UNIT I ALLOYS AND PHASE DIAGRAMS

Constitution of alloys:-

Alloy:- combination of 2 or more elements of which atleast one is a metal

* exhibits metallic properties

* Eg: steels, Cast Irons, Brass, Bronze, etc.

Steel - Fe + C + Si + Mn + P etc.

$$\underset{\text{Main element}}{Fe} + \underset{\text{Alloying element}}{C}$$

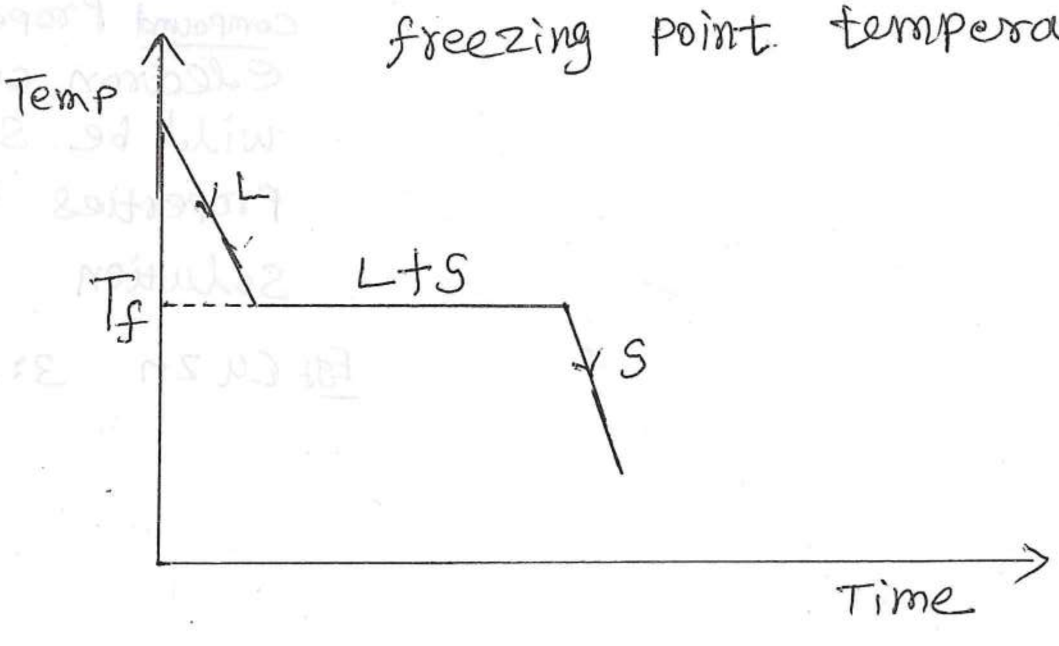
Brass — Cu + Zn

Bronze - Cu + Sn

Phase: Physically distinct, Chemically homogeneous and mechanically separable mixture.

* Pure metals → Allotropic - Phase is describe & interms of crystal structure

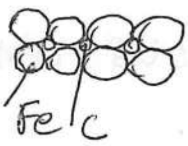
pure metal - definite melting point or freezing point temperatures



Compound:- Generally like metals exhibit definite melting or freezing point temperature

compounds

- Intermetallic compound or valence compound
  - metalic properties
  - complex crystal structures
  - Poor ductility
  - Poor electrical conductivity properties
  - Eg: Mg-Pb, Mg-Sn
- Interstitical compound
  - moving between the spaces
  - Eg: Fe, W, Ti with smaller elements like H, C, B, N, etc



  - Resultant structure becomes rigid
- Electron Compound
  - Hume Rothery

Definite valence atoms to the no. of atoms

Phase diagrams like Cu, Ag, Au, Fe etc.

Eg: Ag Zn
1 2

Total No of valence electrons 3

No. of atoms 2

Ratio is 3:2

Electron compound Properies of electron compound will be same as properties of solid solution

Eg: Cu Zn 3:2

Solid Solution:-

Solution = Solute + Solvent

Two solid atoms are combined in a same crystal lattice. α-Ferrite, γ-Austenite, δ-Ferrite
<727°C 727°C – 1395°C 1395°C – 1539°C

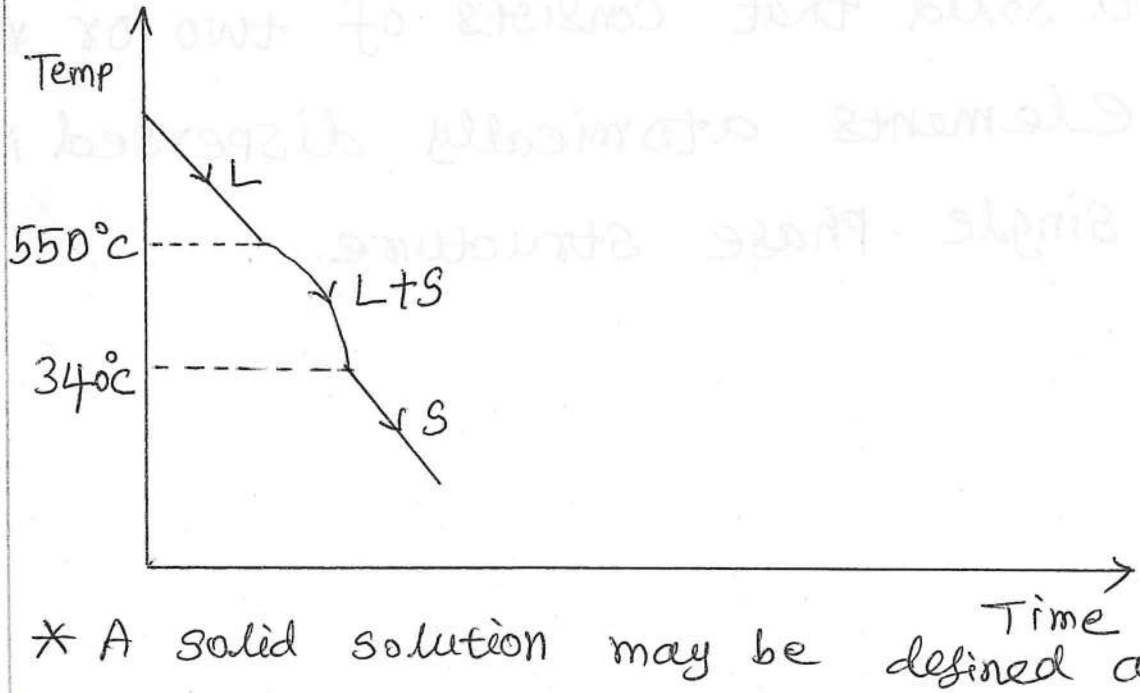
Cooling curve:-

* Freezes over a range of temperature.

Eg:- 50% Sb (antimony) – 50% Bi alloy

melting point temp of Sb = 632°C

melting point temp of Bi = 271°C



* A solid solution may be defined as a solid that consists of two or more elements atomically dispersed in a single phase structure.

* A solid solution is composed of two parts

① Solute
② Solvent

Solid solutions:-

A solid solution is the simplest type of alloy.

A solution can be defined as a homogeneous mixture in which the atoms or molecules of one substance are dispersed at random into another substance

A solid solution may be defined as a solid that consists of two or more elements atomically dispersed in a single-phase structure.

Solute:- A solute is the minor part of the solution or the material which is dissolved

Solvent:- A solvent is the major portion of the solution.

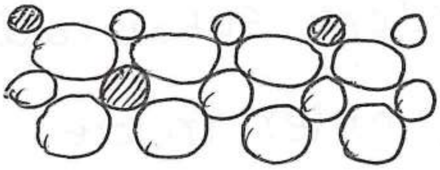
*Both the solute and the solvent can be solid, liquid or gas.

Types of solid solutions

1. substitutional solid solution
   (a) Random
   (b) ordered
2. Interstitial solid solution

1. Substitutional solid solution

* when the solute atoms substitute for parent solvent atoms in a crystal lattice they are called substitutional atoms and the mixture of the two elements is called a substitutional solid solution.



○ Ni (solvent atom)
▨ Cu (solute atom)

A Cu-Ni system is shown in figure as an example for a substitutional solid solution. These two elements are completely soluble in one another at all proportions.

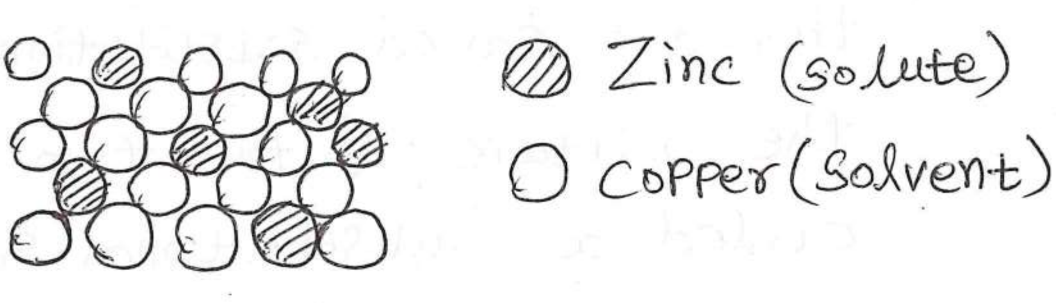
(i) The atomic radii for Cu and Ni are 1.28 Å and 1.25 Å respectively

(ii) Both the Cu and Ni have the FCC crystal structure

(iii) The most common valencies are +1 for Cu and +2 for Ni

(iv) The electronegativities of Cu and Ni are 1.9 and 1.8 respectively

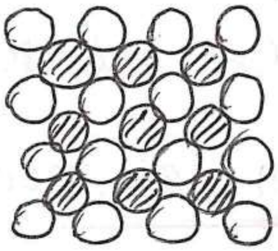
(a) Random (or) Disordered substitutional solid solution



In random substitutional solid solution there is no order in the substitution of the two elements; the solute and solvent atoms are randomly distributed.

In the formation of a substitutional solid solution the solute atoms do not occupy any specific position but are distributed at random in lattice structure of the solvent. This alloy is said to be in a random (or) disordered condition.

(b) ordered substitutional solid solution

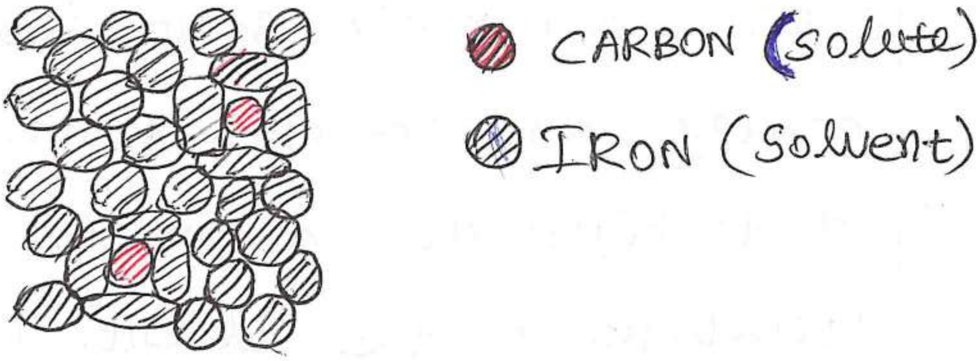


If the solute and solvent atoms takeup some preferred position, then the solution is called ordered substitutional solid solution or super lattice

Diffusion tends to produce uniform distribution of solute and solvent atoms. Thus the solute atoms move into definite orderly positions in the lattice.

Examples are Au-Cu and Cu_2MnAl have ordered crystal structure.

2. Interstitial Solid Solution



In Interstitial Solid solution, the solute atoms fit into the space between the solvent or parent atoms. These spaces or voids are called interstices.

Interstitial solid solution can form only when one atom is much larger than another.

The atoms which have atomic radii less than 1Å are likely to form an interstitial solid solution. such atoms are hydrogen (0.46Å Carbon (0.77Å), nitrogen (0.71Å) and oxygen (0.6Å

Like substitutional solid solutions Interstitial solid solutions also depend on size, valency and electronegativity factors. But they do not depend on the type of crystal structure.

Phase diagrams

* Phase diagrams are graphical representations of what Phases are present in a materials system at various temperatures, Pressures and compositions.

* In other words, a phase diagram is a map showing the structures or Phases present as the temperature and overall compositions of the material are varied.
* Phase diagram are also known as equilibrium diagram or constitutional diagram.

Terminology used in Phase diagram

1. component

components are pure metals and compounds of which an alloy is composed.

Example: Brass is the components of Cu and Zinc

2. System

System may refer to a specific body of material under consideration

Example: A laddle of molten steel is referred as a system

system may also refer to the series of possible alloys consisting of the same components.

Example: Iron - Carbon system

A system having one component is called a unary system and the systems having two, three and four components are Known as binary, ternary and quaternary systems respectively.

3. Alloy

An alloy is a mixture of two or more metals or a metal and a non metal

4. Solid solution

It is a solid that consists of two or more elements atomically dispersed in a single phase structure.

5. Solute

It is the minor part of the solution or the material which is dissolved.

6. Solvent

The material which contributes the major portion of the solution.

7. Phase: A phase may be defined as a homogeneous portion of a system that has uniform physical and chemical characteristics.

8. Equilibrium

Equilibrium is said to exist when enough time is allowed for all Possible reactions to be completed.

The equilibrium State refers to the characteristics of the system that remain constant indefinitely.

9. Solubility limit

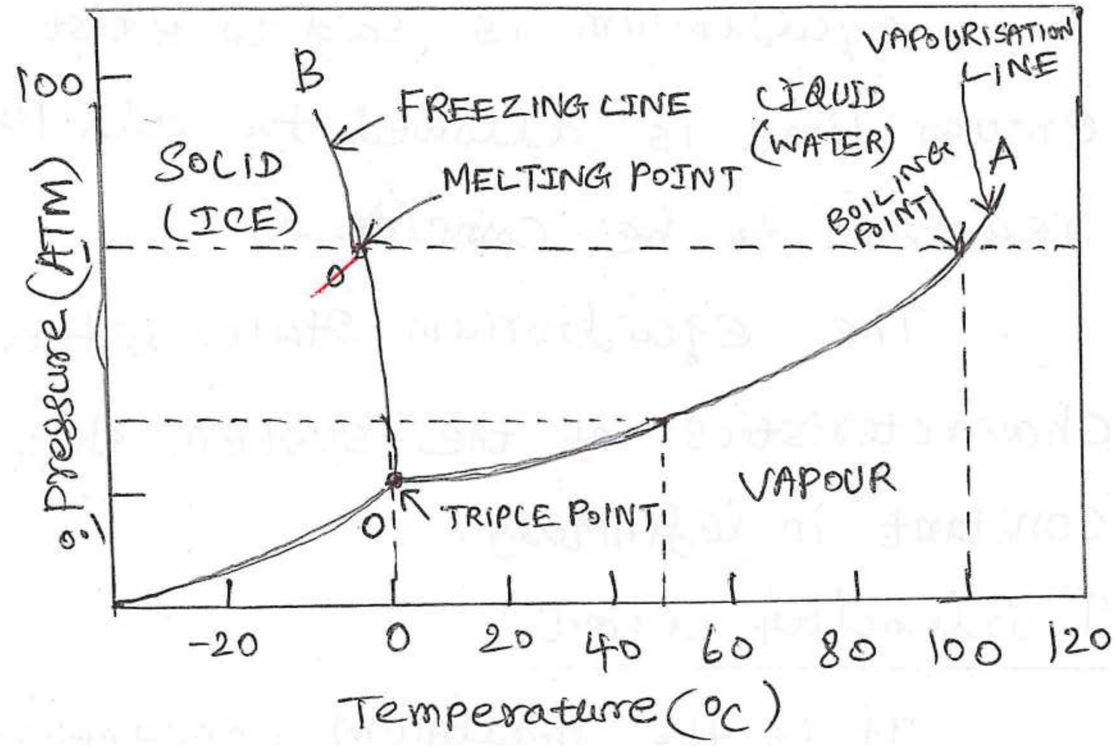
It is the maximum concentration of solute that may be added without forming a new Phase.

The addition of solution in excess of the solubility limit results in the formation of another Solid Solution.

10. Degrees of freedom

It is the number of independent variables that can be changed independently without changing the Phase or Phases of the system

Phase diagram of Pure Substance



A pure substance such as water can exist in solid, liquid or vapour phases depending on the conditions of temperature and pressure. The phase relationships may be represented on a pressure - temperatare diagram. It is known as unary phase diagram for the H_2O system.

The phase diagram is composed of regions of pressure and temperature when only a single phase is stable.

The line OA indicates the vapourisation line and the line OB indicates the freezing line.

Liquid and vapour phases exist along the vapourisation line and Liquid and Solid phases along the freezing line as shown in figure. These lines are also known as two-phase equilibrium lines.

The point O is known as a triple point. Triple point is the point at which three phases of a single material coexist.

Gibbs phase rule

The number of phases present in any alloy depends upon the number of elements of which the alloy is composed.

$$F = C - P + 2$$

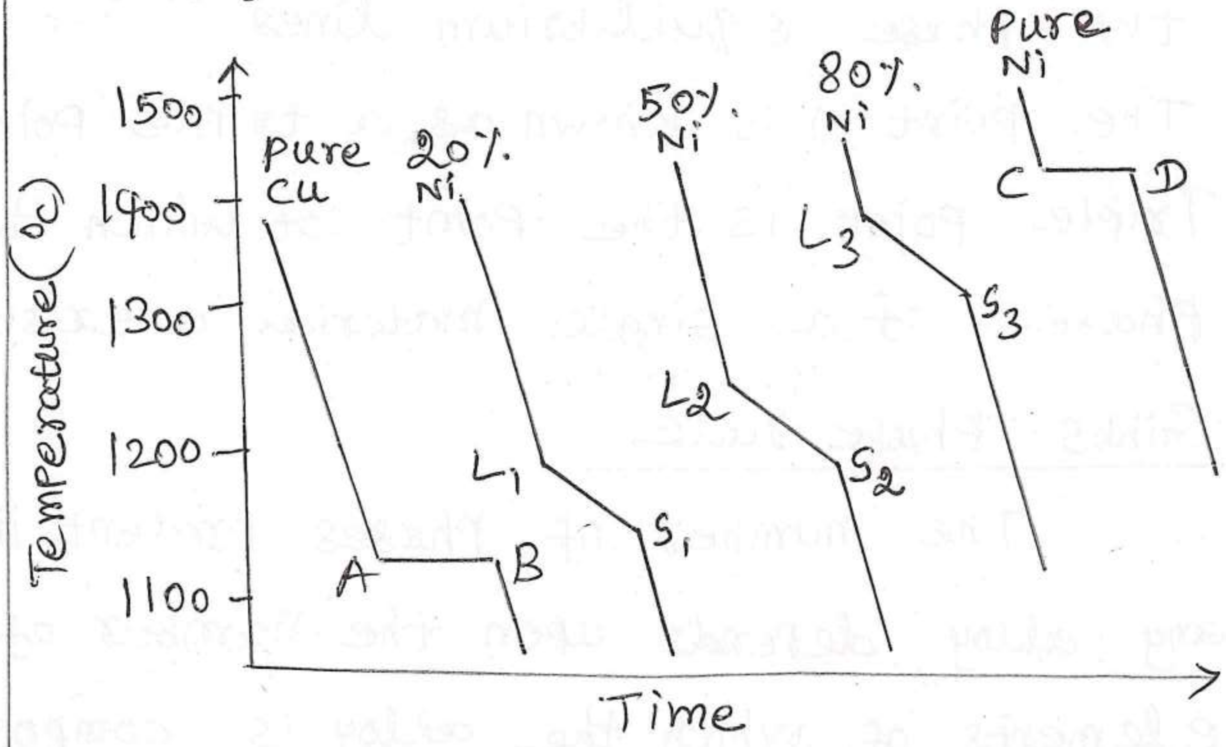
F = Degrees of freedom of the system or the number of variables that may be changed independently without altering the equilibrium

C = Number of components forming the system

P = Number of phases present in the system

construction of Phase diagrams

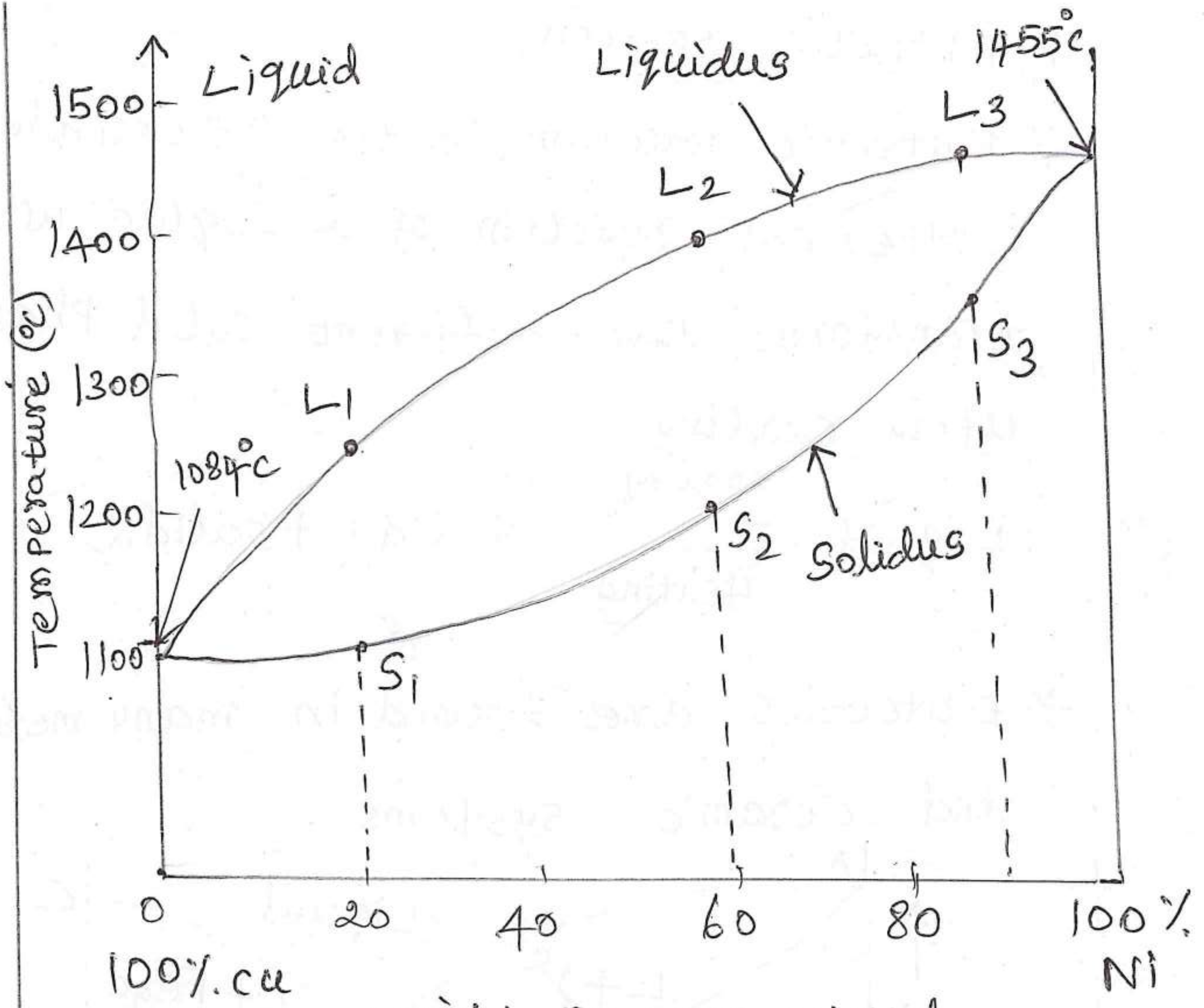
* The construction of the phase diagram for a binary solid solution from series of liquid-solid cooling curves are shown in figure.



* If two metals of a binary solid solution system are mixed in different compositions, melted and cooled.

* The cooling curve for pure metal shows horizontal thermal arrests at their freezing points as shown for pure copper and Nickel.

* Binary solid solutions exhibit slope changes in their cooling curves at the liquidus and solidus lines.



Cu-Ni equilibrium phase diagram

Phase diagrams containing reactions

* There are many types of reaction that occur in binary equilibrium phase diagrams.

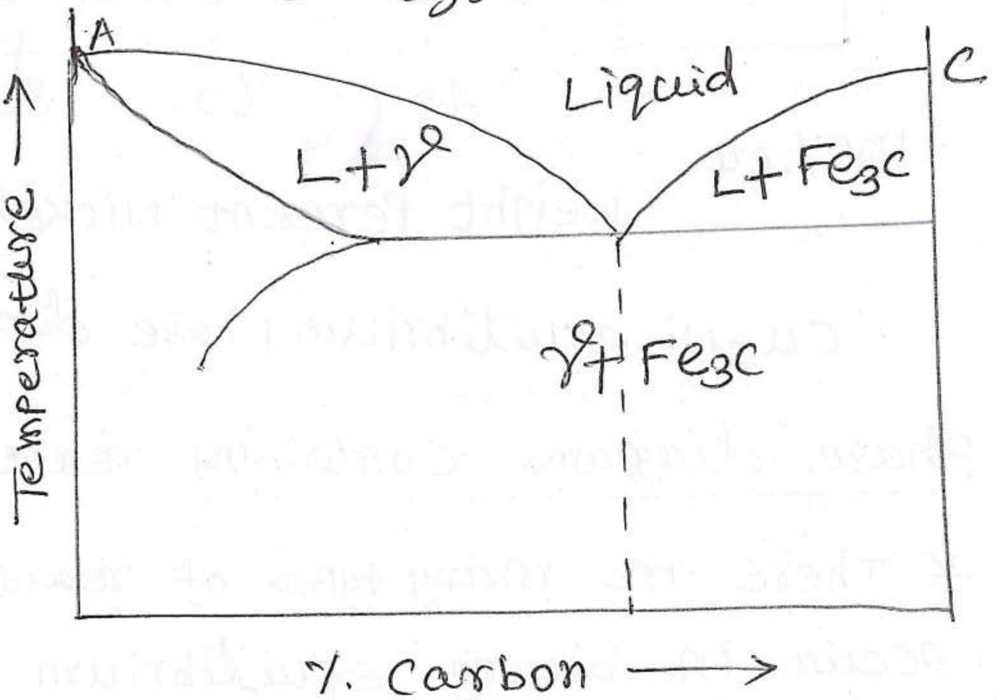
1. Eutectic reaction
2. Peritectic reaction
3. Eutectoid reaction
4. Peritectoid reaction

1. Eutectic reaction

* Eutectic reaction is the reversible, isothermal reaction of a liquid which transforms two different solid phases upon cooling

$$\text{Liquid} \underset{\text{Heating}}{\overset{\text{cooling}}{\rightleftharpoons}} \text{Solid 1} + \text{solid 2}$$

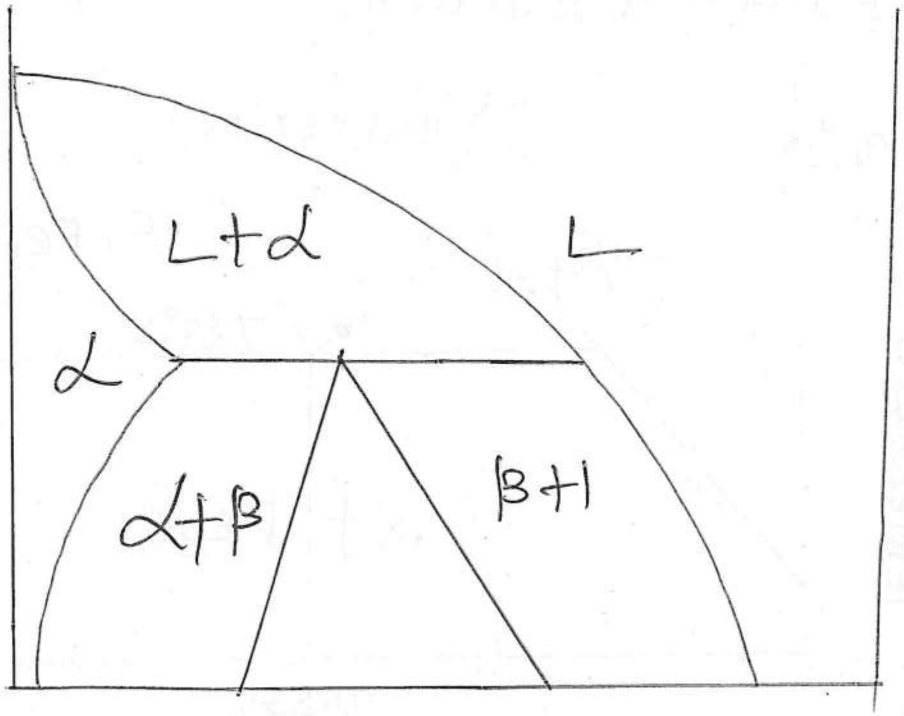
* Eutectics are found in many metallic and ceramic systems



$$\text{Liquid} \underset{\text{Heating}}{\overset{\text{Cooling}}{\rightleftharpoons}} \gamma \text{ iron (austenite)} + \underset{\text{(Cementite)}}{Fe_3C}$$

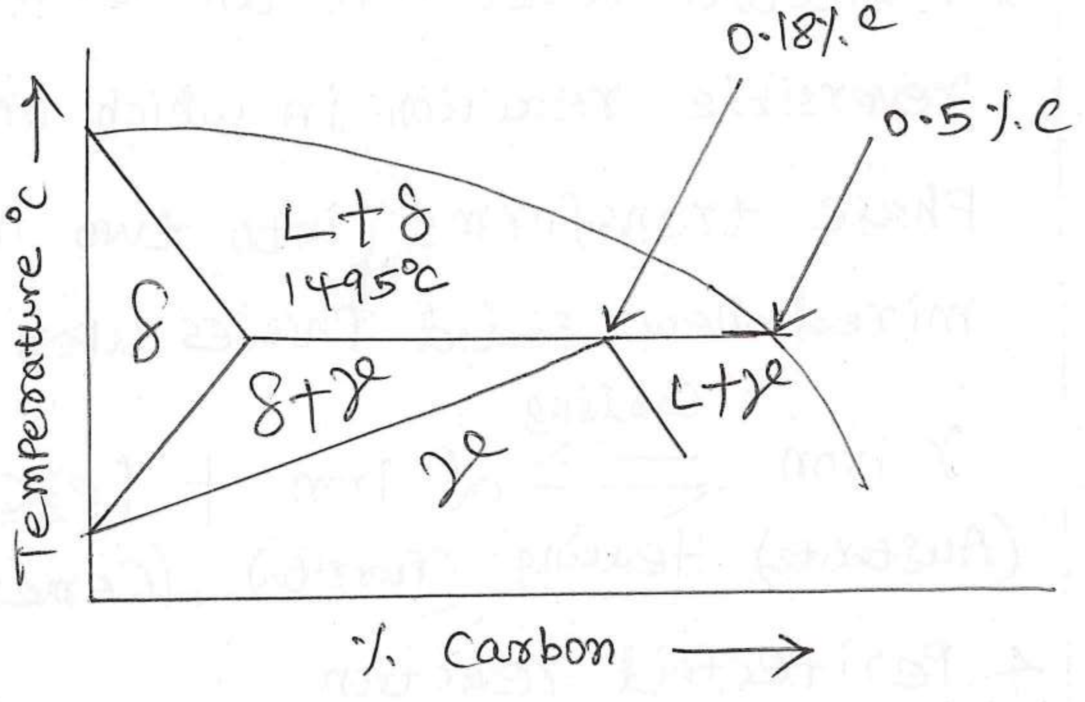
2. Peritectic reaction

* In peritectic reaction upon cooling a solid and a liquid phase transform isothermally and reversibly to a solid phase having a different compositions.



