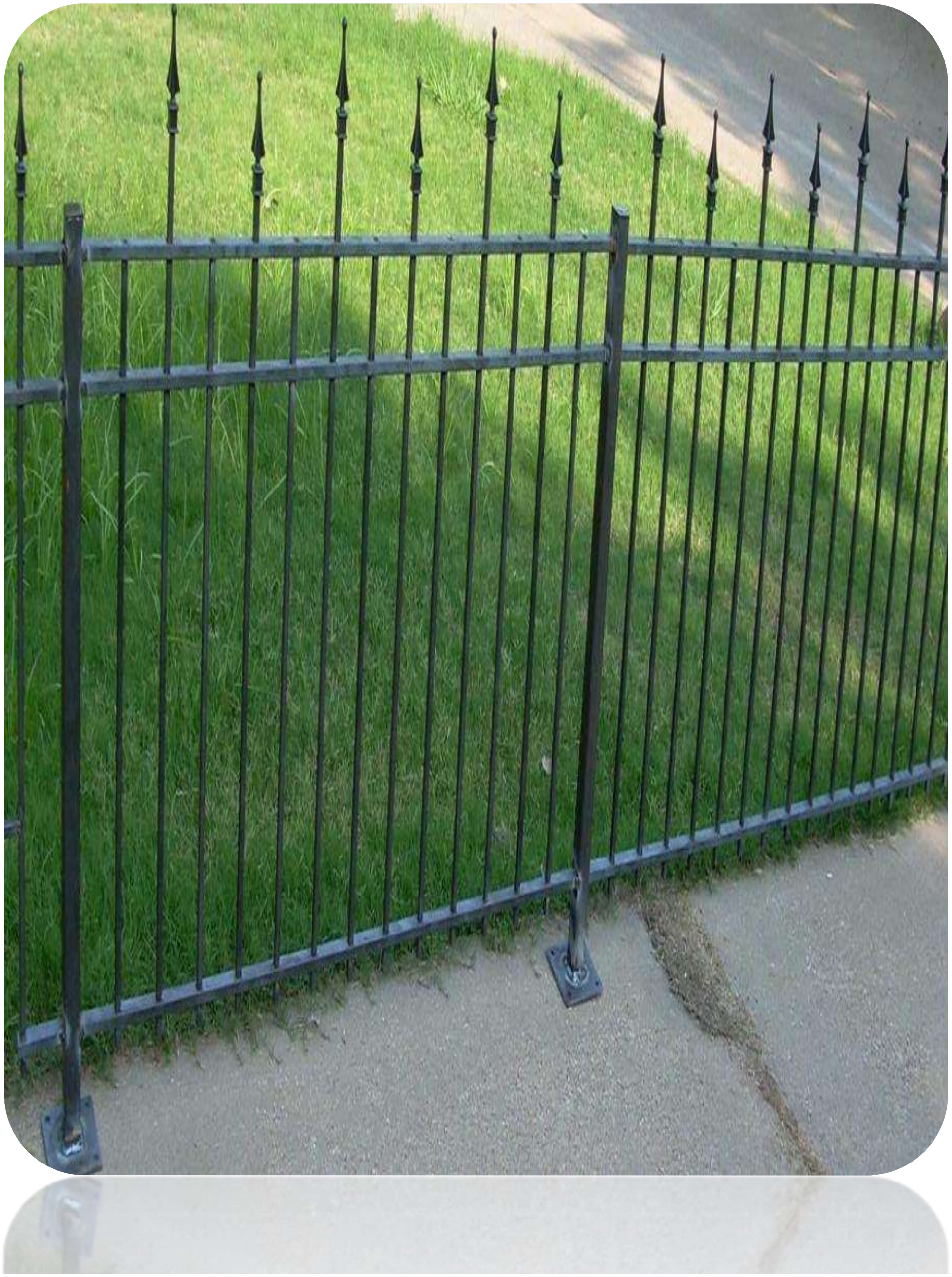
USES :

- It is used in making roofing sheets, corrugated sheets, rods, gas and water pipes, boiler tubes and ornamental iron works such as grills gates and railing and window guards.
- Used for rivets, chains, ornamental iron work, railway couplings, bridges, water and steam pipes.
- Wrought iron is much more expensive to produce than cast.

