

MATERIAL SCIENCE:

- It based on the physics and chemistry of the internal structure of materials.
- investigates Relationships existing between the structure of materials and their properties.
- deals with all materials, e.g. metals, ceramics, glasses, organic plastics and polymers, wood and stone.

METALLURGY:

- Metallurgy is the Science and technology of metals.
- Metallurgy embraces the Practice and Science of
 - (i) Extracting metals from their ores.
 - (ii) Refining of crude metal.
 - (iii) Production of alloys and the study of their constitution, structure and properties.
 - (iv) The relationship of physical and mechanical properties thermal and mechanical treatment of metals and alloys.

CLASSIFICATION OF METALLURGY:-

- * Extractive OR CHEMICAL METALLURGY
- * MECHANICAL METALLURGY
- * PHYSICAL METALLURGY

→ It deals with the liberation of metals by various chemical processes from the ores in which they are found. The extractive metallurgy is also charged with Refining the metals to a purity that can be used in industry.

→ It includes mining, concentration, extraction and refining of metals and alloys.

→ This is subdivided in two categories

→ Ferrous

concerned with iron and steel, and the alloys of iron and steel.

→ NON-Ferrous

encompasses all metals and alloys with the

exception of iron and steel and their alloys.

MECHANICAL METALLURGY:-

Metals owe their importance to their unique mechanical properties, the combination of high strength with the ability to change shape plastically (ductility and malleability).

It is an alloy in which the atoms of solute are distributed in the solvent and has the same structure as that of the solvent. Solid solutions have different compositions with similar structures and are like liquid solutions such as sugar in water.

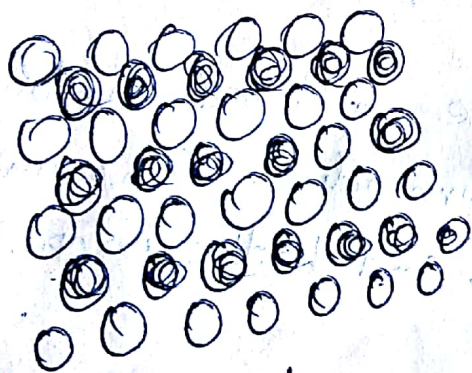
Solid solutions are of two types:

- (i) Substitutional (ii) Interstitial.

→ Substitutional solid solution means the atoms of B element i.e., solute are substituted at atomic sites of A element i.e., solvent. Depending on the distribution of B atoms in A.

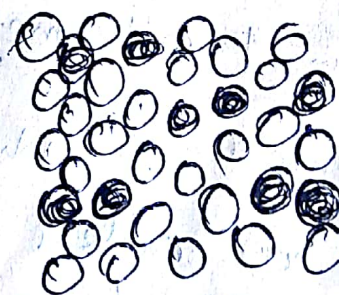
these are classified into two types:

- (A) Regular or Ordered (B) Random or Disordered



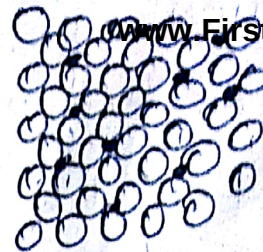
(A) Regular

(Ag-Cu solid solution below 400°C)



(B) Random

The atoms of B occupy the interstitial sites of A. This type of solid solution formation is favoured when the atomic size of B is very much smaller compared to the atomic size of A.



Intermediate Alloy phases :-

- When an alloying element (solute) is added to a given metal (solvent) in such an amount that the limit of solid solubility is exceeded, a second phase appears with the solid solution. It may be solid or intermediate phase.
- This may differ in composition as well as crystal structure from parent metal so properties are also different.
- Some intermediate phases have a fixed composition and they are called as intermediate compounds. Generally these have hard, and brittle properties and high melting points.
- The intermediate phases in which the ratio of number of free electrons to the number of atoms is constant are called electron compounds and they exhibit similar characteristics.

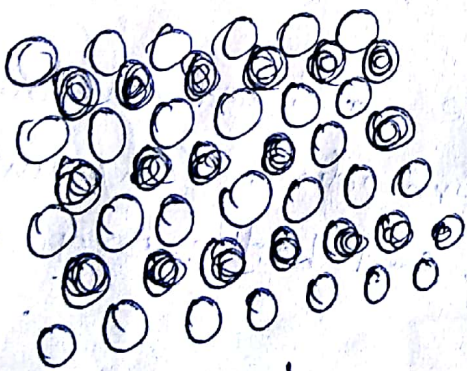
→ It is an alloy in which the atoms of solute are distributed in the solvent and has the same structure as that of the solvent. Solid solutions have different compositions with similar structures and are like liquid solutions such as sugar in water.

Solid solutions are of two types:
(i) Substitutional (ii) Interstitial.

→ Substitutional solid solution means the atoms of B element i.e., solute are substituted at atomic sites of A element i.e., solvent. Depending on the distribution of B atoms in A.

these are classified into two types:

(A) Regular or ordered (B) Random or disordered



(a) Regular

(Ag-Cu solid solution below 400°C)



(b) Random

→ This plasticity enables them to be shaped, e.g. into car Bodies, tin cans, by processes of Mechanical Working such as pressing, drawing, rolling and forging.

PHYSICAL METALLURGY:-

- Few things in nature seems more inanimate than a piece of metal. The casual observer sees only his own reflection in its bright, still surface and nothing of its wild within.
- even metal is completely solid changes of temperature can cause the atoms to rearrange them.
- In a quenching ~~steel~~ steel it can happen in few seconds.

like Solid Solutions, intermediate phase also
Exhibit order-disorder transformation e.g. brass in
Cu-Zn alloy system is disordered above 453 to 470°C
depending on the composition of the alloy and
ordered at lower temperature.

HUME-ROTHERY'S RULES OF SOLID SOLUBILITY

In formation of solid solution, the solubility
limit of solute in the solvent is governed by certain
factors. These are known as Hume-Rothery's Rules
of solid solubility. They are as below:

(i) ATOMIC SIZE FACTOR:

If the atomic sizes of solute and solvent differ
by less than 15%, it is to have a favourable size
factor for solid solution formation. If the atomic
size difference exceeds 15%, solid solubility is
limited.

(ii) CHEMICAL AFFINITY FACTOR:

The greater the chemical affinity of two metals,
the more restricted is their solid solubility and
greater is the tendency of formation of a compound.
Generally, wider the separation of elements in the
periodic table, greater is their chemical affinity.

(iii) RELATIVE VALENCY FACTOR:-

A metal of higher valency can dissolve only a small amount of a lower valency metal, while the lower valency metal may have good solubility for the higher valency metal.

(iv) CRYSTAL STRUCTURE FACTOR:-

Metals having same crystal structure will have greater solubility. Difference in crystal structure limits the solid solubility.

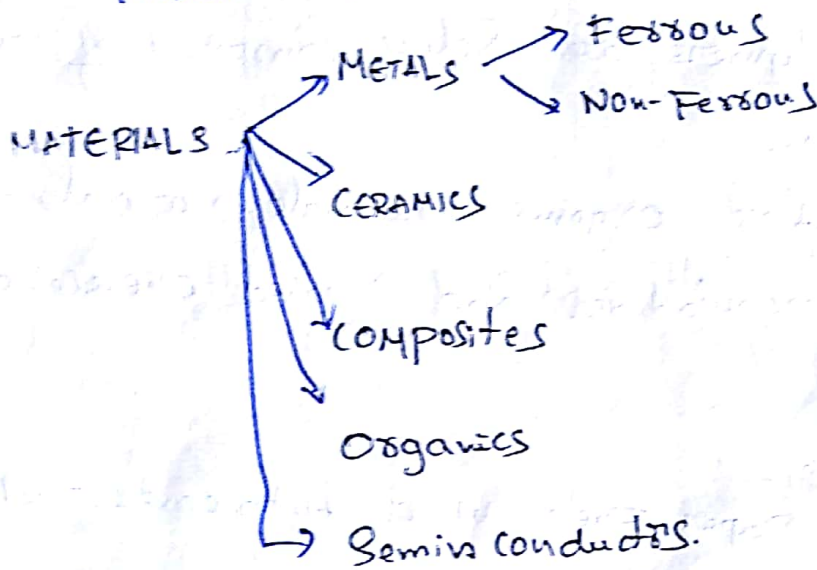
For continuous solid solubility, atomic

size difference should preferably be less than 8% with other factors favourable.

ENGINEERING MATERIALS:-

A material is that out of which anything is or may be made. A material relates itself to matter.

materials comprise a wide range of metals and non-metals which must be operated upon to form the finished product.



(a) METALS:-

Metals are composed of elements which readily give up electrons to provide a metallic bond and electrical conductivity.

Ex: Iron, Aluminium, Copper, Zinc, Magnesium, etc.

(b) CERAMIC MATERIALS:-

→ Ceramics usually consist of oxides, nitrides, carbides, silicates or borides of various metals.

→ Ceramics are any inorganic, non-metallic solids processed or used at high temperatures.

→ Examples:-

Sand, Brick, concrete, Glass, cement, insulators, Silicon Carbide, Tungsten Carbide, Boron Carbide, Refractories, Abrasives, plaster

(c) ORGANIC MATERIALS:-

→ They are polymeric materials composed of carbon compounds. Polymers are solids composed of long molecular chains.

→ There are countless organic materials, natural, Synthetic & manufactured and based chemical on carbon.

Examples:-

Rubber, plastics, paper, Fuels, wood, lubricants, Textiles, Paints and finishes, Adhesives, Explosives.

Applications:-

(i) As electric insulation

(ii) For improving appearance.

(iii) As Fuels.

(iv) As vitamins and medicines

(v) As refrigerants

(vi) As lubricants etc.

POLYMERS:-

polymers include the familiar plastic and rubber materials. Many of them are organic compounds that are chemically Based on Carbon, hydrogen and other non metallic elements.

MECHANICAL PROPERTIES:-

Mechanical properties determine the behaviour of Engineering materials under applied forces and loads.

Various Mechanical properties are:

(1) ELASTICITY:-

Tendency of a deformed solid to seek its original dimensions upon unloading ascribed to a property called elasticity.

(2) PLASTICITY:-

plasticity is that property of a material by virtue of which it may be permanently deformed when it has been subjected to an externally applied force great enough to exceed the elastic limit.

(3) TOUGHNESS:-

→ Toughness is the ability of the material to absorb energy during plastic deformation up to fracture.

→ Toughness refers to the ability of a material to withstand bending or the application of shear stresses without fractures.

(d) COMPOSITES:-

It consists of more than one material type.

Fiber-glass is a familiar examples.

Glass + polymer = Fiber-glass
(strength) (flexibility)

(e) SEMICONDUCTORS:-

Semiconductors have electrical properties that are intermediate between the electrical conductors and insulators.

PROPERTIES OF ENGINEERING MATERIALS:

→ Mechanical properties

→ Thermal properties

→ Electrical properties

→ Magnetic properties

→ Chemical properties

→ Optical properties

→ physical properties

→ Technological properties.

→ Resilience is closely related to toughness.

→ Resilience is the capacity of a material to absorb energy when it is elastically deformed and then upon unloading, to have this energy recovered.

(5) TENSILE STRENGTH:-

Ratio of the maximum load to original cross-sectional area is called Tensile strength or ultimate tensile strength.

(6) YIELD STRENGTH:-

When metals are subjected to a tensile force, they stretch or elongate, as the stress increases. The point where the stretch suddenly increases, is known as yield strength.

(7) IMPACT STRENGTH:-

Capacity of material to resist or absorb shock energy.

(8) DUCTILITY:-

Capacity of a material to undergo deformation under tension without rupture.

(9) MALLEABILITY:-www.FirstRanker.comwww.FirstRanker.com

→ Malleability is the capacity of a material to withstand deformation under compression without rupture as for example in forging and rolling operations.

→ The ability of a metal to be formed by hammering or rolling is called malleability.

(10) BRITTLINESS:-

It is defined as a tendency to fracture without appreciable deformation and is therefore the opposite of ductility or malleability.

(11) HARDNESS:-

It is the resistance of a material to plastic deformation usually by indentation.

(12) FATIGUE:-

When subjected to fluctuating or repeated load, materials tend to develop a characteristic behaviour, which is different from that under steady loads.

(13) CREEP:-

Creep is the time-dependant permanent deformation that occurs under stress.

- Crystallography is the study of the crystal formation of solids
- is a branch of science in which the internal structure of crystals, their properties, external & internal symmetries of crystals are studied.
- When it is applied to metals it is called "Metallography"

→ TERMS ASSOCIATED WITH CRYSTALLOGRAPHY

- | | |
|-----------------------------|---------------------------|
| (1) CRYSTAL | (6) LATTICE PARAMETER |
| (2) STRUCTURE | (7) MILLER INDICES |
| (3) SPACE LATTICE | (8) ATOMIC PACKING FACTOR |
| (4) UNIT CELL | (9) COORDINATE NUMBER |
| (5) CRYSTALLOGRAPHIC PLANES | |

- ① A CRYSTAL is a solid whose constituent atoms or molecules are arranged in a systematic geometric pattern.
- ② The STRUCTURE implies the arrangement and disposition of the atoms within a crystal.
- ③ The atoms arrange themselves in distinct pattern in space called Space Lattice.
- ④ The UNIT CELL is the smallest group of atoms possessing the symmetry of the crystal.
- ⑤ The layers of atoms or the planes along which atoms are arranged are known as ATOMIC (or) CRYSTALLOGRAPHIC PLANES.

of a crystal constitute the LATTICE PARAMETERS of a cell.

(4) MILLER INDICES is a system of notation for designating Crystallographic planes and directions of crystals.

(5) ATOMIC PACKING FACTOR is the ratio of the volume of the atoms per unit cell to the total volume occupied by the unit cell.

(6) coordinate number is the number of nearest atoms directly surrounding a given atom in a crystal i.e., nearest neighbours to an atom in a crystal.

TYPES OF SOLIDS:-

Solids in which atoms are closely packed.

Solids may be classified into three

- Crystalline - if atoms or molecules arranged in regular fashion.
- Amorphous - irregular fashion.
- A combination of two

- All solids are composed of a very large no of atoms that are bonded together in some manner.
- The cohesion between the atoms is dependent upon the character of the individual elements.

- BONDING ENERGY:-

- Defined as the Energy required to return the atoms to an infinite separation.

It is also be expressed as the Energy of formation of 1 mole of a substance from its atoms or ions when brought together from an infinite distance to the equilibrium position.

TYPES OF BONDS:-

(a) primary Bonds →

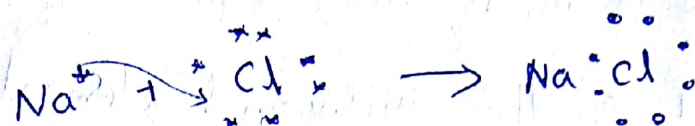
- Ionic
- covalent
- Metallic

(b) Secondary Bonds - Van der Waals Bond.
(Molecular Bond)

- Ionic Bond is also known as electrovalent bond.

hetero polar Bond.

→ It is an Simple example of Interatomic Bonding.

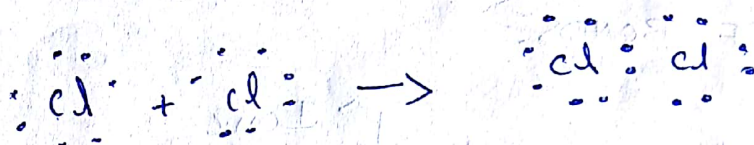


→ It exists between a metallic atom and (sodium)
a non-metallic atom.
(chlorine)

COVALENT BOND:-

→ Covalent Bond is also known as homo polar Bond.

→ When electrons shared between atoms it gives rise to a covalent Bond.



METALLIC BOND:-

→ It applied to metals and alloys.

→ It is an Special form of covalent bonding.

→ In covalent bonding particular atoms in the structure are linked together by particular pairs of the valency electrons shared between them.