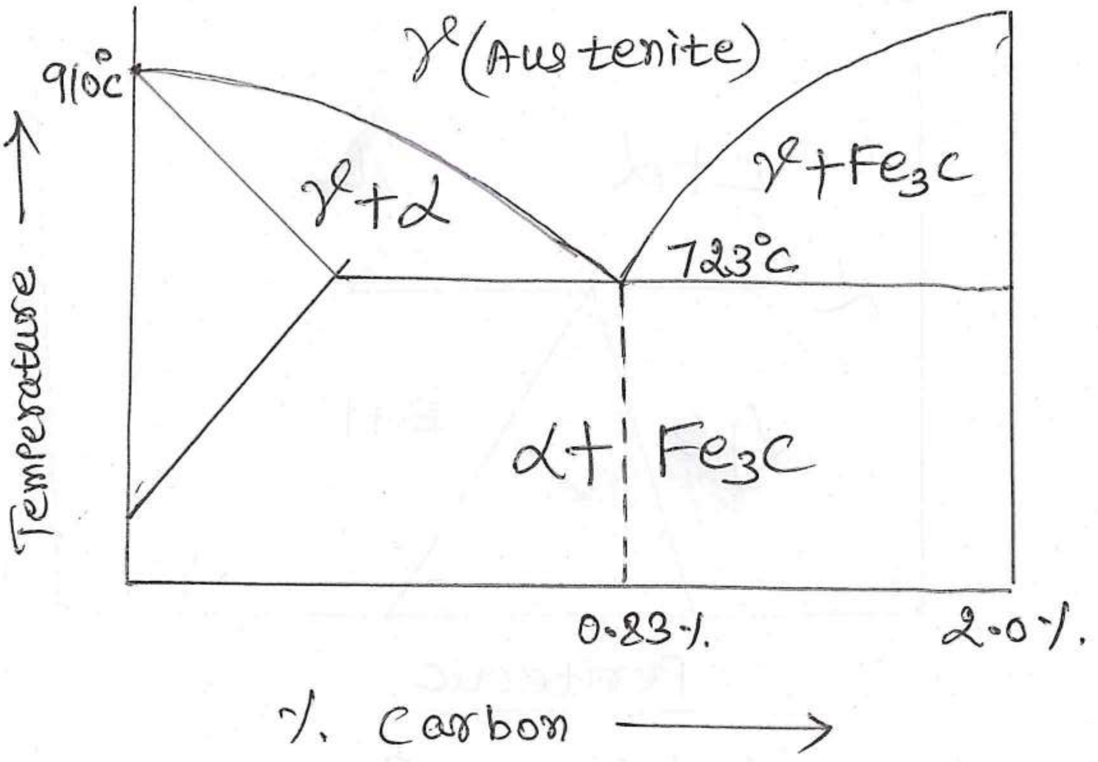
Peritectic

$$L + S_1 \rightarrow S_2$$



$$\text{Liquid} + \delta \text{ iron} \underset{\text{Heating}}{\overset{\text{cooling}}{\rightleftharpoons}} \gamma \text{ iron (Austenite)}$$

3. Eutectoid reaction



* Eutectoid reaction is an isothermal reversible reaction in which one solid Phase transforms into two intimately mixed new solid phases upon cooling

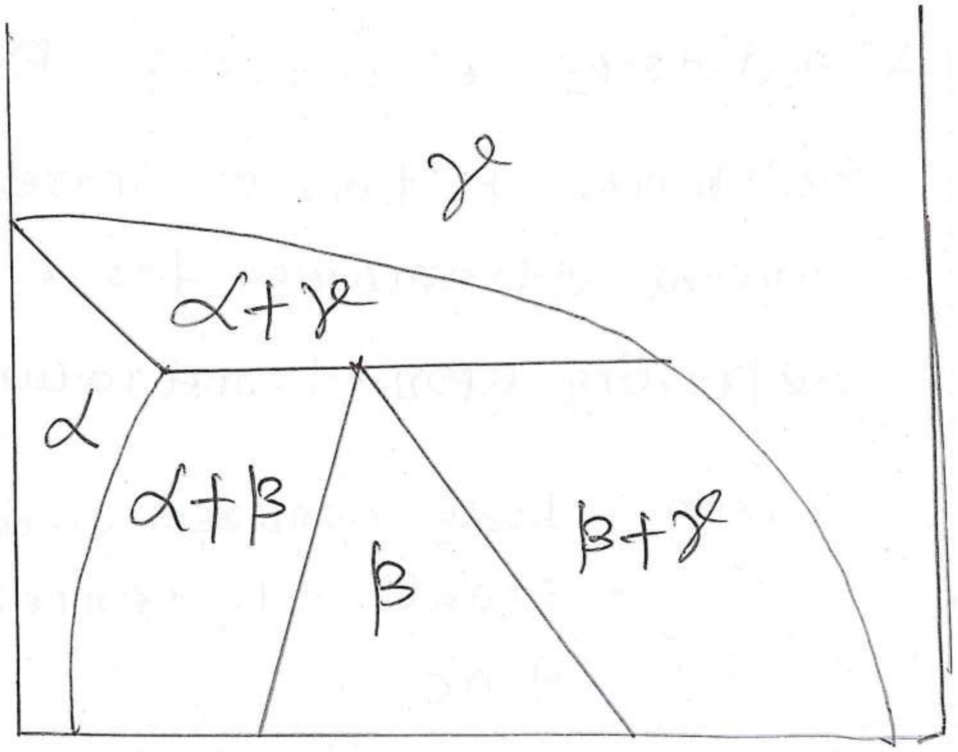
$$\gamma \text{ iron} \underset{\text{Heating}}{\overset{\text{Cooling}}{\rightleftharpoons}} \alpha \text{ iron} + Fe_3C$$

(Austenite) (Ferrite) (Cementite)

4. Peritectoid reaction

* peritectoid reaction is an isothermal reversible reaction in which two solid Phases transform into a third solid Phase upon cooling

$$\text{Solid 1} + \text{Solid 2} \underset{\text{Heating}}{\overset{\text{Cooling}}{\rightleftharpoons}} \text{Solid 3}$$



Peritectoid

$$S_1 + S_2 \longrightarrow S_3$$

Iron - Carbon System

- * Iron has been widely used by man for thousands of years.
- * The availability comparatively low cost and the wide range of properties have made irons and steels material of great importance.
- * Steels and cast irons Containing Varying percentages of carbon and other alloying elements.

Allotropic forms of pure iron

* pure iron is a allotropic metal.

* Allotropy refers to the possibility of existence of two or more different crystal structures for a substance depending upon temperature.

α iron - Body centered cubic (BCC) structure
- stable at temperatures up to 910°C

γ iron - Face centered cubic (FCC) structure
- stable between 910°C and 1394°C

δ iron - Body centered cubic (BCC) structure
- stable between 1394°C and 1539°C [melting point temperature]

Micro-Constituents of iron-carbon alloys

* various micro-constituents of iron-carbon alloys are

1. Ferrite
2. Austenite

3. Cementite
4. Pearlite
5. Ledeburite
6. Martensite
7. Troosite
8. Sorbite and
9. Bainite

1. Ferrite (α iron)

* Ferrite is a primary solid solution based on α iron having BCC structure

* It is interstitial solid solution of carbon in iron.

* Maximum solubility of carbon in iron is 0.025% at 723°c while its solubility at room temperature is only about 0.008%.

* Ferrite is soft, ductile and highly magnetic

* It can undergo extensive cold working

2. Austenite (γ iron)

* Austenite is a primary solid solution based on γ iron having FCC structure

* It is an interstitial solid solution of carbon in iron

* The maximum solubility of carbon in FCC iron is about 2% at 1147°C

* Austenite is normally not stable at room temperature.

* It is soft, tough and highly ductile.

* It is more suitable for fabrication processes.

* It is also a non-magnetic (Paramagnetic)

* It has a greater electrical resistance and co-efficient of expansion than ferrite

3. Cementite

- * Cementite is the name given to the Carbide of iron (Fe_3C)
- * It is hard, brittle, intermetallic compound of iron with 6.67% of carbon
- * The hardness and brittleness of cast iron is beleived due to the presence of cementite

4. Pearlite

- * Pearlite is the eutectoid mixture of ferrite (87.5%) and cementite (12.5%)
- * It is formed when austenite decomposes during cooling. It contains 0.8% of carbon.
- * It consists of alternate thin layers of ferrite and cementite
- * The name derives from its lustrous appearance when viewed in white light under a microscope.
- * It is retatively strong, hard and ductile.

5. Ledeburite

* Ledeburite is the eutectic mixture of austenite (γ iron) and cementite (Fe_3C) containing 4.3% carbon

* In pure iron - carbon alloy it forms at 1147°C

* Most of the engineering alloy materials belong to this range of alloy

* Example: Pig Iron

6. Martensite

* Martensite is the super saturated solid solution of carbon in α iron

* It is formed when a steel is very rapidly cooled from the austenitic stat

* It exhibits a acicular structure.

* It has very hard, more brittle and low ductility properties.

* Internal stresses are set up in the materials leading to the formation of minute cracks.

7. Troosite

* Troosite is the mixture of radial lamallae of ferrite and cementite.

* It is the microstructure consisting ferrite and finely divided cementite produced on tempering martensite below 450°C

* It is formed by the decomposition of austenite when cooled at a rate slower than that which will yield a martensite. and faster than that which will produce a sorbite structure.

* It has hardness intermediate between martensite and sorbite.

8. Sorbite

* Sorbite is the microstructure consisting ferrite and finely divided cementite produced on tempering martensite above 450°c

* It is formed by the decomposition of austenite when cooled at a rate slower than that which will yield a troosite structure and faster than that which will produce a pearlite structure

9. Bainite

* Bainite is a decomposition Product of austenite Consisting of an aggregate of ferrite and carbide.

* Bainite obtained by transformation of Pearlite at higher temperature is called upper bainite (Feathery structure).

* Bainite obtained by low temperature transformation is called lower bainite (Acicular structure).

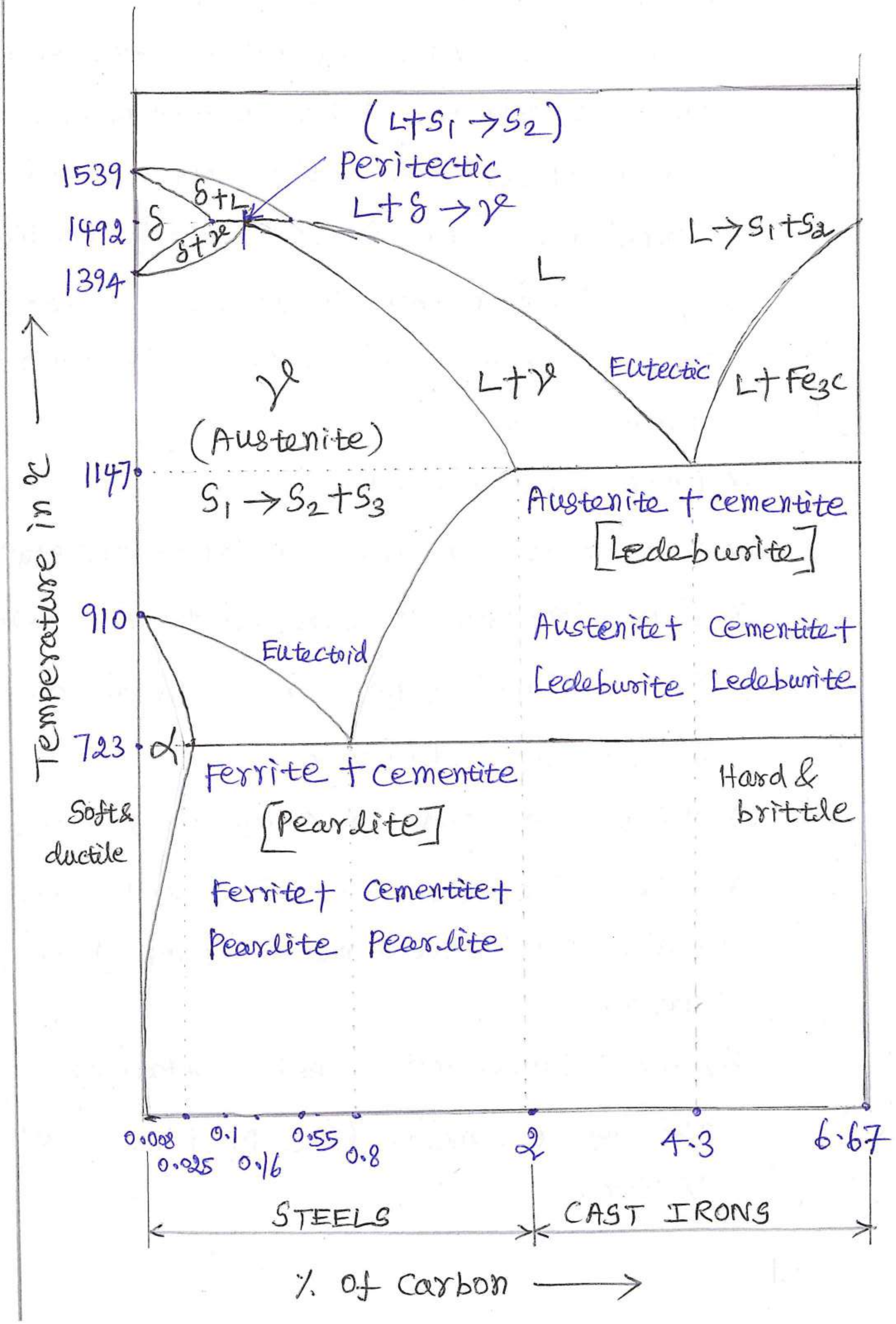
* Lower bainite provides high mechanical properties and it is extensively used for components of machine and structure

* Bainite has hardness in between the hardness of Pearlite and martensite.

Iron - Iron Carbide equilibrium diagram

* Iron - Iron carbide equilibrium diagram is very much useful in understanding the microstructure and Properties of Cast irons and Carbon steels.

Iron – Iron carbide Phase diagram



Classification of steel

* Plain carbon steels are used successfully when the strength and other requirements are not severe. The performance of Plain carbon steels are satisfactory at ordinary temperatures and non corrosive atmospheres.

* The Plain carbon steels are relatively low in cost and certain limitations are given below

* Low hardenability

* Low corrosion and oxidation resistance

* Low strength at elevated temperature

* During rapid quenching to obtain a fully martensitic structure

* Distortion and cracking also occurs

* These deficiencies of Plain carbon steels are overcome by employing alloy steels.

* Alloy steels are steels containing various alloying elements like Ni, Mn, Cr, W, Mo, V, etc.

Purpose of alloying

* To increase hardenability
* To increase strength at ordinary temperature
* To improve high temperature properties
* To increase resistance to corrosion and oxidation
* To increase wear resistance
* To improve toughness at any minimum hardness
* To improve electrical and magnetic properties

Classification of alloy steels

* Alloy steels are classified as follows

Based on total alloy content

1. Low alloy steels - upto and including 5%.
2. Medium alloy steels - more than 5% and upto 10%.
3. High alloy steels - more than 10%.

Based on application

1. structural grade alloy steels - used in construction and transportation industries

2. Stainless steels - corrosion and heat resistant applications
3. Tool and die steels - forming and machining tools
4. Special alloy steels - Special applications

Element	Effects
Boron	Powerful hardenability agent
Chromium	Increases hardenability, wear and corrosion resistance
Cobalt	Improve hot hardness
Copper	Improves corrosion resistance
Lead	Improves machinability
Manganese	*Combines with sulphur to prevent brittleness *Increases hardenability
Molybdenum	Forms stable carbides, inhibits grain growth
Nickel	Toughened, improves corrosion resistance

Element	Effects
Silicon	* Improves strength and hardness * Improves magnetic properties and electrical conductivity
Sulphur	* Improves free machining properties * Lowers ductility and impact strength
Titanium	* Strong carbide former * Increases hardenability
Tungsten	* Improves hot hardness
Vanadium	* Forms stable carbides, * grain refiner

Stainless steels

* Stainless steels are high alloy steels that contain more than 11.5% chromium

* They possess excellent corrosion resistance, oxidation resistance and a pleasing appearance.

* Corrosion resistance is imparted by the formation of strongly adherent chromium oxide on the surface of the steel.

* They are classified into five types

1. Ferritic stainless steels
2. Martensitic stainless steels
3. Austenitic stainless steels
4. Precipitation hardnening stainless steels
5. Duplex stainless steels

Tool and die steels

* The steels used especially for the shaping of metals by cutting, shearing, battering, drawing, extruding, die-casting or rolling are called tool steels.

* They are classified according to AISI as given below

1. Water hardening
2. Shock resisting
3. Cold work
    - (a) oil hardening
    - (b) Medium alloy air hardening
    - (c) High carbon High chromium
4. Hot work
5. High Speed
    - (a) Tungsten base
    - (b) Molybdenum base
6. Mould Steels
7. Special purpose
    - (a) Low alloy
    - (b) Carbon - Tungsten

HSLA steels

- HSLA steels have been developed to improve the strength to weight ratio of steels
- These steels are defined by AISI as a group of steels with chemical composition specially developed to impart higher mechanical properties and in certain of these steels materially greater resistance to atmospheric corrosion than is obtainable from conventional carbon steels.
- They have low carbon contents of usually less than 0.3 %.
- They are not hardened by heat treatments.
- They have yield strength 290 - 550 MPa and ultimate tensile strength in the range of 415-700 MPa.

Cast iron

* cast iron is an alloy of iron and carbon with carbon content exceeding 2.1%

* commercial grades of cast iron differ widely in composition and contain carbon content in the range of 2.3 - 3.75% along with sustantial amount of other elements such as silicon, sulphur and manganese.

* Because of their poor ductility and malleability they are not worked into the desired shape.

* However, they can be melted and cast into complicated shapes.

Properties

1. It is relatively a cheaper material
2. It has fairly low melting range as compared with steel
3. It has high fluidity and ability to make good casting impressions.
4. It has good machinability when

a suitable composition is selected

5. Its corrosion resistance is fairly good

6. It has a high compressive strength with rigidity and resistance to wear.

Classification of Cast iron

SL. NO.	CAST IRON	CARBON FORM
1	White cast iron	All the carbon is in the combined form as iron carbide
2.	Grey cast iron	The carbon is in the free form as 'flakes' of graphite
3.	Malleable cast iron	The carbon is in the free form as irregular round particles of graphit known as temper carbon. This is obtained by heat treatment of white cast iron
4	Nodular cast iron (or) Spheroidal Graphite cast iron	The carbon is in the free form as nodules or spheroids of graphite formed directly during the process of solidification.

5	chilled cast iron	The white cast iron layer at the surface is combined with a grey iron interior
6	Alloy cast iron	They may be of any of the general types and are modified by the addition of alloying elements to obtain Specific properties

UNIT-II Heat Treatment

Purpose of heat treatment

* To relieve internal stresses
* To improve machinability
* To refine grain size
* To soften the metal
* To improve hardness of the metal surface
* To improve mechanical properties
* To improve magnetic and electrical Properties
* To increase resistance to wear, heat and corrosion
* To improve ductility and toughness
* To change the chemical composition

Definition

* Heat treatment may be defined as an operation or combination of operations involving heating and cooling of a metal or alloy in solid state to obtain desirable Properties.

Stages of heat treatment process

Stage 1: Heating a metal or alloy beyond the critical temperature.

Stage 2: Holding at that temperature for a sufficient period of time to allow necessary changes to occur.

Stage 3: Cooling the metal or alloy at a rate necessary to obtain the desired properties. That is cooling at a rate necessary to obtain the desired changes in the nature, form, size and distribution of micro-constituents.

Types of heat treatment processes

1. Annealing
   - (a) Full annealing
   - (b) Process annealing
   - (c) Stress relief annealing
   - (d) Recrystallisation annealing and
   - (e) Spheroidise annealing
2. Normalising

3. Hardening
4. Tempering
5. Austempering
6. Martempering
7. Case hardening
    - (a) Carburising
    - (b) Nitriding
    - (c) cyaniding
    - (d) carbo nitriding
    - (e) Flame hardening
    - (f) Induction hardening

Annealing

* The term annealing refers to a heat treatment in which a material is exposed to an elevated temperature for an extended time period and then slowly cooled.

Three stages of annealing process

1. Heating to the desired temperature
2. Holding or soaking at that temperature
3. cooling or quenching usually to room temperature

Purposes of annealing

* To relieve or remove stresses
* To induce softness
* To alter ductility, toughness, electrical, and magnetic properties
* To refine grain structure
* To remove gases
* To produce a definite mircostructure

Types of annealing

1. Full annealing
2. Process annealing
3. Stress relief annealing
4. Recrystallisation annealing
5. Spheroidise annealing

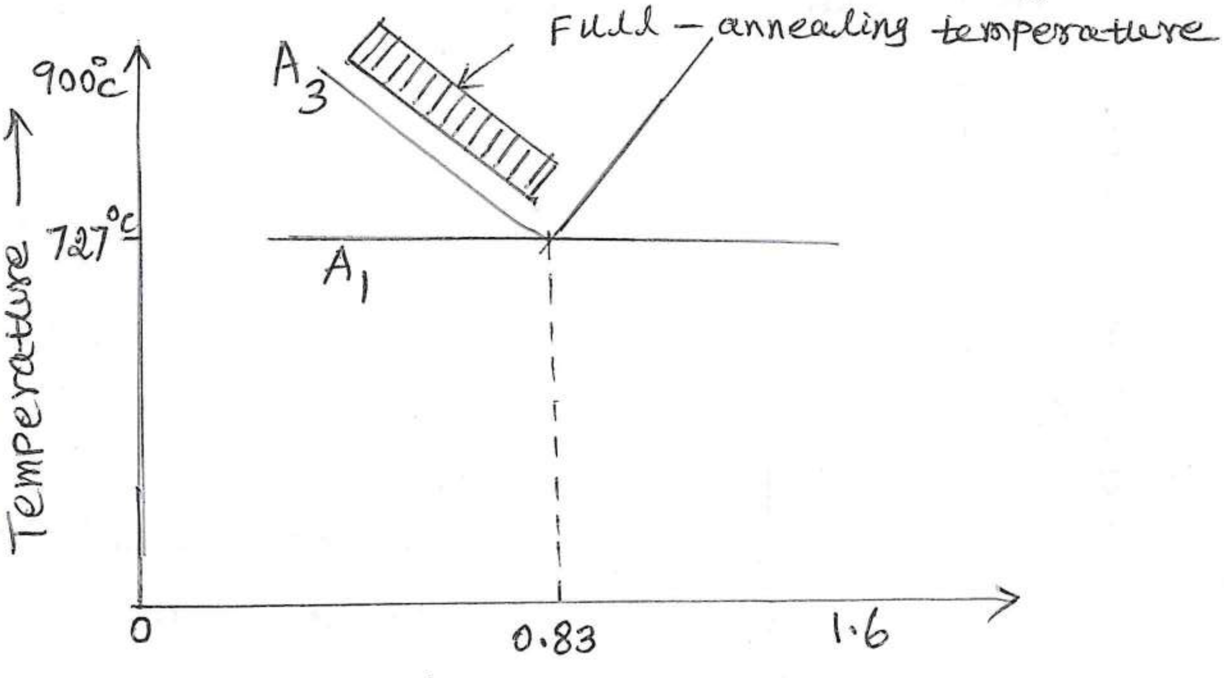
1. Full annealing

* Full annealing consists of heating the steel to a temperature at or near the critical point holding there for a time period and then allowing it to cool slowly in the furnace itself.

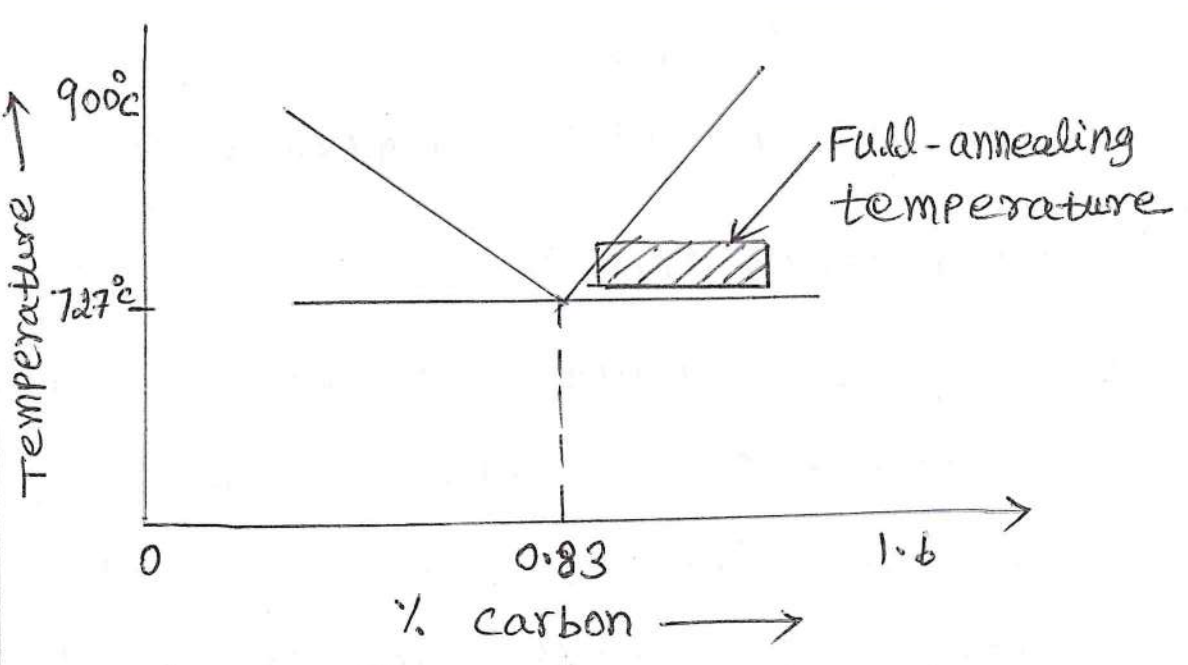
* The main objectives of full annealing are

1. To soften the metal
2. To refine its crystalline structure
3. To relieve the stresses

* The full annealing is specially adopted for steel castings and steel ingots



Full annealing temperatures for hypoeutectoid steel

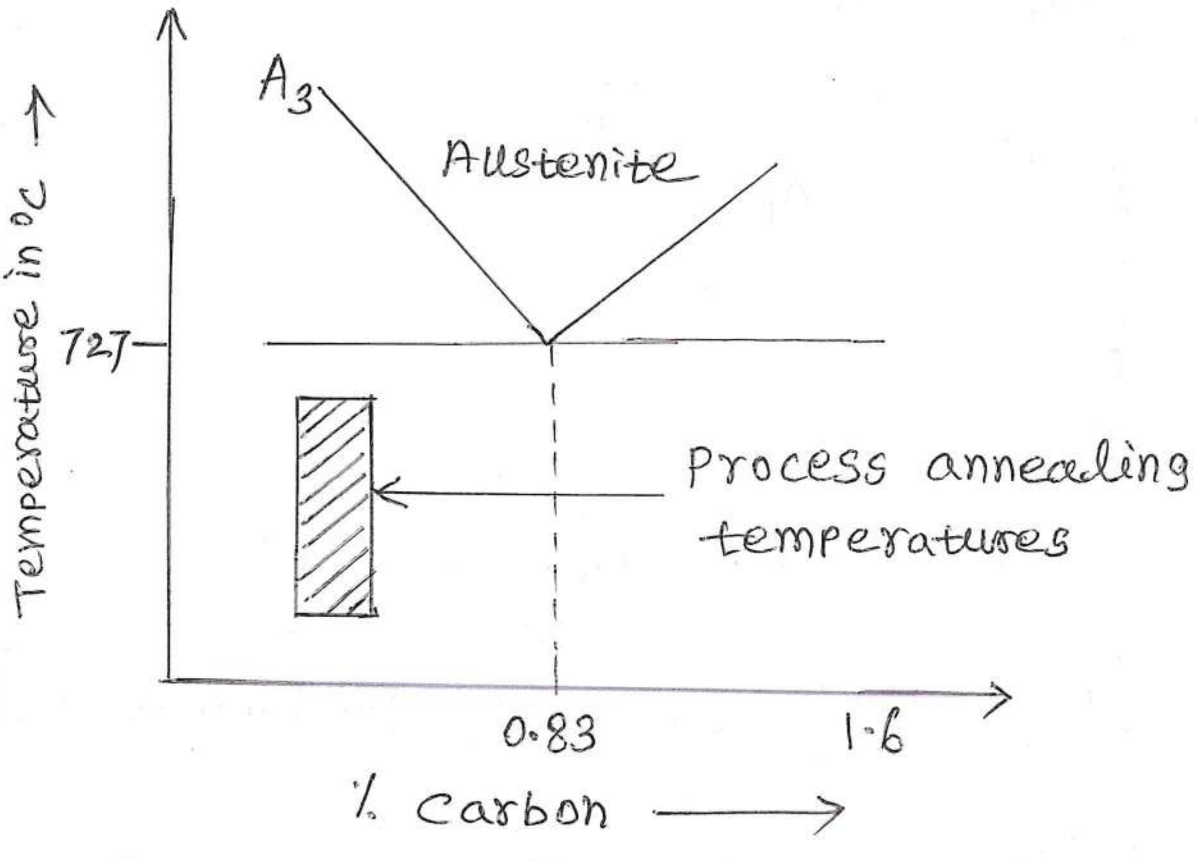


Full annealing temperatures for hypereutectoid Stee

2. Process annealing

* Process annealing is a heat treatment that is often used to soften and increase the ductility of a previously strain-hardened metal.

* It is extensively employed for steel wires and sheet products.



Process annealing temperature

3. Stress relief annealing

* The stress relief annealing is a heat treatment process that is employed to eliminate internal residual stresses induced by casting, quenching, machining, cold working, welding, etc.

- * In stress relief annealing the steel parts are heated in the range of 550°C to 650°C held for a period of time and then cooled slowly.

4. Recrystallisation annealing

- * Recrystallisation is a process by which distorted grains of cold-worked metal are replaced by new, strain-free grains during heating above a specific uniform temperature
- * The temperature at which crystallisation takes place i.e., new grains are formed is called recrystallisation temperature.
- * In this heat treatment process cold worked steel is heated to a temperature above recrystallisation temperature held at this temperature for sometime and then cooled.