- Gates

- Windows

- Railings and fence



MAJOR EXAMPLE ARE-

1. Iron pillar at Delhi, India, containing 98% wrought iron.
2. The Eiffel tower

Iron-Carbon (Fe-C) Phase Diagram

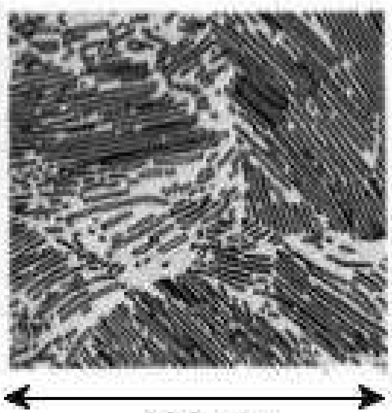
- 2 important points

1. Eutectic (A):

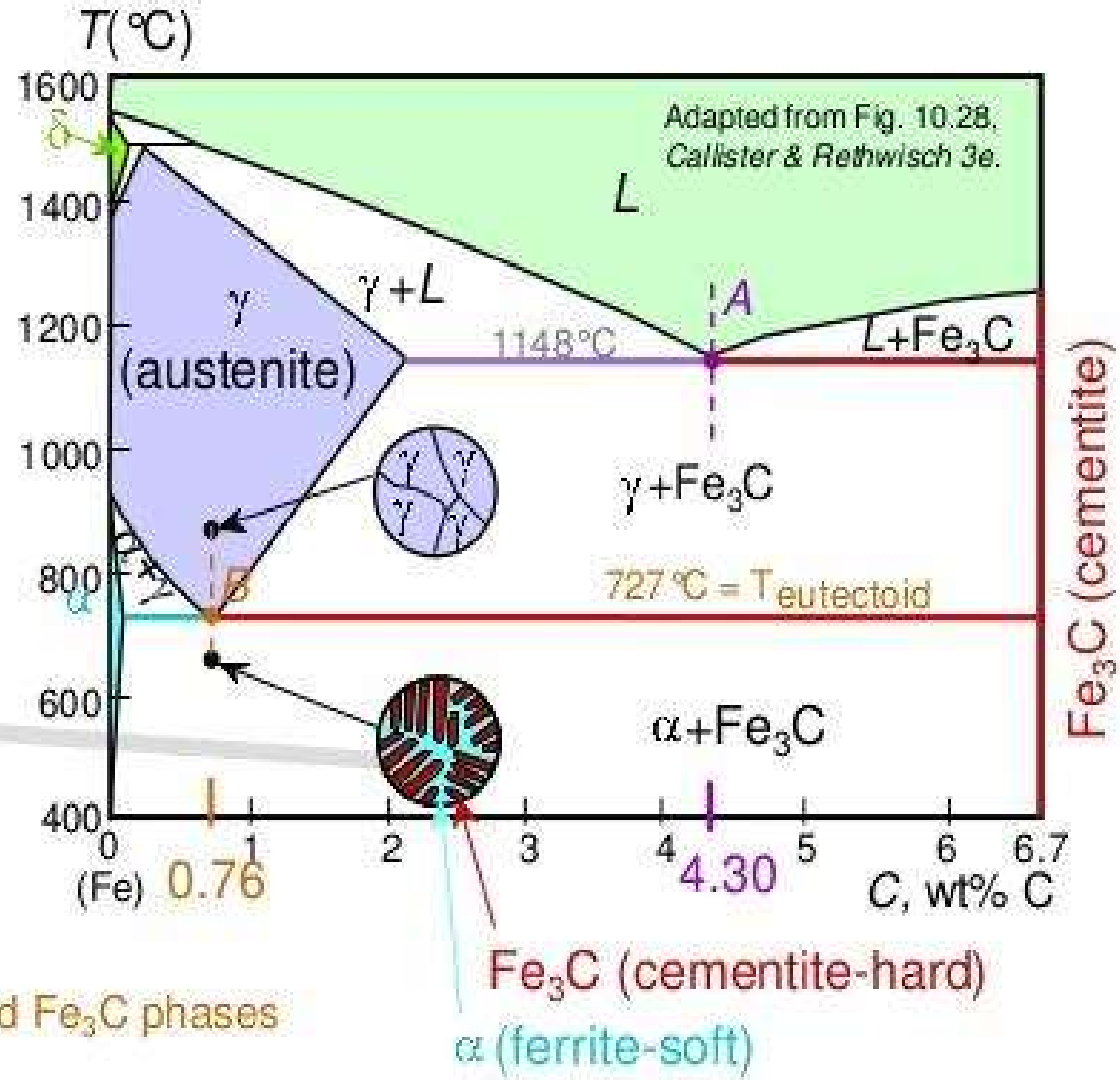
$$L \Rightarrow \gamma + Fe_3C$$

2. Eutectoid (B):

$$\gamma \Rightarrow \alpha + Fe_3C$$



Result: Pearlite is alternating layers of α and Fe_3C phases



CAST IRON

- CAST IRON is an alloy of iron and carbon, containing 2.11 to 6.67% carbon (practical limit is 4.5%).
- In addition to carbon, cast iron contains other elements such as **Si, S, P & Mn**. It is made by re-melting pig iron, scrap, and other additions of Ferro alloys.
- Presence of **high carbon** content **makes** cast iron very hard and brittle.
- Cast iron, being brittle, **cannot** be forged, rolled, drawn, etc., but can only be ‘cast’ into desired shapes and size by pouring the molten alloy of desired composition into a mould of desired shape and are called cast irons.
- Carbon in cast iron, may be in the combined form as cementite, or in free form as graphite, or both, depending on the chemical composition and the rate of cooling of the casting from the molten state.

Chem. Composition Of Different Types Of Cast Irons

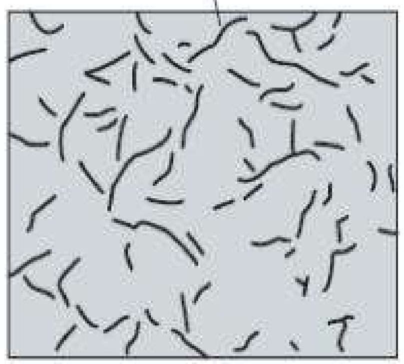
- Depending on chemical specifications, cast irons can be non-alloyed or alloyed.
- Following table lists the range of compositions for non-alloyed cast irons.
- The chemical composition range of **alloyed irons** is much wider, and they contain either higher amounts of common components, such as silicon and manganese, or special additions, such as nickel, chromium, aluminum, molybdenum, tungsten, copper, vanadium, titanium, plus others.

Sr. No.	Type of Iron	Typical Composition				
		C%	Si%	Mn%	P%	S%
1.	White Cast Iron	**2.50–3.50**	0.40–1.00	0.50-0.70	0.15 max	0.4 max
2.	Grey Cast Iron (FG)	**2.00–4.00**	1.00–3.00	0.40-1.00	0.06-0.25	0.10-1.00
3.	Ductile Cast Iron (SG)	**3.00–4.00**	1.80–2.80	0.10–1.00	0.01–0.10	0.01–0.03
4.	Malleable Cast Iron(TG)	**2.00–3.00**	0.60-1.60	0.25-1.25	0.18 max	0.18 max

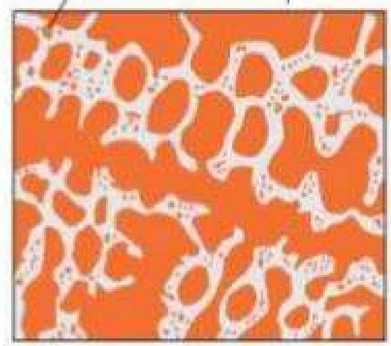
FG : Flake graphite, SG : Spheroidal graphite, TG : Tempered graphite

Types of Cast Iron

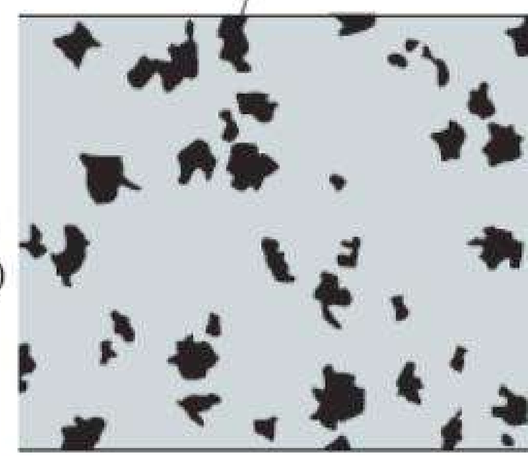
- Depending on chemical composition, cooling rate, types and amount of inoculants that are used we can have
  a. Gray iron
  b. White iron
  c. Malleable iron
  d. Ductile iron
  e. Compacted graphite iron



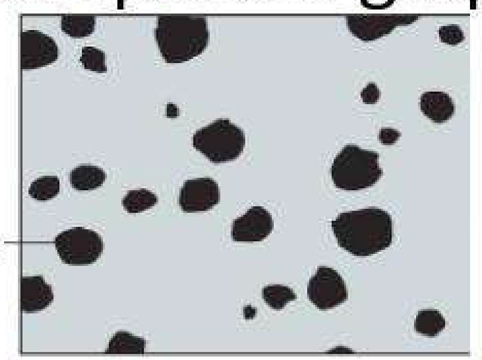
(a)



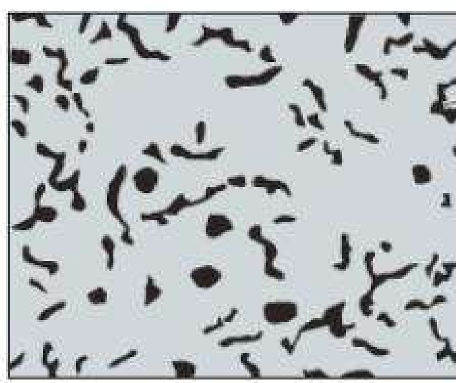
(b)



(c)



(d)



The addition of inoculants in liquid cast iron (grey and ductile irons) allowed to:

•improve the homogeneity of the cast iron structure,

•eliminate the formation of carbides into thin parts or salient angles

•direct the solidification towards the stable diagram, with graphite precipitation

•refine the structure (higher cells count, finer grains in the microstructure)

•improve mechanical properties

•better separate slag and metal,

•decrease the tendency to dross formation (mass of solid impurities floating on the molten metal),

•decrease tendency of micro-shrinkage,

•decrease risk of gas formation

•decrease risk of mold / metal interface defects

CLASSIFICATION OF CAST IRONS

- The quality / type of C.I depends not upon the absolute amount of carbon it contains, but upon …
  (1)the conditions in which that carbon exists i.e. form of free graphite
  (2) the other alloying elements present

- Commonly used Cast Irons are …

I. Non-Alloyed (Only Iron-Carbon Alloys)
   1. White C.I.
   2. Grey C.I.
   3. Ductile C.I. / Nodular C.I. / Spheroidal Graphite Iron (S.G.I.)
   4. Malleable C. I.
   5. Chilled C.I.
   6. Mechanite C.I.