→ Whereas, in metallic bonding, the valency electrons are not bound to any particular pairs of atoms but

move freely throughout the metal and form a negative electron cloud, which shared by positive ions.

→ atoms having small number of valence electrons which are loosely held, so that they easily be released to the common pool (cloud).

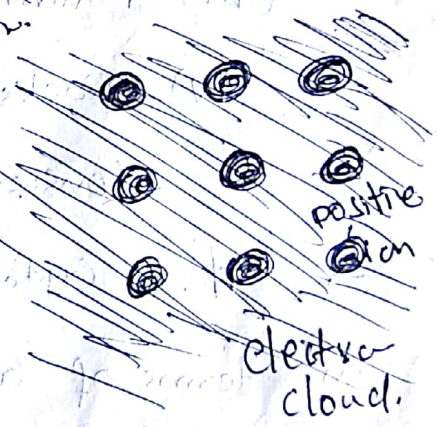
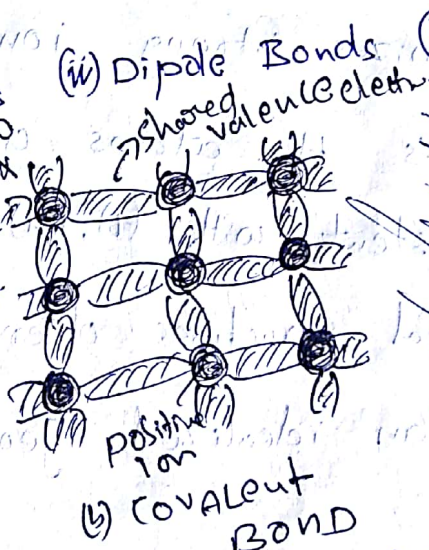
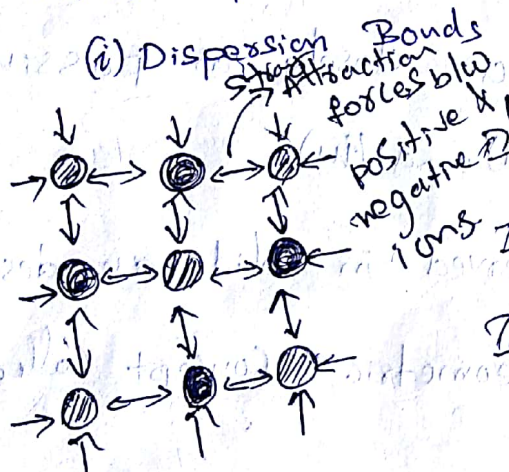
(d) THE VAN DER WAAL BOND (or Intermolecular Bond):-

→ Intermolecular or Van der Waal forces are weak forces that account for mutual interaction between molecules or inert atoms.

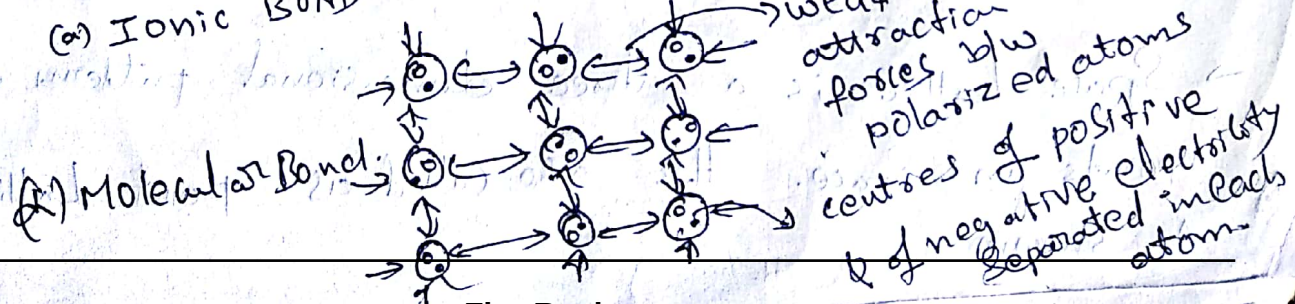
→ weak electrostatic attraction is due to asymmetrical electrical charges in electrically neutral atoms or molecules.

→ Intermolecular forces account for the properties of liquids and many molecular solids, ranging from small molecular weight up to polymers.

→ THREE TYPES



(a) IONIC BOND



CRYSTAL STRUCTURES :-

www.FirstRanker.com

www.FirstRanker.com

→ They are regular three dimensional patterns of atoms in space.

→ This regularity of atomic arrangement in solids come due to geometrical conditions which are imposed by directional bonding and/or close packing of atoms.

→ The most stable arrangement of atoms in a crystal will be that arrangement which minimizes the energy per unit volume i.e., in other words, the one that:

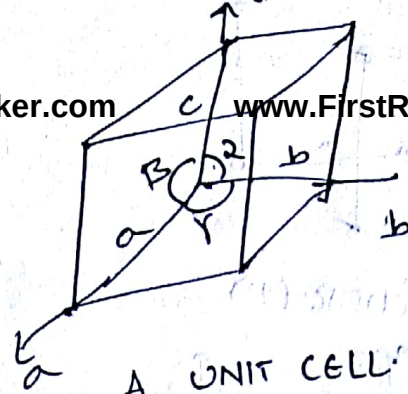
- (i) Preserves electrical neutrality
- (ii) Satisfies the directionality and discreteness of all covalent bonds.
- (iii) Minimizes strong ion-ion repulsion.
- (iv) Packs the atoms as closely as possible consistent with (i), (ii) and (iii)

→ The crystal structures observed in solids are described in terms of an idealized geometric concept called a Space Lattice.

→ Space Lattice is a three dimensional pattern of points in space. This also called as point Lattice. As shown.



A POINT LATTICE



A UNIT CELL

$a, b, c, \alpha, \beta, \gamma \rightarrow$ Lattice parameters

Lattice points can be arranged in only 14 different arrangements (arrays). Called "Bravais LATTICE"

CRYSTAL SYSTEMS AND BRAVAIS LATTICE

SYSTEM	AXIAL LENGTHS AND ANGLES	BRAVAIS LATTICE	LATTICE SYMBOL
CUBIC	Three equal axes at right angles, $a=b=c, \alpha=\beta=\gamma=90^\circ$	Simple Body-centred Face-centred	P I F
TETRAGONAL	Three axes at right angle, two equal, $a=b \neq c, \alpha=\beta=\gamma=90^\circ$	Simple Body-centred	P I
Orthorhombic	Three unequal axes at right angles, $a \neq b \neq c, \alpha=\beta=\gamma=90^\circ$	Simple Body-centred Base-centred (end) Face-centred	P I C F
Rhombohedral	Three equal axes, equally inclined, $a=b=c, \alpha=\beta=\gamma \neq 90^\circ$	Simple	R
Hexagonal	Two equal coplanar axes at 120° third axis at right angles, $a=b \neq c, \alpha=\beta=90^\circ, \gamma=120^\circ$	Simple	P
MONOCLINIC	Three unequal axes, one pair not at right angles $a \neq b \neq c, \alpha=\gamma=90^\circ \neq \beta$	Simple Base-centred (end)	P C
TRICLINIC	Three unequal axes, unequally inclined and none at right angles $a \neq b \neq c, \alpha \neq \beta \neq \gamma \neq 90^\circ$	Simple	P

PHASE DIAGRAMS (OR) EQUILIBRIUM OF DIAGRAMS

- * Phase diagrams also known as equilibrium diagrams are very important tool in the study of alloys.
- * A phase diagram has temperature as its ordinate and alloy composition as abscissa.
- * The objective of phase diagram shows at a glance the phases which exist in equilibrium for any composition of temperature and alloy composition.
- * Equilibrium refers to the state of behavior which exists (or) which tends to be attained, between the phases in the structure of an alloy after a physical or chemical changes has taken place.
- * It shows relationship between the composition, temperature and structure of an alloy in series.
 - Phase separation
 - Solidification of metals and alloys
 - Purification of material
 - The structural changes produced by heat

treatment.

Classification of phase diagrams

- 1) unary
- 2) Primary
- 3) Ternary

Unary: This is also called one component phase diagrams plotted as pressure on the vertical and temperature on the horizontal axis.

Primary: (Two - component) phase diagrams which finds extensive uses and

Ternary: (For three components)

Systems, Phases and Structural Constituents

* A system is a substance (or group of substances) so isolated from its surroundings that is unaffected in overall composition, temperature, pressure & total volume only to the extent allowed by investigator.

* Phase can be defined as any part or portion of a chemical system which possesses distinctive physical characteristics

Q to R remains constant, until whole mass has entirely solidified (at point R)

⇒ Between Q and R, the mass is partly liquid and partly solid, at a point is solid

a: pure metal

b: Binary metal

c: Binary Eutectic metal

PHASE DIAGRAM

* An equilibrium diagram shows the units of composition and temperature within which the various constituents & phases of an alloy are stable;

* In a phase diagram, for each change of phase, adequate time is allowed for the change to complete so that phase change takes place under equilibrium conditions, the phase diagram will be known as phase equilibrium diagram

* Equilibrium conditions are not generally attained during the solidification of welds and casting because due to fast cooling rates, adequate time is not available.

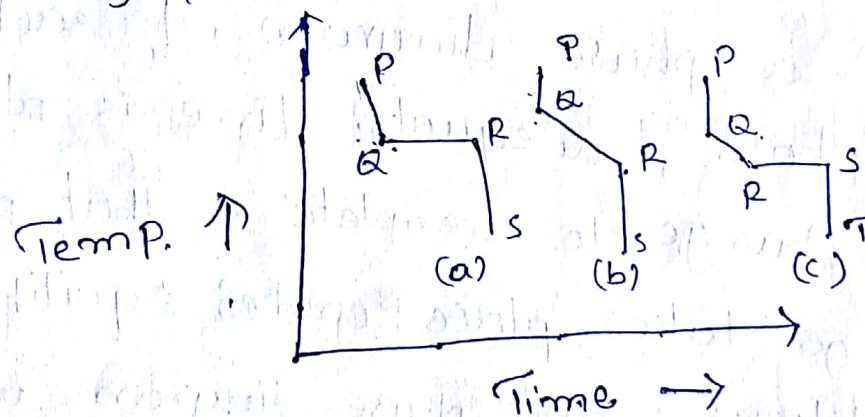
COOLING CURVES (OR) ISOMORPHOUS ALLOY SYSTEMS

A method to determine the temperature at which phase changes (from liquid to solid) occur in an alloy system consists of the following the temperature as a function of time as different alloys in the system are very slowly cooled.

The data obtained in the manner form a cooling curve for each of the alloys.

Types:-

1) Cooling curve for pure metal (or) compound



⇒ Liquid metal cools from 'P' to 'Q' first crystal begin to form at point 'Q'

⇒ From Q to R the melt liberates latent heat of fusion in such amounts that the temperature from

for each change of phase to complete

LEVER RULE

- * To determine the relative amount of two phases, erect an ordinate at a point on the composition which gives the total (b) overall composition of the alloy.
- * The lever rule gives the fraction as two co-existing phases the tie line at the temperature of interest is treated as a lever arm, with the system fulcrum at the overall composition. It should be noted that tie-line rule gives the composition of the co-existing phases, whereas the lever rule gives the fractions (or amounts) of the phases.

CORING

→ Coring or segregation is the non-uniform distribution of constituents in a metal usually a concentration of certain constituents and ^{more} impurities, arising during freezing and generally persisting throughout operations is known as coring or

EUTECTIC SYSTEMS

* In an eutectic reaction, when a liquid solution of fixed composition, solidifies at a constant temperature forms a mixture of two (or) more solid phases without an intermediate partly state this process reverses on heating.

Liquid $\xrightleftharpoons[\text{heating}]{\text{cooling}}$ Solid₁ + Solid₂

Liquid
/ \
Solid₁ + Solid₂

* In eutectic system there is always a specific alloy known as eutectic composition that freezes at a lower temperature than all other compositions.

* Under conditions approaching equilibrium (slow cooling) it i.e. specific alloy freezes at a single temperature like a pure metal in other respects the solidification reaction of this composition is quite different from a mixture of two different solid phases

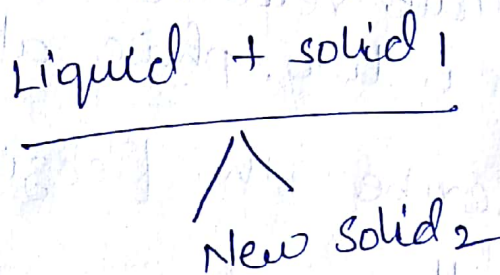
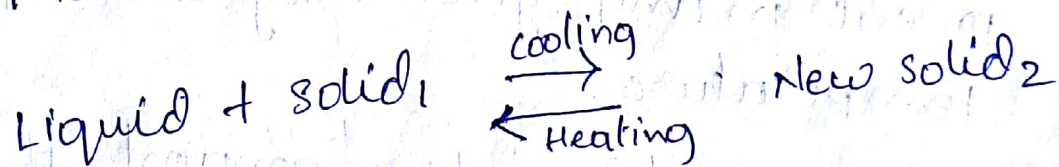
* At the eutectic temperature, two solid phases form simultaneously from a single liquid phase. (14)

* The eutectic temperature and composition determine a point on the phase diagram called the eutectic point.

PERITECTIC REACTION

* It is the reaction that occurs during the solidification of some alloy where the liquid phase reacts with a solid phase to give a solid phase of different structure.

* The reaction reverses on melting (heating)



* Peritectic reaction is actually, just the opposite of the eutectic Reaction

* Assuming very slow rates of cooling, the peritectic reaction will occur only in those alloys.

Equilibrium Diagram

* Equilibrium diagram is a graphical representation of different states of alloy system. It indicates the phases existing in the system at any temperature and composition.

Applications

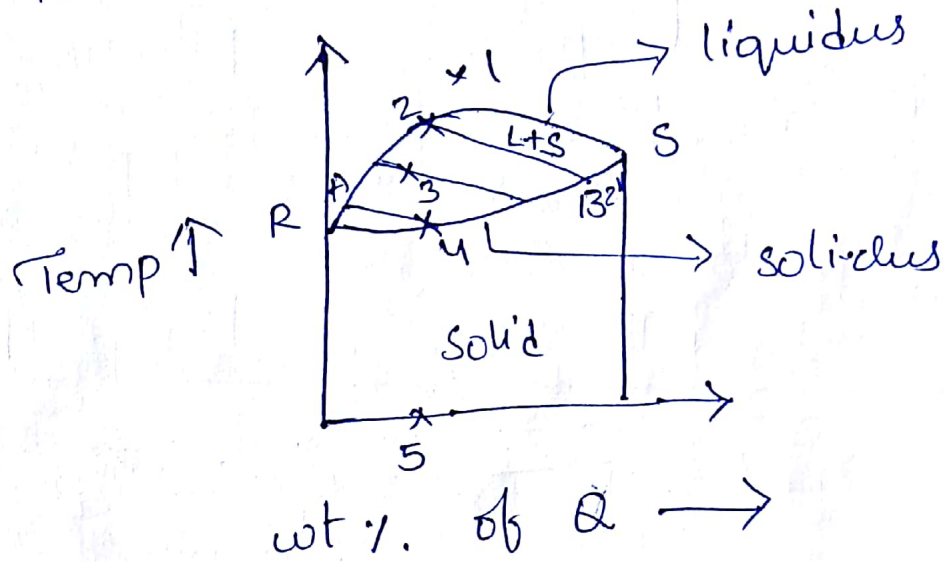
- 1) To predict the safe temperature of heat treatment & working
- 2) To determine the number of phases, types of phases, composition of phases present in any given alloy at a specific temperature.
- 3) To calculate relative amount of the phase present in a two phase alloy.
- 4) To describe the freezing & melting of an alloy

Isomorphous Alloy

There are the system in which two metals are completely soluble in liquid as well as solid state.

Examples
 $Cu-Ni$, $Au-Ag$, $Au-Cu$, $Ag-Cu$, $Ag-Ni$, $Bi-Sb$ etc..