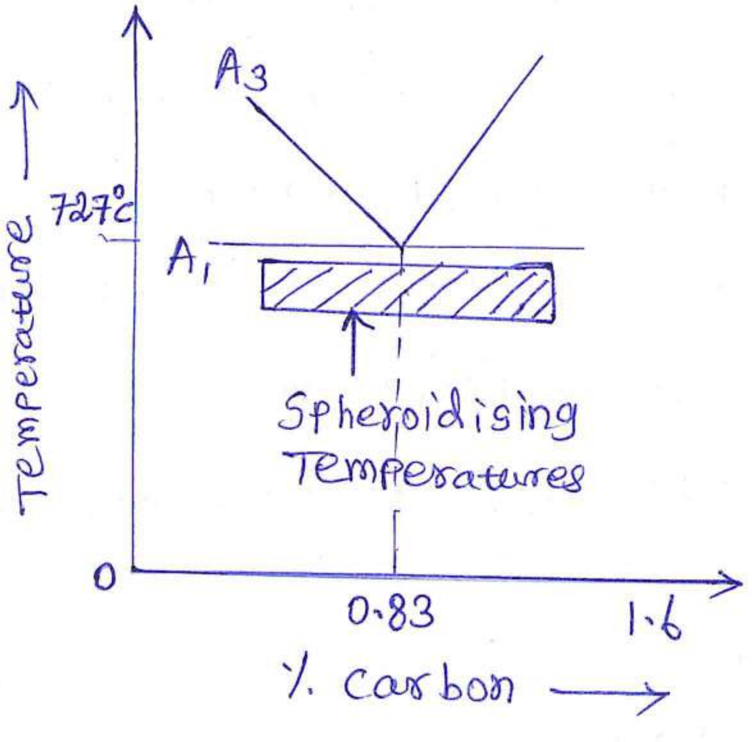
5. Spheroidizing

- * Medium and high carbon steels having a microstructure containing even coarse - Pearlite is too hard to conveniently machine.

* These steels are spheroidise annealed i.e., heat treated to develop the Spheroidite Structure.
* The spheroidized steels have a maximum softness and ductility.
* They are easily machined or deformed.

Objectives of spheroidising

* To soften steels
* To increase ductility and toughness
* To improve machinability and formability
* To reduce hardness, strength and wear resistance.



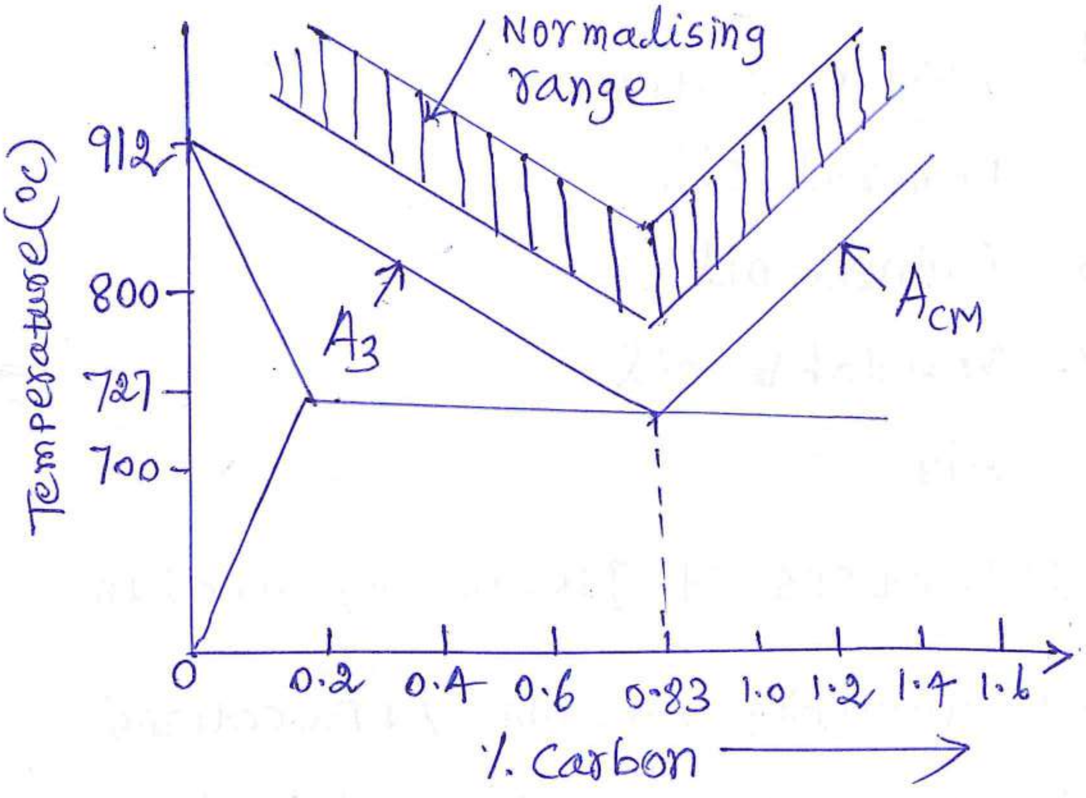
Spheroidising annealing temperatures

Normalising

* Normalising is similar to full annealing but cooling is established in still air rather than in the furnace.

Objectives

* To refine the grain structure
* To increase the strength of the steel
* To provide a more uniform structure in castings and forgings.
* To relieve internal residual stresses due to cold working
* To achieve certain mechanical and electrical properties



Normalising range for carbon steels

Quenching

* Quenching refers accelerated cooling

* The cooling can be accomplished by contact with a quenching medium which may be a gas, liquid or solid

* Most of the times liquid quenching media is widely used to achieve rapid cooling.

Types of quenching medium

1. 5 - 10% Caustic Soda
2. 5 - 20% brine (Nacl)
3. Cold water
4. Warm water
5. Mineral oil
6. Animal oil
7. Vegetable oil
8. Air

Applications of quenching medium

SL.No.	Quenching medium	Applications
1.	Mineral oils	used in hardening alloy steels

SL.NO.	Quenching medium	Applications
2.	Water or aqueous Solution of NaOH or Nacl	used for quenching carbon and low alloy steels
3.	Water and air	Used for rails, pipes and heavy forgings

Selection of quenching medium

1. Desired rate of heat removal
2. Required temperature interval
3. Boiling point
4. Viscosity
5. Flash point
6. Stability under repeated use
7. Possible reactions with the material being quenched
8. cost

Stages of quenching

Stage 1 Vapour-Jacket Stage

* When a piece of hot metal is first inserted into a tank of liquid quenchant that adjacent to the metal

vapourises and forms a gaseous layer separating the metal and liquid.

* In this stage cooling is slow.
* This stage occurs when the metal is above the boiling point of the quenchant

Stage 2: Vapour transport cooling stage

* This stage starts when the hot metal is cooled to a temperature at which the gaseous layer is no longer stable
* Bubbles nucleate and remove the gaseous layer: liquid contacts the metal and vapourises it and thus the process of bubbles formation continues. It provides rapid cooling.

Stage 3: Liquid cooling stage

* Third stage begins when the metal cools below the boiling point of the quenchant.
* All heat transfer occurs through conductio across the solid-liquid interface aided by stirring within the quenchant.

Hardening

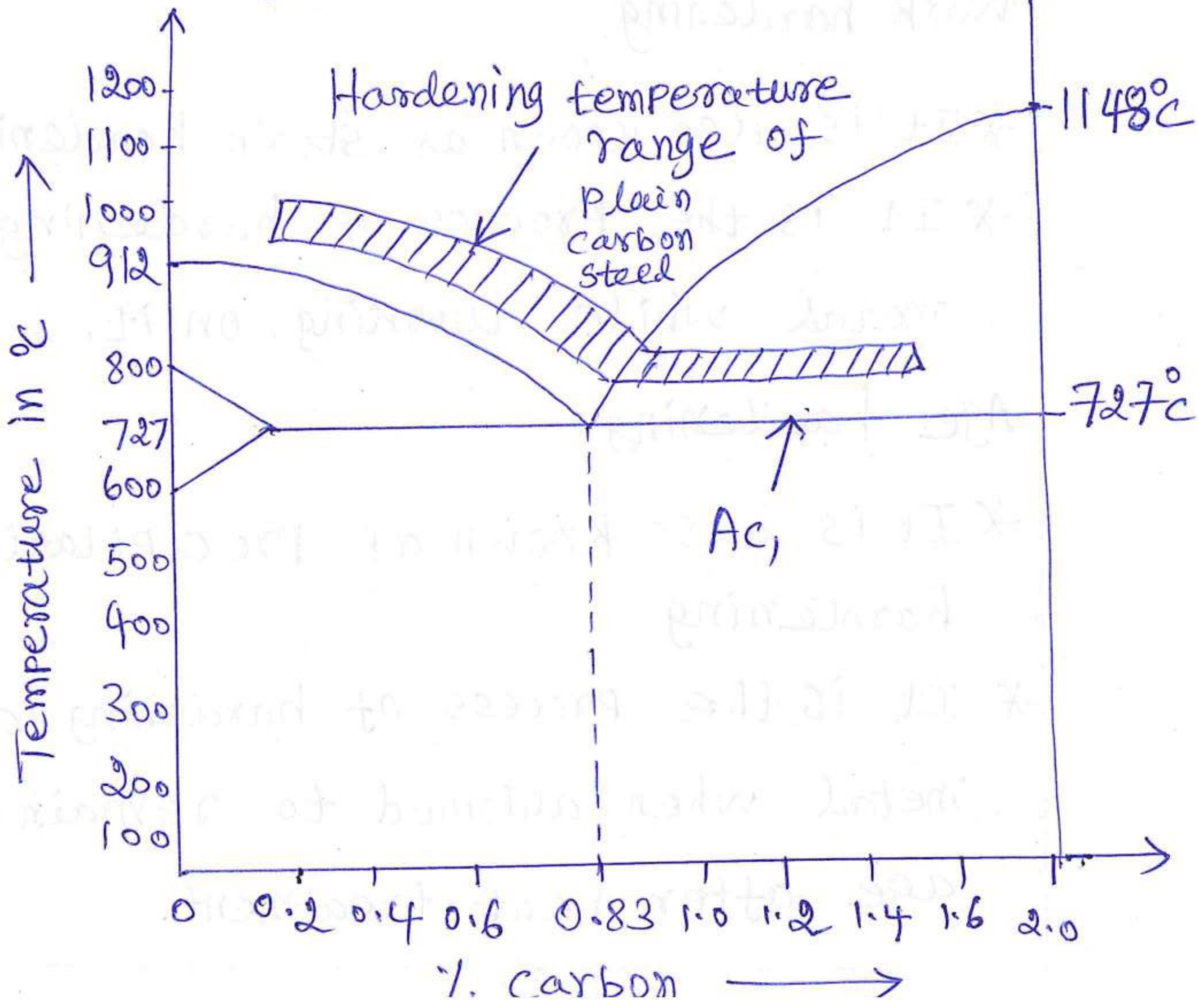
* Hardening refers to the heat treatment of steel which increases its hardness by quenching.

Objectives

* To harden the steel to resist wear
* To enable it to cut other metals

operation

1. Heating
2. Soaking
3. cooling



Factors affecting the hardness

1. carbon content
2. Quenching medium
3. Specimen size
4. other factors
   (a) Specimen shape
   (b) Quenching temperature
   (c) Degree of agi-tation
   (d) Surface condition of Specimen
   (e) Alloying elements

work hardening

* It is also known as strain hardening.
* It is the process of hardening a metal while working on it.

Age hardening

* It is also known as precipitation hardening
* It is the process of hardening a metal when allowed to remain or age after heat treatment.

Tempering:-

- The ductility and toughness of martensite can be enhanced and these internal stresses are relieved by a heat treatment process known as tempering.

Objectives of tempering

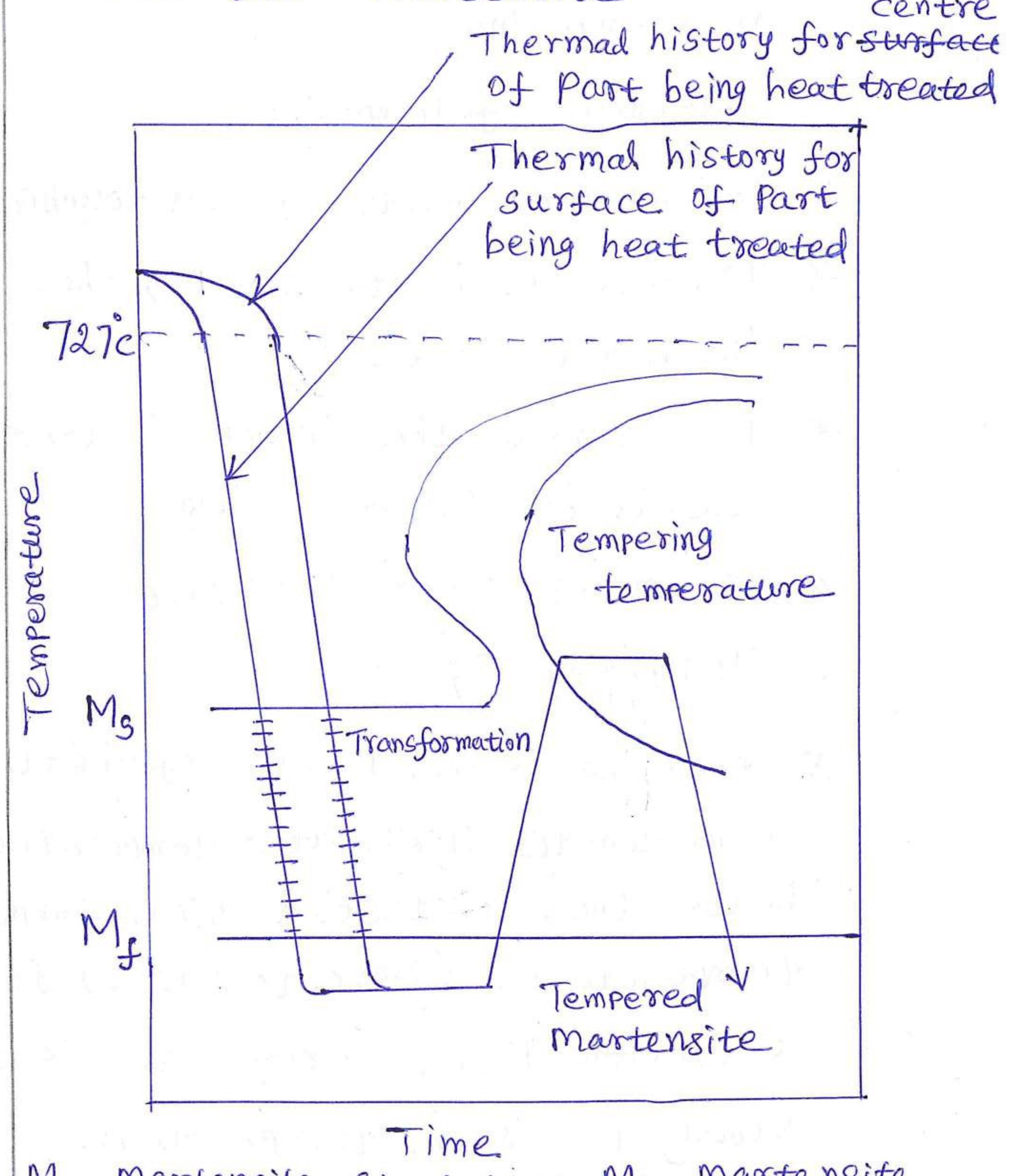
- To improve ductility and toughness
- To reduce brittleness of the hardened steel
- To remove the internal stresses caused by rapid cooling
- To impart wear resistance

Tempering process

- Tempering is the process of heating a martensite steel at a temperature below the eutectoid transformation temperature (250°C to 650°C) for a specific time period and is cooled slowly to room temperature

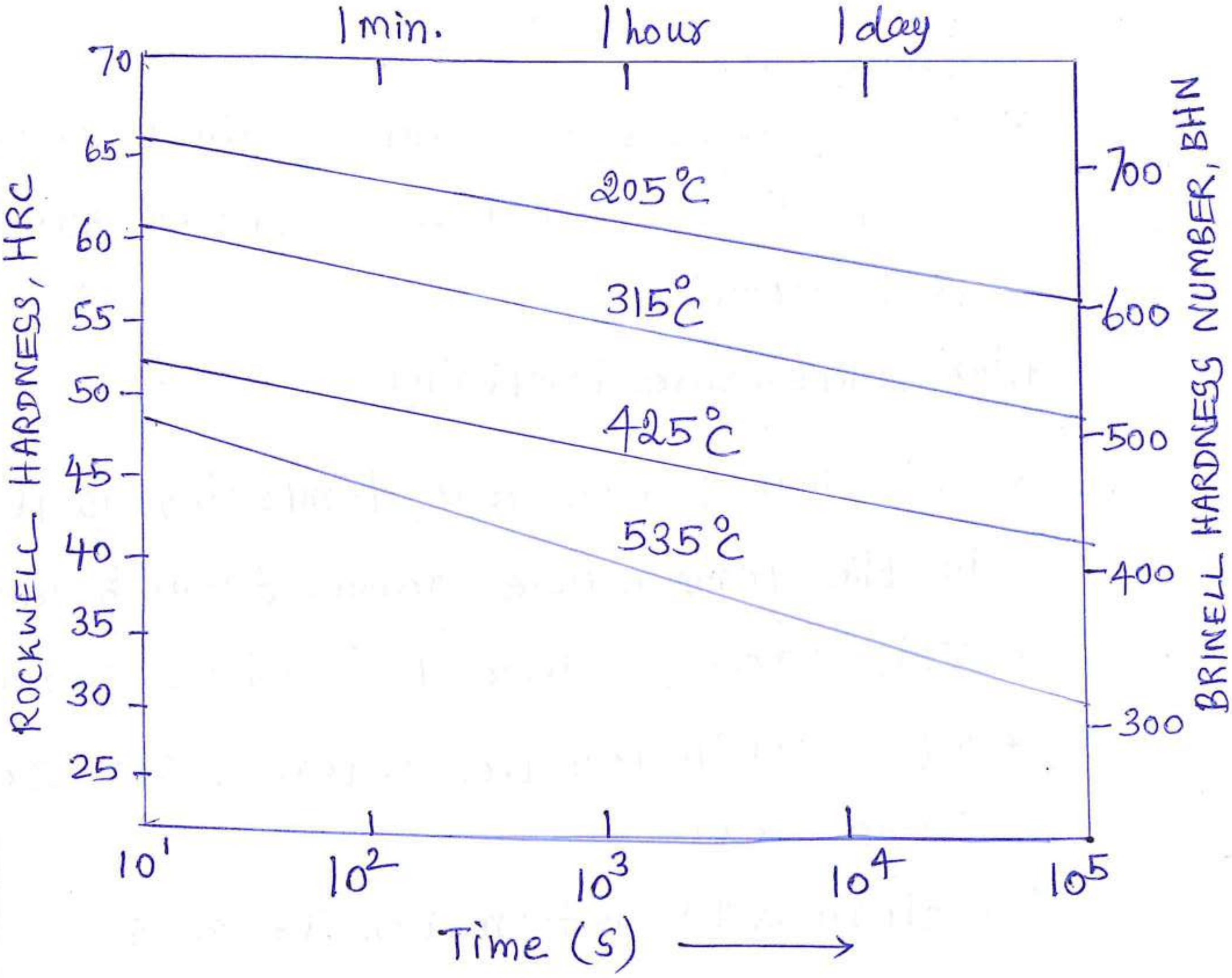
Martensite ⟶ Tempered Martensite
(BCT, single phase) ($\alpha + Fe_3C$ phases)

* Tempered martensite have substantiall improved ductility and toughness than the martensite



M_s - Martensite start temp. M_f - Martensite finish temp.

Tempering process



Hardness Vs Tempering Time for a water quenched eutectoid plain carbon steel

Classification of tempering

Low temperature tempering

* The low temperature tempering is performed in the temperature range from 150°c to 250°c.

* This process is used to retain hard microstructure of martensite.

Medium temperature tempering

* The medium temperature tempering is performe in the temperature range from 350°c to 450°c

* This process develops tempered troostite structure.

* It increases endurance limit and elastic limit. It is applied on spring steels and die steels.

High temperature tempering

* This high temperature tempering is performed in the temperature range from 500°c to 650°c

* This process develops sorbite structure.

* It eliminates the internal stresses completely.

Isothermal transformation diagrams

* The time-temperature-transformation diagram (TTT diagram) which is also called the isothermal transformation diagram is a tool used by heat treaters to predict quenching reactions in steels.

* TTT diagram is a plot of temperature versus the logarithm of time for a steel alloy of definite composition.

Construction of a TTT diagram

* Obtain a large number of relatively small Specimens of same material

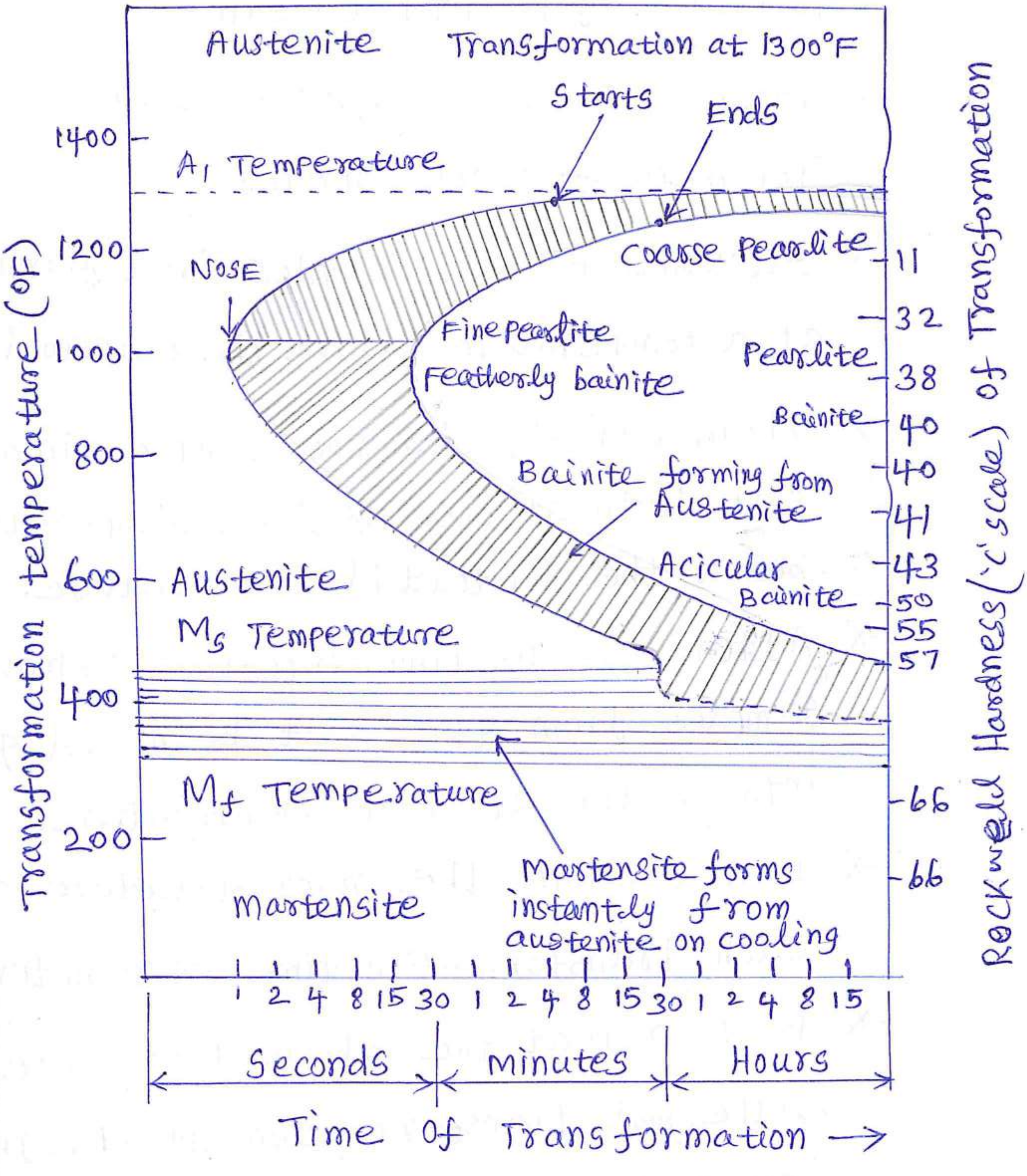
* Austenitize the samples in a furnace at a temperature above the eutectoid temperature

* Then, rapidly cool the samples in a liquid salt bath at the desired temperature below the eutectoid temperature.

* After various time intervals remove the samples from the salt bath and quench into water at room temperature.

* Now examine the microstructure after each transformation time at room temperature

* Now repeat the above procedure for the isothermal transformation at progressively lower temperatures. The data obtained from a series of isothermal reaction curves over the whole temperature range of austenite instability for a given composition of steel is summarised the result is TTT diagram for that steel.



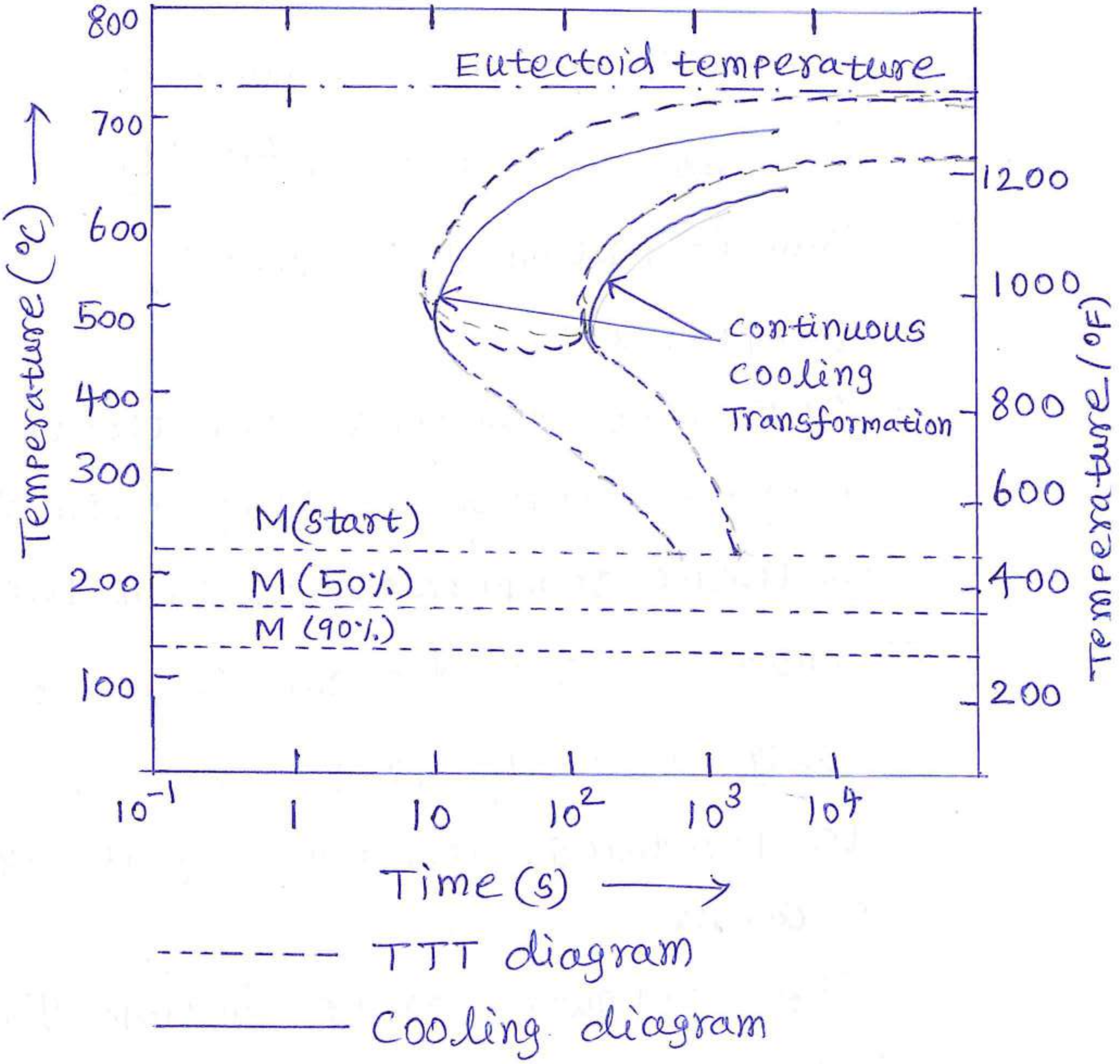
TTT diagram for decomposition of austenite in a eutectoid carbon steel

continuous cooling Transformation diagram

* The data for the construction of TTT diagrams are obtained from the isothermal transformation of martensite at different temperatures.
* But most industrial heat treatments involve continuous cooling from the austenitic temperature to room temperature.
* Thus a TTT diagram may not give a fully accurate representation of the temperatures and times of the transformati occuring.
* The continuous cooling diagram gives a more accurate picture for heat treatments involving continuous cooling.

critical cooling rate

* The slowest rate of cooling of austenite that will result in 100% martensite transformation is known as the critical cooling rate. The critical cooling rate is most important in hardening.



Factors affecting the critical cooling rate

- * Chemical composition of steel
- * Hardening temperature
- * Metallurgical nature of steel

Hardenability

* The term hardenability refers to the ease with which hardness may be attained.

* Steel will transform to hardened structure on quenching is called hardenability.

- * The hardenability of a steel is defined as that property which determines the depth and distribution of hardness induced by quenching from the austenite condition.

Hardness Vs Hardenability

- * The term Hardness is the property of a material by virtue of which it is able to resist abrasion, indentation and scratching. The hardness can be measured by the methods like Brinell, Rockwell and Vickers.
- * Hardenability is the susceptibility of a material to get hardened. The hardenability can be measured by the Jominy end-quenc test method.