II. Alloyed C.I.
   1. Ni-Hard
   2. Ni-Resist

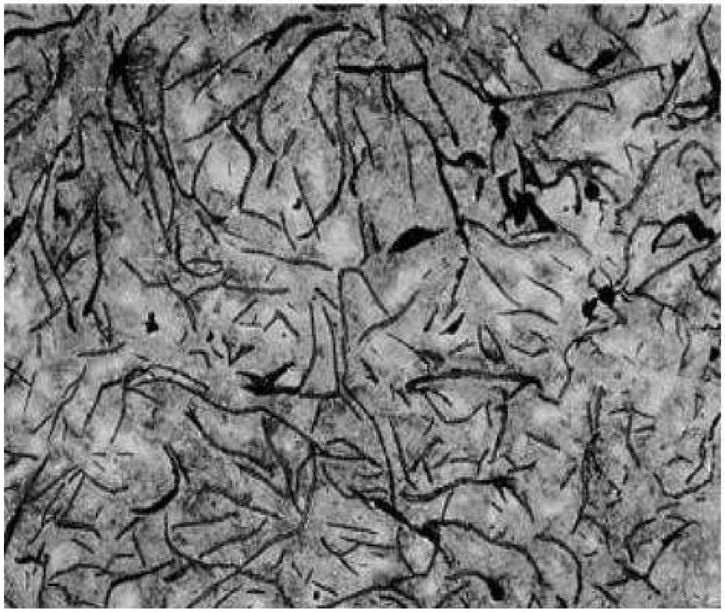
A. Grey Cast Iron

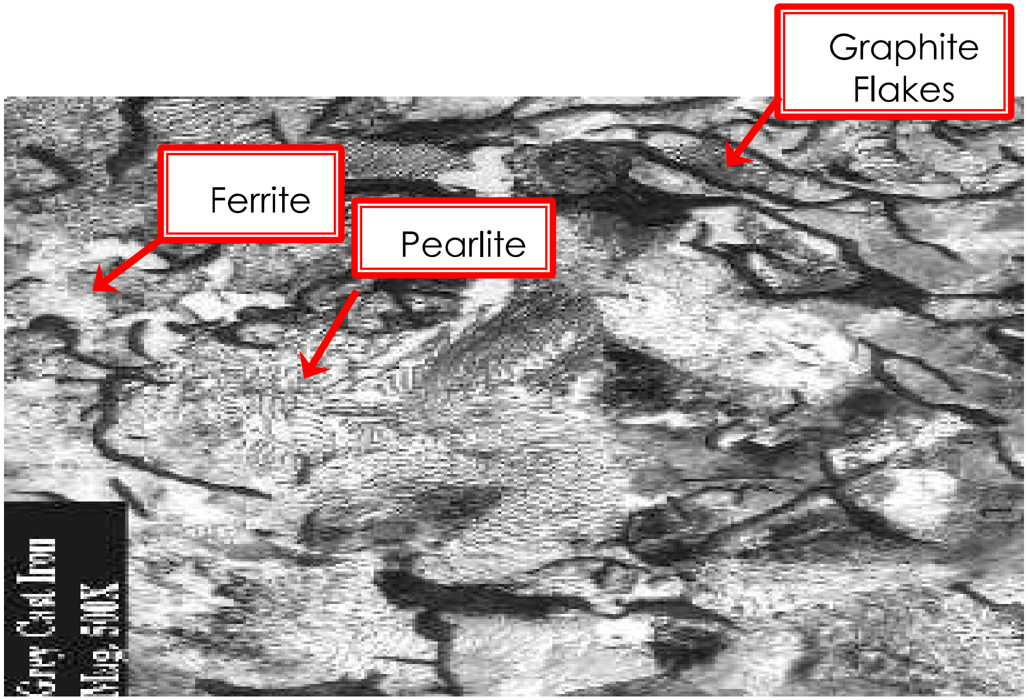
- **Chemical Composition :**

C%	Si%	Mn%	P%	S%	Fe%
2.00–4.00	1.00–3.00	0.40-1.00	0.06-0.25	0.10-1.00	Balance

- Graphite flakes surrounded by a matrix of either Pearlite or α-Ferrite
- Wide range of applications
- Low ductility
- Grey cast iron forms when
    - Cooling is slow, as in heavy sections

- **Micro-Structure :**





3. Properties :

1. Good compressive strength
2. Tensile strength and elasticity is less compared to steel because of graphite.
3. Most widely used because of its excellent Machinability, vibrating damping properties and stress relieving properties.
4. It has good machinability due to presence of free graphite which will act as a lubricant during machining and good shock absorption capacity.
5. Good casting properties.

4. Applications: Applications are as follows …

1. Clutch Plates and Drum Brake
2. Base of any machine tool
3. Engine frames
4. Pistons

B. WHITE CAST IRON

- **Chemical Composition :**

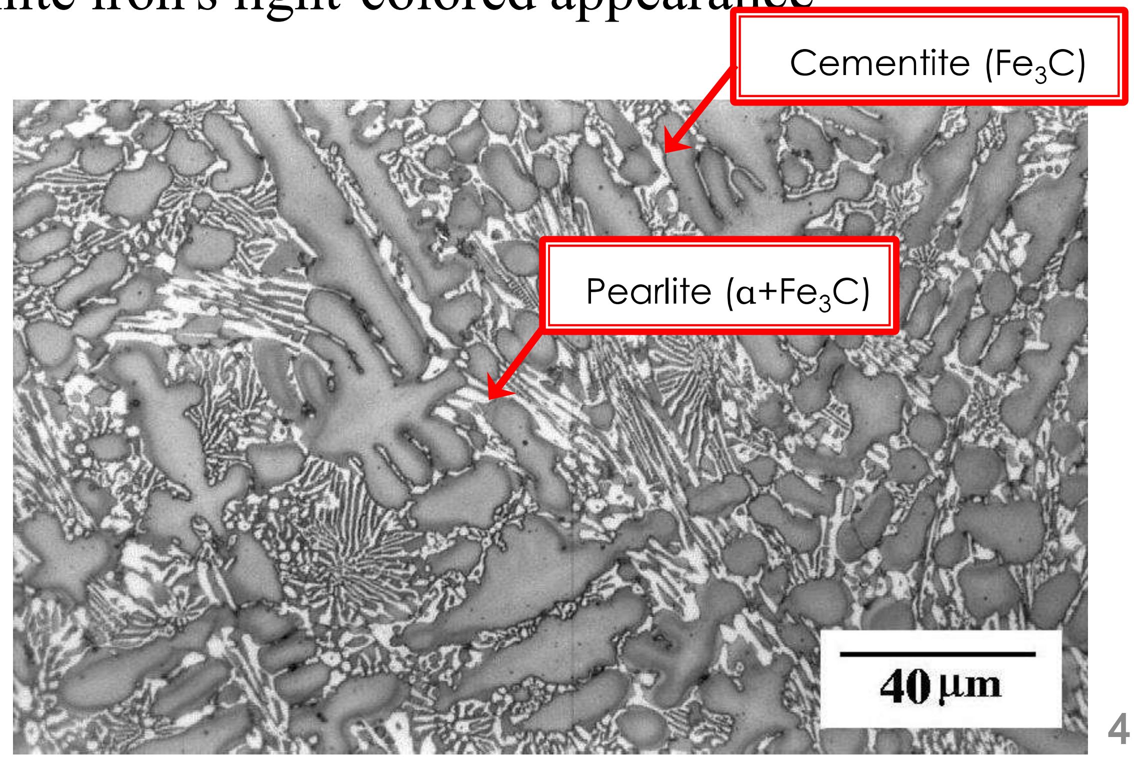
C%	Si%	Mn%	P%	S%	Fe%
2.50–3.50	0.40–1.00	0.50-0.70	0.15 max	0.4 max	Balance