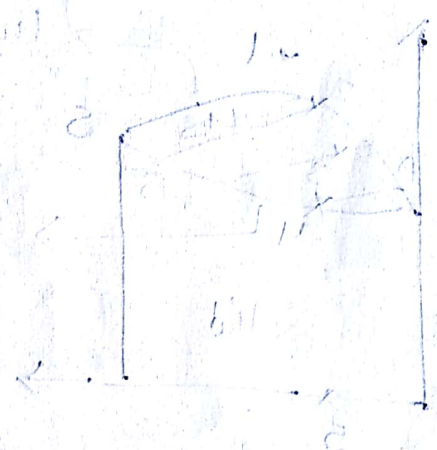
Let us consider the cooling of an alloy with $x\%$ of B from point 1 (liquid state) to point 5 (room temperature). P and Q are two metal whose melting temperature are R and S respectively

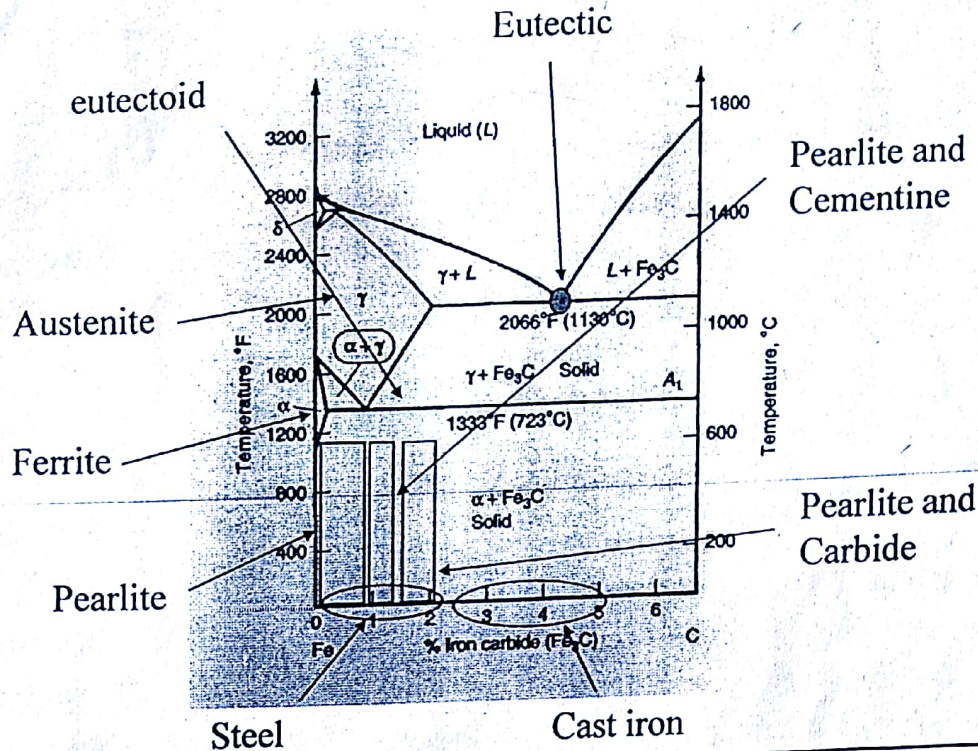


From point 1-2 there will be no change in the state i.e the alloy will be in liquid state. From point 2: the alloy starts solidifying.

The amount solid depends on the temperature i.e as temperature decreases the amount of solid increases and this stage continues upto point 4 where the alloy will be solid state. From point 2-4 the average composition

...ing solid and liquid is given
by the solidus and liquidus
amount of solid and liquid can be obtained
by applying lever rule at a given temper-
ature.



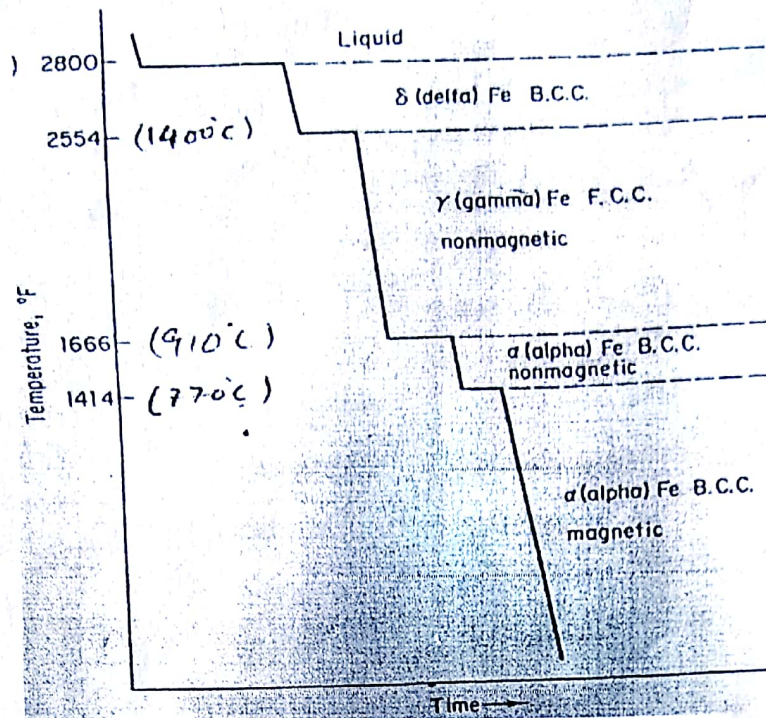


Chinna Dora .D

Outline

- Introduction
- Cooling curve for pure iron
- Definition of structures
- Iron-Carbon equilibrium phase diagram – Sketch
- The Iron-Iron Carbide Diagram - Explanation
- The Austenite to ferrite / cementite transformation
- Nucleation & growth of pearlite
- Effect of C %age on the microstructure of steel
- Relationship b/w C %age & mechanical properties of steel

Chinna Dora .D



Definition of structures

Various phases that appear on the Iron-Carbon equilibrium phase diagram are as under:

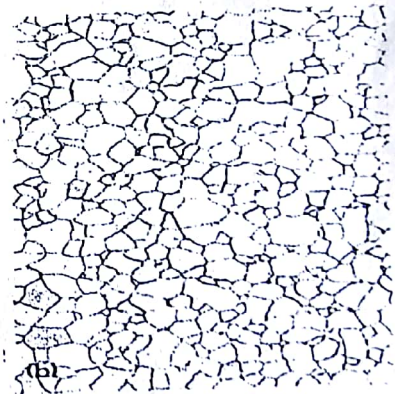
- Austenite
- Ferrite
- Pearlite
- Cementite
- Martensite*
- Ledeburite

- **Ferrite** is known as α solid solution.
 - It is an interstitial solid solution of a small amount of carbon dissolved in α (BCC) iron.
 - stable form of iron below 912 deg.C
 - The maximum solubility is 0.025 % C at 723°C and it dissolves only 0.008 % C at room temperature.
 - It is the softest structure that appears on the diagram.
-

Definition of structures

Ferrite

- Average properties are:
 - Tensile strength = 40,000 psi
 - Elongation = 40 % in 2 in;
 - Hardness > Rockwell C 0 or
> Rockwell B 90



Definition of structures

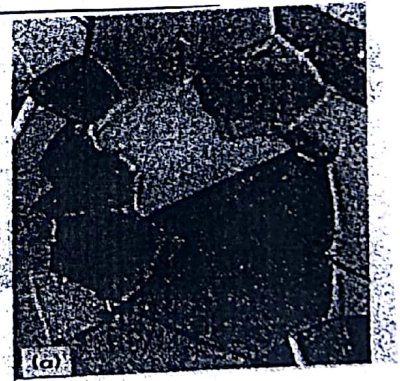
- **Austenite** is an interstitial solid solution of Carbon dissolved in γ (F.C.C.) iron.
 - Maximum solubility is 2.0 % C at 1130°C.
 - High formability, most of heat treatments begin with this single phase.
 - It is normally not stable at room temperature. But, under certain conditions it is possible to obtain austenite at room temperature.
-

Definition of structures

Austenite

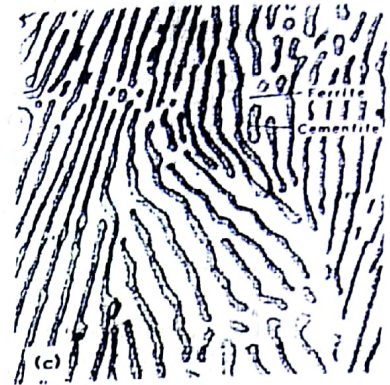
- Average properties are:

- Tensile strength = 150,000 psi;
 - Elongation = 10 percent in 2 in.;
 - Hardness = Rockwell C 40, approx; and
 - toughness = high
-



Definition of structures

- **Pearlite** is the eutectoid mixture containing 0.80 % C and is formed at 723°C on very slow cooling.
- It is a very fine platelike or lamellar mixture of ferrite and cementite.
- The white ferritic background or matrix contains thin plates of cementite (dark).



Chinna Dora .D

Definition of structures

Pearlite

- Average properties are:
 - Tensile strength = 120,000 psi;
 - Elongation = 20 % in 2 in.;
 - Hardness = Rockwell C 20, Rock-well B 95-100, or BHN 250-300.

Chinna Dora .D

Definition of structures

- **Cementite** or iron carbide, is very hard, brittle intermetallic compound of iron & carbon, as Fe_3C , contains 6.67 % C.
 - It is the hardest structure that appears on the diagram, exact melting point unknown.
 - Its crystal structure is orthorhombic.
 - It is has
 - low tensile strength (approx. 5,000 psi), but
 - high compressive strength.
-

Chinna Dora .D

Definition of structures

- **Ledeburite** is the eutectic mixture of austenite and cementite.
 - It contains 4.3 percent C and is formed at 1130°C .
-

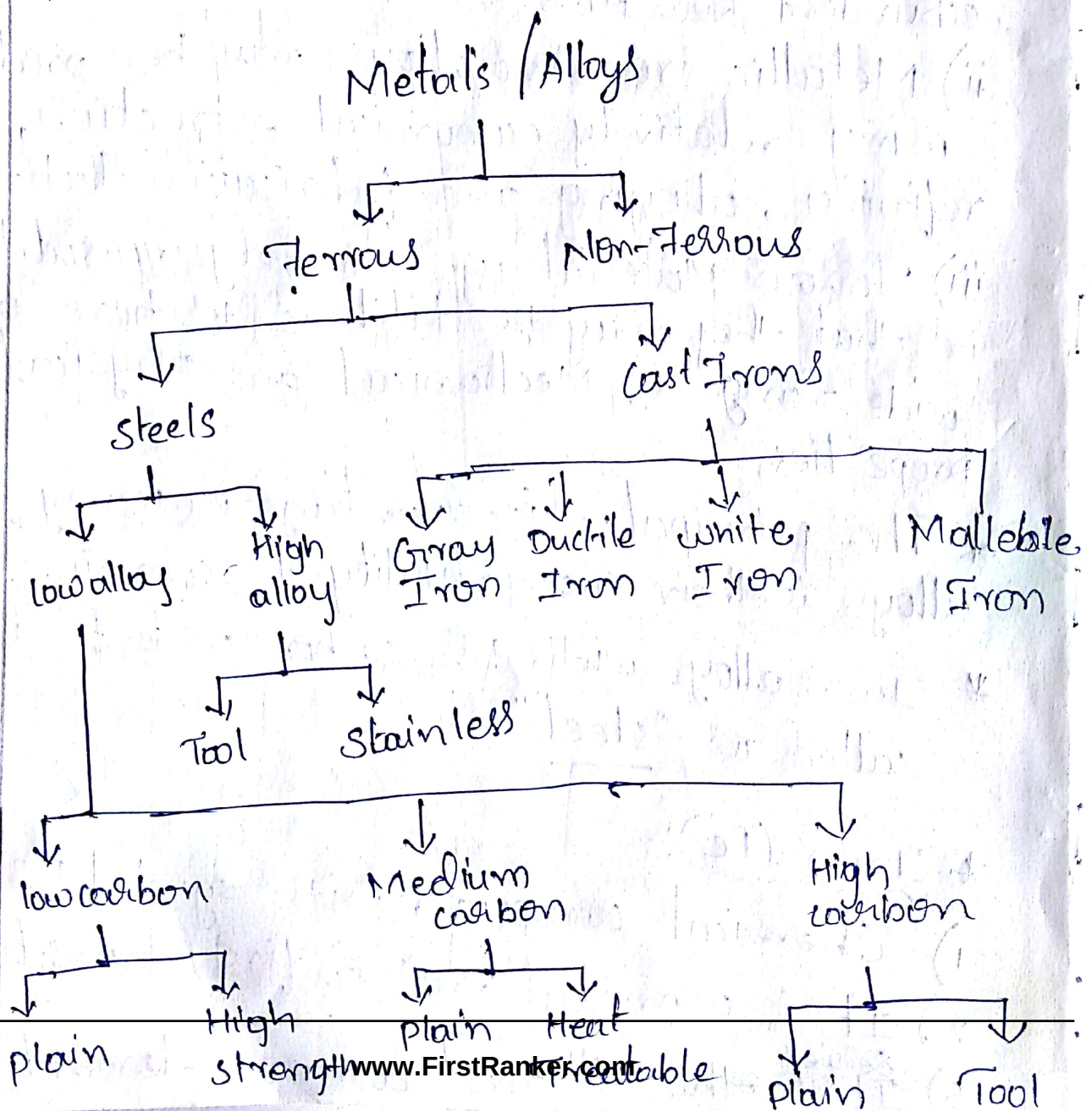
Chinna Dora .D

CAST IRONS AND STEELS.

- * Fe - C alloys with more than 2% carbon are called cast irons.
- * Ferrous material contains iron and the one element people use more than all other is iron.
- * The widespread use of ferrous alloy is accounted for by three factors.
 - i) Iron containing compounds exist in abundant quantities within the earth crust
 - ii) Metallic iron and alloys may be produced using relatively economical extraction, refining, alloying and fabrication techniques.
 - iii) Ferrous material are extremely versatile in that they may be tailored to have a wide range of mechanical and physical properties.
- * The principal disadvantage of many ferrous alloys is their susceptibility to corrosion.
- * Iron alloys with less carbon content are called as "steel".
- * Iron (Fe):-
 - 1) Chemical compound with symbol Fe, 26
 - 2) It is a metal in the first transition
 - 3) It is the 4th most common element in series

4) M.P: 1538°C B.P: 2862°C Basics

- * Carbon (C) and Silicon (Si) are the main alloying elements with the amount ranging from 2.1 - 4% weight percentage by carbon and 1-3% weight % by silicon respectively.
- * The melting point temperature closely from 1150°C to 1200°C

Classification

* Pig iron is the intermediate product of smelting iron ore with a high carbon fuel such as coke, usually with limestone as a flux, charcoal and anthracite have also been used as fuel.

* Pig iron has a very high carbon content typically 3.5 - 4.5% along with silica and other impurities.

* Pig iron produced in a blast furnace is the first product in the process of converting iron ore into useful metal. The iron ore becomes pig iron when impurities are burned out in a blast furnace, although still containing some impurities, pig iron has a metal content

* Pig iron from the blast furnace has the following composition.