Factors affecting hardenability

- * The composition of steel
- * The austenitic grain size
- * The structure of the steel before quenchin
- * The quenching medium and the method of quenching

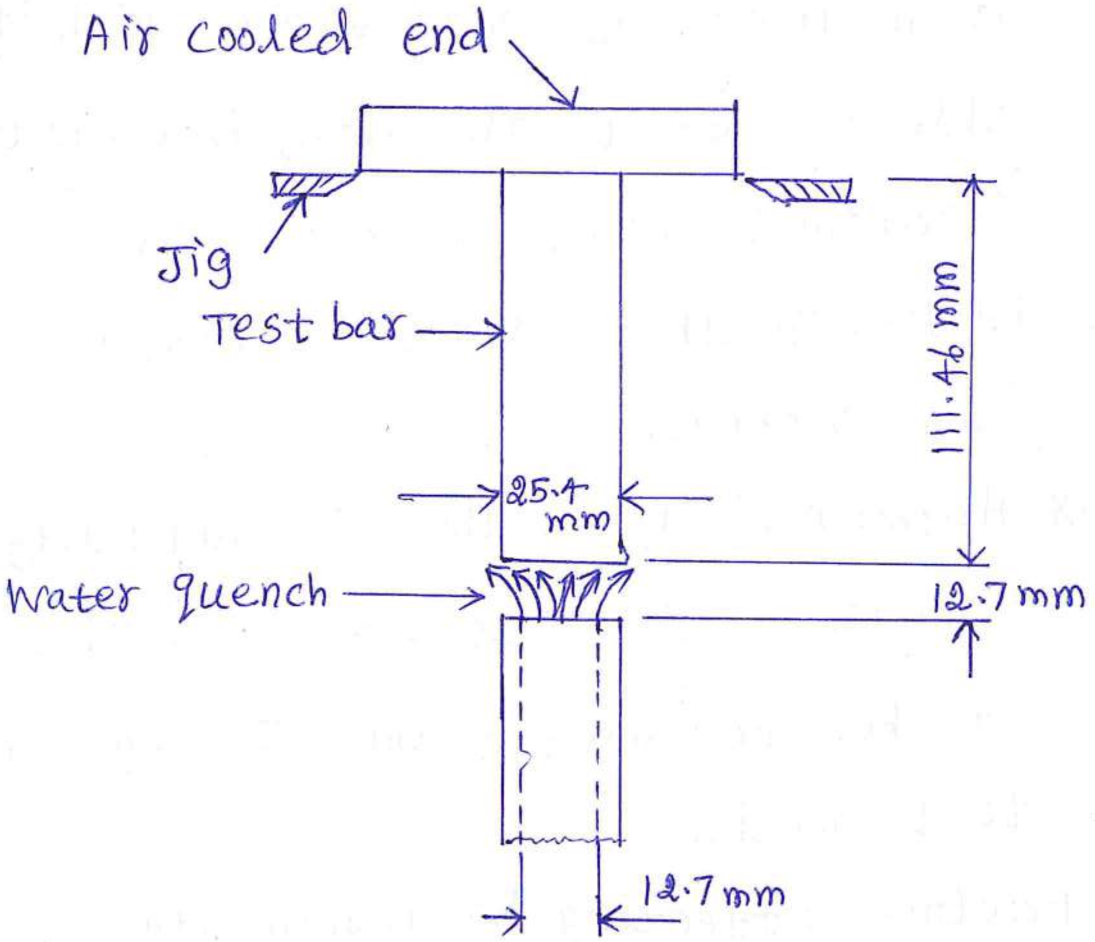
Jominy end quench Test

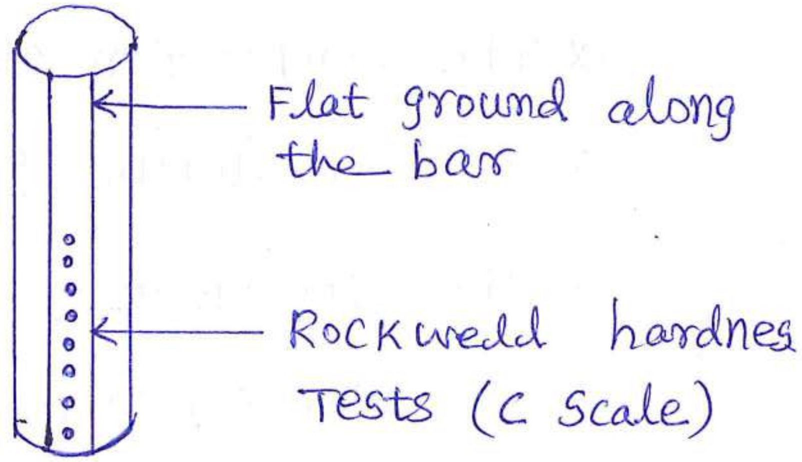
* It is relatively easy to perform

* It has excellent reproducibility

* It gives information useful to a designer and manufacturer

End quench specimen





Testing procedure

* The standard test piece is heated to above the upper critical temperature of the steel.

* It is then very quickly transformed from the furnace and immediately dropped into position in the frame of the apparatus.

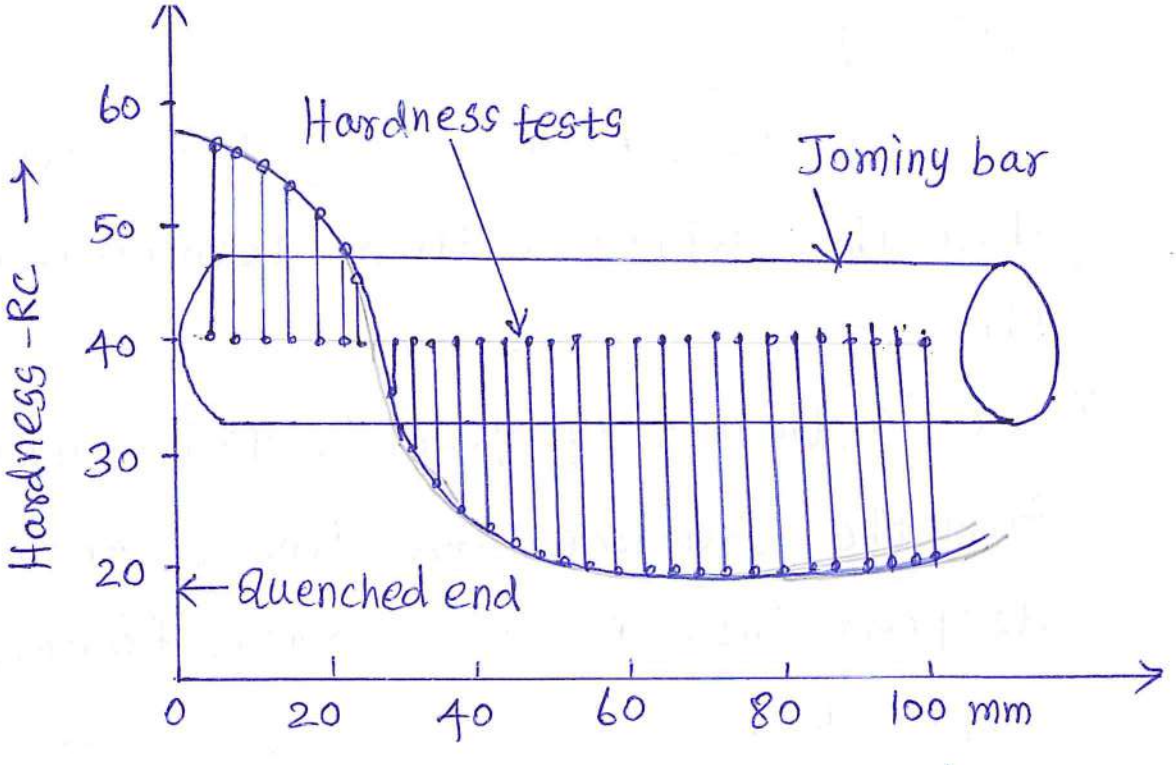
* Here it is quenched at one end only by a standard jet of water at 25°C

* Thus different rates of cooling are obtained along the length of the test piece.

* when the test piece has cooled a flat approximately 0.4 mm deep is ground along the length of the bar.

* Now Rockwell hardness 'c' scale readings are taken every 1.6 mm along the length from the quenched end.

* Finally the results are plotted as shown in figure.



Distance from quenched end →

Typical hardness distribution in Jominy bars

Martempering

* Martempering also known as marquenching is a interrupted cooling procedure used for steels to minimise the stresses, distortio and cracking of steels that may develop during rapid quenching

Martempering Process

* Heating the steel above its critical range to make it all austenite
* Quenching the austenized steel in hot oil or molten salt at a temperature just slightly above the martensite start temperature (M_s)

- Holding the steel in the quenching medium until the temperature is uniform throughout and stopping this isothermal treatment before the austenite to bainite transformation begins.
- Cooling at a moderate to room temperature usually in air to prevent large temperature differences between center and surface.

Advantages of martempering

- minimised quenching stresses
- Minimised chances of formation of quenching cracks.
- Less distortion or warping

Application

- Mostly used in alloy steels

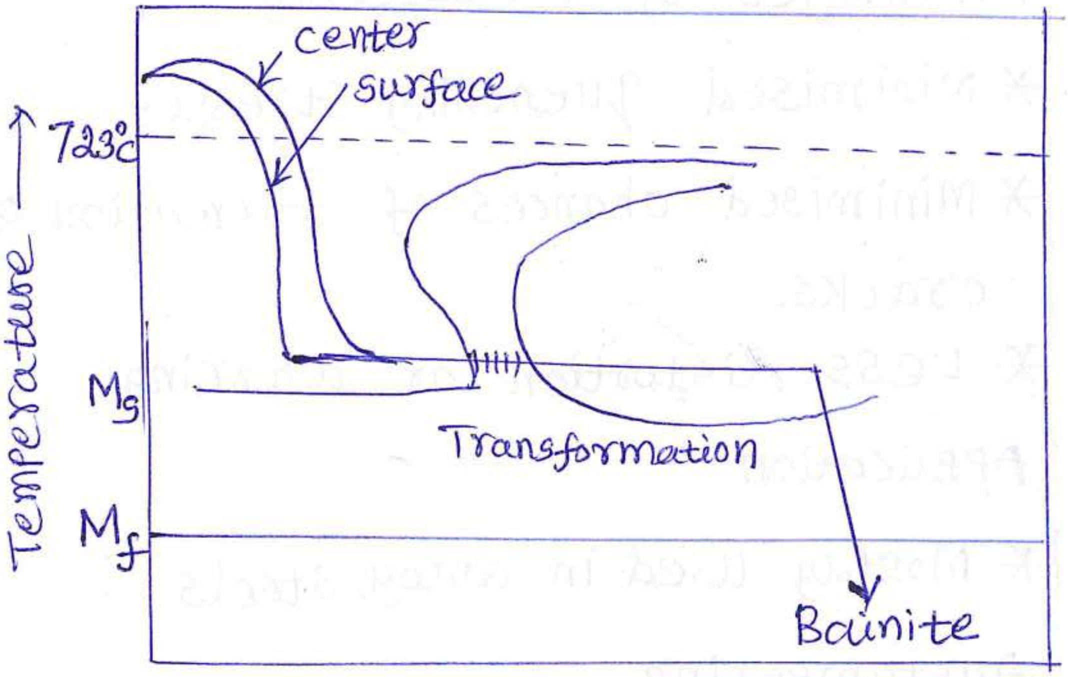
Austempering

- Austempering is an isothermal heat treatmen process usually used to reduce quenchin distortion and to make a tough and strong steels.

Austempering process

- Austenitizing the steel

- * Quenching the austenized steel in a molten salt bath at a temperature just above the martensite start temperature (M_s) of the steel.
- * Holding the steel isothermally to allow the austenite to bainite transformation to take place.
- * Slow cooling to room temperature in air



Austempering Process

Applications

- * Small tools, springs, retainers, automobile seat belt components, link chains, lawn mover blades and various machinery parts.

Advantages

* Improved ductility
* Increased impact strength and toughness
* Decreased distortion of the quenched material
* Less danger of quenching cracks

Disadvantages

* Need for a special molten salt bath
* Used only for a limited number of steels
* Only small sections (upto 9mm thick) are suitable for austempering because big sections cannot be cooled rapidly to avoid the formation of pearlite.

Case hardening (Surface heat treatment)

* In many applications it is desirable that the surface of the components should have high hardness, while the inside or core should be soft. The treatments given to achieve this desirable properties are called case hardening or surface hardening.

Types of surface heat treatments

I. Diffusion methods

- (a) Carburizing
- (b) Nitriding
- (c) Cyaniding
- (d) Carbo nitriding

II. Thermal methods

- (a) Flame hardening
- (b) Induction hardening

Carburizing

* Carburizing is the process of Carbon atoms are introduced onto the surface of low carbon steels to produce a hard case of surface while the interior or core remains soft

* Steels for Carburizing should have Carbon from 0.10% to 0.20%.

Process of Carburizing

* In Carburigation when a piece of low-carbon steel is Placed in a Carbon Saturated temperature. Then the carbon will diffuse into the Steel and carburizing it

Methods of carburizing

1. Pack carburizing
2. Gas carburizing
3. Liquid carburizing

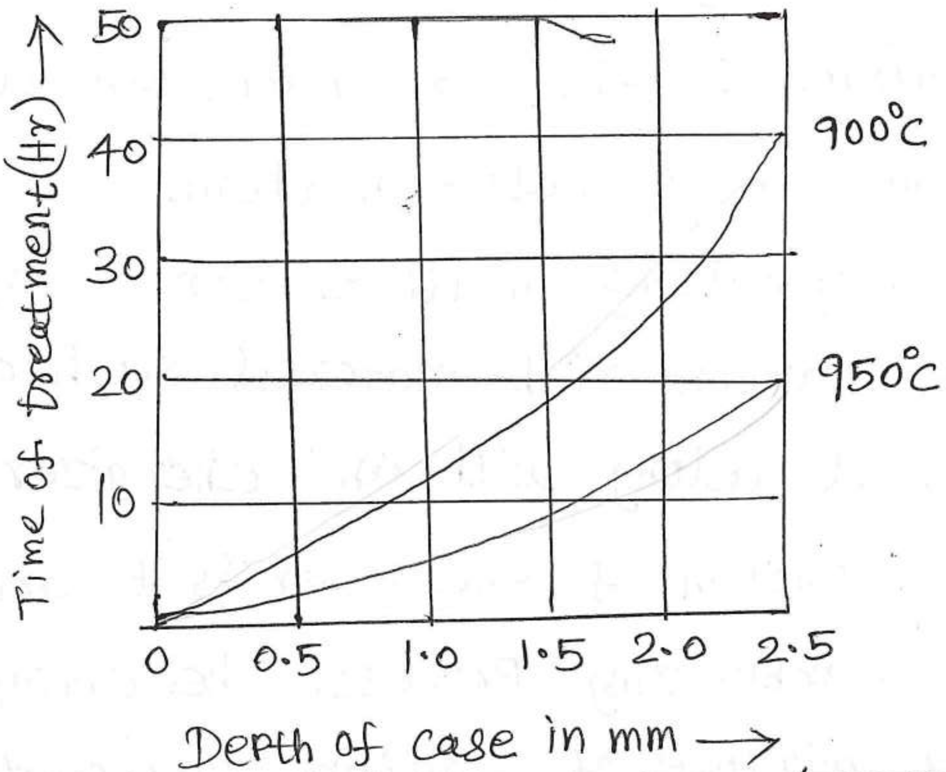
Pack carburizing (or) Solid Carburizing

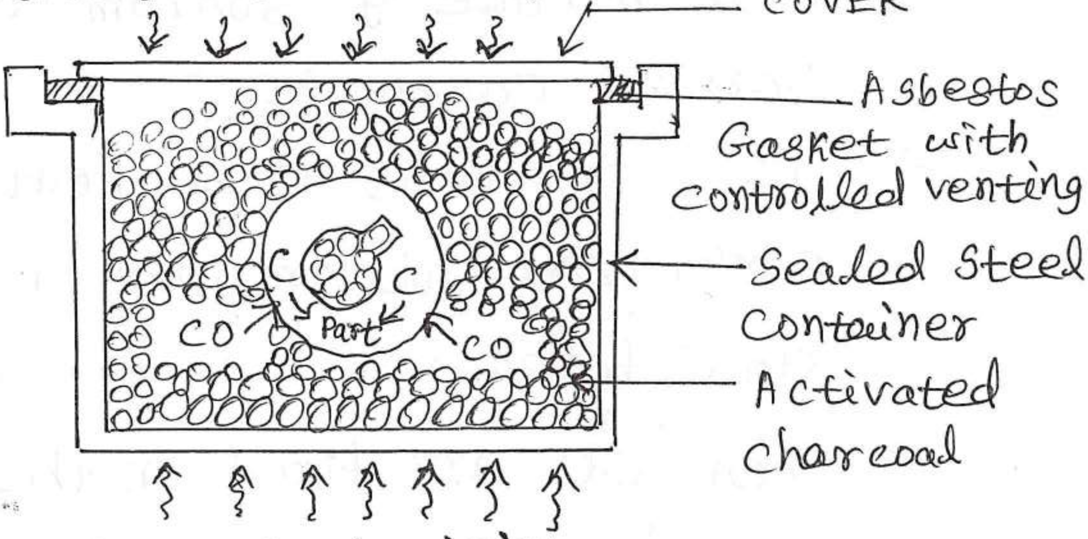
* In pack carburizing the components to be treated are packed into steel boxes along with the carburizing mixture so that a space of roughly 50 mm exists between them.
* The carburizing mixture consists of some carbon rich material such as charcoal along with an energizer.
* The function of energizer is to accelerate the carburizing process. The energizer is a mixture of sodium carbonate and barium carbonate.
* The components to be heat treated and carburizing mixture are packed into steel boxes.
* Then lids are fixed on the boxes.

- Then heat treatment is done at carburizing temperature such as 900°c to 950°c.

- It is maintained at this temperature for upto 6 hours according to the depth of case required.

- Then heat treated components are quenched.





Pack carburizing

$$BaCO_3 \rightleftharpoons BaO + CO_2$$

$$CO_2 + C \rightleftharpoons 2CO$$

$$2CO + 3Fe \rightleftharpoons Fe_3C + CO_2$$

Gas carburizing

* Gas carburizing can be done with any carbonaceous gas. In general natural gas, propane or generated gas atmospheres are most frequently used.

Procedure

* Gas carburizing is carried out in both continuous or batch type furnaces.

* In this process, the components are heated around 900°C in a furnace in which the carburizing gas such as methane, probane or butane is circulated

* The carburizing gas contains CO and hydrocarbons which decompose at red heat and deposit the carbon on the component surfaces.

* The thickness of the case formed depends upon the rate of flow of the gases and the temperature

$$3\,Fe + 2\,CO \rightleftharpoons Fe_3C + CO_2$$

$$Fe_3C + 2\,H_2 \rightleftharpoons 3Fe + CH_4$$

$$3\,Fe + CO + H_2 \rightleftharpoons Fe_3C + H_2O$$

$$CO_2 + CH_4 \rightleftharpoons CO + 2\,H_2$$

$$CH_4 + 3\,Fe \rightleftharpoons Fe_3C + 2\,H_2$$

Liquid carburizing

* It is also known as salt carburizing.
* It is carried out in baths of molten salt which contains 20% to 50% sodium cyanide, 40% sodium carbonate and varying quantities of sodium or barium chloride.
* The cyanide rich mixture is heated in iron pots to a temperature of 870 to 950°C.
* The workpiece which is carried out in wire baskets is immersed for periods of about 5 minutes upwards, according to the depth of case required.

$2\,NaCN + 2\,O_2 \longrightarrow Na_2CO_3 + 2N + CO$

Advantages

- The temperature of the liquid salt bath is uniform throughout
- Temperature can be controlled by pyrometers
- The basket of work can be quenched direct from the bath.
- The surface of the work remains clean

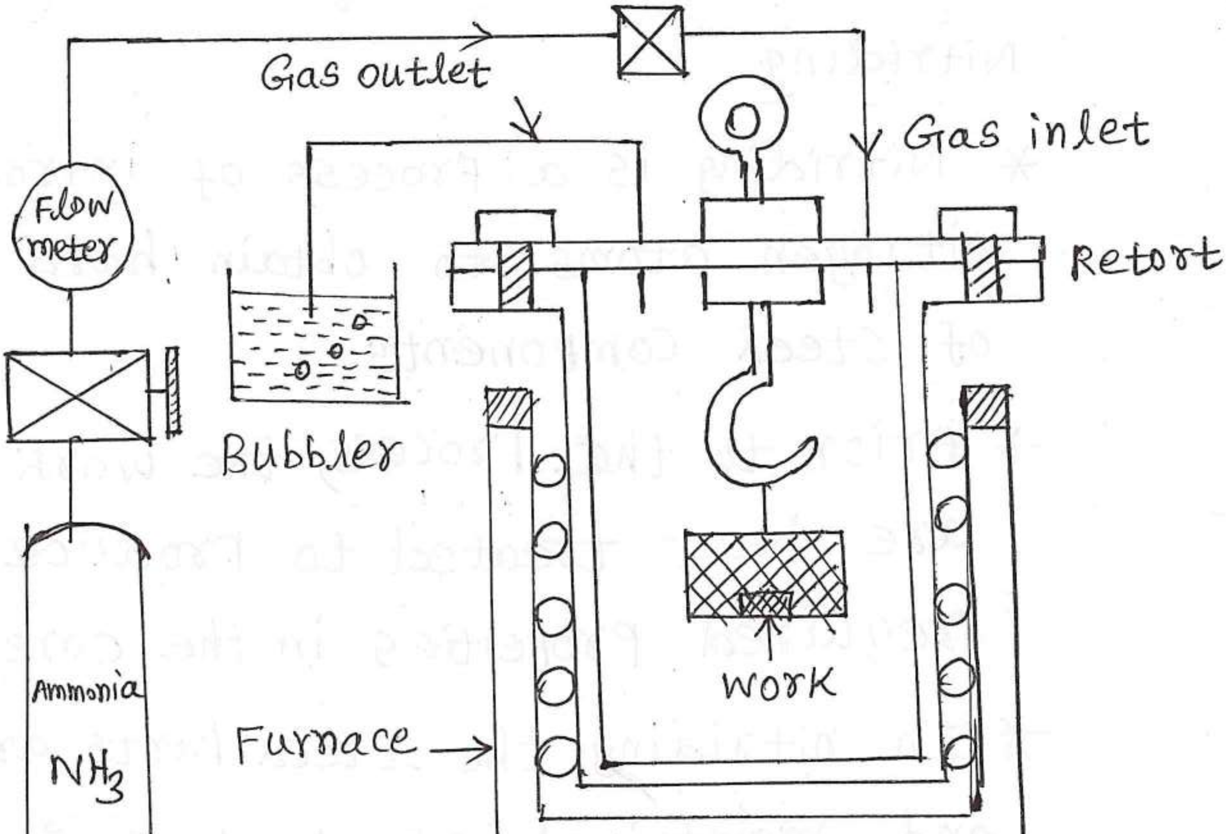
Nitriding

- Nitriding is a process of introducing nitrogen atoms to obtain hard surface of steel components.
- Prior to the process, the work pieces are heat treated to produce the required properties in the core.
- In nitriding the steel parts are heated and maintained at about 500°C for 40 to 100 hours.
- This treatment takes place in a gas tight chamber through which ammonia gas is allowed to circulate.

* Some of the ammonia decomposes and releases single atoms of nitrogen.

$$NH_3 \rightleftharpoons 3H + N(\text{atom})$$

* This atomic form of nitrogen(N) is absorbed on the surface of steel component.
* The resulting nitride case can be harder than carburized steels.



Gas Nitriding system

Advantages:-

* An extremely hard surface is formed.
* The treatment is conducted at low temperature minimising the crack and distortion.

* Hardness of surface layer is increased.
* cheapest Process

cyaniding

* cyaniding also called as liquid carburizing.
* It is a process of introducing both nitrogen and carbon to obtain hard surface of the steel components.
* It is done by immersing the workpiece in a cyanide bath as in liquid carburizing.
* Metals usually hardened by cyaniding Process are Plain Carbon or alloy steels containing around 0.2% carbon.

procedure

* In cyaniding process the steel components are heated in a bath of molten sodium cyanide and sodium carbonate at a temperature of 950°C.
* During this treatment both carbon and nitrogen diffuse into the surface of the steel.

$$2NaCN + O_2 \longrightarrow 2NaCNO$$

$$2NaCNO + O_2 \longrightarrow Na_2CO_3 + CO + 2N \text{ (Atomic)}$$

$$2CO \longrightarrow CO_2 + C \text{ (Atomic)}$$

* After cyaniding the components require quenching to obtain hardness.

* The case depth of 0.1 mm to 0.5 mm may be readily obtained by this process.

Advantages

* It requires less time and lower temperature than carburizing.

* It provides lower warping and distortion of workpiece than carburizing.

* Resistance to corrosion and wear is high.

Disadvantages:-

* It is costly process

* cyaniding bath is toxic.

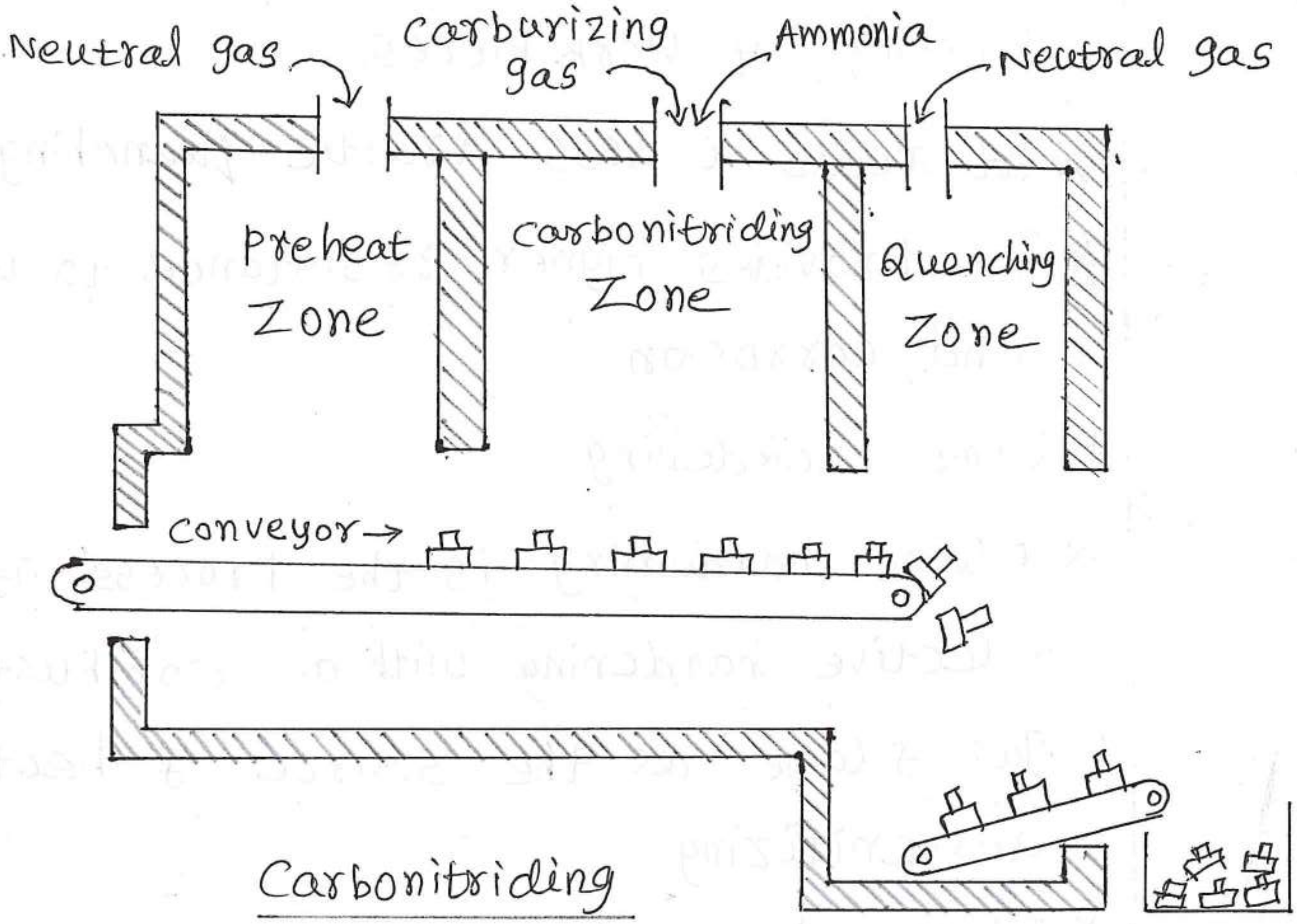
Applications

* Automobile parts such as gears, shafts, pins, brakes, cams, sleeves, springs, etc.

Carbonitriding

* carbonitriding process is carried out in a gas atmosphere furnace using a carburising gas such as propane or methane mixed with ammonia

* The organic gas serves as the source of Carbon and ammonia gas serves as the Source of nitrogen.



Carbonitriding

* The workpiece is heated to 850°C in the mixture of above gases for 2-10 hours.
* This is followed by quenching and tempering is employed at 180°C.
* Now, both Carbon and nitrogen diffuse simultaneously, Carbon diffuse at higher rate.

Advantages:-

* It requires lower heat treating temperatures and hence there is less distortion and warping of work pieces.
* It needs a less drastic quenching
* It provides higher resistance to wear and corrosion

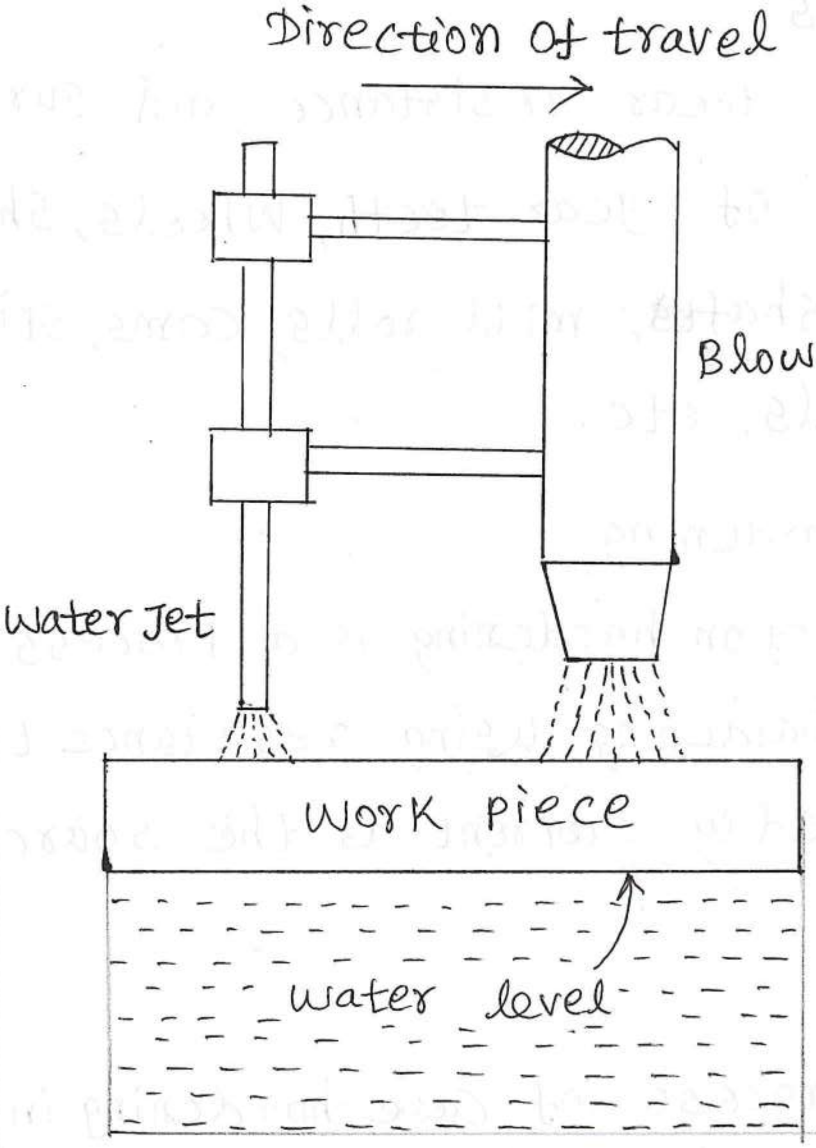
Flame hardening

* Flame hardening is the process of selective hardening with a combustible gas flame as the source of heat for austenitizing
* Flame hardening can be performed only on steels with high carbon content (0.4%c)

Principle of Flame hardening

* The surface to be hardened is heated to a temperature above its upper critical temperature by means of a traveling oxy-acetylene torch.
* Then it is immediately quenched by a jet of water issuing from a supply built into the torch-assembly.

* Thus the surface hardening results when the austenitized surface is quenched by the water spray that follows the flame.



Advantages

* No distortion of work piece because only small section of steel is heated.
* More efficient and economical
* More suitable for small quantities
* cost of equipment is less

Disadvantages

* very thin sections got distorted excessively.
* overheating may cause cracks

Applications

* Improve wear resistance and surface hardness of gear teeth, wheels, sheaves, bushings, shafts, mill rolls, cams, spindles, hand tools, etc.