  - Carbon is present in the form of cementite (Fe_3C)
  - White Fractured surface
  - Obtained by rapid cooling

•Large amount of carbide phases in the form of flakes, surrounded by a matrix of Pearlite

•The absence of graphite causes white iron's light-colored appearance

- **Micro-Structure:**



4. **Properties:** As follows …

    1. Hardness (350-550 BHN) Hard, Brittle and cannot be machined.
    2. It does not contain graphite but contains Cementite and Pearlite. Due to high content of Cementite, it appears white.
    3. It has good wear resistance and good compressive strength.

5. **Applications:** Limited application due to excessive hardness i.e. poor Machinability and brittleness. However, it has few applications like …

    1. Wearing plates
    2. Pump liners
    3. Mill liners
    4. Grinding balls
    5. It is a raw material for manufacturing Malleable C.I.

C. Ductile Cast Iron / Nodular Cast Iron / Spheroidal Graphite (S.G.) Iron

1. Manufacturing process:

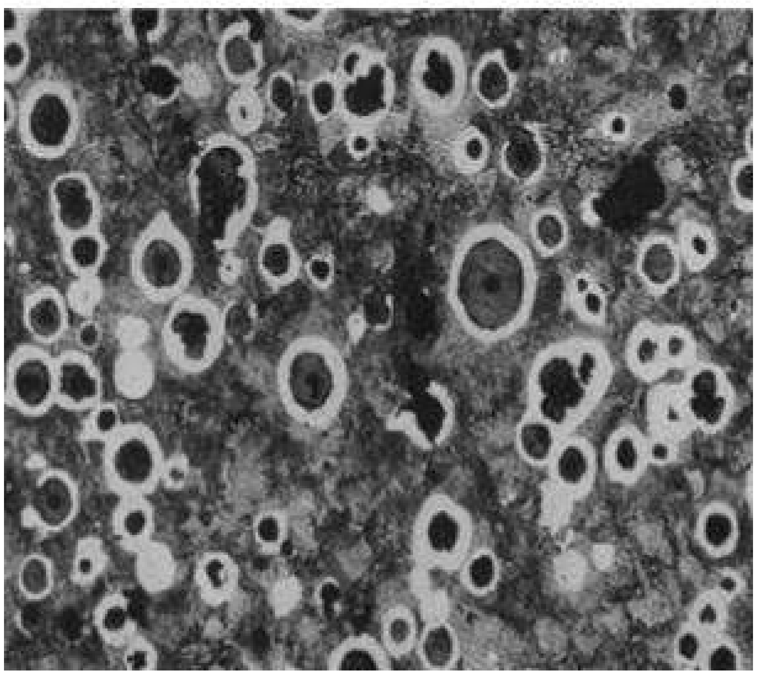
- **Magnesium Treatment for de-sulphurization**
- SG Iron is an improved version of G.C.I. i.e. with increased toughness.
- Toughness is improved because the graphite precipitation takes place in spheroidal / nodular form instead of regular flake form.
- This can be achieved by adding small amount (0.1-0.8%) of Magnesium as an alloying element to the C.I. in liquid state (molten metal).
- This alloying element must be a powerful de-sulphuriser i.e. the alloying element must have a higher tendency to combine with Sulphur as compared to Iron (Fe).
- Magnesium (Mg), Boron (B), Cerium (Ce), Lithium (Li)and Sodium (Na) are some of the powerful de-sulphurisers.
- Due to addition of de-sulphuriser, the % of free S in the metal decreases to below 0.02% and this leads to graphite formation in nodular form.

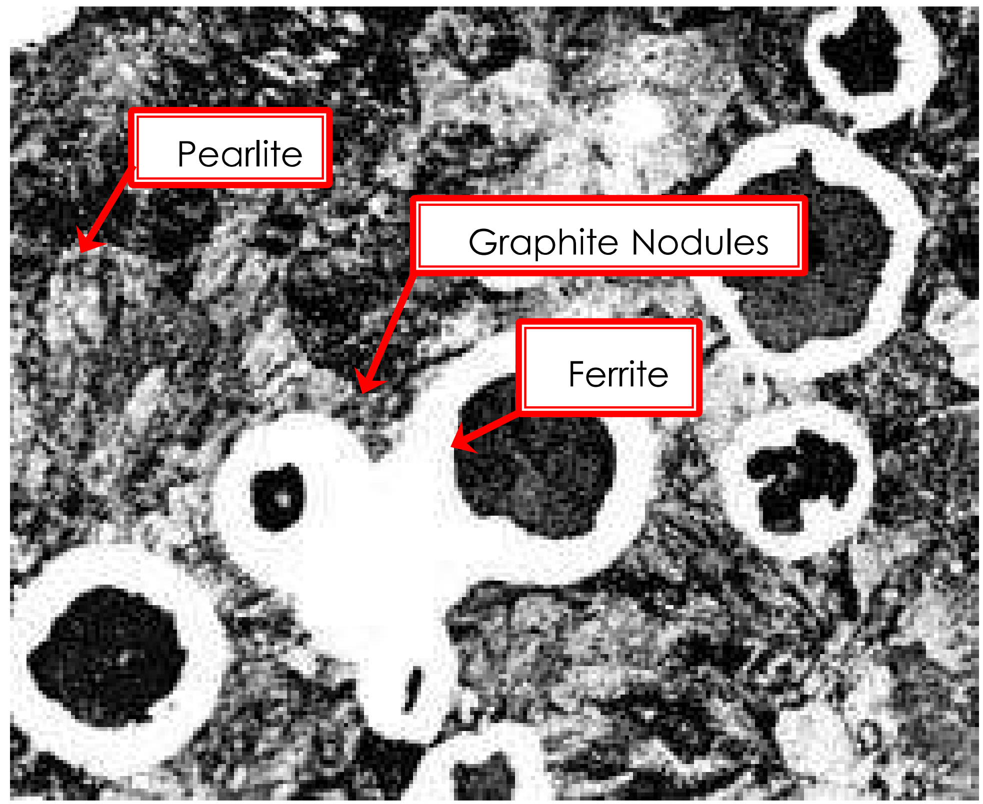
1. Chemical Composition :