Carbon = 3-4%

Phosphorus 0.3 - 1.7%

Silicon = 1-3%

Sulphur less than 1%

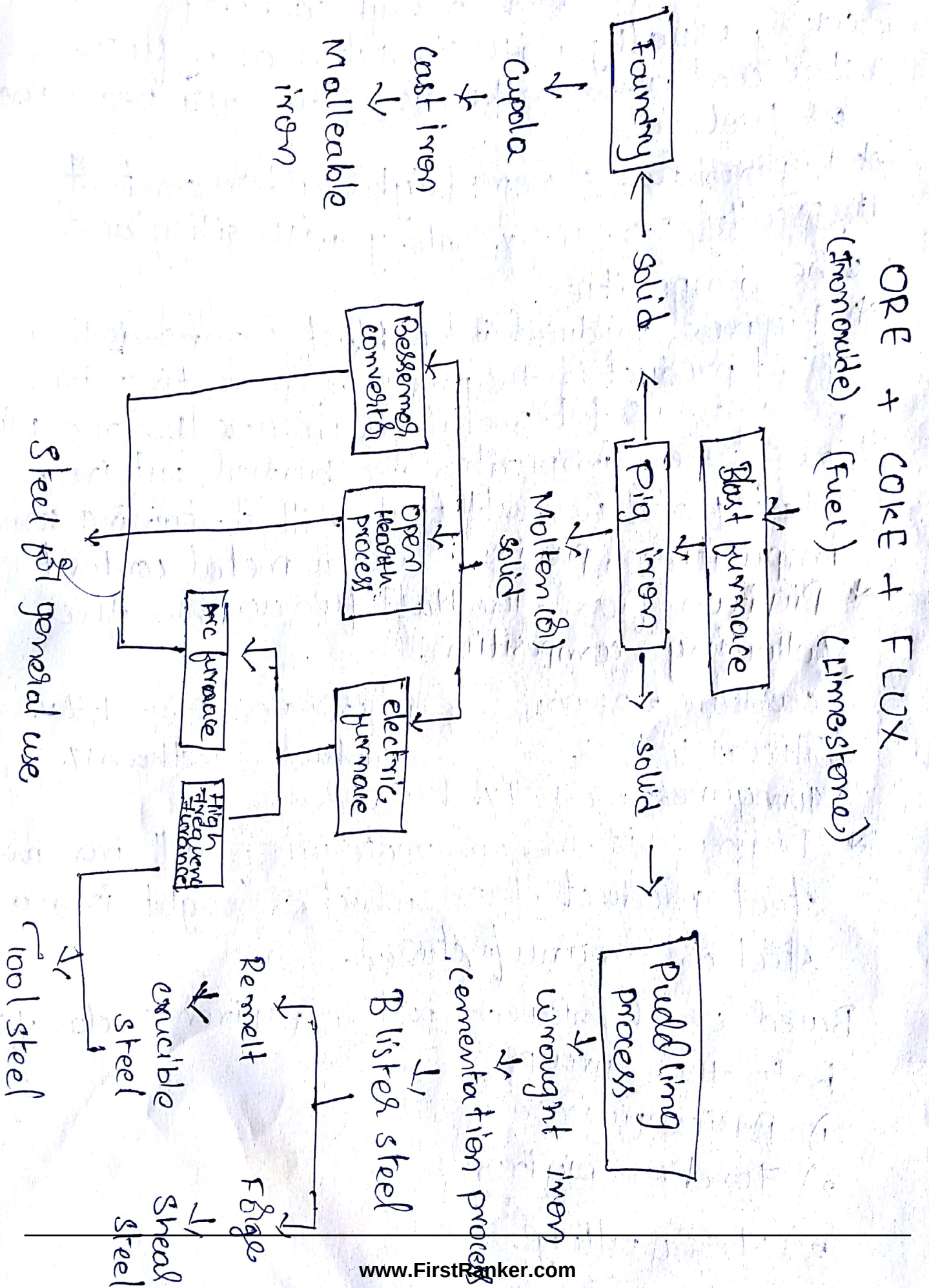
Manganese = 0.1 - 1%

Iron

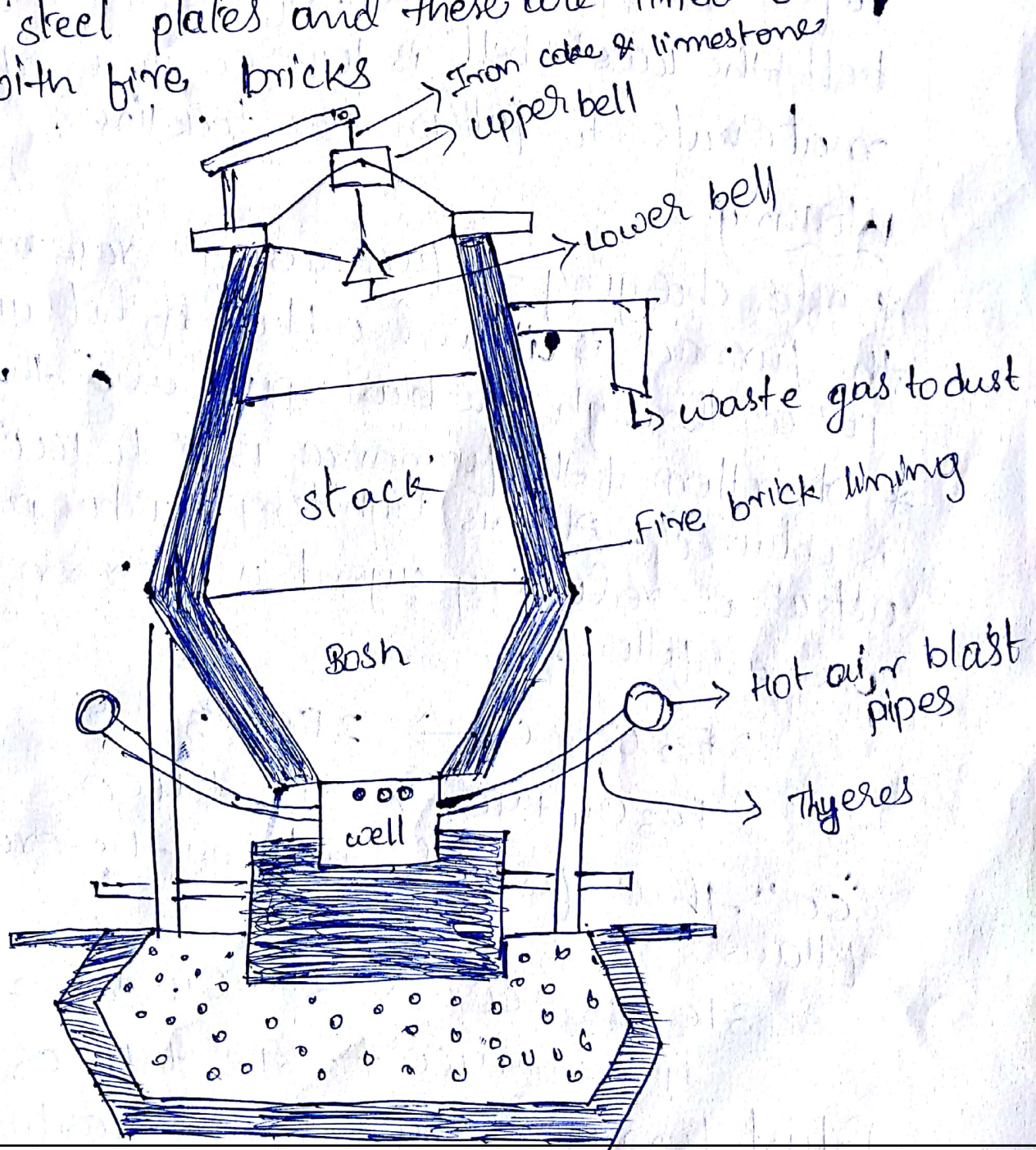
* Pig iron is the raw material for all iron and steel product, from which wrought iron and steel are manufactured.

Based on chemical composition pig iron is classified into these groups:

- 1) Basic pig iron
- 2) Foundry pig iron
- 3) Ferro alloys.



- 1) It is named as a very high temperature is developed inside it by means of forcing a blast of heated air.
- 2) Its height is about 30mts and dia is 8mts.
- 3) To permit proper flow of material it is made narrow at the top and bottom.
- 4) The outside of the furnace is constructed of steel plates and these are lined on the inside with fire bricks.



* The top of the furnace is at the top of the "bosh" and its diameter depends on the output.

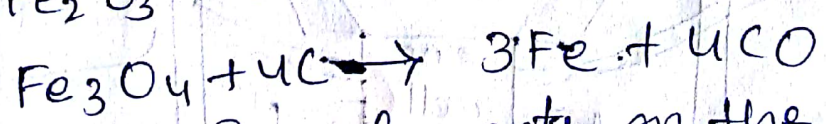
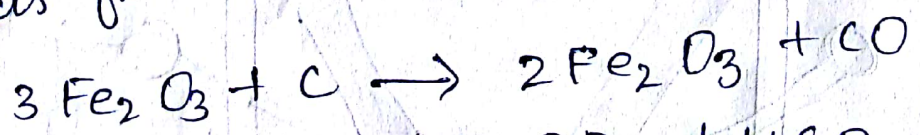
* The raw material after weighing in the desired proportions are raised to the top of the blast furnace through mechanical charging equipment.

* The materials are charged first on the upper bell which is then lowered allowing them to fall on the lower bell. After closing upper bell the lower bell is lowered to enable the materials to fall on the stock line.

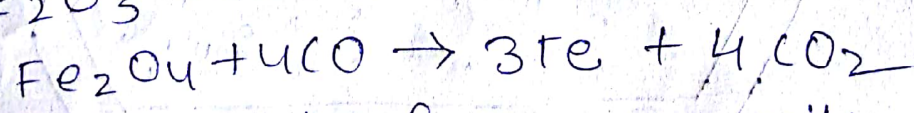
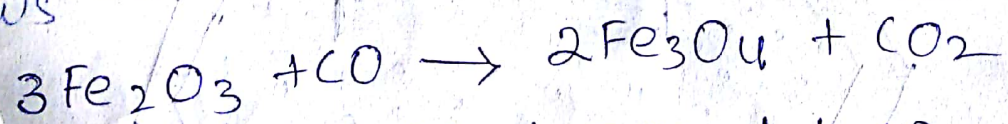
Working

* After charging the furnace with raw materials the furnace is lit and a blast of hot air is passed through the blast pipe and tuyeres.

* At bottom of the furnace 1350° to 1600°C temp is obtained. At this high temp. carbon present acts as a reducing agent and rxn on the ore as follows



"CO" thus formed reacts on the ore as follows



Blast furnace slag has a composition with the following ranges.

Alumina = 12 to 20%
Silica = 3 to 8%
Mn = 2 to 14%
Sulphur = 2 to 25%

Effects of impurities on iron

* The impurities (such as silicon, phosphorus, sulphur and manganese) effect the iron in the following ways.

- 1) Silicon
→ increases the fluidity of Metal
→ Induces the stiffness of iron
- 2) Phosphorus
→ Brittleness at ordinary temp
- 3) Sulphur
→ Encourage the formation of blow holes
- 3) Manganese
→ Increase the hardness and brittleness.

CAST IRON

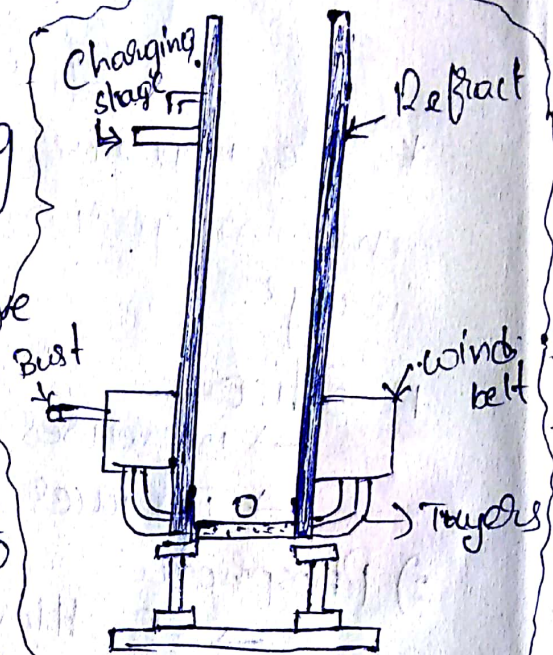
* The product of blast furnace i.e pig iron is unsuitable for castings as it contains impurities in high percentage to render it suitable for desired purpose it is refined in the furnace known as "cupola", the refined product is termed as cast iron.

Cupola:-

* It is very similar to a blast furnace in principle i.e. it is a vertical shaft furnace, into which the raw material and fuel are charge at top
* Air from combustion of fuel is introduced

through one or more rows of tuyeres at short distance above the bottom

In a cupola, the first operation is to let the fire ~~at bottom~~ when the fire is burning strongly, coke is added gradually till the level above the tuyers is about 0.6 mts. this coke serves as a bed for the alternative charges of metal and coke which follow when the shaft



of the cupola is filled with charging door to the blast is put on and combustion of the coke near the tuyers increases rapidly until a very intense heat is attained.

* The gases of combustion move upwards and pass on a portion of the heat to the metal and coke waiting to descend.

* In 9.5 to 10 min the first charge of metal starts melting and trickles down through the coke and finally collect at the bottom the cupola

* Since cupola is only concerned with the melting of the metal and it is not with the reduction of ores as in the blast furnace, and it is considerably smaller than a blast furnace of the same output



varies from 1 to 2 meters with a height of 4 to 5 times in diameter.

CLASSIFICATION, COMPOSITION, PROPERTIES AND USES OF CAST IRON

Cast iron may be classified as follows:

- 1) Grey cast iron
- 2) White cast iron
- 3) Mottled cast iron
- 4) Nodular cast iron
- 5) Malleable cast iron
- 6) Alloy cast iron

Grey cast iron

- * Grey cast iron is characterised by presence of a large portion of its carbon in the form of graphite flakes
- * Although grey iron is often defined as steel containing graphite its properties are far different from those of steel
- * Owing to its low specific gravity, graphite occupies over three times as much space as an equal weight of metal
- * From 6 to 10 percent of the volume of a typical grey iron is occupied by graphite



- * the strength properties of grey cast iron are improved by reducing the flake size and distributing the flakes uniformly
- * Grey iron basically is an alloy of carbon and silicon with iron. It contains 2.5, 3.8% carbon, 0.1 - 2.8% Si, 0.4 - 1% Mn, 0.15% P and 0.10% S
- * When fractured a bar of grey cast iron gives gray appearance.

Applications

- 1) Piston rings
- 2) Cylinder blocks and heads for I.C engines
- 3) Gas and water for underground purposes
- 4) Frames for electric motor
- 5) Rolling mills and general machinery parts.

- * The composition of white cast iron is as follows. graphite carbon 0.5%, iron 94%, combined carbon 3.5% and other impurities
- * White cast iron derives its name from the fact that its freshly broken surface shows a bright white fracture.
- * Unlike grey iron, white cast iron has almost all its carbon, chemically bonded with the iron - as iron oxide, Fe_3C (iron-carbide) is very hard and brittle constituent.
- * Thus white cast iron possesses excellent abrasive wear resistance.
- * By using a fairly low silicon content cast iron may be made to solidify as white iron.
- * The solidification range of white iron is $2550 - 2065^{\circ}F$
- * White iron is the first step in the production.

Properties

- * Hard brittle
- * Highly resistance to wear
- * Tensile strength is good.

Uses

- 1) used for parts subjected to excessive wear
ex: rim of freight car wheel
Railway brake block
- 2) used for making malleable castings

MOTTLED CAST IRON

* The composition is iron 93.5%, graphite 1.75%, combined carbon 1.75% and remaining impurities

Properties

- * It is a mixture of gray cast and white cast iron.
- * Fluidity is good.
- * Strength and hardness varies according to the ratio of free carbon to combined carbon
- * hard and brittle
- * Less tendency to rust than grey iron

Uses

→ used for man hole covers and pipes.

* Unlike long flakes as in grey cast iron, graphite appears as rounded particles (or) nodules (or) spheroids in Nodular cast iron.

* Nodular cast iron contains 3.2 - 4.2 % Carbon, 1.1 - 3.5 % Si, 0.3 - 0.8 % Mn, 0.08 % P and 0.2 % S.

* It possesses excellent castability and wear resistance.

* Ductile cast iron possesses very good machinability.

* It is also called ductile cast iron and it is produced by nickel-magnesium alloy.

* It behaves like steel.