Induction hardening

* The induction hardening is a process of selective hardening using resistance to induced eddy current as the source of heat

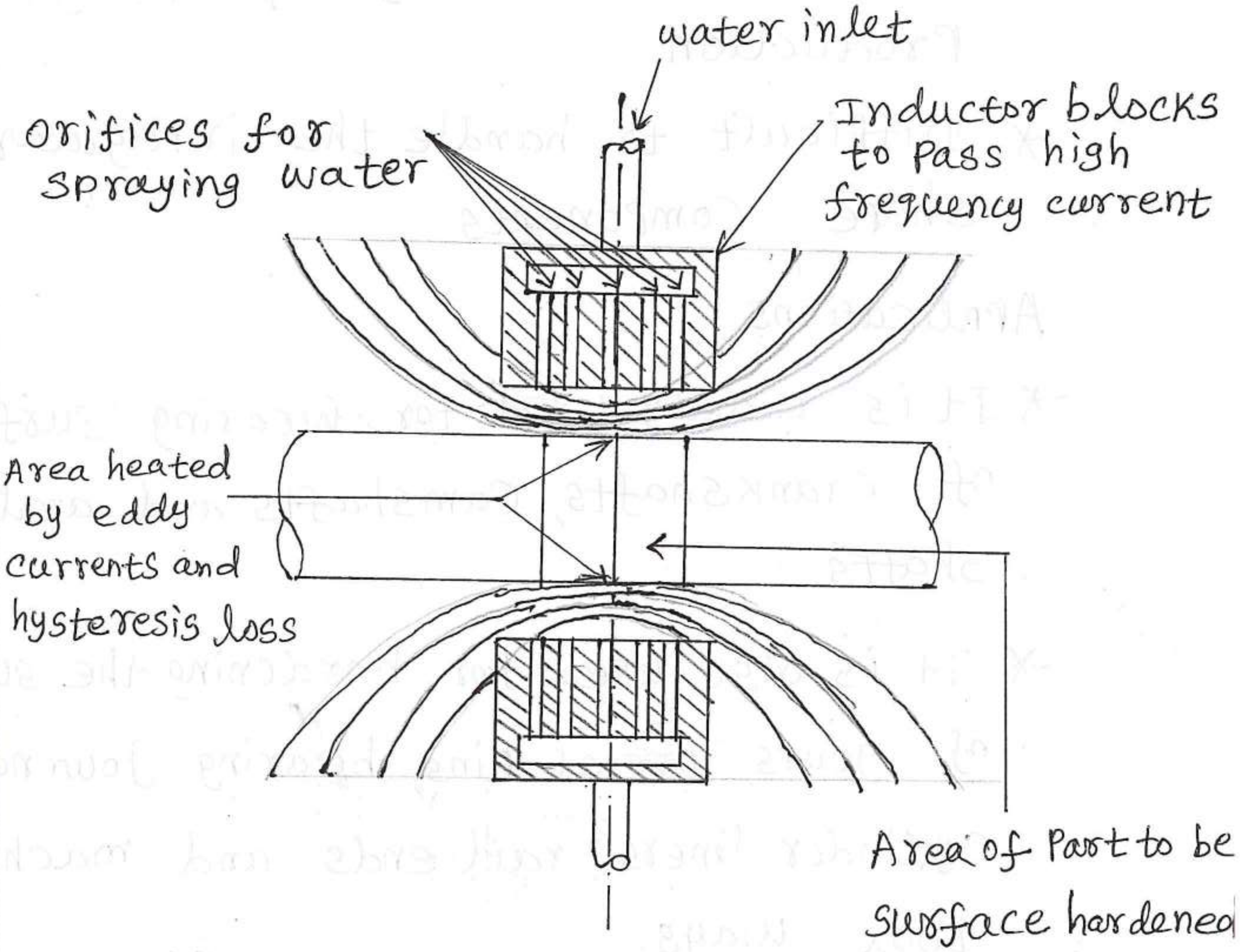
Procedure

* It is a process of case hardening in which the surface to be hardened, is surrounded by a inductor block which acts as an primary coil of a transformer.
* The inductor block is shown in figure. A high frequency current of about 2500 HZ is passed through the inductor block.

* Now the surface is heated due to the induced eddy current and hysteresis loss in the surface of material.

* When the surface attains the hardening temperature (800°C for alloy steels), water is sprayed on the surface through numerous small holes in the block.

* Due to this rapid cooling, a case depth 3mm is obtained in about 5 seconds.



Induction hardening

Advantages

* Case depth can be exactly controlled
* operating cost is less
* It is used for mass production
* Higher hardness and higher fatigue strength is produced

Disadvantages

* Requires large Capital equipment expenditures
* Economical for large quantity Production
* Difficult to handle the irregular shape components

Applications

* It is widely used for wearing surfaces of crankshafts, camshafts and axle shafts.
* It is also used for hardening the surfaces of gears, wrist pins, bearing journals, cylinder liners, rail ends and machine tool ways.

UNIT-III FERROUS AND NON FERROUS METALS

Effect of alloying additions on steel

Manganese (Mn) (0·3 to 2% in alloy Steel)

* Increases the strength and hardness
* Increases hardenability
* Promotes an austenitic structure
* Lowers the critical temperature range.

Silicon (Si) (2% in alloy steel)

* Improves electrical and magnetic properties
* Improves oxidation resistance
* Strengthens low alloy steels
* Increases hardenability of steels

Chromium (Cr) (0·3 to 4% in alloy steel)

* Increases corrosion resistance
* Increases hardenability
* Increases high temperature strength
* Improves the wear resistance

Nickel (Ni) (0.3 to 5% in alloy steel)

* Strengthens the annealed steel
* Toughens the pearlitic & ferritic steels
* Increases hardenability
* Improves resistance to fatigue

Tungsten (W)

*Forms hard and abrasion resistant Particle in tool steels

* Promotes red hardness and hot strength

* Raises the softening temperature

Molybdenum (Mo): (0.1 to 0.5% in alloy steel)

*Improves high temperature creep resistance

*Reduces brittleness in Ni-cr steels

* Stabilizes carbides

* Increases hardenability

Vanadium (v) (0.1 to 0.3% in alloy steel)

* Raises softening temperature of hardened steels

* Increases strength and ductility

* Promotes fine grain size

Titanium (Ti)

*Strong carbide forming element

* Reduces martensitic hardness and hardenability in medium chromium steels

* Prevents formation of austenite in high chromium steels

Aluminium (Al) (Less than 2% in alloy steel)

* Restrict nitride formation
* Restrict grain growth
* Deoxidizes efficiently

Cobalt (Co)

* Increases strength
* Decreases hardenability

Niobium (Nb)

* Strong carbide former
* Increases creep resistance

Copper (Cu) (0.2 to 0.5% in alloy steel)

* Increases strength
* Increases corrosion resistance

Lead (Pb)

* Insoluble in iron
* Improves machinability

Alloy steels :-

1. Stainless steels
2. Tool steels
3. HSLA steels
4. Maraging steels

1. stainless steels :

- * stainless steels are alloys of iron, chromium and other elements.
- * It is highly resistant to corrosion
- * Their predominant alloying element is chromium. (at least 11% Cr)
- * Their corrosion resistance property can be improved by Nickel and Molybdenum additions.
- * chromium form a protective passive film on the steel surface to prevent oxidation.

Properties of stainless steels

- * Good corrosion and oxidation resistance
- * High resistance to scaling
- * High ductility and formability
- * Good weldability and machinability
- * High creep strength

Applications

- * pipings and Heat exchangers
- * Storage tank in chemical industries
- * cutting tools

2. Tool Steels

* Tool steels are used to make tools which are required for cutting and shaping of materials.

Properties of tool steels

* High hardness
* Greater wear resistance
* Good toughness
* High impact strength
* High thermal conductivity
* Low Co-efficient of friction

Types of tool steels

1. Plain carbon steels
2. Low alloy tool steels
3. High speed steels

1. Plain carbon steels

* These steels contain carbon from 0% to 1.4% and are hardened by oil or water quenching.

* They have low cost, good machinability, and high impact resistance

* These Steels are used for Keys, spanners, stamping dies, twist drills, etc.

2. Low alloy tool Steels

* These steels contain alloying elements like Vanadium, chromium, Tungsten and silicon.

* These steels can retain the sharpness and Serviceability of cutting edge than plain carbon steels.

* These steels are widely used for Pneumatic tools, pavement breakers, etc.

3. High speed Steels (HSS)

* High speed steels may be operated as cutting tools at much higher cutting speeds.

* HSS operate at cutting speeds two to three times higher than for carbon steels.

* High speed steels are retain their cutting properties at temperatures up to 600°c.

Applications of HSS

* Lathe, planer and shaping tools, milling and gear cutters, reamers, broaching tools, dies and drills, etc.

3. HSLA Steels (High Strength Low Alloy steels)

- * HSCA steels were developed to improve the strength to weight ratio.
- * HSCA steels have often tensile strength from 600 MPa to 1000 MPa.
- * It contains carbon in the same range as mild steels (0.15% – 0.25%) and other alloying elements
- * The other alloying elements are copper, vanadium, nickel and molybdenum.
- * These steels are ductile, formable and machinable.
- * HSCA steels are designed to provide better mechanical properties.
- * HSCA is stronger than plain carbon steels.

Applications of HSLA

- * HSCA steels are used in cars, trucks, cranes, bridges, roller coasters and other structures

4. Maraging Steels

- Steels with tensile strengths greater than 1000 MPa are called Maraging steels.
- A typical composition of maraging steel is 0.03% C, 18% Ni, 3-8% each of Co and Mo, a fraction of a percent each of Ti and Al.
- Maraging steels are strengthened by a process of martensitic transformation followed by age or precipitation hardening.

Properties of maraging steels

- Ultra-high strength at room temperature
- Simple heat treatment which results in minimum distortion

- Superior fracture toughness
- Easy fabrication and good weldability

Applications

- Shafts, clutches, rocket casing and other aerospace applications
- Extrusion press rams, mandrels in tube production and gears.

Cast iron

* Cast iron is a class of ferrous alloys with carbon content above 2.14 wt%.
* Low tooling and production cost
* Good machinability without burning
* Ability to cast into complex shapes
* Excellent wear resistance and high hardness
* High damping capabilities

Composition of cast iron

Carbon 3% - 4%
Silicon 1% - 3%
Manganese 0.5% - 1%
Sulphur up to 0.1%
Phosphorus up to 1.0%

Types of cast iron

1. Grey cast iron
2. White cast iron
3. Malleable cast iron
4. Spheroidal Graphite cast iron
5. Alloy cast iron

1. Grey cast iron

* Grey cast iron is the oldest and most common form of cast iron.

* The composition of grey cast iron is mentioned below.

Carbon	3% to 3.5%
Silicon	1% to 2.75%
Manganese	0.4% to 1%
Phosphorus	0.15% to 1%
Sulphur	0.15% to 1%
Iron	Remaining content

* Its fracture has a grey appearance

* The grey colour is due to the fact that carbon is present in the form of free graphite.

* It contains carbon in the form of flake graphite in a matrix which consists of ferrite, pearlite or a mixture of the two.

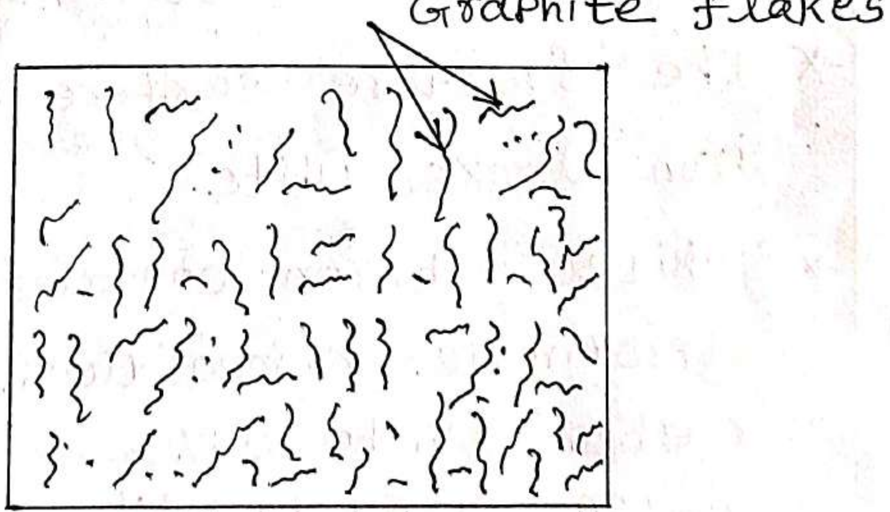
* The presence of graphite flakes gives grey cast iron with excellent machinability and self-lubricating properties.

Properties of grey cast iron

* Excellent machinability
* Low ductility
* Impact resistance is low
* Damping capacity is high
* High thermal conductivity
* Excellent dry and normal wear properties

Advantages of grey cast iron

* Graphite acts as a chip breaker and a tool lubricant
* very high damping capacity
* After formation of protective scales, it resists corrosion in many common engineering environments.



Grey cast iron

Disadvantages

- Low impact strength
- Graphite acts acts as a void and reduces strength
- more expensive to produce the high strength grey cast iron

Applications of grey cast iron

- Erection of machinery
- Locomotive and internal combustion engine cylinder blocks
- Flywheels, car wheel drums and Agricultural components.

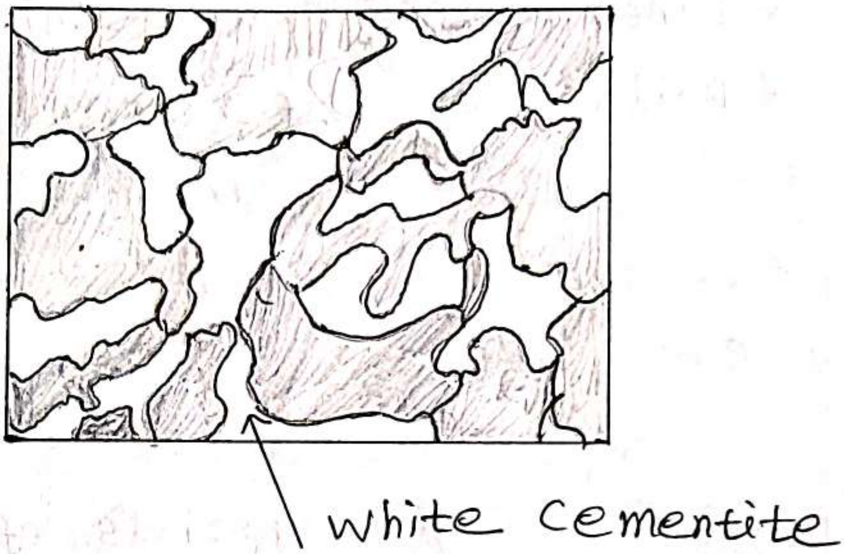
2. white cast iron

- In white cast iron, the carbon is present in the combined form and the alloy is called white cast iron.
- The fracture surface of this cast iron looks white.
- white cast iron contains the following approximate compositions.

carbon	2% to 2.3%
Silicon	0.85% to 1.2%
manganese	0.1% to 0.4%
Phosphorus	0.05% to 0.2%
Sulphur	0.12% to 0.35%

- carbon is in the form of carbide in this white cast iron

microstructure of white cast iron



white cast iron

Properties of white cast iron

- It is very hard and brittle
- High compressive strength
- It is very hard. so, maching is difficult

Advantages

- Extremely hard
- Abrasion resistant

Disadvantages

- It cannot be machined easily
- It is very brittle

Applications of white cast iron

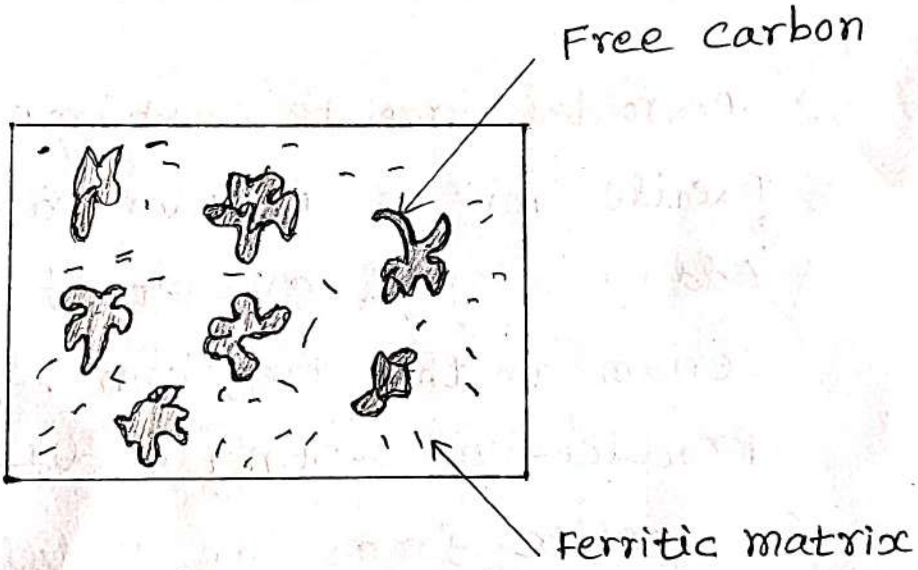
- Used for inferior castings
- Balls for grinding mills
- Liners for cement mixers
- Boils for paper manufacture

3. Malleable cast iron

- If cast iron is cooled rapidly, white cast iron forms.
- This white cast iron is reheated to about 1700°F for long periods of time in the presence of materials containing oxygen, such as iron oxide.
- At high temperature, cementite decomposes to small compact particles of graphite.
- If the cooling is very slow, more free carbon is released.
- Figure shows the ferritic malleable cast iron, which has a ferrite matrix and the tempered carbon particles are embedded into the matrix.
- Malleable cast iron contains 2.5% carbon, 1% silicon and remaining are other impurities like manganese, sulphur, and phosphorus.

- A wide variety of physical properties for malleable cast iron can be obtained by heating and cooling the white cast iron by adding alloying elements.
- Malleable cast iron can be ferritic or Pearlitic depending upon the cooling rate.

Microstructure of malleable cast iron



Advantages of Malleable cast iron

- Excellent machinability
- Reasonable ductility
- Good shock resistance Properties
- High resistance to corrosion
- High Strength and toughness

Disadvantages

- Malleable cast iron decreases in volume during Solidification.

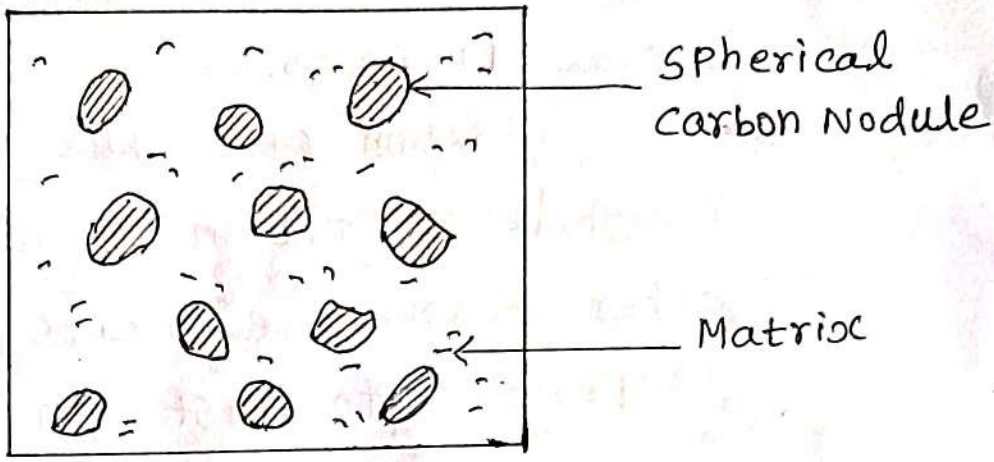
Applications of Malleable cast iron

* Connecting rods, universal joint yokes, Transmission gears, compressor crankshaft and hubs.
* Flanges, pipe fittings, valve parts for rail road, marine and other heavy duty applications.

4. Spheroidal Graphite Cast Iron (Nodular cast iron)

* Spheroidal Graphite Cast iron is also called Ductile iron or Nodular cast iron.
* Adding a small amount of Magnesium and cerium to the grey iron before casting produces a distinctly different microstructure.
* Graphite forms as nodules or sphere like particles instead of flakes.
* In this cast iron, the carbon varies from 3.2% to 4.1% and sulphur is added less than 0.02%.
* The matrix phase surrounding these sphere like particles is either pearlite or ferrite depending on heat treatment.

Microstructure of Spheroidal Graphite cast iron



Spheroidal Graphite cast iron

Properties of Spheroidal Graphite cast iron

* High fluidity
* High Strength and ductility
* Good machinability and weldability
* Good wear resistance
* Good resistance to fatigue

Advantages of spheroidal Graphite cast iron

* High ductility with more than 18% elongation.
* High tensile strength
* High performance at low cost
* Low Shrinkage during casting

Applications of spheroidal Graphite cast iron

* Cast iron pipes, crank shafts, connecting rods, Truck axles, Front wheel Spindle supports, suspension system components, power transmission yokes and wheel hubs.

5. Alloy cast iron

- Alloy cast irons are developed for Special Purposes.
- The addition of nickel, chromium, molybdenum, titanium, silicon, copper and other alloying elements gives special properties to cast iron
- The reason for using nickel in cast iron is to obtain density and pressure tightness in castings with large and varying sections.
- cast iron alloyed with 10% nickel and 6% manganese becomes non-magnetic.

Properties of Alloy cast iron

- High oxidation resistance
- High corrosion resistance
- High wear resistance
- High temperature resistance

Applications of Alloy cast iron

- Nickel cast iron is used in cylinder liners, caustic pots, pipes, etc.
- chromium cast iron with nickel is used in pumps, pistons and piston rings, crank cases and brake drums

Copper

*It is one of the most widely used non-ferrous metal.

* It is highly resistance to corrosion

* Most of the copper alloys cannot be hardened by heat treatment process.

* copper may be cast, forged, rolled and drawn into wires.

properties of copper

*Excellent resistance to corrosion

* Non- magnetic properties

* High thermal and electrical conductivity

* very good machinability

* It canbe soldered, welded and brazed.

Applications of copper

*It is used to make electrical parts like wire, switches, etc.

* Heat exchanges tubes, steam pipes and condensor.

Copper alloys

Brass (copper-zinc alloys)

* The most widely used copper zinc alloy is brass.

* It is a binary alloy of copper with zinc each 50%

* By adding small quantities of other elements, the properties of brass may be greatly changed.

Properties of brass

* The melting point of brass ranges from 800°C to 1000°C

* The metal is soft, ductile, high tensile strength and good surface finish characteristics

* It is non-magnetic and poor conductor of electricity

Applications

* Jewellery, cartridge casings, automotive radiators and musical instruments.

* Ornamental fittings, Plumbing fittings, screws and bullets

Bronze

* The alloys of copper and tin are usually termed as bronzes.
* The usual range of composition is 75 to 95% copper and 5 to 25% tin.
* Bronzes are alloys of copper, tin, aluminium, silicon and nickel.
* The metal is comparatively hard and rolled into wires, rods and sheets very easily.
* Some common types of bronze are given below

1. Phosphor bronze
2. Silicon bronze
3. Beryllium bronze
4. Manganese bronze

1. Phosphor bronze

* A common type of phosphor bronze has the following composition

Copper 87% to 90%
Tin 9% to 10%
Phosphorus 0.1% to 0.3%

* This metal is resistant to salt water corrosion

* It is used for bearings, worm wheels, gears, nuts for machine lead screws, pump parts, linings and springs.

2. Silicon bronze

* It contains 96% copper, 3% silicon and 1% manganese or zinc
* corrosion resistance properties are good
* It can be cast, rolled, stamped, forged and pressed either hot or cold.
* It can be welded by usual methods.
* It is widely used in boilers, tanks, etc.

3. Beryllium bronze

* It contains 97.75% copper and 2.25% beryllium
* It has high yield point, High fatigue limit and excellent corrosion resistance.
* wear resistance of beryllium copper is 5 times that of Phosphor bronze.
* It is widely used in springs, heavy duty electrical switches, cams and bushes.

4. Manganese bronze

* It contains 60% copper, 35% zinc and 5% manganese
* High resistant to corrosion

* It is harder and stronger than Phosphor bronze

* It is generally used for bushes, plungers, feed pumps, rods, etc.

* Worm gears are frequently made from Manganese bronze.

Cupronickel (copper-nickel alloy)

* Cupronickel is an alloy of copper, nickel, iron and manganese.

* Cupronickel does not corrode in seawater.

* Cupronickel is used in thermocouples.

* 55% copper and 45% nickel alloy is used to make very accurate resistors

* It is used for marine hardware, propellers, crankshafts, fishing boats and hulls of premium tug boats.

* It is also used for bullet envelopes due to its high ductility and corrosion resistance.

* Most of the silver coins are coated with cupronickel.

Aluminium

* It is a light metal, with a density about one third that of steels.

* It is a very good conductor of electricity

* It is very soft and ductile

* Good corrosion resistance

* Low specific gravity

Properties of Aluminium

Melting point - 660°C

Crystal structure - FCC (Face centred cubic)

Tensile Strength - 45 MPa

Electrical resistivity - $2.66 \times 10^{-8}\ \Omega m$

Corrosion resistance - Excellent

Density - $2.7 \times 10^{3}\ Kg/m^3$

Applications

* It is used for making Aeroplane parts, house hold items, electric wires, furniture, Surgical instruments and foils.

* It is used in chemical plants and food processing equipment due to its corrosion resistance.

* It is also used for making paints in the form of powder.

Aluminium alloys

* To make the aluminium casting, aluminium is alloyed with small amounts of copper and Zinc in the proportion of

* 12.5 to 14.5% Zinc and

* 2.5 to 3% Copper

* Casting and forging alloys having high strength used in aeroplane construction. That Aluminium alloy is in the proportion of

* zinc 5%, magnesium 3%

* copper 2.2%

* Nickel up to 1%

Al-cu alloys

* There are two important Al-cu alloys

1. Duralumin
2. Y - alloy

1. Duralumin

* An important wrought alloy is duralumin.

* This is composed of major proportion of aluminium, 3.5 to 4.5% copper, 0.4 to 0.7% manganese and 0.4 to 0.7% magnesium

- It is an important Al-cu alloy due to its age-hardening property.
- After working, if the metal is allowed to age for 3-4 days, it will be hardened. This phenomenon is called age-hardening.

2. Y- alloy

- Y-alloy contains copper, nickel and magnesium.
- This alloy contains 3.5 to 4.5 % copper, 1.8 to 2.3% nickel and 1.2 to 1.7% magnesium.
- This alloy provides good strength at high temperature.
- It is widely used in the form of sheet and strip.
- After proper heat treatment, it may be brought to minimum tensile strength of 350 N/mm^2.
- Y-alloys are used for pistons and other components in aero-engines.

Bearing alloys

* If the metal alloys are used to make bearings, then they are called bearing alloys.

Properties of bearing alloys

* Bearing alloys have high thermal conductivity.
* Good resistance to corrosion and casting qualities.
* sufficient hardness, wear resistance and low co-efficient of friction.
* They are tough and shock resistant

classification

* Bearing alloys are classified as follows.

1. White metals
2. copper-base bearing alloys
3. Aluminium base alloys
4. Plastic materials
5. Ceramics

* Those alloys in which tin, lead and Cadmium are predominating elemenes are designated as white metal bearing alloys.

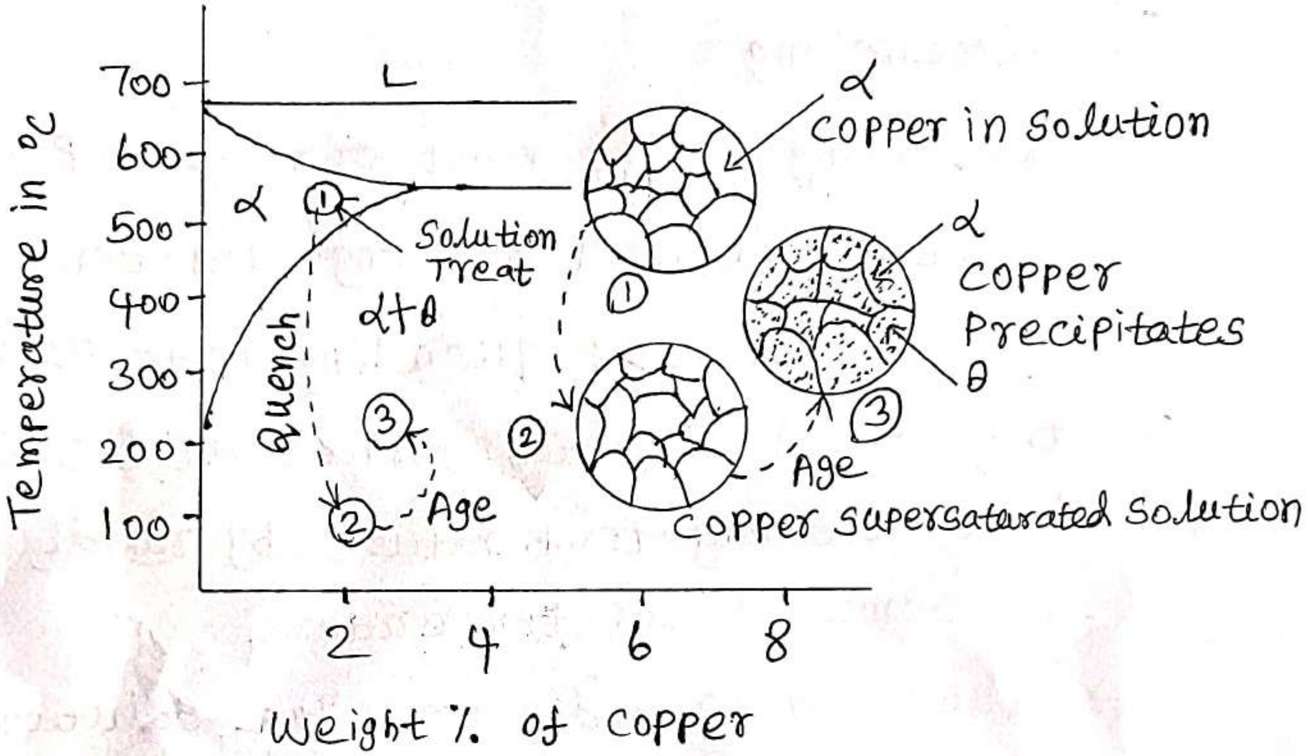
* copper-base bearing alloys are harder and stronger than white metals.

* This alloy is used for bearings which is required to resist heavier pressures.
* Tin-base white metals are used where bearings are required high pressure and load. Lead-base alloys are used for the same properties.
* Cadmium base bearing alloys are especially used at elevated temperatures.
* The compressive strength of cadmium base bearing alloys are greater than tin-base alloys.

Precipitation hardening

* In designing alloys for strength to develop an alloy with a structure that consists of particles dispersed in a ductile matrix.
* Such a dispersion can be obtained by choosing an alloy that is in single phase at elevated temperatures.
* When alloy is strengthened by this thermal treatment is called precipitation hardening.
* Precipitation hardening of Cu-Al alloy consists of three main steps.

1. Solution treatment
2. Quenching
3. Age hardening



* The precipitation hardening process for a Cu-Al alloy is shown graphically.
* The phase diagram is simply a map showing the structure of phases present as the temperature and overall composition of the alloy are varied.

1. Solution heat treatment

* For precipitation hardening reaction, necessary to produce a solid solution.
* The main objective is to take the maximum amounts of soluble elements in the alloy into solid solution.

* The process consists of soaking the alloy at a temperature sufficiently high and for a period long enough to achieve a nearly homogeneous solid solution.