C%	Si%	Mn%	P%	S%	Fe%
3.00–4.00	1.80–2.80	0.10–1.00	0.01–0.10	0.01–0.03	Balance

2. Desulphurised and moderate to slow cooling

3. Micro-Structure :





3. **Properties:** As follows …

    1. Very good Machinability
    2. It is ductile (no stress concentration) and has good toughness.
    3. High fluidity which permit castings of intricate shapes.
    4. It possesses damping capacity intermediate between G.C.I and steel.
    5. Due to its good wear resistance, shock resistance and strength

4. **Applications:** As follows …

    1. Crankshafts of automobiles like trucks
    2. Metal working rolls
    3. Punches
    4. Dies
    5. Gears

D. Malleable Cast Iron

- Malleable cast iron is obtained from hard and brittle white iron through a controlled heat conversion process.
- In order to obtain a malleable iron castings, it is first cast into moulds of white cast iron. Then by a suitable heat treatment (i.e. annealing), the combined carbon of the white cast iron is separated into nodules of graphite.

- The following methods are used for this purpose

(1) White-heart process

- The white iron castings are packed in iron or steel boxes surrounded by a mixture of new and used hematite ore.
- The boxes are slowly heated to a temperature of 900 to 950°C and maintained at this temperature for several days. During this period, some of the carbon is oxidized out of the castings and the remaining carbon is dispersed in small specks (very small shape) throughout the structure.
- The heating process is followed by the cooling process which takes several more days.

(2) Black-heart process

- The castings used contain less carbon and sulphur. They are packed in a neutral substance like sand and the reduction of sulphur helps to accelerate the process.
- The castings are heated to a temperature of 850 to 900°C and maintained at that temperature for 3 to 4 days. The carbon in this process transforms into globules, unlike white-heart process.

(3) Pearlitic Malleable

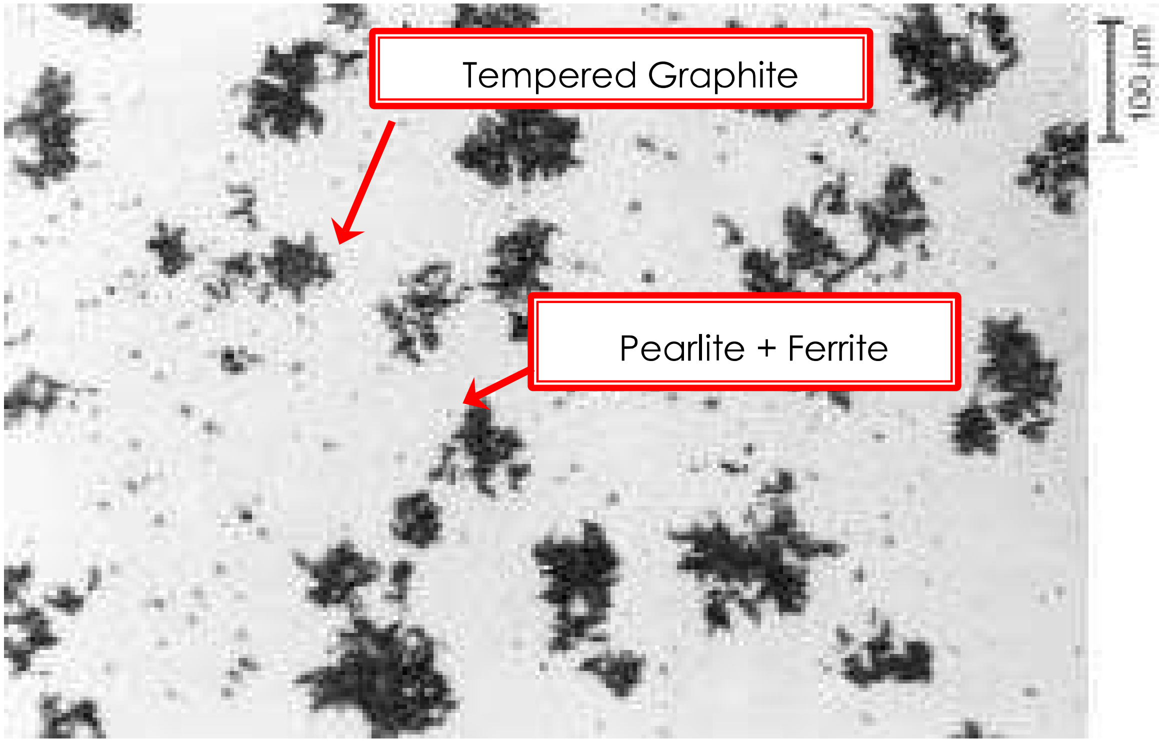
- Process is same except that micro-structure will have only Pearlite + Tempered Carbon

- **Chemical Composition**

C%	Si%	Mn%	P%	S%	Fe%
2.00–3.00	0.60-1.60	0.25-1.25	0.18 max	0.18 max	Balance

- White C.I is hard & brittle so it is not used where shock and vibration is important.
- Malleable C.I is manufactured by annealing white cast iron.
- So $Fe_3C \longrightarrow Fe + C$ (fine graphite)
- When the carbon is formed by dissociation of Fe3C , it develops clusters of graphite.. The resultant microstructure provide some ductility or malleability to nonductile iron casting, hence known as malleable cast iron.

- **Micro-Structure**



3. **Properties:** As follows …

    1. High yield strength
    2. It has good malleability, Castability.
    3. By proper heat treatment, good strength, ductility and wear resistance is obtained.

4. **Applications:** Applications are as follows …

    1. Steering Brackets
    2. Support Brackets
    3. Cam-shafts
    4. Railway carriage fittings
    5. Hardware
    6. Automotive industry

Chilled Cast Iron

- It is a white cast iron produced by quick cooling of molten iron.
- The quick cooling is generally called chilling and the cast iron so produced is called chilled cast iron.
- All castings are chilled at their outer skin by contact of the molten iron with the cool sand in the mould. But on most castings, this hardness penetrates to a very small depth (less than 1 mm).
- Sometimes, a casting is chilled intentionally and sometimes chilled becomes accidently to a considerable depth.
- The intentional chilling is carried out by putting inserts of iron or steel (chills) into the mould.
- When the molten metal comes into contact with the chill, its heat is readily conducted away and the hard surface is formed.
- Chills are used on any faces of a casting which are required to be hard to withstand wear and friction.

Alloy Cast Iron

- Because the cast iron is supposed to be very hard, brittle, lacking in tensile strength and weak to withstand shocks it is alloyed with other metals to improve its properties.
- Amongst the alloying metals, nickel is predominating alloying constituent whose addition to the extent of 0.5 to 1.5% avoids the tendency of chilling or hard spots.
- Example : Acicular and Spheroidal
- Acicular-Ni & Mo addition
- Spheroidal- Graphite content in spheroidal form, which is converted from flaky form by alloying with a small amount of magnesium and cesium. This change will increase tensile strength and produces a tough metal which can undergo bending and twisting.