Uses

- 1) Paper industries machinery
- 2) I.C. engine parts
- 3) Valves and fittings
- 4) Pumps and compressors
- 5) Construction machinery
- 6) Earth moving machinery

Characteristics:

- 1) Malleable cast iron is one which can be hammered and rolled to obtain different shapes.
- 2) Malleable cast iron is obtained from hard and brittle white iron through a controlled heat conversion process.
- 3) Malleable cast iron possess high yield strength.
- 4) It can be used from -60 to 1200°F .
- 5) It has solidification range $2550 - 2065^{\circ}\text{F}$.
- 6) It contains 2-3% carbon, 0.6-1.3% Si, 0.2-0.6% Mn, 0.15% P and 0.10% S.
- 7) It is obtained by giving long time annealing to cast iron. It is soft, tough and easily machined.

Procedure how to get malleable cast iron:

* The white cast iron casting along with silica is packed in steel pot in heated muffle oven. The temperature is maintained at 870°C for 60 hours and casting is on cooling slowly in the furnace.

- 1) Rail Road
- 2) Electrical line hardware
- 3) Gear case
- 4) Automotive industry
- 5) Crank shaft sprockets etc..

ALLOY CAST IRON

* Two examples of alloy cast iron

- 1) Acicular
- 2) Spheroidal

Acicular:

It has nickel and molybdenum as the leading constituent and is employed for crankshafts

Spheroidal cast iron:

It has graphite content in spheroidal form which is converted from flakes form by alloying with a small amount of magnesium and cerium the change in graphite increases the tensile strength and produce a tough metal and which can undergo bending and twisting.

* Steel is an alloy of iron and carbon.

Classification of steel

- 1) Plain carbon steel
- 2) Mild steel
- 3) Medium carbon steel
- 4) High carbon steel
- 5) Alloy steel
- 6) Prominent alloy steel

Plain carbon steel

* A plain carbon steel is an alloy of iron and carbon and it is malleable.

* Carbon steels are different from cast irons as regards the percentage of carbon.

* Carbon steels contain 0.10 to 0.15% carbon whereas cast iron contains 1.8 to 4.2% carbon.

* Carbon steels can be classified as

- 1) Low carbon steel (8) mild steel
- 2) Medium carbon steel
- 3) High carbon steel

* Mild steel (1) low carbon
classified as follows

1) Dead mild steel

* Dead mild steel is used for making steel wire, sheets, rivets, screw, pipe and chain

* It has a tensile strength of 790 N/mm^2 and a hardness of about 115 BHN

* Mild steel containing 0.15 to 0.20% carbon.

2) Medium carbon steels

* Medium carbon steel containing carbon from 0.30 to 0.70%.

* It is used for key stock, connecting rods, axles, gear shafts, wires and rods.

3) High carbon steels

* High carbon steels contain carbon 0.7 to 1.5%.

* pneumatic drill bits, wrenches, jaws for vices, wire for structural work.

* Steel containing 0.8 to 0.9% carbon have a tensile strength of about 660 N/mm^2 these steels are used for Rock drills,

Railway rails, machines chisels etc..

* Steel is considered to be alloy when the maximum of the range given for the content of alloying elements exceeds one or more of the following limits:

Mn 1.65%, Si 0.6%, Cu 0.06%, (or) in which a definite range of a definite maximum quantity of any of the following elements is specified (or) required within the recognized field of constructional alloy steel Al, B, C, upto 3.99%, Co, Mo, Ni, Ti, W, V (or) any other alloying element added to obtain a desired alloying element added to effect

* The composition of alloy steel is

C: 0.2 - 0.4% Mn: 0.5 - 1.0%

Si: 0.3 - 0.6% Ni: 0.4 - 0.7%

Cr: 0.4 - 0.6% Mo: 0.15 - 0.3%

Fe: Balance

Advantages and Disadvantages of alloy steel

Advantages	Disadvantages
1) Greater hardenability	1) Cost
2) Less distortion and cracking	2) Special handling
3) Less grain growth	3) Brittleness
4) Higher elastic ratio	4) Tendency towards austenite retention
5) Greater ductility at high strength	

Purpose of alloying

www.FirstRanker.com

www.FirstRanker.com

- 1) Strengthening of the ferrite
- 2) Improved corrosion resistance
- 3) Better hardenability
- 4) Grain size control
- 5) Greater strength
- 6) Improved machinability
- 7) Improved ductility
- 8) Improved Toughness.

Effect of alloying elements

Carbon:

Carbon content in steel affects

- 1) Hardness
- 2) Tensile strength
- 3) Machinability
- 4) Melting point.

Nickel:

- increases toughness and resistance to impact
- Does not unite with carbon
- Strengthen steels

Silicon:

- improves oxidation resistance
- Strengthens low alloy steels
- Act as a deoxidiser

www.FirstRanker.com

HADFIELD'S MANGANESE STEEL

It is an austenitic steel possessing excellent strength and toughness with high wear resistance under impact loads as experienced in material handling and earth moving machinery such as crushers, caterpillars, shovels, bulldozers, jaw crushers, plate coal grinding mills etc.

→ Hadfield Manganese steel contains carbon 1.2 - 1.4%, rest of the iron Manganese 12 - 14%.

→ Hadfield manganese steel is austenitized (i.e. micro structure changed to austenite) by heating it to $1050^{\circ} - 1100^{\circ}\text{C}$, kept at that temperature for sufficient time and then quenched in water.

→ Before using this steel it is plastically deformed on its surface by hammering thus, a layer of austenite.

- **first stage graphitization:** cementite decomposes to the stable austenite and graphite phases
- **second stage graphitization:** slow cooling through eutectoid temperature to make *ferritic malleable iron*
- *when austenite is cooled in air or oil Pearlitic malleable iron is obtained (pearlite or martensite.)*

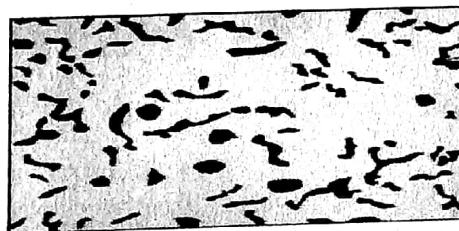
Drawing: is a heat treatment that tempers the martensite or spheroidizes the pearlite

Application

Connecting rods, transmission gears, and differential cases for the automotive industry, and also flanges, pipe fittings, and valve parts for railroad, marine, and other heavy-duty services

parts of power train of vehicles, bearing caps, steering gear housings, agricultural equipment, railroad equipment

- **Compacted graphite cast iron:**
- contains rounded but interconnected graphite also produced during solidification
- intermediate between flakes and spheres with numerous rounded rods of graphite that are interconnected to the nucleus of the eutectic cell.



Compacted
(vermicular)
graphite

- **vermicular graphite:**
- forms when ductile iron fades
- permits strengths and ductilities that exceed those of gray cast iron, but allows the iron to retain good thermal conductivity and vibration damping properties.
- **Ductile or nodular cast iron**



CAST IRON

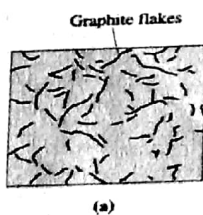
Iron-carbon alloys with more than 2.11% carbon are called cast iron.

It pass through the eutectic reaction during solidification.

- Properties
 - Inexpensive
 - Have good fluidity
 - Have low liquidus temperature
 - Readily castable

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
- **Gray cast iron**



- a. The least expensive and most common type
 - b. Characterized by formation of graphite
 - c. Typical composition ranges from 2.5-4.0% C, 1.0-3.0% Si, and 0.4-1.0% Mn.
 - d. contains small, interconnected graphite flakes that cause low strength and ductility.
-
- e. It is the most widely used cast iron

f. It is named for the dull gray color of the fractured surface.

g. The gray irons are specified by a class number of 20 to 80.

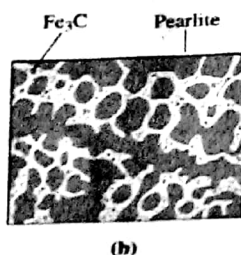
- **Properties**

- a. high compressive strength,
- b. good machinability,
- c. good resistance to sliding wear,
- d. good resistance to thermal fatigue,
- e. good thermal conductivity, and
- f. good vibration damping.

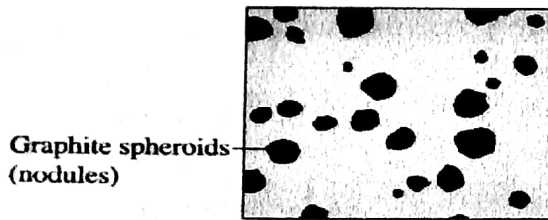
- **Application;**

- a. Damping vibrational energy
 - Base structures for machines and heavy equipment
- b. High resistance to wear.
- c. High fluidity at casting temperature
 - Intricate shapes; Low casting shrinkage allowance.
 - (strength is not a primary consideration)
 - Tensile strength 120 – 300 MPa
 - Small cylinder blocks, cylinder heads, pistons, liners, clutch plates, transmission cases.
 - gears, flywheels, water pipes, engine cylinders, brake discs, Machinery beds

- **White cast iron**



- a. is a hard, brittle alloy containing massive amounts of Fe₃C.



(d)

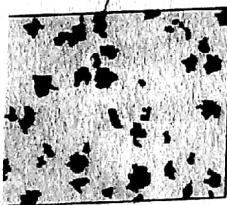
- contains spheroidal graphite particles.
- produced by treating liquid iron with a carbon equivalent of near 4.3% with magnesium
- Steps
 - **Desulfurization:** CaO is used to remove sulfure and oxygen from the liquid.
 - **Nodulizing:** Mg in dilute form (MgFeSi alloy) is added, a residual of 0.03%Mg must be present after treatment in order for spheroidal graphite to grow
- **inoculation:** heterogeneous nucleation of the graphite is essential
- **Fading:** occurs by the gradual, nonviolent loss of Mg due to vaporization and/or reaction with oxygen
- **Application:**
 - valves, pump bodies, crankshafts, high-strength gears (heavy duty gears) and machine, rollers, slides, die material having high strength and high ductility.

b. A fractured surface of this material appears white, hence the name.

c. Features promoting formation of cementite over graphite

- A low carbon equivalent (1.8-3.6 %C, 0.5-1.9%Si, 0.25-0.8%Mn) and
- Rapid cooling
- A group of highly alloyed white irons are used for their hardness and resistance to abrasive wear.
- **Application:**
 - a. brake shoes, shot blasting nozzles, mill liners, crushers, pump impellers and other abrasion resistant parts.
 - b. wear-resistant surface, example, as rollers in rolling mills. Generally, white iron is used as an intermediary in the production of yet another cast iron, **malleable iron**
- White fracture surface
- No graphite, because carbon forms Fe_3C or more complex carbides
- Abrasion resistant
- Often alloyed
- **Malleable cast iron**

Graphite nodules

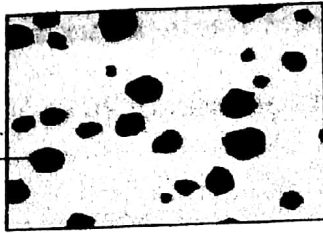


(c)

- a. formed by the heat treatment (in range of 900°C) of unalloyed 3%C white cast iron (carbon equivalent 2.5%C, 1.5%Si)
- b. the cementite dissociates into its component elements (graphite clumps, or nodules)
- c. It exhibits better ductility than gray or white cast irons. It is also very machinable.

• **The production steps**

Graphite spheroids
(nodules)

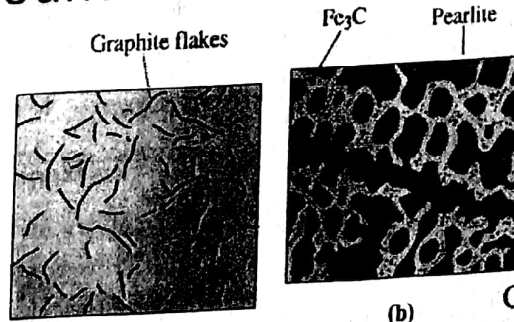


(d)

- contains spheroidal graphite particles.
- produced by treating liquid iron with a carbon equivalent of near 4.3% with magnesium
- Steps
 - **Desulfurization:** CaO is used to remove sulfure and oxygen from the liquid.
 - **Nodulizing:** Mg in dilute form (MgFeSi alloy) is added, a residual of 0.03%Mg must be present after treatment in order for spheroidal graphite to grow
- **inoculation:** heterogeneous nucleation of the graphite is essential
- **Fading:** occurs by the gradual, nonviolent loss of Mg due to vaporization and/or reaction with oxygen
- **Application:**
 - valves, pump bodies, crankshafts, high-strength gears (heavy duty gears) and machine, rollers, slides, die material having high strength and high ductility.

- Depending on chemical composition, cooling rate, types and amount of inoculants that are used we can have

- Gray iron
- White iron
- Malleable iron
- Ductile iron
- Compacted graphite iron

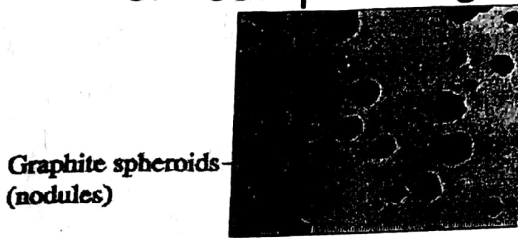


(a)

(b) Graphite nodules



(c)



(d)



Compacted (vermicular) graphite

Gray cast iron

- The least expensive and most common type
- Characterized by formation of graphite
- Typical composition ranges from 2.5-4.0% C, 1.0-3.0% Si, and 0.4-1.0% Mn.
- contains small, interconnected graphite flakes that cause low strength and ductility.
- It is the most widely used cast iron
- It is named for the dull gray color of the fractured surface.
- The gray irons are specified by a class number of 20 to 80.

Properties

- high compressive strength,
- good machinability,
- good resistance to sliding wear,
- good resistance to thermal fatigue,
- good thermal conductivity, and
- good vibration damping.

Gray CI

- **Application;**
 - Damping vibrational energy
 - Base structures for machines and heavy equipment
 - High resistance to wear.
 - High fluidity at casting temperature
 - Intricate shapes; Low casting shrinkage allowance.
 - (strength is not a primary consideration)
 - Tensile strength 120 – 300 MPa
 - Small cylinder blocks, cylinder heads, pistons, liners, clutch plates, transmission cases.
 - gears, flywheels, water pipes, engine cylinders, brake discs, Machinery beds

Heat Treatment for alloys

Heat treatment

"A combination of heating and cooling operation -s timed and applied to a metal or an alloy in the solid state to produce desired properties" is known as heat treatment

Effect of alloying elements on Fe-Fe₃C system

- Alloying elements have significant effect on the iron-iron carbide equilibrium diagram.
- The addition of some of these alloy elements will widen the temperature range through which austenite (γ -iron) is stable while other elements will constrict the temperature range.
- What this means is that some elements like will lower the critical temperature of steel.