2. Quenching

* Quenching is the most critical step in the sequence of heat treating operations.
* The objective of quenching is to preserve the solid solution formed at the solution heat-treating temperature, by rapidly cooling to some lower temperature.
* Quenching rapidly cools the solution and freezes the atoms in solution.
* The quenching cools the material so fast that the atoms of the alloying elements do not have time to diffuse out of the solution.

3. Age hardening (Ageing)

* Ageing is the process where the solute particles diffuse out of solution and form into clusters that distort and strengthen the material.
* After solution treatment and quenching, hardening is achieved either at room temperature or with a precipitation heat treatment.

- In some alloys, sufficient precipitation occurs in a few days at room temperature to yield stable products with properties that are adequate for many applications.
- These alloys are precipitation heat treated to provide increased strength and hardness in wrought or cast products.
- Precipitation heat treatments are low-temperature and long-term processes.
- Temperatures range from 115°c to 190°c and time varies from 5 to 48 hours.

UNIT IV

NON - METALLIC MATERIALS

INTRODUCTION

In the previous unit we have discussed about the ferrous and non-ferrous materials that are widely used in engineering applications. In addition to these engineering materials there are a number of non-metallic materials which have substantial importance in engineering practices. The most important non-metallic materials include polymers [such as plastics, rubbers and adhesives], ceramics and composites.

In recent decades there is a large increase in the polymer materials. Polymers are widely used in number of applications, including toys, home appliances, structural and decorative items, coatings, paints, adhesives, automobile typres, foams and packaging. In the same way ceramic materials are used in varried engineering applications including tools for grinding and cutting, seals, bearings and other components for engines and pumps.

The composite engineering materials are used to produce a wide range of products varying from those used in high-strength aircraft components to road building tarmacadam and concrete.

POLYMERS:

Almost all biological systems are built of polymers, which not only perform mechanical functions [like wood, bone, cartilage, leather] but also contain and regulate chemical reactions [Leaf, veins, cells]. People have used these natural polymers for thousands of years now. Many of our useful plastics, rubbers and fibre materials are synthetic polymers.

CHARACTERISTICS OF POLYMERS:

① Low density

② Good thermal and electrical insulation properties.

③ High resistance to chemical attack.

④ Ease of fabrication

⑤ Relatively low cost.

Some of the disadvantages of polymer materials are

① Low strength

② Low elastic modulus values

③ Low softening temperatures.

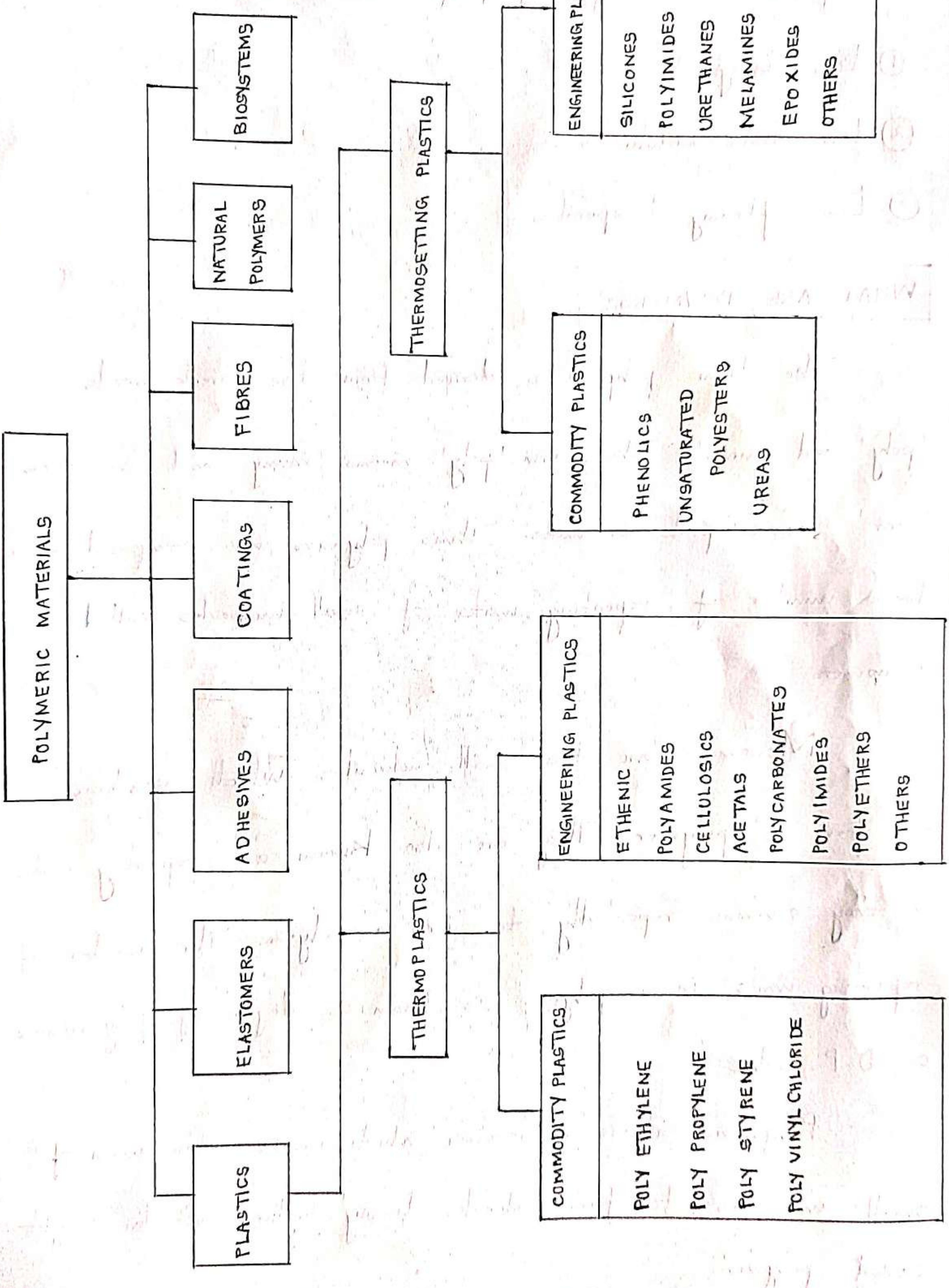
WHAT ARE POLYMERS?

The term polymer is derived from two Greek words 'poly' and 'mers'. The term 'poly' means 'many' and the term 'mer' means parts or units. Thus polymers are composed of a large number of repeating units of small molecules called monomers.

Monomers are the small molecules which combine to form a polymer. They are also Known as repeating units as they combine repeatedly to form a polymer. The number of repeating units in a polymer is known as degree of polymerisation or D.P. value.

Polymerisation is a reaction which involves the union of small molecules to form molecules having higher molecular weight called polymer.

CLASSIFICATION OF POLYMER:



TERMINOLOGY USED IN POLYMERS:

① Monomer:

It is a small molecule consisting of a single mer i.e., a single unit / blocking block.

② Polymer:

It is a macromolecule formed by the repeated linking of many monomers.

③ Polymerisation:

It is the process of forming a polymer.

④ Homopolymer:

It is a polymer made out of identical monomer.

⑤ Copolymer:

It is a polymer which is obtained by adding different types of monomers.

⑥ Degree of polymerisation:

It is the number of repetitive units present in one molecule of a polymer. It is a parameter used to designate the average chain size of a polymer.

⑦ High-polymers:

Solid polymers which have very high molecular weights (ranging between 10,000 and 1,000,000 g/mol) are called high-polymers.

⑧ Oligo-polymers:

Oligo-polymers or oligomers are liquid / gas polymers with very short chains

TYPES OF HOMOPOLYMERS:

⑨ Linear polymers:

Linear polymers are those in which the mer units are joined together end to end in single chains.

⑩ Branched polymers:

Branched polymers are those in which side-branch chains are connected to the main ones.

⑪ Cross-Linked polymers:

In cross-linked polymers, adjacent linear chains are joined one to another at various positions by covalent bonds.

⑫ Network polymers:

Network polymers have three active covalent bonds which form three dimensional network instead of the linear chain framework.

TYPES OF COPOLYMERS:

⑬ Random copolymer:

In this the two different units are randomly dispersed along the chain.

⑭ Alternating copolymer:

In this the two mer units alternate chain positions.

⑮ Block copolymer:

In this the identical mers are clustered in blocks along the chain.

⑯ Graft copolymer:

In this homopolymer side branches of one type may be grafted to homopolymer main chains that are composed of a different mer.

⑰ Isomerism:

It is a phenomenon wherein different atomic configurations are possible for the same configuration.

POLYMERISATION:

It is the process of forming a polymer by linking together of monomers. The polymerisation mechanism can be divided into two categories as

① Addition polymerisation and

② Condensation polymerisation

ADDITION POLYMERISATION:

Addition polymerisation also known as chain reaction polymerisation is a process by which two or more chemically similar monomers are polymerised to form long chain molecules.

THREE STAGES IN ADDITION POLYMERISATION:

① Initiation

② Propagation and

③ Termination.

CONDENSATION POLYMERISATION:

Condensation polymerisation also known as step-growth polymerisation is the formation of polymers by stepwise intermolecular chemical reactions that normally involve at least two different monomers.

POLYMER ADDITIVES:

Polymers use additives to improve their properties and performance.

Additives are added to polymers

① To improve mechanical properties.

② To reduce the cost.

③ To improve the thermal processing such as moldability

④ To improve surface and chemical characteristics.

⑤ To improve the appearance and aesthetic properties.

The various polymer additives include:

① Filler materials - Wood flour, Silica flour, sand, glass

② Plasticizers - Polyvinyl chloride, adipates, acetate copolymers.

③ Stabilizers - Hindered amines, benzophenons.

④ Colorants - Metal oxides, dyes, carbon, etc.,

⑤ Flame retardants - Antimony oxide, borates, reactive bromates

⑥ Reinforcements - Carbon fiber, glass fiber, fabrics

⑦ Lubricants - Silicone, waxes, glycerides, etc.,

PLASTICS:

A plastic may be defined as an organic polymer which can be moulded into any desired shape and size with the help of heat, pressure or both.

NATURAL PLASTICS:

The plastics which are available as such in the nature are called natural plastics. Examples are resins, lac and casein.

SYNTHETIC PLASTICS:

The plastics which are prepared artifically are called synthetics. Examples are urea, polystyrene, acrylic.

SOURCES OF RAW MATERIALS FOR PLASTICS:

① Animal and vegetable by-products

② Coal by products.

③ Petroleum by products.

CLASSIFICATION OF PLASTICS:

① Thermoplastics

② Thermosetting plastics.

① THERMOPLASTICS:

Thermoplastics are also known as thermoplasts are the plastics whose plasticity increases with the increase in temperature. It soften when heated and harden when cooled. They are soft and ductile.

<u>Examples are</u>

Polythenes
Polystyrenes
Polyvinyl
Acrylics

② THERMOSETTING PLASTICS:

Thermosetting plastics are also known as thermosets are plastics which become permanently hard when heat is applied and do not soften upon subsequent heating. They are stronger, harder, more brittle, more resistant to heat and solvents than thermoplastics.

Examples are

① Polyesters

② Phenolic

③ Urea formaldehyde

④ Epoxides

HYDROCARBON PLASTICS:

① POLYETHYLENE (PE)

* Polyethylene also known as polythene is made by the polymerisation of ethene i.e., ethylene $CH_2 = CH_2$.

* It is made from petroleum or natural gas feed stocks.

TYPES:

① Low density polyethylene (LDPE)

② High density polyethylene (HDPE)

③ Linear low density polyethylene (LLDPE)

④ Ultra-high-molecular weight polyethylene (UHMWPE)

CHARACTERISTICS:

① They have excellent resistance to most solvents and chemicals.

② They are tough and flexible

③ Non-toxic

④ Possess good electrical insulation properties.

APPLICATIONS:

Toys, seals and gaskets, flexible bottles.

② POLYPROPYLENE (PP)

Polypropylene is formed by from the monomer propene i.e., propylene $[CH_2 = CH - CH_3]$

CHARACTERISTICS:

* They are stiffer, harder and stronger than PE
* Have excellent fatigue resistance
* Light in weight.
* Have good chemical and thermal resistance
* Low cost.

APPLICATIONS:

Extruded pipes, bottle caps.

③ POLYSTYRENE (PS):

Polystyrene is made from ethyl-benzene.

CHARACTERISTICS:

* They are low cost, brittle, glassy, transparent polymers.
* They have excellent moldability
* Good dimensional stability

TYPES:

① HIPS [High Impact Polystyrene]

② ABS [Acrylonitrile-Butadiene-Styrene]

③ SAN [Styrene-Acrylonitrile]

APPLICATIONS:

Lighting panels, Egg boxes.

④ POLYVINYL CHLORIDE (PVC)

PVC is made by polymerisation of the monomer vinyl chloride [$CH_2 = CHCL$]

CHARACTERISTICS:

- * They are good low cost
- * Rigid, but can be made flexible with plasticizers.
- * They are often copolymerised.
- * Good flame, electrical, chemical, oil, abrasion and weather resistance.

TYPES:

① Unplasticised PVC (UPVC)

② Plasticised PVC (PPVC)

③ Chlorinated PVC (CPVC)

④ Polyvinylidene chloride (PVDC)

APPLICATIONS:

Pipes, valves, fittings, phonograph records.

⑤ POLYTETRAFLUORO ETHYLENE (PTFE)

PTFE is the most widely used fluorocarbon polymer.

CHARACTERISTICS:

- * They are chemically inert
- * They have excellent electrical properties
- * They have low co-efficient of friction
- * They possess relatively weak and poor cold-flow properties

Other fluorocarbon polymers are

① Polyvinylidene fluoride (PVDF)
② Polyvinyl fluoride (PVF)
③ Perfluoro alkoxy ethylene (PFA)

APPLICATIONS:

Anti-corrosive seals, chemical pipes and valves, high temperature electronic parts.

⑥ POLYMETHYL METHACRYLATE [PMMA]

PMMA also commonly known as perspex or plexiglass is produced by the addition polymerisation of methyl methacrylate.

CHARACTERISTICS:

- * They are hard, rigid and high impact strength thermoplastic
- * Highly transparent to light
- * Can be easily formed
- * Can be readily coloured and have excellent decorative properties.

APPLICATIONS:

Camera lens, Flash lights, Safety glasses, drafting equipments.

⑦ POLYACRYLONITRILE (PAN)

PAN is an acrylic polymer made by the addition polymerisation of acrylonitrile.

CHARACTERISTICS:

- * They are highly stable material.
- * Have Good resistant to oils and greases.

APPLICATIONS:

Used for synthetic fibre manufacture.

(8) POLYAMIDES (PA):

PA also known as nylons are the products of condensation reactions between an amine and an organic acid. They are designated as nylon 6, nylon 6/6, nylon 6/10, nylon 6/12, nylon 11 and nylon 12.

CHARACTERISTICS:

- Crystalline thermoplastics with good mechanical properties.
- Very strong and tough.
- Good abrasion resistance
- High impact strengths.
- High softening temperatures, so moulding is difficult
- Good resistance to solvents and chemicals, but affected by phenols
- Tend to absorb water.

APPLICATIONS:

Many automotive parts, fibres, ropes, gears, cam

⑨ ACETAL (POM) :

It is also known as polyacetal and polyoxymethylene based on polymerisation of formaldehyde.

CHARACTERISTICS

- * Have good strength, stiffness, toughness
- * Low co-efficient of friction
- * Have outstanding fatigue life and solvent resistance
- * Retain their properties at temperatures upto 120°C.

APPLICATIONS:

Pens, Bearings, Gears, Cams.

⑩ POLYCARBONATE (PC)

PC is a linear heterochain polymer made from the condensation of bisphenol A and carbonic acid.

CHARACTERISTICS:

- * Have very good impact resistance and ductility
- * Dimensionally stable
- * Transparent and low water absorption materials.

* Low fatigue and weak resistance

* Can be attacked by organic solvents and are susceptible to stress cracking

APPLICATIONS:

Safety helmets, shields and goggles, lenses, CDs, sterilisable medical components.

(11) POLYETHYLENE TERAPHTHALATE (PET):

PET also known as polyester or PETP is a linear polyester made by the condensation polymerisation of ethylene glycol and teraphthalic acid.

CHARACTERISTICS:

* High strength, high stiffness thermoplastics
* Produced as fibres, as transparent films and as moulding materials.
* Have excellent fatigue and wear strength.
* Possess good resistance to humidity, acids, greases, oils and solvents.

* Can be reinforced with glass fibre.

APPLICATIONS:

Photographic films, recording tapes, soft drink bottles, domestic goods and automotive components.

⑫ POLYETHER ETHER KETONE (PEEK)

PEEK is a linear- crystalline hetero-chain polymer.

CHARACTERISTICS:

* Melting point is as high as 330°C.

* Low flammability

* Good fatigue and chemical resistance

* Good dimensional stability

* Possess better mechanical properties.

APPLICATIONS:

Aerospace applications, High temperature engineering components.

(13) POLYPHENYLENE OXIDE (PPO)

PPO is an amorphous linear heterochain polymer.

CHARACTERISTICS:

- * Possess good mechanical properties
- * Low mould shrinkage
- * Very good dimensional stability
- * Good resistance to hydrolysis.

APPLICATIONS:

Computer components, Washing machine components.

(14) POLYPHENYLENE SULPHIDE (PPS):

PPS is a linear heterochain polymer. PPS is similar to PPO.

CHARACTERISTICS:

- * Good resistance to chemicals and solvents.
- * Good flame resistance
- * Difficult to pigment.

APPLICATIONS:

Pumps, pipes, gaskets, electronic components.

(15) POLYIMIDES (PI):

PI are a group of linear aromatic polymers. Produced by a condensation reaction between pyromellitic dianhydride and a diamine.

CHARACTERISTICS:

- * Good mechanical properties.
- * Excellent thermal resistance
- * Good resistance to organic solvents.
- * Transparent to microwaves and not affected by radiation

APPLICATIONS:

Printed circuit boards, Fibres for space shuttle and adhesives.

(16) POLYAMIDE - IMIDE (PAI)

PAI similar to PI is also a linear aromatic polymer for use at higher temperatures.

CHARACTERISTICS:

* Expensive
* Attacked by alkalis.

APPLICATIONS:

Valves, bearings, components for gas turbine and spark ignition engines.

⑰ POLYFORMALDEHYDE (PF)

Phenolics are based on phenol and formaldehyde. Also termed as phenol formaldehyde (PF)

CHARACTERISTICS:

* They are hard, rigid
* Low thermal conductivity and good electrical insulation properties.
* Good resistance to oils, greases
* Low cost

APPLICATIONS:

Electrical plugs, sockets, switches, telephones

(18) UREA FORMALDEHYDE (UF)

UF is produced by condensing urea monomers with formaldehyde.

CHARACTERISTICS:

* Similar to phenolics
* Hard and rigid
* Good electrical insulation properties.
* Good resistance to chemicals.
* Light in colour.

APPLICATIONS:

Bottle caps, cups, saucers, plates

CERAMICS:

The word ceramic derives from the Greek 'Keramos' which means 'burnt stuff' or pottery.

CHARACTERISTICS:

① They are non-metallic

② Strong, hard, brittle

③ Possess high melting / temperature

④ Good thermal and electrical insulators

⑤ Resistant to oxidation and corrosion.

⑥ High compressive strength

ENGINEERING CERAMICS:

Also known as technical / industrial ceramics or advanced ceramics. They are mainly oxides, carbides, sulphides and nitrides of metals.

CHARACTERISTICS:

- * High resistance to abrasion and wear
- * High strength at high temperature.
- * Good chemical stability
- * Good electrical insulation characteristics.

① ALUMINA (Al_2O_3):

* Alumina is nothing but an aluminium oxide. It is produced from bauxite ($Al_2O_3 \cdot 2H_2O$) which is the main ore from which metallic aluminium is manufactured.

CHARACTERISTICS:

* Have excellent hardness, wear resistance and chemical inertness properties
* More stiffer than steels
* More stronger in compression
* Possess very good environmental resistance.
* Poor Thermal conductors.
* Possess low neutron absorption.
* Blended with other ceramics such as zirconia to improve its tensile and toughness properties

APPLICATIONS:

Used for manufacture of spark plug insulators, rocket nozzles, support members in electrical and electronic devices, dental and medical uses.

② SILICON CARBIDE (SiC)

SiC is a hard, semiconducting ceramic material. The two principal types of SiC are α - SiC and β - SiC. Depending upon the mode of manufacture the following different types of SiC ceramics are as follows.

ⓐ Reaction bonded SiC

ⓑ Clay - bonded SiC

ⓒ Hot - pressed SiC

ⓓ Sintered SiC

ⓔ Re crystallised SiC

ⓕ Nitride - bonded SiC

CHARACTERISTICS:

* Have higher tensile strength, stiffness, hardness

* Outstanding oxidation resistance.

* High thermal conductivity

* Better dimensional stability and polishability

* Not very tough.

APPLICATIONS:

- * Used as abrasives for grinding wheels.
- * Used for precision optical mirrors.
- * Used as coatings.
- * Used for refractory tubes and containers.

③ SILICON NITRIDE (Si_3N_4)

Si_3N_4 is a very useful engineering ceramics which is resistant to most strong acids.

TYPES:

① Reaction bonded Si_3N_4

② Hot pressed Si_3N_4

③ Sintered Si_3N_4 (SSN)

④ Pressureless Sintered Si_3N_4 (PSSN)

CHARACTERISTICS:

- * Resistant to most strong acids.
- * Greater thermal shock resistance
- * Low density and Low weight

* Low thermal expansion.

* Better toughness than Al_2O_3 and SiC

* Very porous.

APPLICATIONS:

Used as cutting tool materials, automotive and gas turbine parts.

④ PARTIALLY STABILISED ZIRCONIA (PSZ)

PSZ is nothing but a zirconium oxide (ZrO_2) has been blended and sintered with some other oxide such as MgO, CaO and yttria (Y_2O_3) to control crystal structure transformations.

CHARACTERISTICS:

* Have better fracture toughness

* Better tensile strength

* Low thermal conductivity.

APPLICATIONS:

Used for superalloy rotor blades in jet turbines

⑤ SIALONS ($Si_3 Al_3 O_3 N_5$)

The name sialon is an acronym derived from the ingredients involved namely Si – Al – O – N. They are formed when Al and Oxygen partially substitute for Silicon and Nitrogen in silicon nitride.

CHARACTERISTICS:

- * Tough and have higher strength.
- * Good mechanical properties.
- * Retain hardness at higher temperature.
- * Light weight
- * Low co-efficient of thermal expansion.

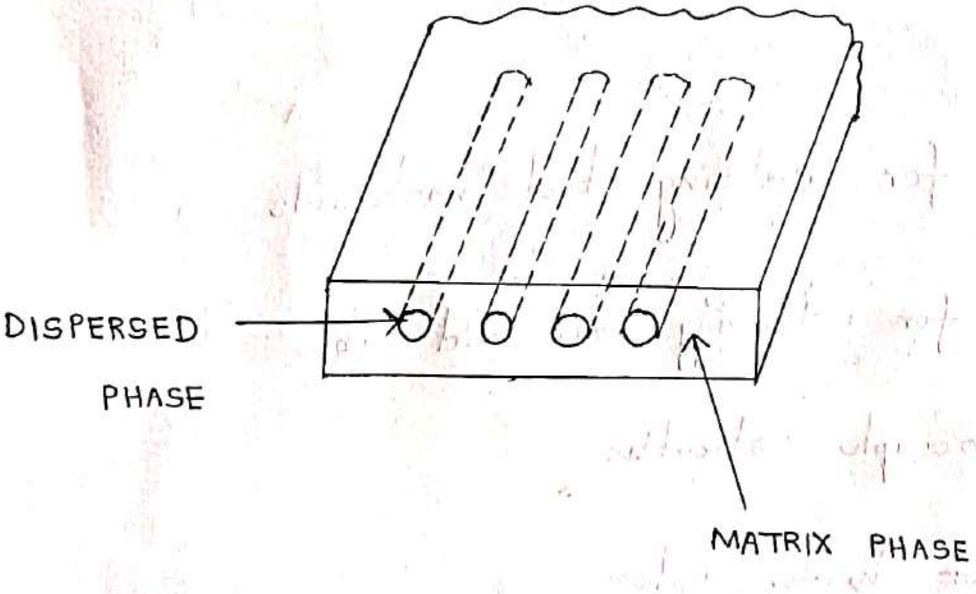
APPLICATIONS:

- * Used for cutting tool materials
- * Dies for drawing wire and tubes.
- * Thermocouple sheaths.
- * Radiant heater tubes.

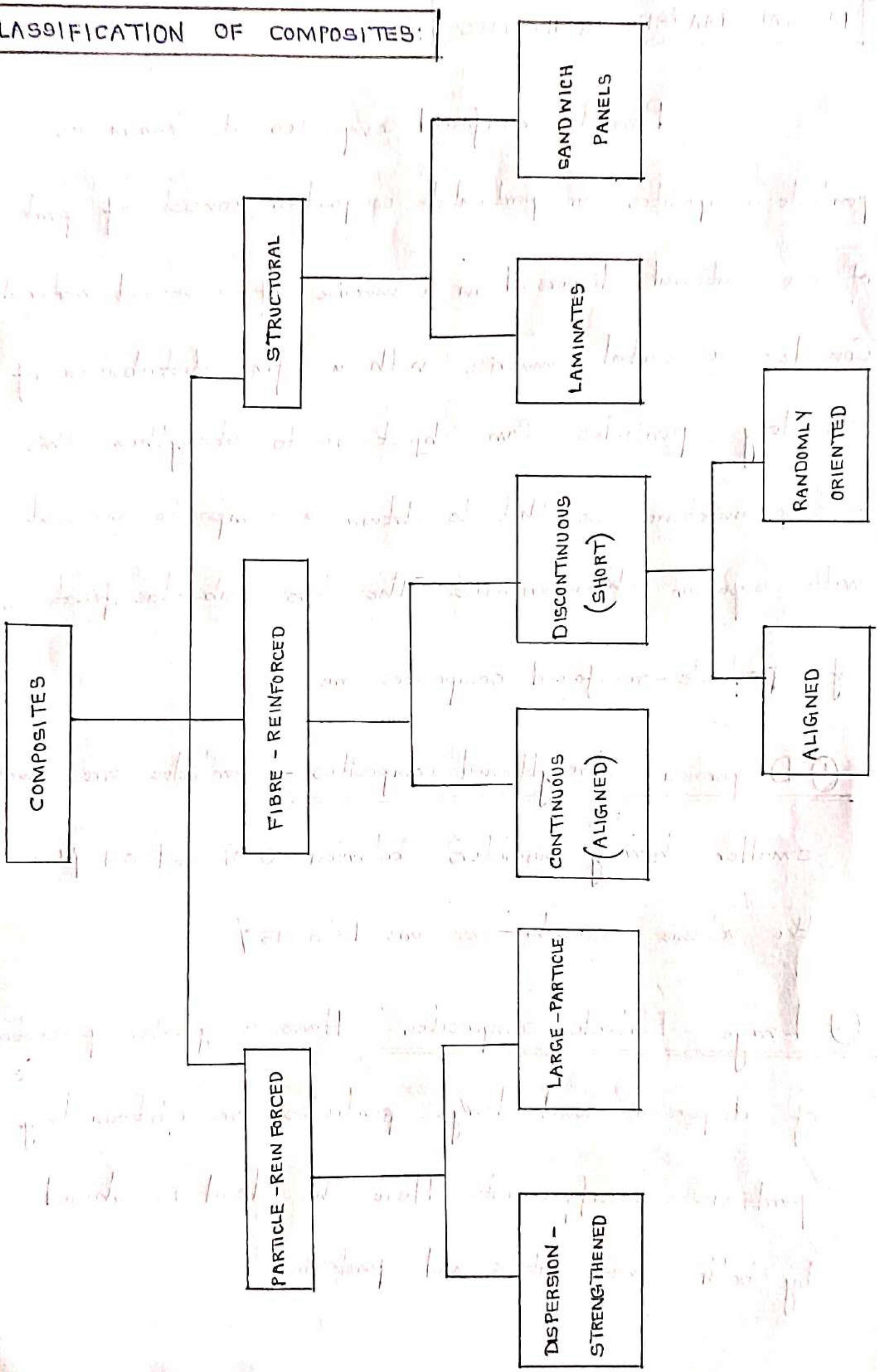
COMPOSITES:

It is defined as a material composed of two or more different materials with the properties of the resultant material being superior to the properties of the individual materials that make up the composite. Wood is a natural composite, cement concrete, fibre glass are artificial or synthetic composite. It is composed of two phases

① Matrix phase
② Dispersed phase



CLASSIFICATION OF COMPOSITES:



METAL MATRIX COMPOSITES:

Particle - reinforced composites also known as particle composites or particulate composites consist of particles of one material dispersed in a matrix of a second material. Consider a metal matrix with a fine distribution of secondary particles. Our object is to strengthen this matrix- mixture so that to obtain a composite material with superior characteristics. The two sub-classifications of particle - reinforced composites are

① Dispersion - Strengthened composites - particles are much smaller having diameters between 0.01 and 0.1 μm the volume concentrations are 1 to 15%.

② Large - Particle composites - Have a greater percentage of dispersion and large particles we obtain large-particle reinforcement. Here the load is shared by both the matrix and particles.

FIBRE -REINFORCED COMPOSITES

Fibre-reinforced composites are those in which the dispersed phase is in the form of a fiber. The functions of the matrix are to bond the fibres together, to protect them from damage and to transmit the load from one fibre to another.

CHARACTERISTICS:

① The length, diameter, orientation, amount and properties of the fibres.

② The properties of the matrix.

③ The bonding between the fibres and matrix.

ADVANTAGES AND LIMITATIONS OF COMPOSITE MATERIALS

ADVANTAGES:

① Composite materials exhibit superior mechanical properties

② They are light weight materials.

③ In aerospace applications the power-to-weight ratio is about 16 with composites compared to 5 with conventional materials.

④ Easy to fabricate

⑤ Good corrosion resistance

⑥ Assembly is easy

LIMITATIONS:

① Higher cost

② Cannot be used for high temperature applications.

APPLICATIONS OF COMPOSITES:

① Commercial aircraft

② Military air craft

③ Missiles

④ Space hardwares

⑤ Automobile and trucks

⑥ Electrical and electronics

⑦ Marine applications

⑧ Sporting equipments

⑨ Other applications include bridge building, joint implants.

UNIT V

MECHANICAL PROPERTIES AND TESTING

PROPERTIES OF ENGINEERING MATERIALS:

There are many thousands of different engineering materials available today. But they can be placed into one or other of the following categories

① Metals

② Polymers

③ Ceramics and inorganic glasses

④ Composites.

MECHANICAL PROPERTIES:

Mechanical properties are those characteristics of material that describe its behaviour under the action of external forces.

① Elasticity - To retain its original size and shape

② Plasticity - Permanent deformation without fracture.

③ Ductility - Can be drawn into wires

④ Malleability - Can withstand deformation under compression

⑤ Brittleness - Fracture without any appreciable deformation

⑥ Hardness - Ability to resist abrasion, identation.

⑦ Toughness - Absorb maximum energy before fracture.

⑧ Stiffness - Ability to resists deformation

⑨ Resilience - Ability to stores energy and resists shocks

⑩ Creep - Deforms continuously under a steady load.

⑪ Endurance - Can withstand varying stresses.

⑫ Strength - Can withstand or support an external force.

⑬ Impact strength - Can resist or absorb shock energy.

⑭ Fatigue - Deforms under the fluctuating or repeated loads.