4. Plain Carbon steel / carbon steel

- Plain carbon steel is a type of steel having a maximum carbon content of 2.0% along with small percentages of sulphur, phosphorus and manganese etc.
- Most widely used kind of steel.
- Numerous applications because of good workability, castability and machinability.
- The properties of carbon steel depend primarily on the amount of carbon it contains.
- Most carbon steel has a carbon content of less than 1% practically.
- Carbon steel is made into a wide range of products, including structural beams, car bodies, kitchen appliances, and cans.

4.1.1 Classification of Carbon steel

- Plain carbon steel can be divided in to various classes based on

I. Carbon content

II. Applications

III. Steel manufacturing methods

(i) Based on carbon content

A. Low carbon steel or mild steel

- containing carbon up to 0.3%.
- Improvement in the ductility by heat treatment is concerned but has no effect in respect of its strength properties.
- Most stampings made from these steels
- Bullets, nuts and bolts, chains, etc that do not need great strength

B. Medium carbon steels

- Having carbon content ranging from 0.25 to 0.60%, improves in the machinability by heat treatment.
- It must also be noted that this steel is especially adaptable for machining or forging and where **surface hardness is desirable**.
- Can be used in most machine elements, car axles, rails and other parts that require strong metal.

C. High carbon steels

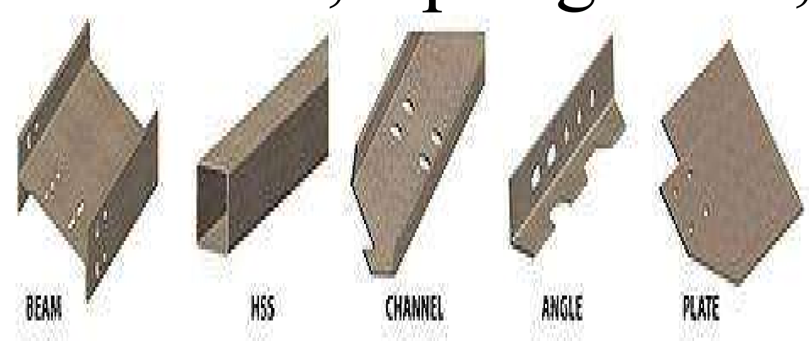
- Steel-containing carbon in the range of 0.60 to 1.5% and is especially classed as high carbon steel.
- In the fully heat-treated condition it is very hard and it will withstand high shear and wear and will thus be subjected to little deformation.
- Used in applications like cutting tools or press machinery where surface subject to abrasion – tools, knives, chisels

(ii) Based on application

- Steel may be classified in to:

  Structural steel, tool steel etc.

- There are six groups of tool steels: water-hardening, cold-work, shock-resisting, high-speed, hot-work, and special purpose. The choice of group to select depends on cost, working temperature, required surface hardness, strength, shock resistance, and toughness requirements.
- These can be further subdivided on the basis of specific application for ex. Rail steel, spring steel, boiler steel, sheet steel, etc



(iii) Based on Manufacturing Process

- Steel may be manufactures by any one of the following ways and are classified accordingly.
- For example steel manufactured using acid Bessemer process is called "*Bessemer Steel*"
- Following are the types of steel based on manufacturing method

I. Bessemer Steel
II. Open Hearth Steel
III. Electric furnace Steel
IV. Crucible Steel

PLAIN CARBON STEELS

Carbon %	Properties	Applications
0.01 - 0.10	• Soft, ductile • No useful hardening by heat treatment except by normalizing, but can be work-hardened. • Weldable.	• Pressings where high formability required
0.10 - 0.25	• Strong, ductile • No useful hardening by heat treatment except by normalizing, but can be work-hardened. • Weldable.	• General engineering uses for a mild steel
0.25 - 0.60	• Very strong • Heat treatable to produce a wide range of properties in quenched and tempered conditions. • Difficult to weld. • Can become brittle below room temperature.	• Bars and forgings • Connecting rods • Springs • Hammers • Axle • Shafts requiring strength and toughness.

PLAIN CARBON STEELS

Carbon %	Properties	Applications
0.60 - 0.90	• Strong, whether heat treated or not. • Ductility lower when less carbon is present	• Used where maximum strength rather than toughness is important. • Tools, wear resisting components (piano wire and silver steels are in this group).
0.90 - 1.50	• Wear resistant and can be made very hard at expense of toughness and ductility. • Cannot be welded. • Tend to be brittle if the structure is not carefully controlled	• Cutting tools like wood chisels, files, saw blades.

5. Alloy steel

- **Alloy steel** is steel that is alloyed with a variety of elements in total amounts between 1.0% and 50% by weight to improve its mechanical properties.

- Plain carbon steels are relatively cheap, but have a number of Property limitations.

These include:

1. Cannot be strengthened above about 690 N/mm^2 without loss of ductility and impact resistance.
2. Not very hardenable i.e. the depth of hardening is limited.
3. Low corrosion and oxidation resistance.
4. Have poor impact resistance at low temperatures.

•Limited application of plain carbon steel can be minimized by addition of one or more elements.

•The properties of steel depends on both carbon and alloying elements.

•The principal alloying elements used are: manganese (Mn), nickel (Ni), chromium (Cr), molybdenum (Mo), tungsten (W), vanadium (V), cobalt (Co), silicon (Si), boron (B), copper (Cu), aluminium (Al), titanium (Ti) and niobium (Nb).

5.1 EFFECT OF ALLOYING ELEMENTS ON PROPERTIES OF STEEL

Type of Property	Properties	Selection of Alloying element for improving properties
Physical	Grain Size	Mo, V
Chemical	Corrosion Resistance	Cr, Ni
Mechanical	Strength, Hardness, Fatigue Elasticity	Mo, V, Cr, Ni, C, W Si
Electrical	-	-
Thermal	Co-eff. Of thermal expansion	Ni
Magnetic	Permeability	Si, Ni, Co
Optical	-	-
Technological	Machinability	Mn, S, Pb

1. **Molybdenum (Mo) :** It provides hardenability, increases strength and impact resistance of high temperature (creep strength), retards grain growth at high temperature.

2. **Vanadium (V)** : It is a strong de-oxidizer, it increases hardenability, it refines the grain and reduces grain growth, it improves fatigue resistance.

3. **Chromium (Cr)** : It improves corrosion resistance, increases hardenability, provides strength, wear resistance and oxidation resistance at elevated temperatures.

4. **Nickel (Ni) :** It provides toughness, corrosion resistance, deep hardening and increases impact resistance at very low temperature.

5. **Carbon :**This increases hardness and strength.

6. **Tungsten :** It forms hard abrasion resistance particles, imparts red-hardness, increases hardenability to a great extent. It is an important alloying element in HSS.

7. **Silicon :** It acts as de-oxidizer, promotes resistance to high temperature oxidation, increases strength and hardness, increases magnetic permeability and decreases hysteresis loss.

8. **Manganese** : It de-oxidizes, contributes to strength and hardness. It counter-effects sulphur, increases hardenability, decreases the critical cooling rate.