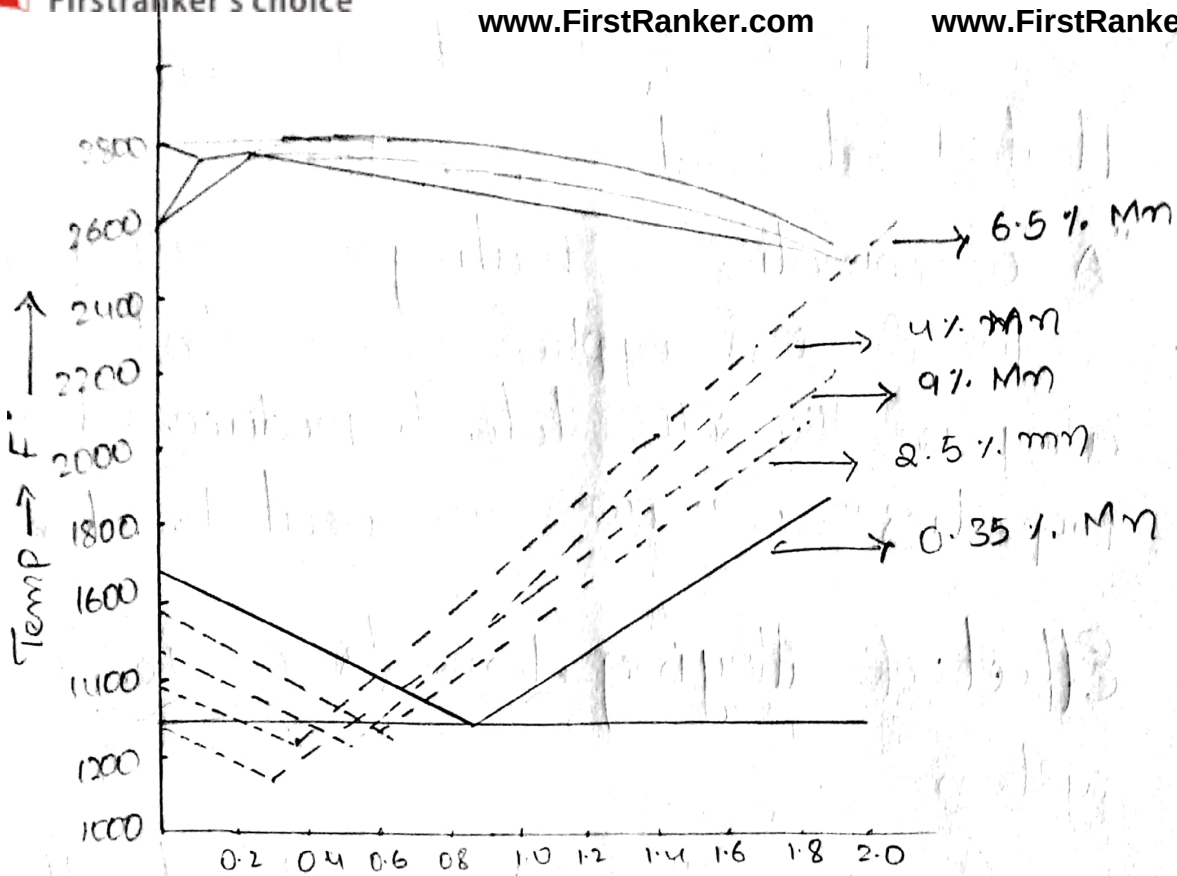


Figure (1)

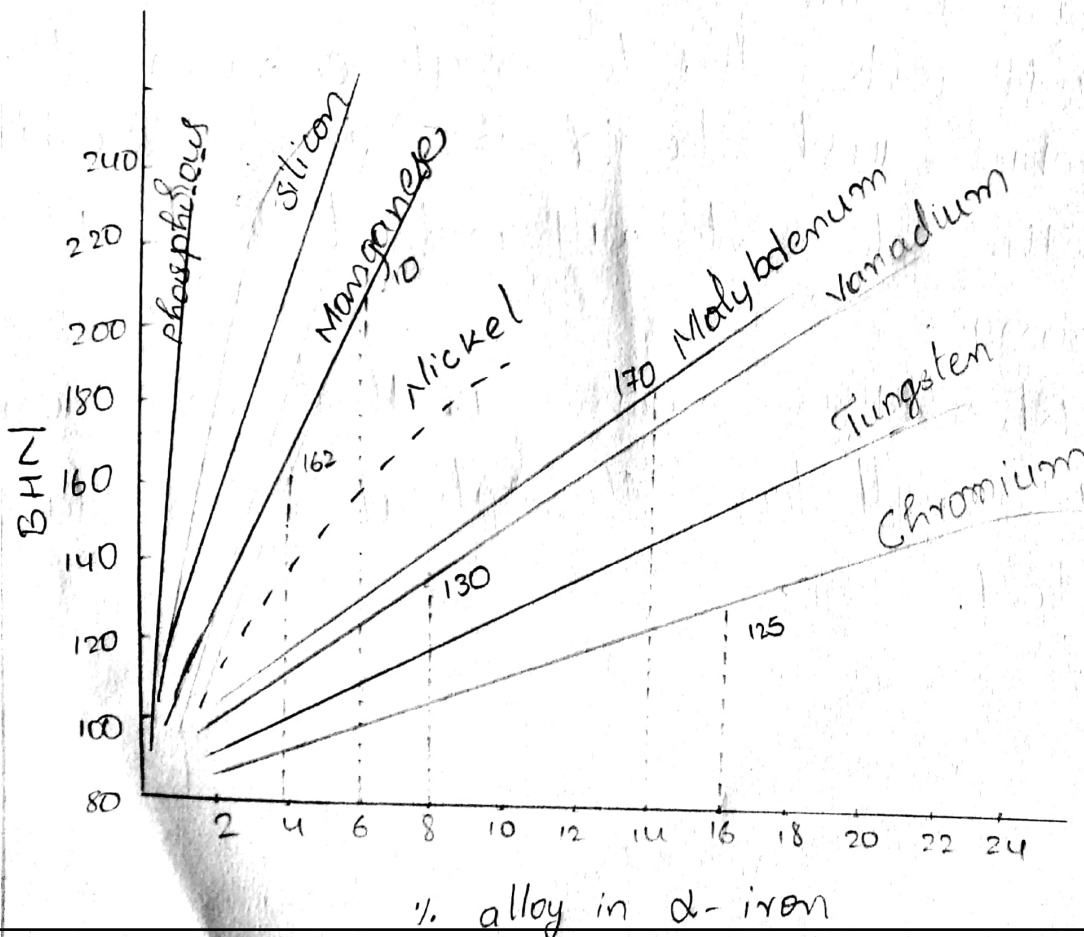


Figure (2)

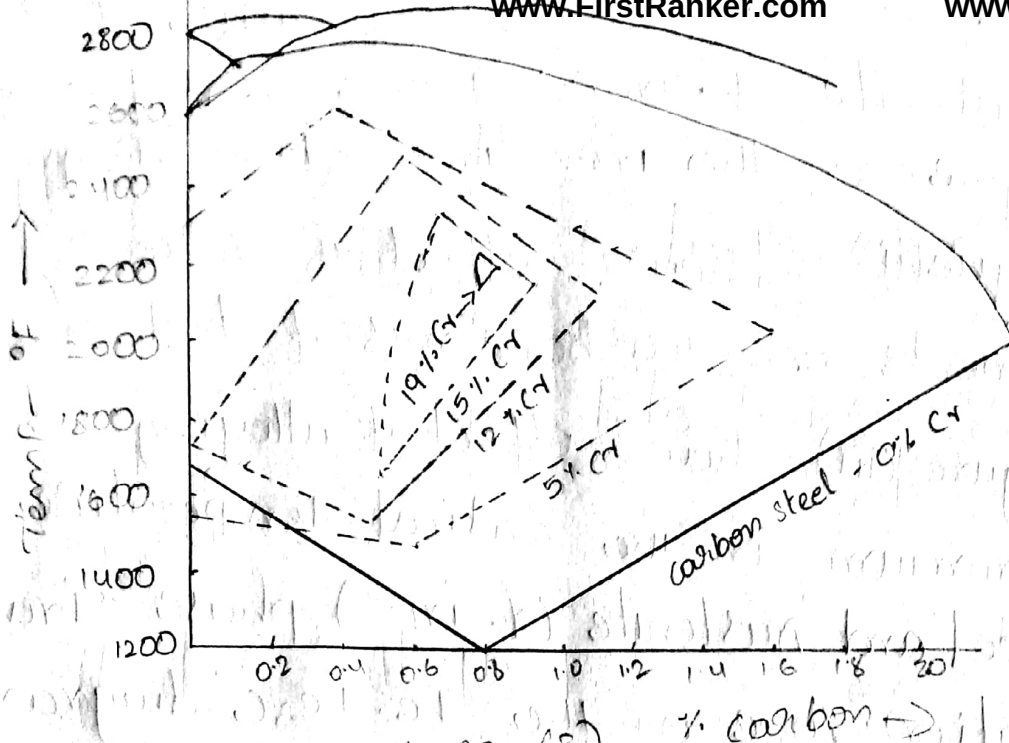


Figure (5) % carbon →

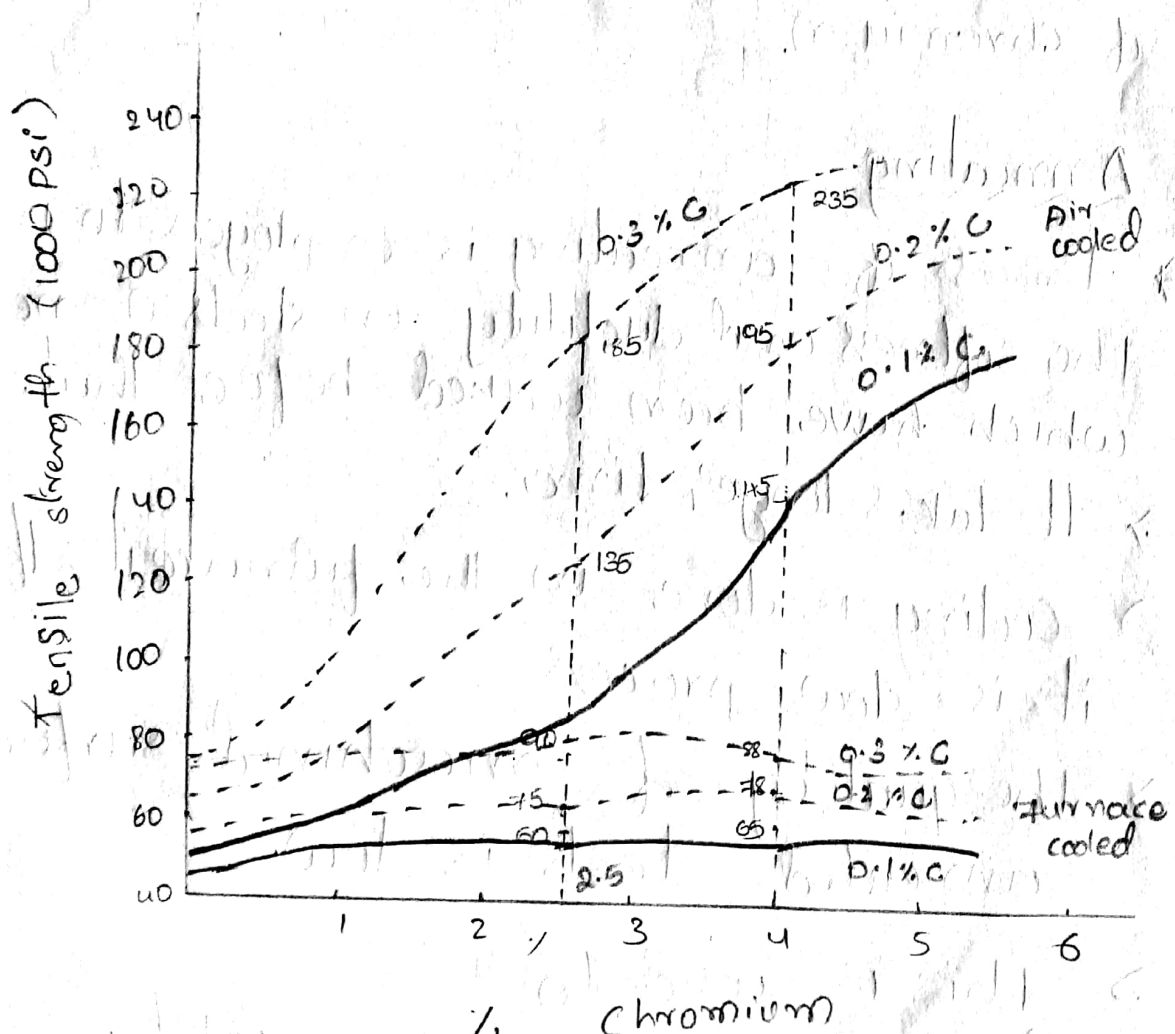


Figure (4)

the effect of alloying with manganese on the critical temperature of steel and Austenite (γ -iron) phase transformation zone on the iron-iron carbide diagram.

- Figure (ii) shows effect of various alloying elements on the hardness of steel.
- Figure (iii) shows effect of alloying with chromium on the critical temperature of steel and Austenite (γ -iron) phase transformation zone on the Fe-Fe₃C diagram.
- Figure (iv) shows effect of different % of carbon on the tensile strength of steel in the presence of chromium.

Annealing

- Process of annealing is employed to improve the softness and ductility on steels & metals which have been worked before that.
- It takes longer time.
- Cooling is done in the furnace itself, so it is slow process.
- The quality of machined surface of annealed steels is low.
- This is used to
 - (i) Improve machinability
 - (ii) Relieve internal stress caused by a

- Grain structure is coarse.
- Annealing treatment is more expensive than normalizing.
- Annealed steels are less harder than the normalized ones
- Improves machinability of medium carbon steels.

Normalizing

- Process of normalizing is employed to refine the grain structure of steels which has undergone cold or hot working.
- It does not take much time.
- Cooling is done in still air.
- The quality of machined surface of normalized steel is high.
- This is used to
 - (i) Improve machinability.
 - (ii) Release internal stresses caused by cold working in the previous phase
- Grain structure is finer.
- Compared to annealing it is a less expensive method of heat treatment.
- Normalized steels are harder than the annealed steels.

Steels.

Hardening

Hardening is divided into following types

Flame Hardening

1. In this method, the surface of the steel is heated by an oxyacetylene flame and then quenching it immediately in cold water.
2. Selective heating can be possible by this method.
3. Cost of the equipment is less
4. Requires skilled labour.
5. Maintenance cost is less.
6. Production of hardened zone less than 1/16 inch depth is difficult.
7. Possibility of overheating and damaging the part is more.

Induction hardening

1. In this method, steel component is placed in a coil and a high frequency current is passed through the coil, which induces eddy current in the

the surface layer, thus heating it to austenite state.

- Selective heating is not possible.
- Cost of the equipment is more
- High maintenance cost.
- Hardened zone less than $1/16$ inch depth can be easily produced.
- As the process is carried out automatically there is no chance of overheating and damaging of the parts.

Quench Hardening

- It is a heat treatment process in which steel is heat to austenite phase followed by rapid cooling in a liquid medium such as oil or water.
- It improves the hardness and wear resistance of the steel.
- Metal in heat $30-50^{\circ}\text{C}$ above upper critical temperature for hypo eutectoid steels $30-50^{\circ}\text{C}$ above lower critical temperature for hyper eutectoid.

1. It is a heat treatment process for non-ferrous alloys consisting of two stages i.e., solid solution treatment, and aging.

2. It improves the hardness and strength of the alloys.

3. This process is carried out at low temperature where precipitation rate is slow due to which ductility of alloys increases.

Tempering

→ Tempering is a heat treatment process that is carried out for hardened steels.

→ It is immediately process that is carried out for hardened steels. done after hardening so that the high internal stresses produced due to hardening are relieved.

→ It increases ductility of the steel and reduces hardness.

Tempering is classified into the following types. depending on the transformation behaviour:

(a) Low temperature tempering ($100-200^{\circ}\text{C}$)

(b) Medium temperature tempering ($200-500^{\circ}\text{C}$)

(c) High temperature tempering ($500-700^{\circ}\text{C}$)

Objectives

- (i) To relieve the metal from internal stresses produced during hardening.
- (ii) To ensure stable structure of the metal.
- (iii) To increase the ductility of the metal and reduce hardness.
- (iv) To increase toughness and shock-resistance of metal.

Hardenability

It is defined as ability of steel to develop its maximum hardness when subjected to normal hardening and quenching.