FACTORS AFFECTING MECHANICAL PROPERTIES:

① Grain size

② Heat treatment

③ Atmospheric exposure

④ Low and high temperatures.

DEFORMATION OF METALS

When force is applied on a metal piece then the size or shape will be altered. Any changes in the size or shape of the metal is called as deformation of the metal.

CLASSIFICATION:

① Elastic deformation - It is the deformation of a body which completely disappears as soon as the external load is removed from the body. It obeys Hook's law.

② Plastic deformation - It is the deformation of a body which remains even after removing the external load from the body.

MECHANISM OF PLASTIC DEFORMATION

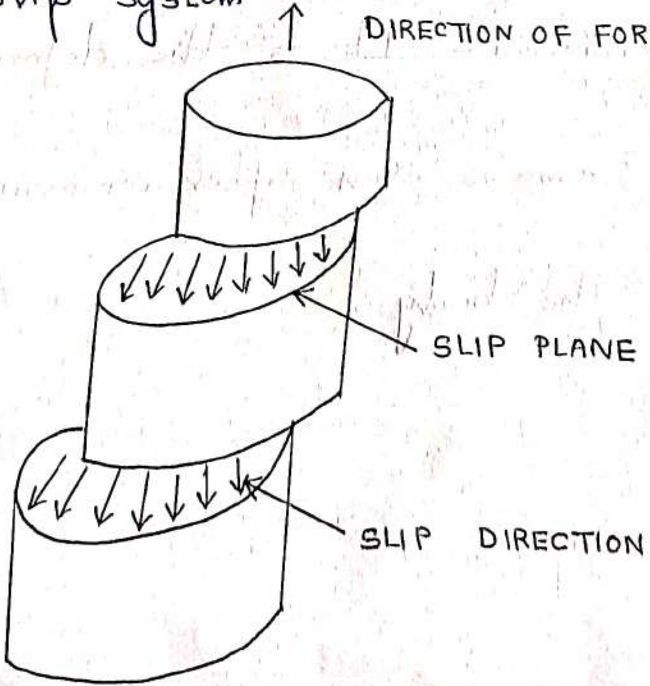
The two modes of plastic deformation are

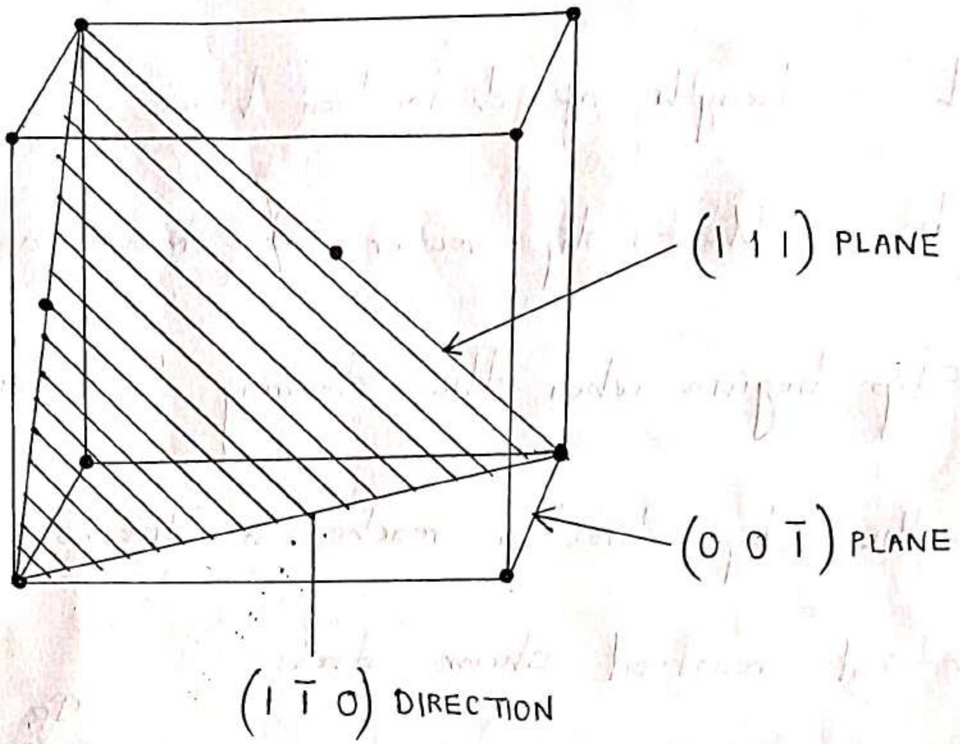
① Slip

② Twinning

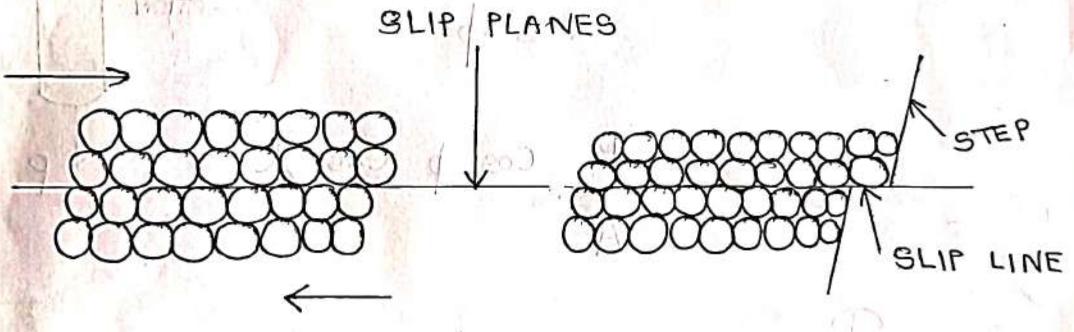
DEFORMATION BY SLIP:

Slip may be defined as the sliding of blocks of the crystal over one another along definite crystallographic planes called slip planes. The combination of a slip plane and slip direction is known as slip system.





MECHANISM OF SLIP



ⓐ BEFORE SLIP

ⓑ AFTER SLIP

The slip occurs by translatory motion along sliding planes and rotation of the specimen. The energy of a dislocation is given by the relation

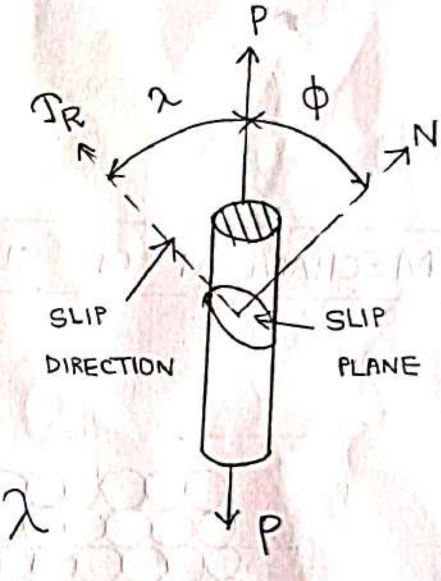
$$E \propto G \cdot l \cdot b^2$$

G = Shear modulus

L = Length of dislocation line

b = Unit slip vector, also known as Burger's vector.

Slip begins when the shearing stress on the slip plane in the slip direction reaches a threshold value called the critical resolved shear stress.



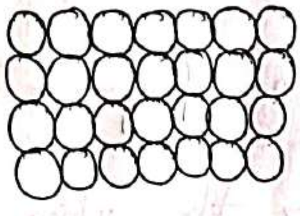
$$\tau_{cr} = \frac{P \cos \lambda}{\frac{A}{\cos \phi}}$$

$$= \frac{P}{A} \cos \phi \cos \lambda$$

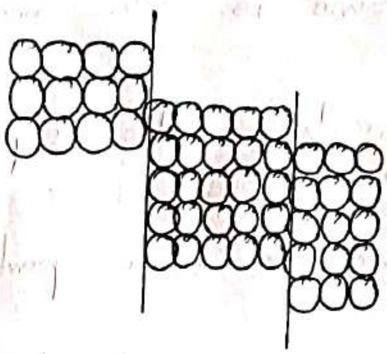
$$\tau_{cr} = \sigma \cos \phi \cos \lambda$$

The term $\cos \phi \cos \lambda$ is known as the Schmid's factor. The stress required at a given temperature to initiate slip in a pure and perfect single crystal for a material is constant. This is known as Schmid's law.

DEFORMATION BY TWINNING:



ⓐ BEFORE TWINNING



ⓑ AFTER TWINNING

Twinning is the process in which the atoms in a part of a crystal subjected to stress rearrange themselves so that one part of the crystal becomes a mirror image of the other part. Like slip twinning almost takes place in special planes called twinning planes

TYPES:

① **Mechanical Twins** - Twins that are produced by mechanical deformation are called mechanical twins. They are produced in BCC or HCP metals

② **Annealing Twins** - Twins that are produced by annealing are called annealing twins. It mostly occurs in FCC metals.

FRACTURE AND ITS PREVENTION

Fracture is the mechanical failure of the material which will produce the separation or fragmentation of a solid into two or more parts under the action of stresses. The fracture is caused due to the presence of submicroscopic defects known as cracks. Then the initial crack is propagated to cause complete failure.

TYPES OF FRACTURE:

① BRITTLE FRACTURE

It is defined as a fracture which takes place by the rapid propagation of crack with a negligible deformation. Brittle fracture is increased with decreasing temperature.

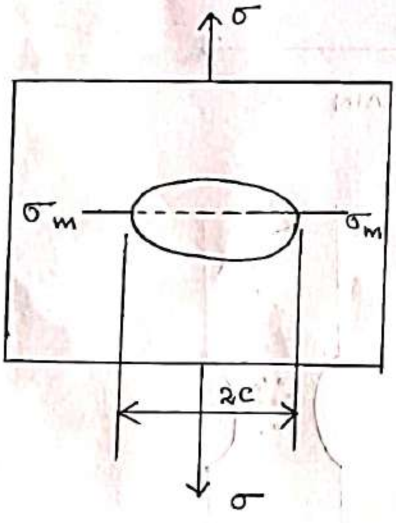
② GRIFFITH THEORY

It is proved that the stress at which a material fractures is far below the lower value of the ideal breaking strength calculated from the atomic strength.

Griffith postulation is as follows

① In a brittle material there are many fine cracks. These cracks concentrate the applied stress at their tips or ends.

② When the stress at the tips of a crack exceeds the theoretical stress values the crack expands and fracture occurs.



$$\sigma_m = 2\sigma\sqrt{\frac{c}{\rho}}$$

σ = Tensile stress applied to the specimen

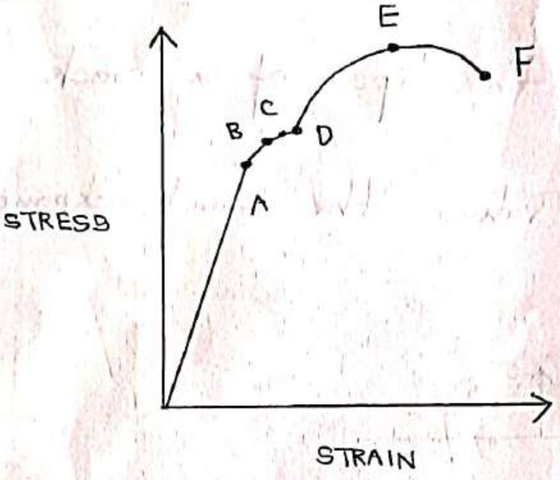
σ_m = Maximum stress at the tip of crack

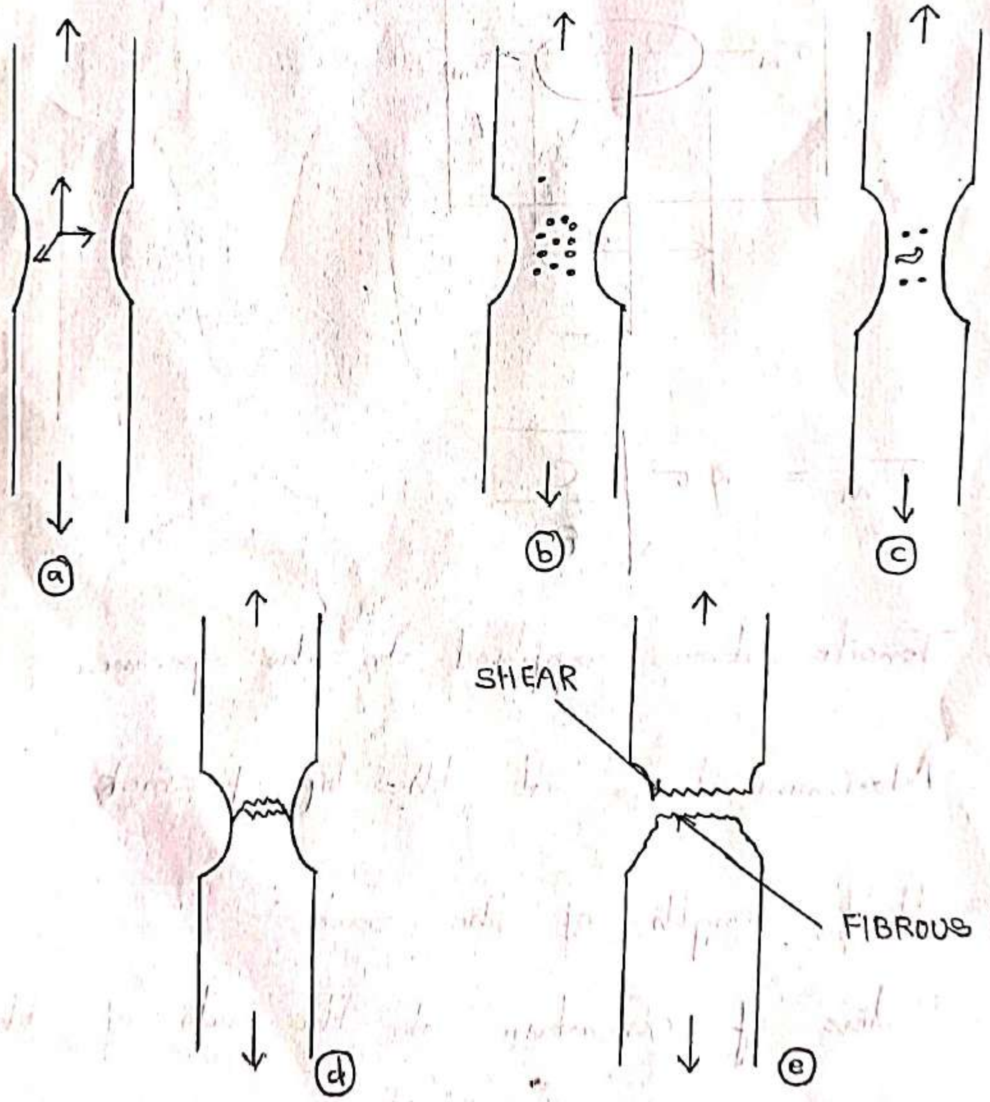
c = Half length of the crack

ρ = Radius of curvature at the ends of the ellipse.

② DUCTILE FRACTURE

It may be defined as the fracture which takes place by a slow propagation of crack with appreciable plastic deformation.





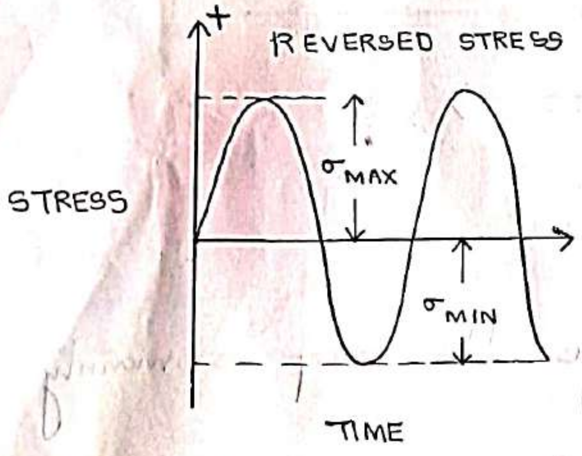
③ FATIGUE FRACTURE:

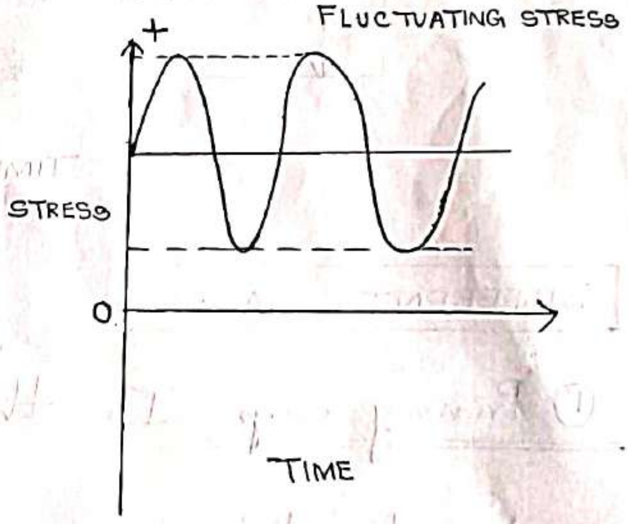
It is defined as the fracture which takes place under repeatedly applied fatigue stresses. Three main features than distinguishes the fatigue fracture are

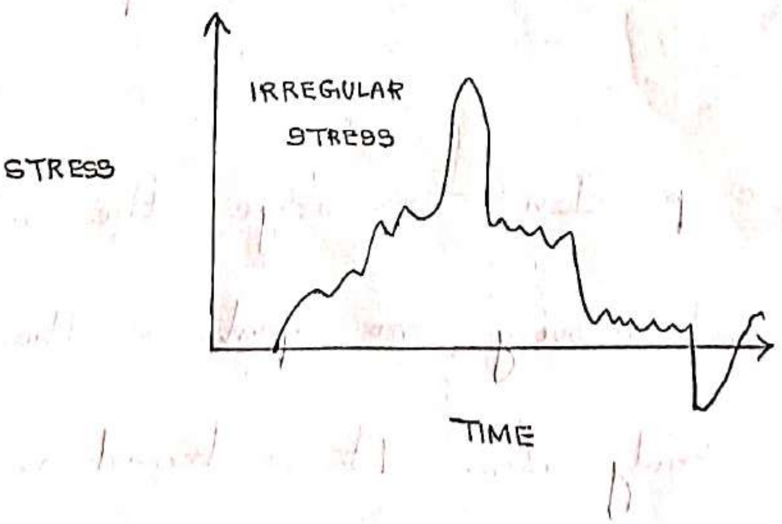
① Loss of strength

② Loss of ductility

③ Increased uncertainity in strength and service life.

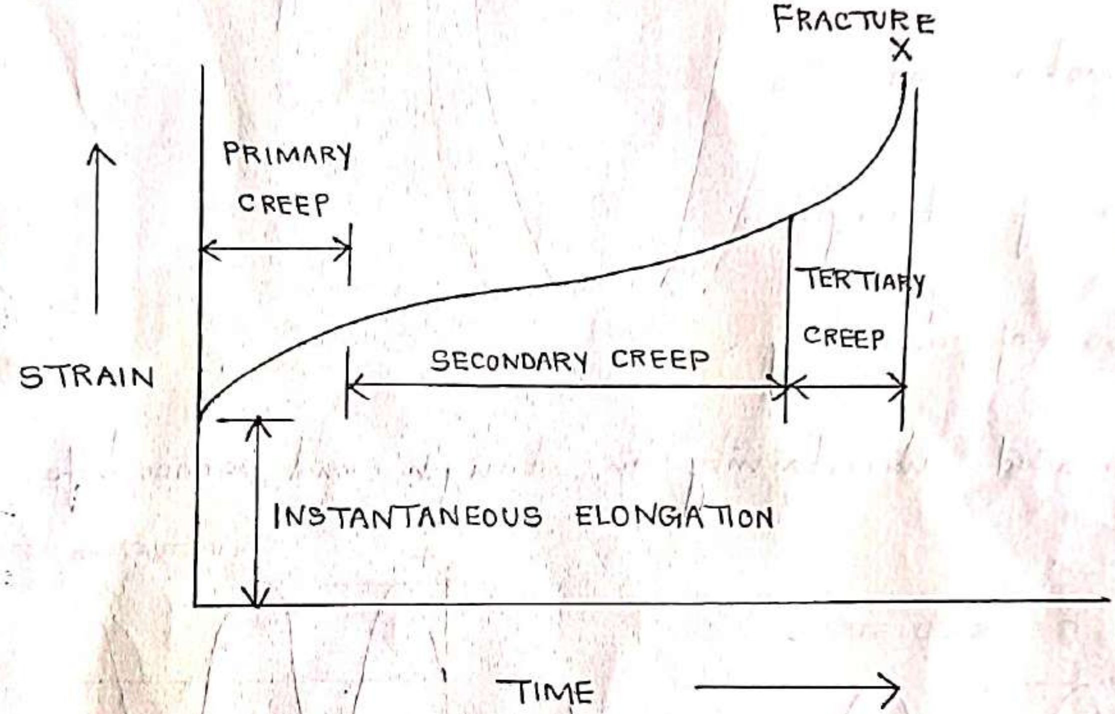






④ CREEP FRACTURE

It is defined as the property of a material by virtue of which it deforms continuously under a steady Load.

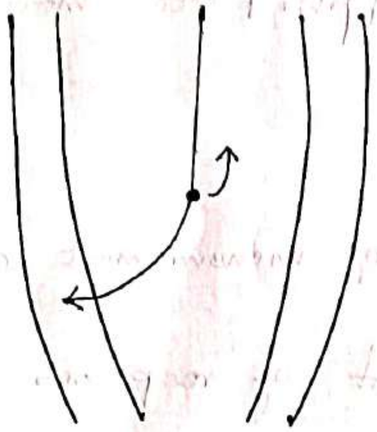


DIFFERENT STAGES

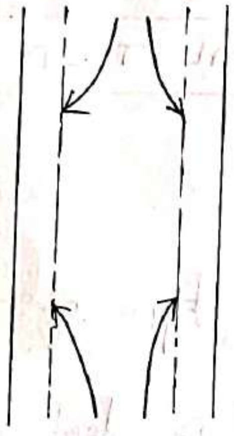
① Primary creep: In this stage the creep is mainly due to dislocation movement. The creep rate decreases with time.

② Secondary creep: In this stage the rate of work hardening and recovery are equal so the material creeps at steady rate. It is termed as steady state creep.

③ **Tertiary Creep:** In this stage creep rate increases with time until fracture occurs.



DISLOCATION CLIMB



VACANCY DIFFUSION

GRAIN BOUNDARY SLIDING

MECHANICAL TESTS OF METALS:

Testing is an essential part of any engineering activity. Testing is applied to materials, components and assemblies.

It consists of measurement of fundamental properties or measurement of responses to particular influences such as load, temperature and corrodants.

CLASSIFICATION OF MECHANICAL TESTS.

① Destructive Test:

In this type of testing the component or specimen to be tested is destroyed and cannot be reused. Ex are tensile test, impact test, bend test etc

② Non destructive Test:

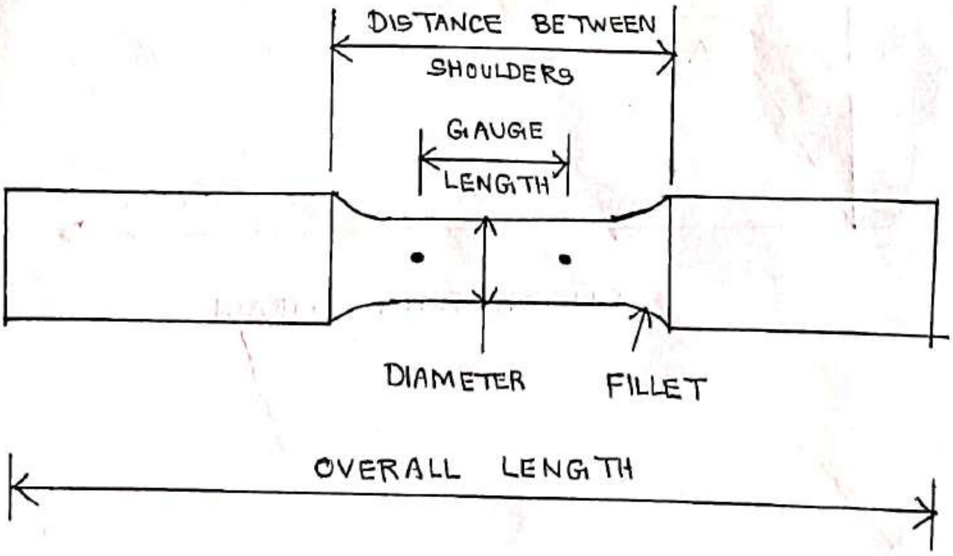
In this type of testing the component or specimen to be tested is not destroyed and can be reused after the test. Examples are radiography, ultrasonic inspection etc.

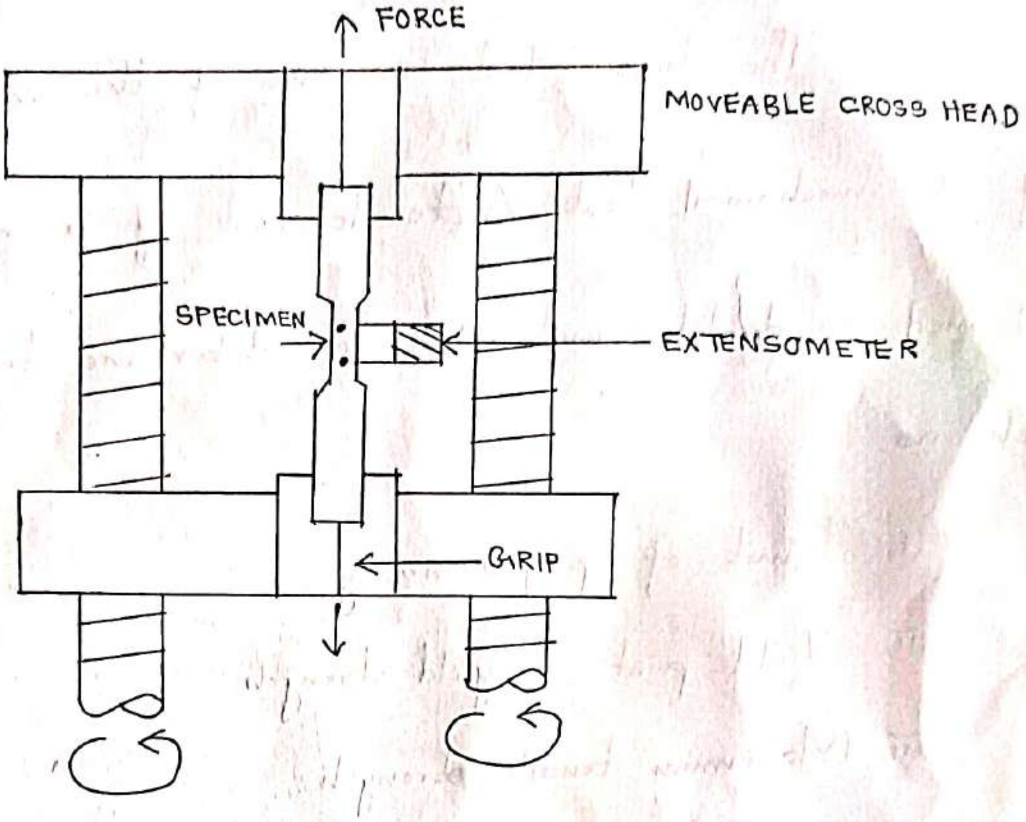
TENSILE TEST:

The tensile test is one of the most widely used of the mechanical test. A tensile test of a material is performed on ductile materials to determine tensile properties such as

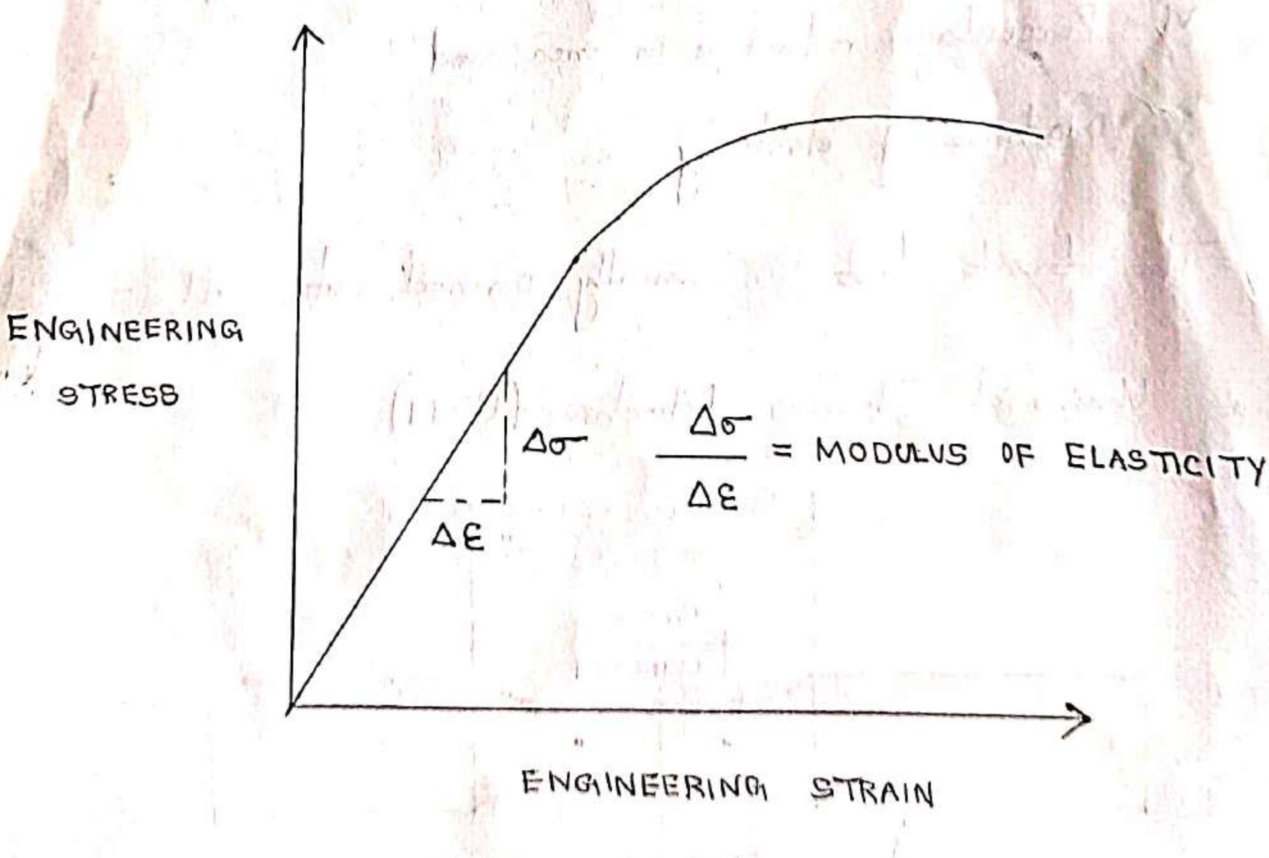
- i, Limit of proportionality
- ii, Yield point or yield strength
- iii, Maximum tensile strength
- iv, Breaking strength
- v, Percentage elongation
- vi, Percentage reduction in area and
- vii, Modulus of elasticity

The tensile test is usually carried out with the help of a Universal Testing Machine (UTM)





UNIVERSAL TESTING MACHINE



The specimen to be tested is fastened to the two end jaws of the UTM. Now the load is applied gradually on the specimen by means of the movable cross head till the specimen fractures. During the test the magnitude of the load is measured by the load cell. A strain gauge or extensometer is used to measure the specimen elongation.