9. **Sulphur :** It is generally considered as an impurity. It combines with iron to form FeS. This causes failure at high temperature. S% should be limited to 0.05% except in one special steel called "free cutting steel"

5.2 Classification of alloy steel

- Alloy steel can be classified on the basis of

1. Amount of alloying elements
2. Principal alloying element
3. Application of steel
4. Microstructure of steel

1. Based on amount of alloying elements

- Low alloy steel (0-5 % alloying addition)
- Medium alloy steel (5-10 % alloying addition)
- High alloy steel (more than 10 % alloying addition)

2. Based on principal alloying elements

- Ni steels
- Cr steel
- Cr-Ni steels
- Ni-Cr-Mo steels
- Ni-Cr-V steel

3. Based on application of steel

- Spring steel
- Bearing steel
- Corrosion resistant steel
- Creep resistance steel
- Die steel
- Cryogenic steel

4. Based on Microstructure of steel

- Pearlitic steel
- Ferritic steel
- Martensitic steel
- Bainitic steel
- Austenitic steel

5.3 Properties of alloy steel

- Good Hardenability
- Good Machinability
- Strength is achieved by heat treatment
- Higher Corrosion resistance
- Wear resistance
- Retention of hardness and strength at high temperature.

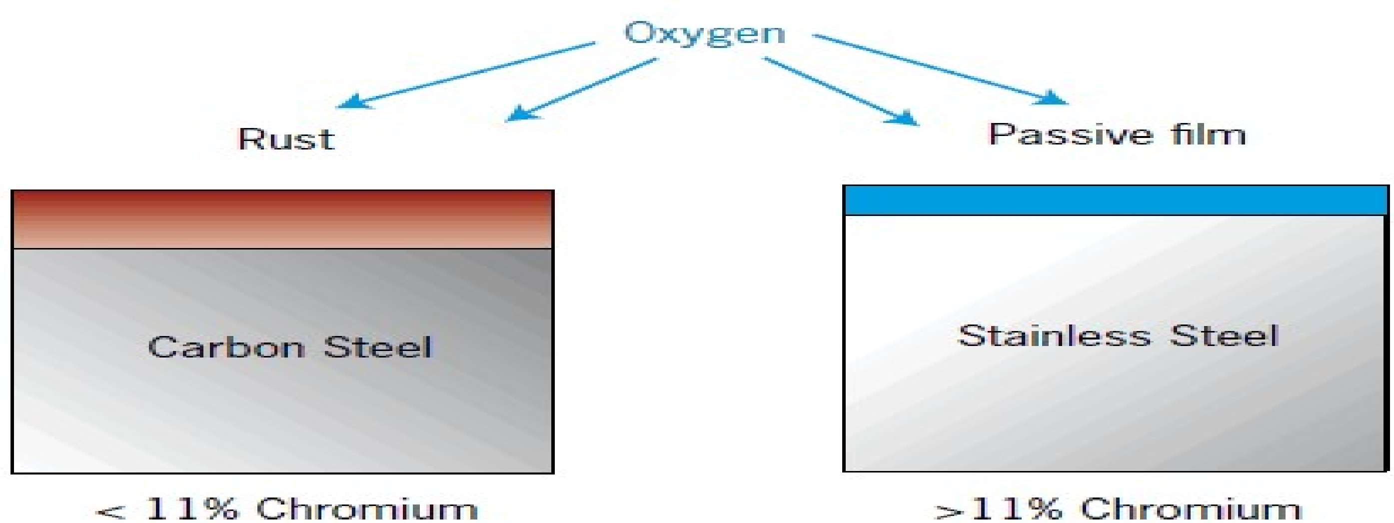
5.4 Application of alloy steel

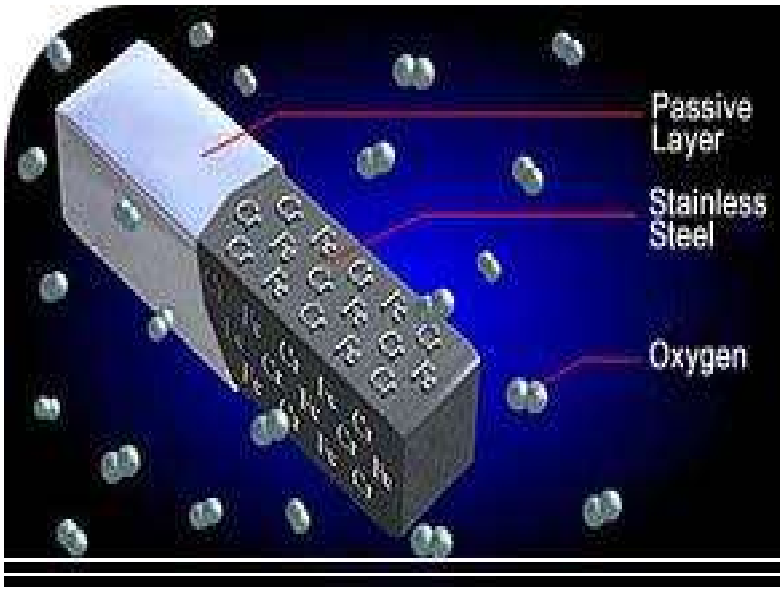
- Structural purpose
- Chemical industries
- Electrical machines
- Springs
- Metal cutting tools
- High temperature application

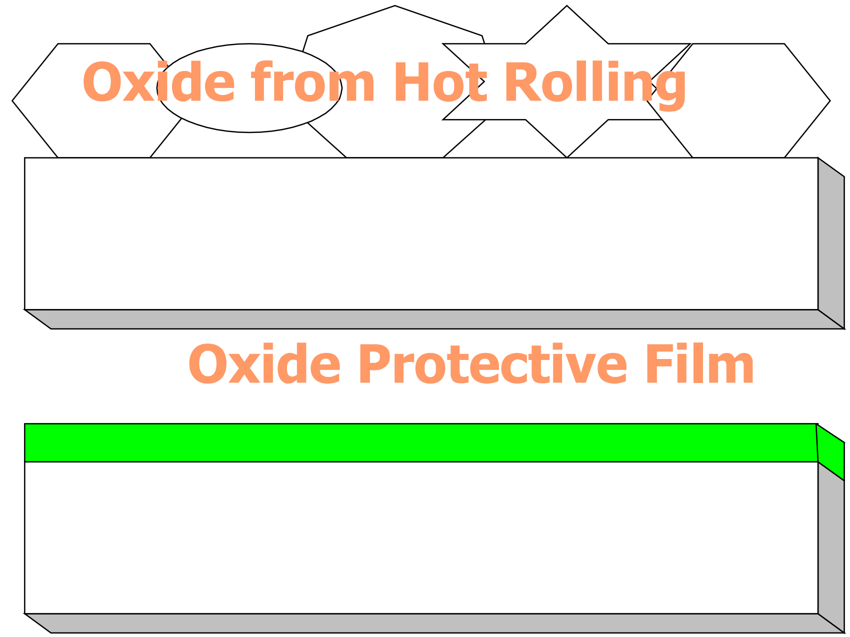
5.5 Stainless steel

- The steel which contains chromium content more than 11% known as stainless steel.
- Stainless steel does not readily corrode, rust or stain with water as ordinary steel does. It is also called **corrosion-resistant steel.**
- **Stainless steels** are primarily know for their corrosion resistance, high strength, and ductility and chromium content.
- Stainless steel differs from carbon steel by the amount of chromium present.