Jominy and Quench Hardenability test

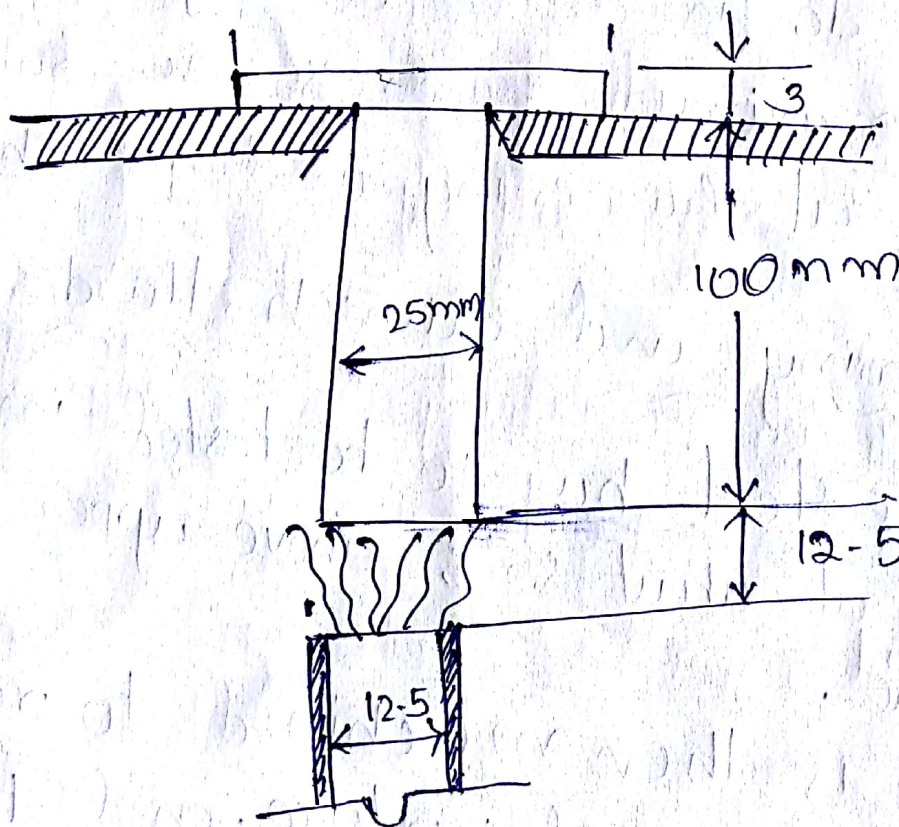
- The steel bar to be tested is first normalized at about 85°C above upper critical temperature.
- It is then machined to remove the de-carburized surface and to bring it to exactly 25 mm in diameter, then it is heated in non-oxidizing atmosphere 40°C above the upper critical temp.
- It is then transferred immediately to a

standardized critical temperatures

www.FirstRanker.com

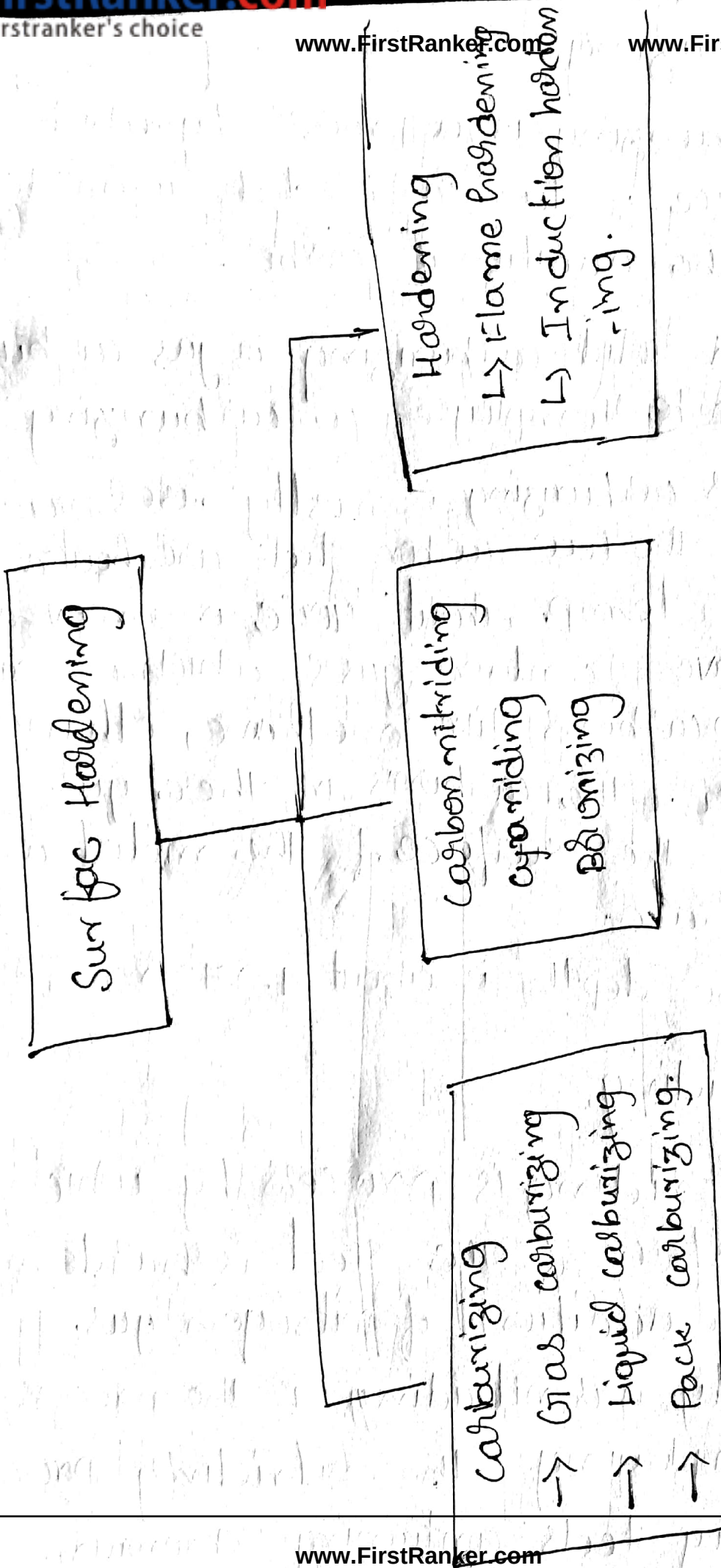
www.FirstRanker.com

- And it is quenched in such a manner that only one end of 100 mm long specimen comes in contact with a stream of water from a 12.5 mm diameter.
- The specimen cools rapidly at quenched end and progressively less rapidly towards the opposite end.
- Hardness determination are made on ground surfaces at intervals of 1.5 mm from the quenched end.



Jominy and Quench Test

Surface - Hardening Methods



→ Carburizing is a process by which the surface of low carbon steels is hardened by the addition of carbon.

→ Both solid carburizing & gas carburizing can be employed for carburizing process

→ Gas carburizing is mostly used now-a-days which the low carbon steels are heated to a proper temp. about 900°C in an oven. The oven contain gases which are rich in hydrocarbons like methane, ethanes and coal gas. The carbon's in these gases combine with the surface of the metal and make it hard.

→ Case depth is about 1.27 mm

Nitriding

→ Nitriding is process by which the surface of the steel is hardened by the addition of nitrogen gas.

→ Only gas nitriding is the process for employing the nitriding process.

→ Alloy steels containing chromium aluminium molybdenum and manganese are used in this process, which is done in an electrical furnace at a temperature of 500°C . The

process is carried out in the presence of ammonia gas. The gas separates as nascent nitrogen and reacts with steel's surface to form nitrides which are very hard.

4. Case depth is about 0.381 mm.

Age hardening Treatment

→ Age-hardening is the process of ~~heat~~ increasing strength and hardness of some metal alloys. This process has significant role among heat treatment processes employed for non ferrous alloys. It is also known as precipitation hardening.

→ The particles of the precipitate act as obstacles of dislocation movement for strengthening the heat-treated alloys.

→ Age hardening occurs only in alloys where decrease in solid solubility with decrease in temperature.

Cryogenic Treatment of alloys

→ In cryogenic treatment of the alloy is subjected to deep freezing temperature as low as -185°C (-301°F) but usually -75°C is sufficient.

→ It is done to eliminate retained austenite during quenching.

 **FirstRanker.com** FirstRanker's choice www.FirstRanker.com www.FirstRanker.com

At hardening temperature, the steel has a solid solution of carbon and iron.

→ During quenching, the amount of martensite formed depends on the lowest temperature encountered. At any given temperature of quenching, there is a certain amount of martensite and the balance is untransformed austenite.

→ This untransformed austenite is very brittle and can cause loss of strength, hardness, dimensional instability, cracking etc.

→ Most of the low carbon and medium carbon steel during quenching to room temperature transforms to 100% martensite.

→ But the high carbon and high alloys steels consists of retained austenite at room temperature.

→ In order to eliminate the retained austenite cryogenic treatment is carried out.

Non Ferrous Metals and alloys

Copper (Cu)

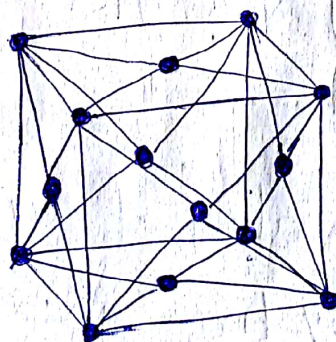
- Copper is a chemical element with symbol "Cu"
- It's atomic number is 29
- It is a soft malleable; and ductile metal with very high thermal and electrical conductivity.
- It has a melting point 1085°C

Alloys of copper

- 1) Bronze
- 2) Brass

Structure of copper

- Copper has Face centered cubic structure. (FCC)



FCC structure

- copper and its alloy have a range of yellow to red/gold colour and when polished develop a bright metallic lustre.

- A freshly exposed surface of a pure copper has

Properties of copper

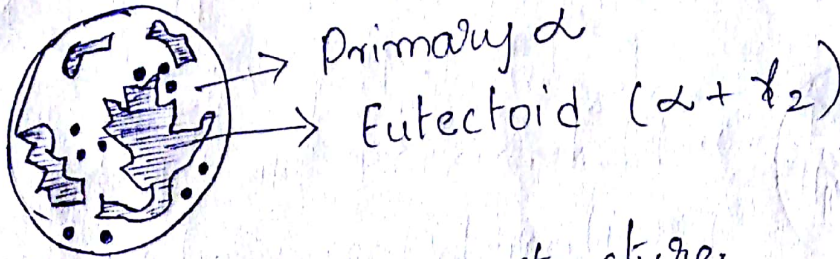
- Copper has good ductility and malleability because of its FCC structure.
- It has good electrical and thermal conductivity.
- It is non magnetic and has pleasing reddish colour.
- It has an ability of getting alloyed with many other metals which helps in improving its properties.
- It has a fairly good corrosion resistance to general atmospheric conditions.
- It has melting point of 1085°C and boiling point of 2562°C .
- It has density 8.96 g/cm^3 .

1) Bronze

- Bronze is an alloy of copper.
- Copper with 12% tin gives bronze.

Bronze is classified into different types

- 1) Aluminium bronze
- 2) Tin bronze.
- 3) Phosphor. bronze.
- 4) Beryllium Bronze.
- 5) Manganese bronze.



eg: Aluminium bronze structure

- Aluminium bronzes are the alloys of copper and aluminium.
- Here aluminium is the alloy element in the copper base.
- The maximum solubility of Al in Cu is 9.4%.
- Eutectoid transformation occurs at 11.8% Al.
- Certain properties of bronze can be improved by adding elements like Fe, Ni, Mn and Si.
- In general aluminium bronze has 4-11% aluminium.

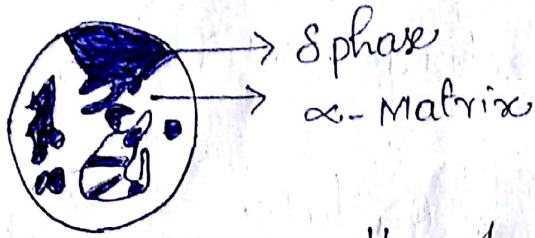
Properties

1. Good strength
2. Good heat resistance
3. High corrosion resistance
4. Good cold working properties etc..

Applications

used in making of bearing, gears, slide valves, pump parts, cams, valves seats etc..

Structure



→ Tin bronze is the alloy of copper and tin.
 → Solubility of tin in copper is 13-5% at 798°C and 15.8% at 586°C remains constant at 520°C and 11% at 350°C and 1% at room temperature.
 → There are different bronzes based on the tin content.
 They are

- i) Alloys upto 8% tin
- ii) Alloys upto between 8-12% tin
- iii) Alloys between 12-20% tin
- iv) Alloys between 20-25% tin

Properties

1. Good affinity toward oxygen.
2. Oxide layer on solidified metal reduces ductility, so they are mechanically weak and porous.
3. Single phase α solid solution has good ductility and malleability.

Applications

1. Used to form sheets & wires & coins
2. Used for bearings, pumps, heavy load bearings, gears, marine fittings.
3. Alloys with (20-25% tin) are used for making bells hence called bell metal.

These are the alloy of copper and tin containing phosphorus.

Phosphorous bronze is divided into two types

1) Wrought Phosphorous Bronze.

→ It has 2.5 to 8% tin and 0.1 to 0.35% phosphorous

→ These are single phase α solid solutions.

2) Cast phosphorous Bronze

→ It contains 5-13% tin and 0.3-1% phosphorous

→ As ph increases the fluidity of metal increases and hence general soundness of casting.

→ The formation of Cu_3P compound makes casting more brittle and makes it unsuitable. Therefore the ph content should not exceed 1%.

Properties

1. It has high strength and toughness
2. It is resistance to corrosion.
3. It has low friction co-efficient
4. It has good load bearing capacity.

Application

1. used in making gears, bellows, clutch discs, pump parts, lining, springs, diaphragms etc.
2. used in bearing which is used as a self lubricant.

Beryllium Bronzes

- These are produced by in cast and wrought forms
- As temp $\uparrow$ solubility of beryllium $\downarrow$.
- Alloy is heated at around 800°C and quenched in water and then heated at $300-320^{\circ}\text{C}$ for 2 hours. This is called precipitation or aging treatment.



γ - phase

Structure of beryllium Bronze.

- It has nominal 1.92% beryllium and 0.20-0.30% cobalt.

Properties

1. Good corrosion resistance
2. Good fatigue resistance
3. Has low elastic hysteresis and non-sparking characteristics.
4. High resilience.
5. Good bearing properties.
6. 2% beryllium content alloy have 130-140 kg/mm² tensile strength and 350 BHN hardness.

Applications

1. used for gears, bearings, flexible bellows, diaphragms, springs and some tools.
2. used as moulds for forming plastics.
3. used in electrical contacts.

3) Manganese bronze

→ Manganese bronze contains a composition of copper, zinc, lead and small amounts of manganese.

Properties

- Manganese bronze is stronger and harder.
- It has excellent corrosion resistance.

Applications

- It is used in manufacturing of bushes, rods, feed pumps, plungers, worm gears etc.

2) Brass

- It is also alloy of copper.
- Copper with zinc makes out brass.

Brass is classified into two types

- 1) α - brasses (cold working)
- 2) $(\alpha + \beta)$ brasses (hot working)

1) α - brasses

→ They are soft, ductile, malleable and have fairly good corrosion resistance in annealed condition. All the α - brasses are suitable for cold rolling, wire drawing, press work, and such other operations.

Some important α - brasses are as follows

It contains zinc between 2 to 5%. Zinc is used as a deoxidiser for the deoxidation of copper.

Applications

→ It is used for caps for detonators in ammunition factories.

Properties

→ It is very ductile

ii) Gilding metals

→ They contain zinc 5 to 15%.

→ They have different shades of colour from reddish to yellowish according to zinc content.

Applications

→ They are used for bullet envelopes, drawn container, condenser tubes, coins, needles, emblems, dress jewelry because of colour like gold.

iii) Cartridge brass

→ It contains about 30% zinc.

→ It is also known as 70-30 brass



Structure of cartridge brass

Properties

→ It has maximum ductility and malleability

Applications

→ It is used for forming by deep drawing, stretching, trimming, spinning and press work operations

→ It is used for cartridge cases, radiator fins, lamp fixtures, rivets and springs.