COMPRESSION TEST:

For compression tests specimens are made of cubical or cylindrical shape to avoid eccentric loading. The specimen to be tested is fitted in between compression plates of the UTM. Now the compression load is gradually applied on the specimen and the corresponding reduction in lengths of the specimen are recorded.

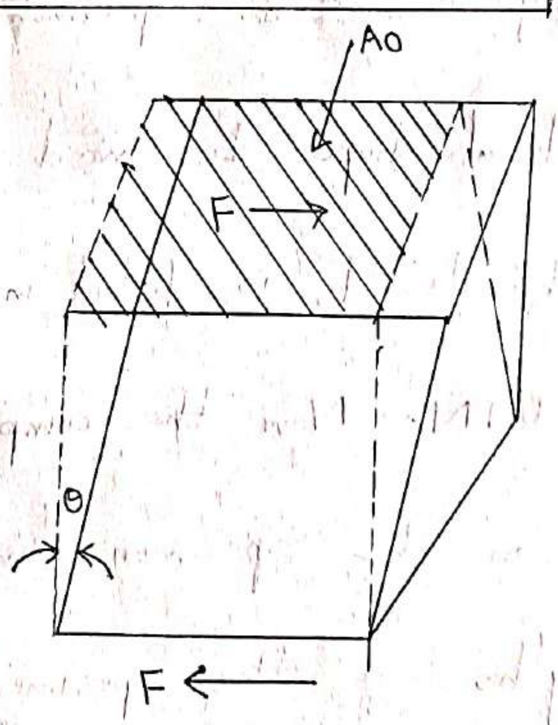
SHEAR TESTS:

There are two main types of test which may be used for the determination of the properties of a material in shear. They are

① Test performed using a pure shear force

② Test performed using the application of a torque to a cylindrical specimen i.e., torsion test

SHEAR TEST USING A PURE SHEAR FORCE



Shear stress or shear strength is the value of load applied tangentially to shear it off across the resisting section.

$$\tau = \frac{F}{A_0}$$

F = Shear force applied

A_0 = Area of shear

Shear strain is defined as the tangent of the strain angle θ

Shear strain $\gamma = \tan\theta$

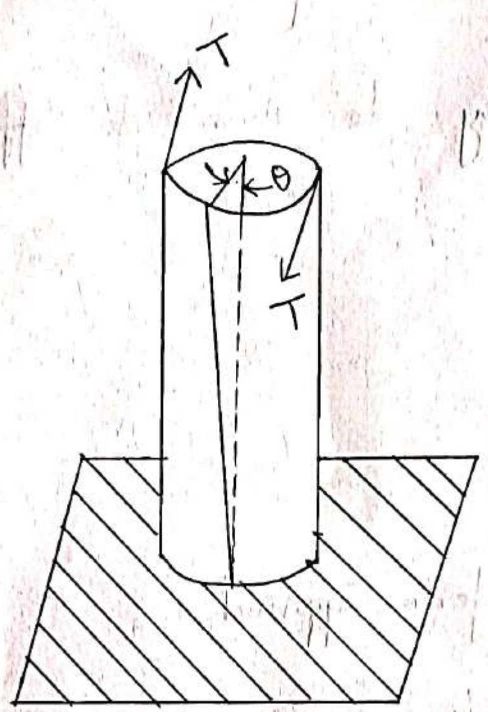
PROCEDURE:

Double shear system for round bar test pieces using a fork and eye device.

Double knife shear system for specimens with a rectangular section.

The shearing of a disc from sheet materials using a punch and die.

TORSION TEST:



Torsion is a variation of pure shear wherein a structural member is twisted in the manner.

Torsional forces produce a rotational motion about the longitudinal axis of one end of the member relative to the other end.

$$\frac{\tau}{r} = \frac{T}{J} = \frac{G\theta}{L}$$

τ = Shear stress

r = Radius of the cylinder

T = Applied Torque

J = Second polar moment of area

G = Modulus of rigidity of the material

θ = Angle of twist in radians

L = Gauge length of the test piece

HARDNESS TESTS:

Hardness may be defined as the ability of a material to resist scratching, abrasion, cutting or penetration.

TYPES:

① Brinell hardness test

② Vickers hardness test

③ Rockwell hardness test

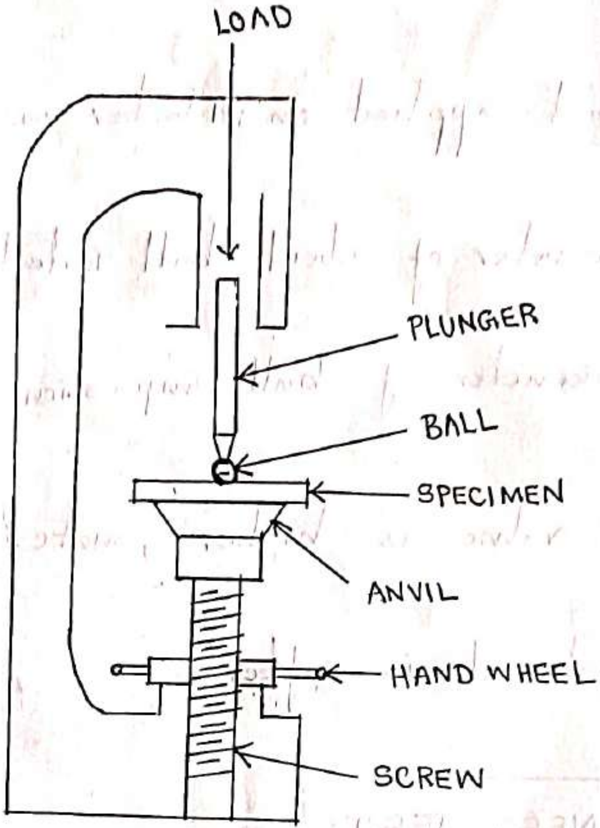
BASIC COMMON PRINCIPLE:

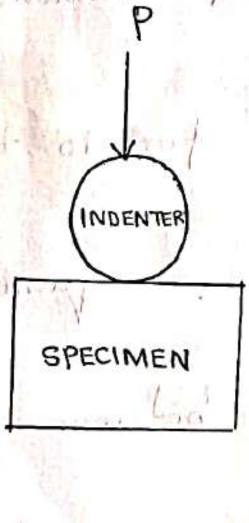
The three hardness test have the same basic principle as below. The hardness is measured from an identation produced in the component by applying a constant load on a specific identer in contact with the surface of the component for a fixed time.

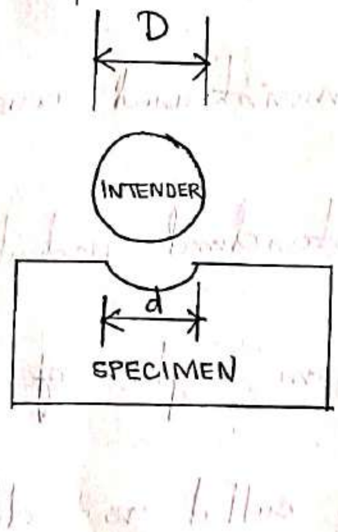
An indenter is pressed into the surface of the material by a slowly applied known load and the extent of the resulting impression is measured mechanically or optically. A large impression for a given load and indenter indicates a soft material and a small impression indicates a harder material.

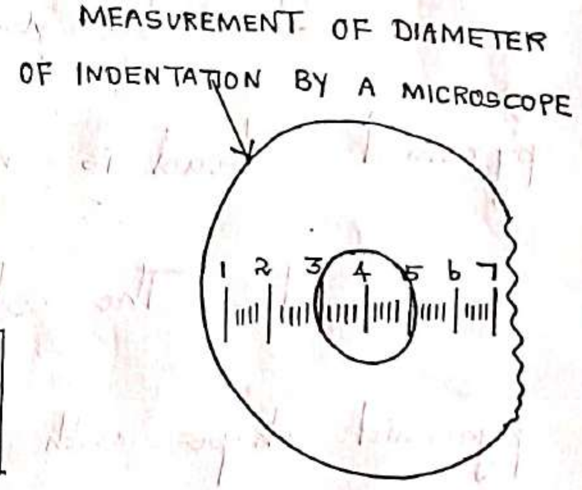
BRINELL HARDNESS TEST:

In this test a hardened steel ball indenter is forced into the surface of the metal to be tested. Diameter of the hardened steel [or tungsten carbide] idddenter is 10 mm. Load ranges between 500 kg and 3000 kg in 500 kg increments. During a test the load is maintained constant for 10 to 15 seconds.









$$\text{Brinell hardness number BHN} = \frac{\text{Load on the ball}}{\text{Area of indentation of steel ball}}$$

$$BHN = \frac{P}{\frac{\pi D}{2}\left[D - \sqrt{D^2 - d^2}\right]}$$

P = Load applied on indenter in kg

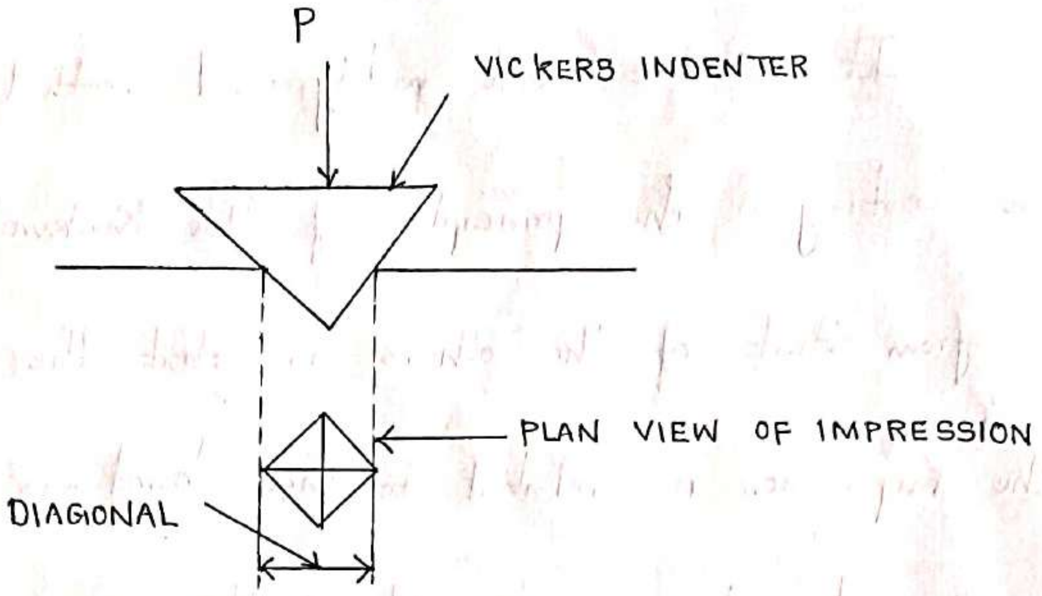
D = Diameter of steel ball indenter in mm

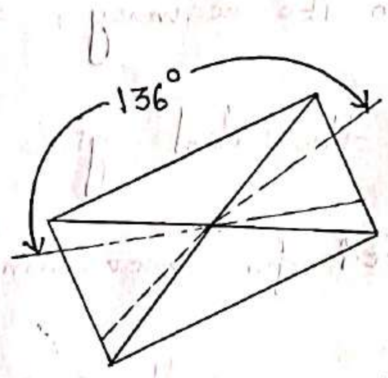
d = Diameter of ball impression in mm

If BHN value is higher, material is harder, if it is less material is softer.

VICKERS HARDNESS TEST:

Indenter used is square-based diamond pyramid. Load is maintained constant for 10 to 15 seconds. The standard indenter is a square pyramid shape with an angle of 136° between opposite faces. This test is called as diamond-pyramid hardness test.





$$\text{Vicker Hardness Number (VHN)} = \frac{\text{Applied load}}{\text{Surface area of impression}}$$

$$= \frac{2P \sin\frac{\theta}{2}}{D^2} = \frac{1.8544P}{D^2}$$

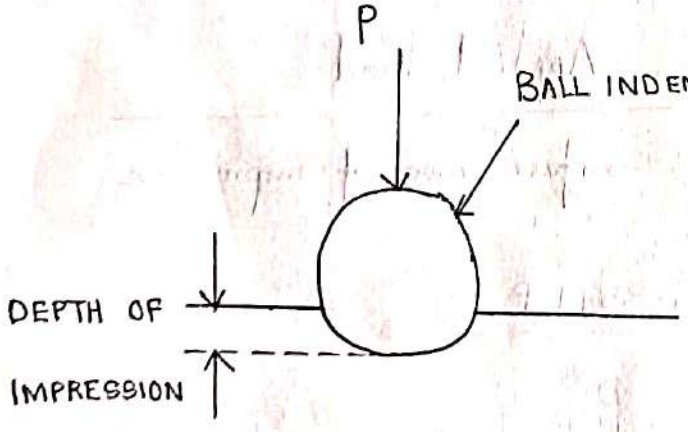
P = Applied load in kg

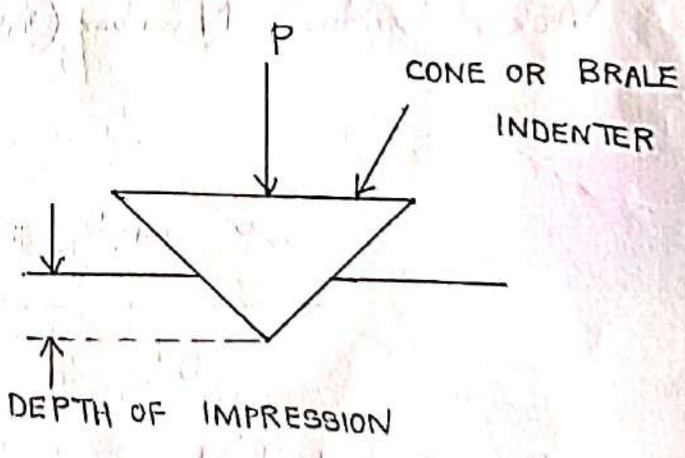
θ = Angle between the opposite faces of diamond = 136°

D = Mean diagonal length in mm

ROCKWELL HARDNESS TEST.

It is the most widely used method of hardness testing. The principle of the Rockwell test differs from that of the others in that the depth of the impression is related to the hardness rather than the diameter or diagonal of the impression. It is widely used due to its accuracy, simplicity and rapidity. In this test the dial gives a direct reading of hardness; no need for measuring indentation diameter or diagonal length using the microscope.





ROCKWELL SCALES:

① B - SCALE:

1/16 inch diameter steel ball indenter is used. Load of 100 kg is applied.

② C- SCALE:

120° diamond cone indenter is used. Load of 150 kg is applied. Called as BRALE

PROCEDURE:

Material is held on anvil. Test piece is raised by turning the hand wheel till it just touches the indenter. Minor load of 10 kg is applied to seat the specimen. Then dial indicator is set at zero. Now major load is applied [100 kg for B-scale and 150 kg for C-scale] to the indenter to produce a deeper indentation. After the pointer come to rest major load is removed. Now the pointer indicates the Rockwell hardness number (RHN)

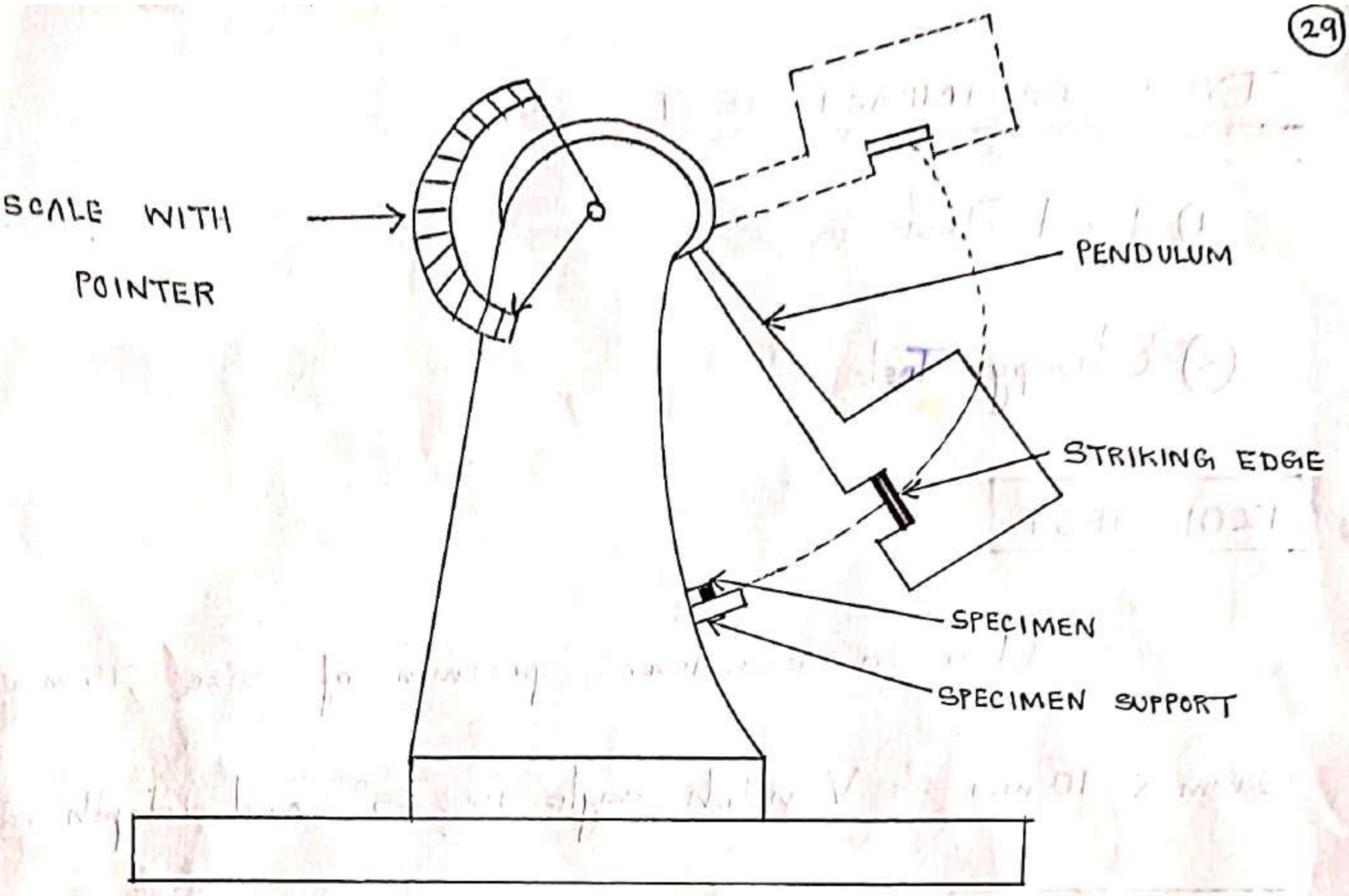
IMPACT TEST.

The impact test is performed to study the behaviour of materials under dynamic load i.e suddenly applied load.

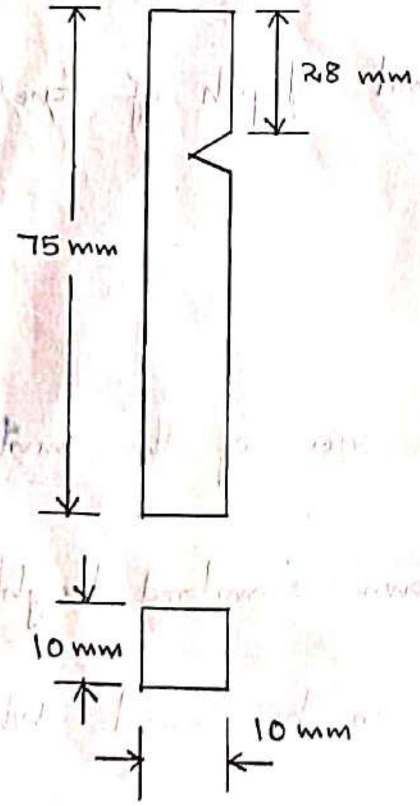
The capacity of a metal to withstand blows without fracture is known as impact strength or impact resistance.

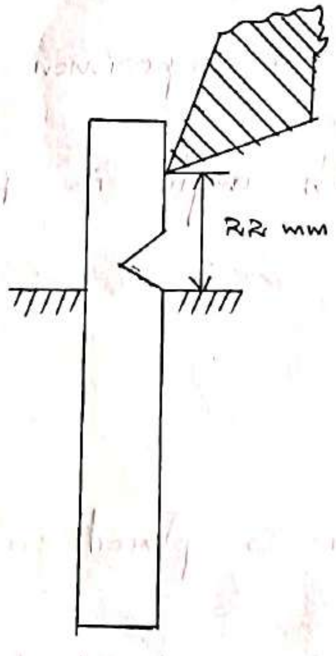
This test indicates the toughness of the material i.e., the amount of energy absorbed by the material during plastic deformation.

The notch sensitivity refers to the tendency of some normal ductile material to behave like a brittle materials in the presence of notches. In an impact test a notch is cut in a standard test piece which is struck by a single blow in a impact testing machine.



IMPACT TESTING MACHINE





TYPES OF IMPACT TEST

① Izod Test

② Charpy Test

IZOD TEST

Uses a cantilever specimen of size 75 mm X 10 mm X 10 mm. V notch angle is 45° and depth is 2 mm

CHARPY TEST

Uses a specimen of size 55 mm X 10 mm X 10 mm. V- notch angle is 45° and depth of the notch is 2mm

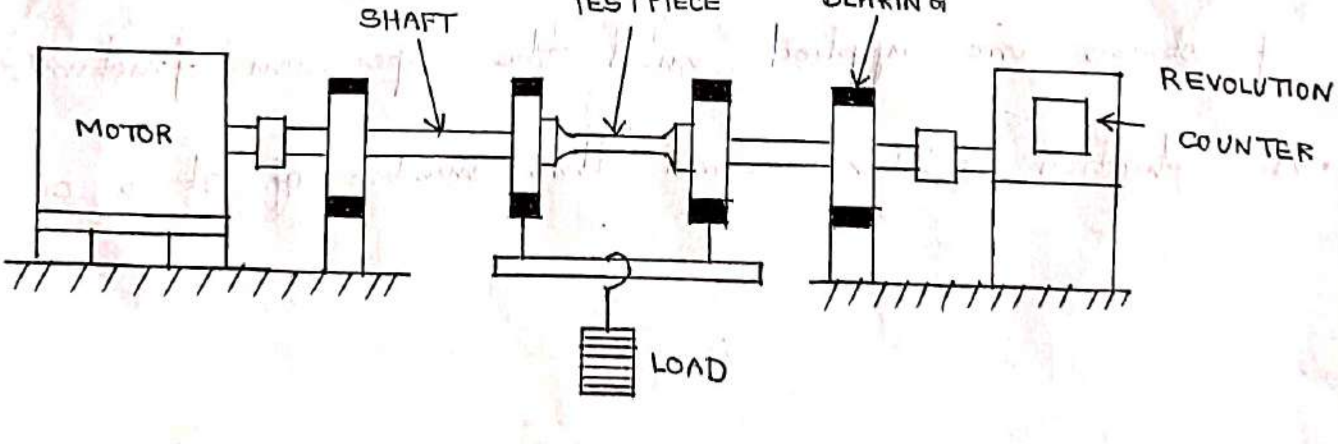
PROCEDURE:

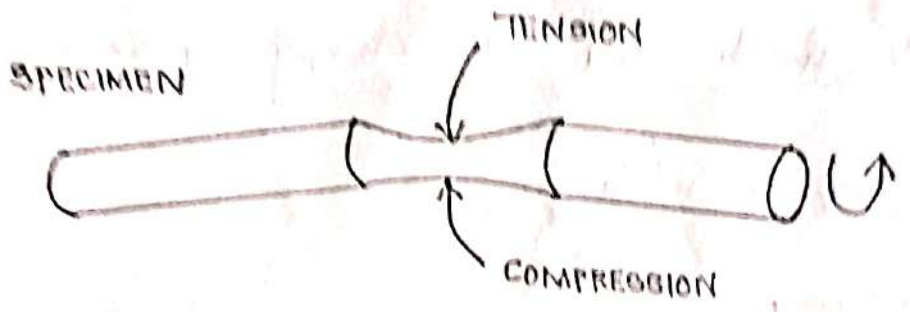
Specimen is placed in the vice of the anvil. Pendulum hammer is raised to known standard height depending on the type of specimen to be tested. When the pendulum is released its potential energy is converted into kinetic energy before it strikes the specimen

It may be noted that the Izod specimen is hit above the V- notch and the charpy specimen will be hit behind the V- notch.

FATIGUE TESTS:

It determines the resistance of material to repeated pulsating / or fluctuating loads. The capacity of material to withstand repeatedly applied stresses is known as fatigue. The endurance limit is defined as the maximum stress which a specimen can endure without failure when this stress is repeated for a specified number of cycles

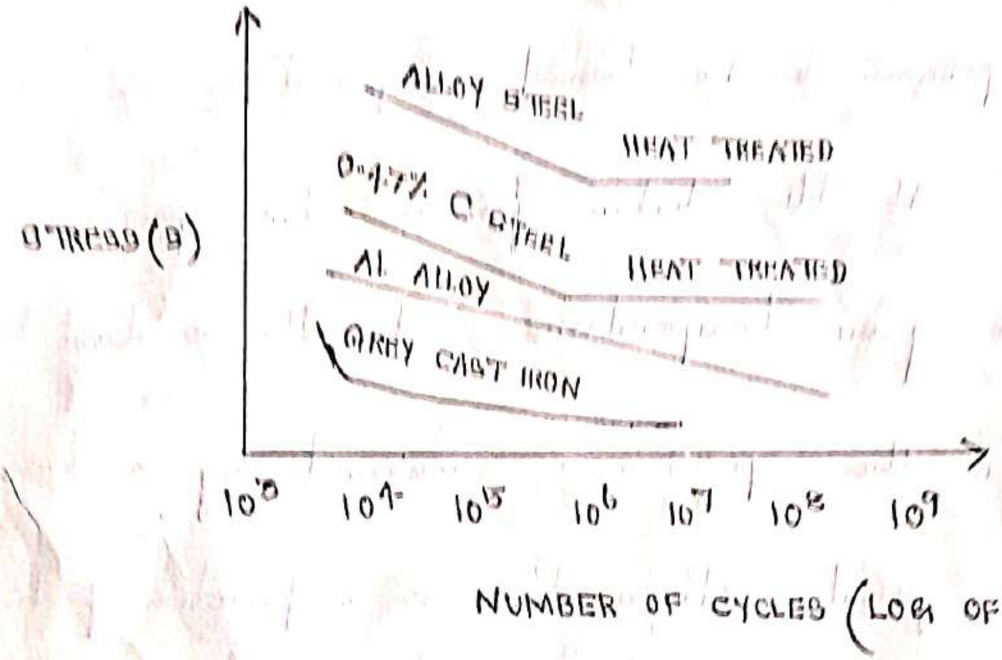




The test specimen is placed on the machine.

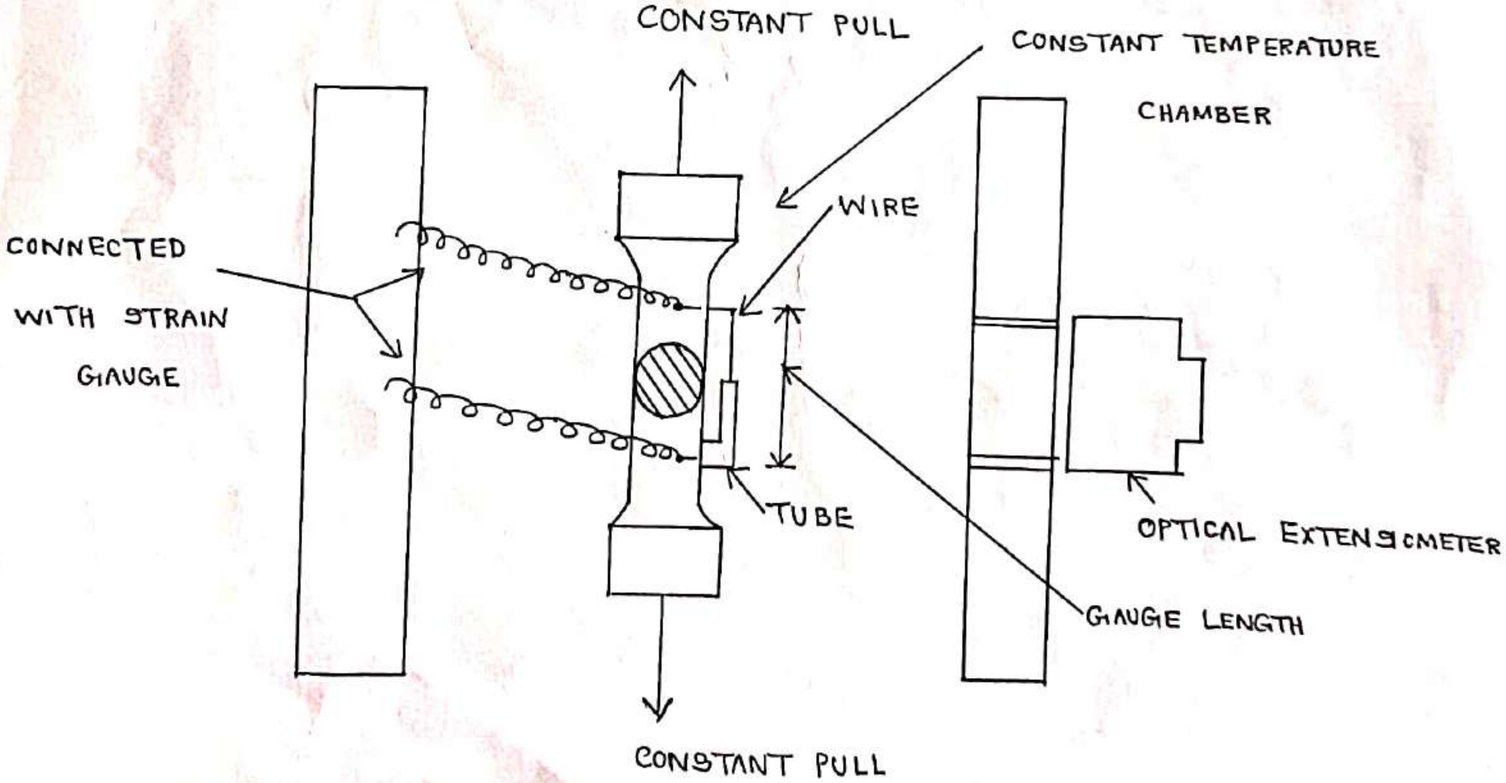
Now the specimen is rotated using an electric motor. When the specimen is rotating it can be noted that the upper surface of the specimen is subjected to tension and its lower surface experiences compression.

As the specimen rotates there is sinusoidal variation of stress between a state of maximum tensile stress and a state of maximum compressive stress. The cycles of stress are applied until the specimen fractures. A reduction counter records this number of stress cycles.



CREEP TEST:

Creep is defined as the continuous deformation of a metal under a steady load. The purpose of creep test is to determine the creep limit



PROCEDURE

The specimen to be tested is placed in an electric furnace. At the electric furnace the specimen is heated to the given temperature, under the constant load. The strain in the specimen is measured by a strain gauge or an optical extensometer as a function of time. The above test is repeated for four to five specimens at each temperature under different loads.