- Unprotected carbon steel rusts readily when exposed to air and moisture. This iron oxide film (the rust) is active and accelerates corrosion by forming more iron oxide, and due to the dissimilar size of the iron and iron oxide molecules (iron oxide is larger) these tend to flake and fall away.
- Stainless steels contain sufficient chromium to form a passive film of chromium oxide, which prevents further surface corrosion and blocks corrosion from spreading into the metal's internal structure, and due to the similar size of the steel and oxide molecules they bond very strongly and remain attached to the surface.

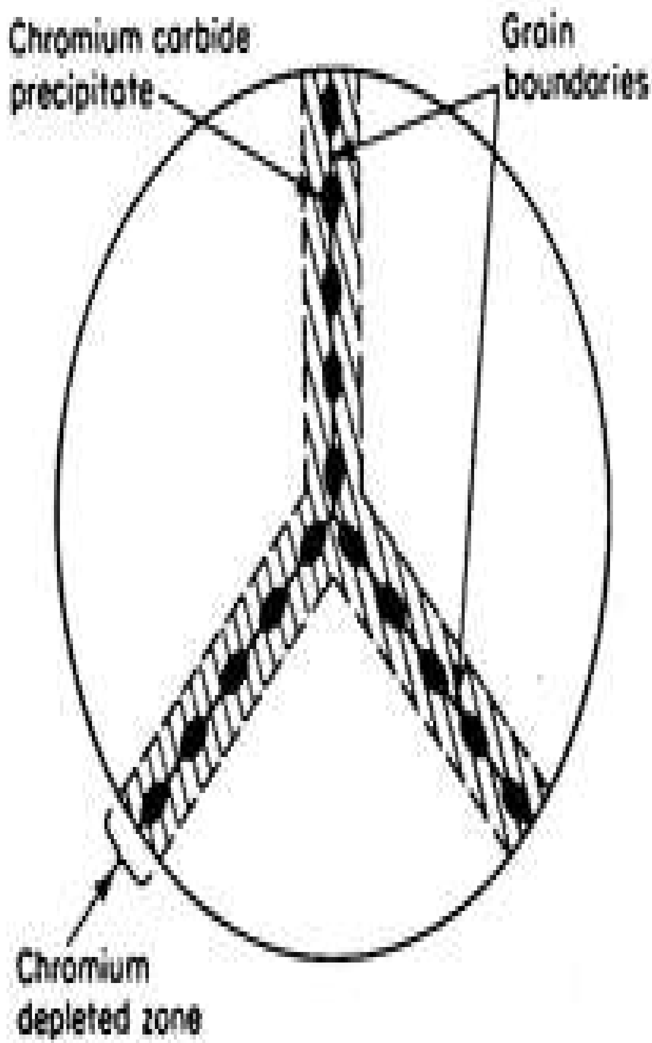






- Chromium Oxide from Hot Rolling must be removed by Pickle
- Ordinary Oxide Protective Film is not a Problem

- The reason for the name stainless is due to the fact that in the presence of oxygen, the steel develops a thin, hard, adherent film of chromium.
- Stainless steels tend to have lower carbon content because increased carbon content lowers the corrosion resistance of stainless steels.
  - Since the carbon reacts with chromium it decreases the available chromium content which is needed for developing the protective film.



- Sensitization is the loss of alloy integrity. It results from chromium depletion in the vicinity of carbides precipitated at grain boundaries. This causes the steel or alloy to become susceptible to intergranular corrosion or intergranular stress corrosion cracking (SCC).
- Sensitization requires specific combinations of: Temperature, Time, Composition

5.5.1 General Properties of Stainless Steels

- **Excellent corrosion resistance**
- **Electrical Resistivity**
  - Surface & bulk resistance is higher than that for plain-carbon steels
- **Thermal Conductivity**
  - About 40 to 50 percent that of plain-carbon steel
- **Melting Temperature**
  - Plain-carbon: 1480-1540 °C
  - Martensitic: 1400-1530 °C
  - Ferritic: 1400-1530 °C
  - Austenitic: 1370-1450 °C
- **Coefficient of Thermal Expansion**
  - Greater coefficient than plain-carbon steels
- **High Strength**
  - Exhibit high strength at room and elevated temperatures
- **Surface Preparation**
  - Surface films must be removed prior to welding

5.5.2 Classification of Stainless steel

Austenitic Stainless steel

- 18Cr and 8Ni wt% (18/8 stainless). They contain a maximum of 0.15% carbon, a minimum of 16% chromium and sufficient nickel and/or manganese to obtain good properties.
- These are the most popular of the stainless steels because of their ductility, ease of working and good corrosion resistance.
- Non-magnetic
- Non-hardenable by heat treatment
- Crystallographic form – face centered cubic
- Very easy to weld
- Good toughness

Ferritic Stainless steel

- They contain between 10.5% and 27% chromium and very little nickel, if any.

- Non-hardenable by heat treatment
- Crystallographic form – body centered cubic
- Magnetic
- High ambient temperature strength
- Resistant to chloride stress corrosion cracking
- Subject to hydrogen embrittlement

Martensitic stainless steel

- They contain 11.5 to 18% chromium and significant amounts of carbon about 0.1 % C.
- Heat treatable to high hardness levels
- They also have a body-centered cubic crystal structure in the hardened condition
- Hard to impossible to weld
- Magnetic
- Metallurgical structure is martensite
- Heat treatable to very high strengths and hardness – stainless tool steel

Duplex stainless steel

- 22-25% Cr, 0.02%C, N 0.15, Cu 0.7
- Magnetic
- Non-hardenable by heat treatment
- Contains both austenite and ferrite
- Easy to weld
- High strength
- Subject to hydrogen embrittlement.
- Stainless steels are strength (approximately twice that of austenitic stainless steels)
- The high yield strength offers designers the use of thin-wall material (which can lead to major reductions in weight) with adequate pressure-containing and load-bearing capacity.
- Improved toughness and ductility (compared to ferritic grades)

Precipitation hardening Stainless steel

- 16% Cr-0.05%C, Nb 0.25
- Magnetic
- Crystallographic form – martensitic with microprecipitates
- Heat treatable to high strength levels
- Weldable
- Magnetic
- Extremely high strength after precipitation heat treatment
- Reasonably ductile in solution annealed condition
- Corrosion resistance similar to Austenitic stainless steel.

- The Austenitic Stainless Steel: austenite structure is retained in the room temperature by Ni (acts as substitution atom): It has high corrosion resistance.
- Ferritic Stainless Steel: Less nickel content than austenitic stainless steel: Used for applications not requiring the high corrosion resistance of the austenitic stainless steels. Less expensive
- Martensitic Stainless steel: Excellent for applications for springs, and cutlery.
- Precipitation hardening stainless steel: increased resistance to dislocation motion, thereby increased strength, or hardness. Used for corrosion resistance structural members.

5.5.3 Application of stainless steel

- The alloy is milled into coils, sheets, plates, bars, wire, and tubing to be used in cookware, cutlery, household hardware, surgical instruments, major appliances, industrial equipment (for example, in sugar refineries) and as an automotive and aerospace structural alloy and construction material in large buildings. Storage tanks and tankers
- This also influences its use in commercial kitchens and food processing plants, as it can be steam-cleaned and sterilized and does not need paint or other surface finishes.
- Stainless steel is used for jewelry and watches with 316L being the type commonly used for such applications. It can be re-finished by any jeweler and will not oxidize or turn black.
- Fire Extinguishers, pots & pans, etc