→ It contains about 30% zinc and 1% tin

Properties

→ It has good corrosion resistance.

Applications

→ It is used for condenser tubes and heat exchangers in steam power plants.

→ A typical brass admiralty brass contains about 22% Zn, 2% Al and 0.04% As and is widely used for marine application.

2) α - β Brasses

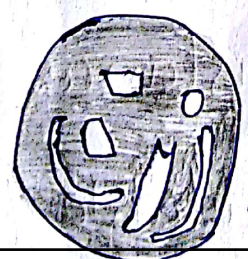
→ Commercial α - β brasses contain zinc between 32-40%. They are hard and strong when compared to α -brasses and are fabricated by hot working processes.

α - β Brasses classified as follows:

i) Muntz metal

→ It contains copper of 60% and zinc - 40%.

→ It is also known as 60-40 brass (S1) yellow brass.



Structure of Muntz metal

1. Muntz metal have good machinability
2. It has high strength and excellent hot working properties.
3. Tensile strength is 480 ~~N/mm²~~ Mpa
4. Elongation upto 50 % for cast and 40 % for hot rolled.

ii) Leaded brass

→ It contains Cu-62.5% Zn-36% Pb-1.5%.

Properties

- It possess good machinability and resistance to corrosion.
- It has low ductility and impact values.

Applications

- used in making of plates, keys, clock parts etc. --
- It is used in automotive parts such as gears, valve parts etc. --

iii) Naval brass

→ It contains Cu-60% Zn-39% Sn-1%.

→ It has

Properties

- It has good resistance to corrosion.
- It is more suitable for hot rolled forging and castings.

→ used for structural applications and forgings.

→ Making of valve stems, propeller shafts, pump impellers etc. ---

iv) High Tensile brass

→ Alloy elements such as Al, Fe, Mn, Sn and Ni are frequently added to 60-40 brass to increase its tensile strength. Brasses containing one or more of the above elements are called high tensile brasses.

Properties

→ It has good resistance to sea water corrosion

→ It has tensile strength 40 to 55 kg/mm² and elongation between 20 to 30%.

Applications

→ It is widely used for marine engine pumps, ships propellers, gears, valve bodies and other applications.

Brazing brass

→ It contains zinc about 50%.

→ It is known as 50-50 brass.

Properties

→ It is brittle due to the presence of β phase

Applications

→ Has no application due to brittle nature.

(AL)

→ Aluminium is a chemical element with symbol "Al" and atomic number 13.

→ It is a silvery white, soft, non magnetic, ductile metal in the boron group.

→ It has FCC structure and ductile & malleable

Properties of aluminium

→ It has melting point 660°C and boiling point 2470°C

→ It has density of 2.70 g/cm^3

→ It has very good thermal and electrical conductivity

→ It has good corrosion resistance.

→ It has high strength to weight ratio

→ It has high specific strength, good formability and high reflectivity.

→ It is very ductile and non-magnetic.

→ It is light weight (specific gravity - 2.7 gm/cm^3)

Applications of Aluminium

→ It used for making of cooking utensils, combs, collar buttons, toasters, mixers, electrical conductors, food containers, paint, name plates, ashtrays, flower pots, coins etc.

LM Series for Cast Aluminium Alloys

Composition, per cent.

Sr. No.	Trade name	Si	Cu	Mg	Mn	Others	
						Zn	3.0
1	LM-1	3.0	7.0	—	—	—	—
2	LM-2	10.0	2.0	—	—	—	—
3	LM-4	5.0	3.0	—	0.5	—	—
4	LM-4	5.0	3.0	—	0.5	Fe Ti	0.8 0.2
5	LM-5	—	—	5.0	0.5	—	—
6	LM-6	11.5	—	—	—	—	—
7	LM-8	5.5	—	0.6	0.5	Ti	0.15
8	LM-9	11.5	—	0.4	0.5	—	—
9	LM-10	—	—	10.5	—	Ti	0.2
10	LM-11	—	4.5	—	—	Ti	0.15
11	LM-12	—	10.0	0.25	—	—	—
12	LM-13	12.0	0.9	1.2	—	Ni	2.5
13	LM-14	0.3	4.0	1.5	—	Ni Ti	2.0 0.2
14	LM-16	5.0	1.2	0.5	—	Ni	0.3
15	LM-17	11.5	—	—	—	Ni	3.0
16	LM-18	5.0	—	—	—	—	—
17	LM-23	2.5	1.8	0.2	—	Ni Fe Ti	1.2 1.0 0.2
18	LM-24	8.5	3.5	—	—	—	—
19	LM-25	7.0	—	0.3	—	—	—

It is used in transportation industry in the manufacture of bicycles, motor vehicles and buses, aeroplanes and marine vessels.

Alloys of Aluminium

- For engineering applications, large number of alloys have been developed for satisfying the specific service requirements.
- The most common alloying elements are Cu, Mg, Zn, Mn, Si, Ni, Fe and Ti.
- Strengthening of some of the alloys can be done by such processes as work hardening and precipitation hardening or both. The various Aluminium alloys are designated by LM series (BS 1490/1949). The detailed list of LM alloys is given in table

i) Aluminium - silicon alloys:

Structure



- (a) LM-6 (Si - 11.5%)
- (b) LM-8 (Si - 5.5%)
- (c) LM-9 (Si - 11.5%, Mg - 0.4%)

structure



(a) LM-1 (Cu - 7% , Si - 3%)

(b) LM-2 (Cu - 2% , Si - 10%)

(c) LM-4 (Cu - 3% , Si - 5%)

iii) Aluminium - magnesium Alloys

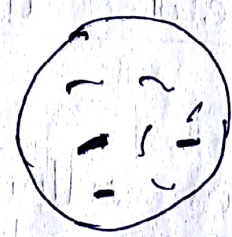
(a) LM-13 (Mg - 1.2% , Si - 12% , Cu - 0.9%)

(b) LM-14 (Mg - 1.5% , Si - 0.3% , Cu - 4%)

(c) LM-10 (Mg - 10.5%)

(d) LM-25 (Mg - 0.3% , Si - 11%) etc ..

structure



iv) Duraluminium

structure



→ It contains Al - 94% , Cu = 3.5 to 4.5% , Fe - 0.5% , Si - 0.5% , Mg - 0.4 to 0.7% , Mn = 0.5%

Properties

→ Tensile strength is high (400 MPa)

→ Hardness is 56-95 BHN

It can be easily forged and stamped.
It has high electrical conductivity;

v) γ-alloy

→ It is composition of AL-92.5% ; Cu-4% ; Ni-2%
Mg = 1.5 %.

Properties

- It is strengthened at 200°C
- At elevated temperatures, it retains high strength and hardness.
- It is easy to cast and hot working process.

Applications

- It is used for components such as piston heads, cylinder heads and crank case of I.C engines.
- It is also used for die castings, pump rods and in sparking chisels.

ii) Magnelium

→ It is composition of AL-85% to 95% ; Cu-0% to 25%
Mg - 1% to 5.5% ; Ni - 0% to 1.2% ; Sn - 0% to 3%
Fe - 0% to 0.4% ; Mn - 0% to 0.03% ; Si - 0.2% to 0.6 %

Properties

- It possess high tensile strength, machinability and less weight.
- This alloy can be welded and elongated.

Applications

- It used in aircrafts and automobiles

industrial to manufacture components like gear box housing, luggage racks, ornamental fixtures, handles of door etc --

vii) Hinduminium - RR 350

→ It contains about 5% Cu and 1.5% Ni with small amounts of Mn, Ti, Sb, Co and Zr.

→ It is so

Properties

→ It is superior to V-alloy at elevated temperature service particularly in respect of creep resistance.

Applications

→ It is used in Aero engines and other continuous elevated temperature service applications upto 300°C.

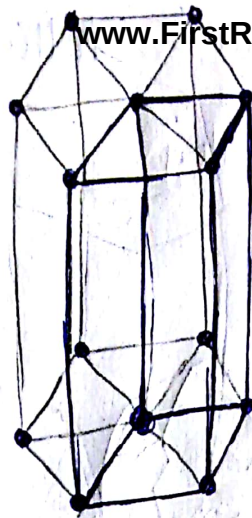
TITANIUM

→ Titanium is a chemical element with symbol "Ti" and atomic number 22.

→ It is a lustrous transition metal with a silver colour, low density and high strength.

→ It has hexagonal close-packed structure (hcp)





HCP structure

Properties of Titanium

- It has melting point of 1668°C and Boiling point of 3287°C
- It has low density 4.506 g/cm^3
- It has high strength
- It has excellent corrosion resistance upto 1000°F
- It the 4th abundant element in the earth's crust
- It is expensive to obtain it from its ores.

Application of Titanium

- Because of excellent strength to weight ratio it is widely used in our crafts.
- It is also used in armor plating, naval ships, spacecraft and missiles.

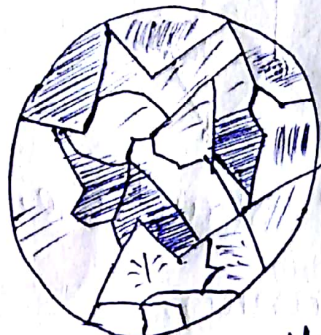
Titanium alloys exist in three different forms

They are

- 1) α - Titanium alloys
- 2) α - β - Titanium alloys
- 3) β - Titanium alloys.

1) α -Titanium Alloys

Structure



→ It is composed fully an α -phase of 92-5% titanium and 5% aluminium and the remaining 2-5% constitutes of tin.

→ Aluminium and tin are α -stabilizers

Properties

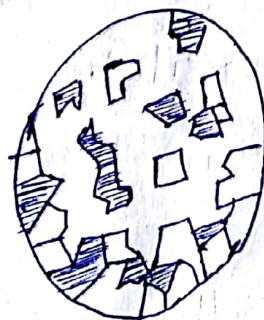
→ These alloys have the properties of weldability and are strong and can retain their strengths at high temperatures also.

Applications

→ These alloys are used for steam turbines.

2) α - β Titanium Alloys

Structure



→ These alloys are composed of sufficient amount of β -stabilizing elements. The alloys of this type

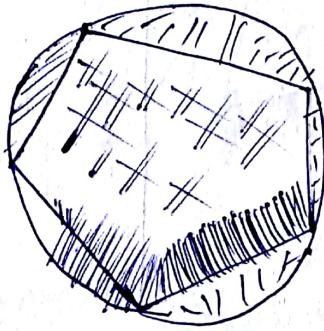
have 90% titanium, 6% aluminium and the remaining 4% is vanadium. The α stabilizer is due aluminium and β -stabilizer is due to vanadium. (10)

Properties

- The α - β alloys can be increased in strength by heat treatment- quenching.
- This can also be welded, forged and machined.

β -Titanium Alloys

Structure



- These alloys are composed sufficient amount of β -stabilizers elements. The structures can be made entirely β at room temperature.
- This is the composition for this alloy is 77% titanium, 13% vanadium, 11% chromium and remaining 3% is aluminium.

Properties

- These β -alloys are readily cold worked in solution treated, quenched conditions to give very high strength.

- It have low ductility.

CERAMIC AND COMPOSITE MATERIALS

Ceramics

The inorganic compounds of metallic and non-metallic elements which are bonded together by either ionic & covalent bond are called as ceramics.

Based on application, ceramics are two types

1. Traditional ceramics materials
2. Engineering ceramics materials.

Traditional ceramics materials

- Traditional ceramic materials are generally clay products, cement and silicate glasses.
- The pottery from clay are produced by forming and burning the clay. This is the oldest and earliest process used in preparing ceramic materials.
- The porcelain enamels and clay products like brick, tile and other similar product are also included in type.
- The most distinct and important of all ceramic material is the refractories used in industries like fire clay products and heavy refractories like

Engineering Ceramic Materials

- Engineering ceramic materials & advanced ceramics are the inorganic, highly engineered, high performance and value added objects with unique and superior qualities.
- These ceramics are developed for the properties such as high temperature resistance, greater chemical resistivity, superior electrical and mechanical properties etc...
- Some of the new engineering ceramics used in the industry are pure oxide ceramics, nuclear fuels based on O_2 , electro-optic ceramics, magnetic ceramics, ceramic nitrides, metal-ceramic.

Properties of ceramics

- Ceramics are hard and brittle
- They do not have elongation & reduction in area.
- They cannot be plastically moulded.
- They have excellent compressive strength
- They have highest hardness of engineering materials.

→ They have good chemical resistance.

→ They have less thermal expansion.

Applications

→ Ceramic kilns, electrolytic cells for production of aluminium.

→ used in furnaces.

→ used in making of building bricks, roofing tiles, stoneware, etc.....

Glasses

Glasses are defined as the transparent silica products, which can be either amorphous or crystalline depending upon the heat treatment.

Properties

→ Glasses are resistant to devitrification.

→ They are available in clear and clear state.

→ They are easily fusible at comparatively low temperatures.

→ They are resistant to water.

Proper

Application:

1. Window glass.

2. Bottles,

4. Plate glass.

5. Cheaper table ware etc..

Ceramics

Glasses are following types

1. Pyrex glass

2. Alumina silicate glass.

Pyrex Glass (Heat Resistant Glass)

The trade name used for Borosilicate glass is pyrex glass.

Composition

Composition by weight

silica - 80 parts.

Boron oxide - 14 parts

Sodium - 4 parts.

Alumina - 2 parts.

Some trace of potassium oxide, calcium oxide and magnesium oxide are also added.

Properties

→ Good chemical durability for resistance to heat and thermal shocks.

→ It possess good corrosion resistance and high light transmission

Applications

→ This is used in

- i) Gauges and measuring instruments.
- ii) Mirrors of telescope.
- iii) Electronic tubes.
- iv) Laboratory equipments.
- v) Piping seals and pump impellers.

Alumina silicate Glass

Composition

Alumina - 57%

Aluminium oxide - 20%

Sodium oxide - 1%

Calcium oxide - 5.5%

Boron oxide - 4%

Magnesium - 12%

Properties

→ They have high strength and greater thermal shock resistance.

→ Excellent resistance to corrosion from weathering, water and chemicals.

→ This type of glass can be easily worked on economical (i.e., lower investment).

Applications

- i) Manufacturing of glass fibres.
- ii) Higher performance powder tubes
- iii) Stove top cookware.
- iv) High temp. thermometers.

Cermets

A cermet is a composite material composed of ceramic (cer) and metallic (met) materials. A cermet is ideally designed to have optimal properties of both ceramic and metal.

Properties of cermets.

1. High strength and hardness.
2. Resistance to high temp.
3. Corrosion resistant
4. Better wear resistant.

Application of cermets

→ Cermets are used as cutting and drilling tools in machine tools.

→ They are used in resistors, capacitors, and vacuum tubes (valves).

They are also used in light weight protective coating on clothes.

Abrasive materials

- Abrasives are generally made from ceramic materials.
- These are hard and mechanically resistant materials.
- These are generally used for grinding or cutting.
- Softer materials can also be worn off by an abrasive.

Properties

- Abrasives are hard materials.
- They possess great uniform hardness.
- They can wear off softer materials.

Applications

1. Brick and concrete saws
2. Wire drawing dies
3. Used in sand paper.
4. Used for wood finishing
5. Cleaning of aircraft engine parts.
6. Used for grinding precious metals, brass and aluminium.

Nanomaterials describe in principle materials of which a single unit is sized between 1 and 1000 nanometers (10^{-9} meter) but is usually 1 - 100 nm

Properties

- Nano materials are electro^{con}ductive/anti static.
- They are antimicrobial
- Self-cleaning / Dirt free
- They have fire resistance, UV protection
- They have insulation / thermal conduct^{ion}
- They are moisture absorbents.
- They are ultra hard and light weight material.

Applications

- Next generation computer chips
- Machinable ceramics.
- Better insulation materials
- Kinetic energy penetrators with enhanced lethality.

- Tougher and harder cutting tools.
- High power magnets.
- High energy density batteries.
- Low cost flat panel display.
- phosphorous for high definition TV.
- Aerospace material etc.