UNIT-I

Materials Science – Investigating relationships that exist between the structure and properties of materials.

Materials Engineering – On the basis of these structure-property correlations, designing or engineering the structure of a material to produce a pre-determined set of properties.

STRUCTURE

Structure of a material usually relates to the arrangement of its internal components.

Subatomic - Structure involves electrons within the individual atoms and interactions with their nuclei.

Atomic level- structure encompasses the organization of atoms or molecules relative to one another.

Microscopic – Which contains large groups of atoms that are normally agglomerated together.

Macroscopic – Viewable with the naked eye.

SOLID SOLUTIONS

- Metals usually form homogenous liquid solutions in the liquid state
- Even after their transformation to a solid crystalline state, the metal retain their homogeneity and their solubility, a solid solution is said to have formed.

Cu atoms are solvent atoms and Zn atoms are solute.

They form individual crystal structure of their own and form substitutional solid solution

According to Hume- Rothery rule, a solid solution may form

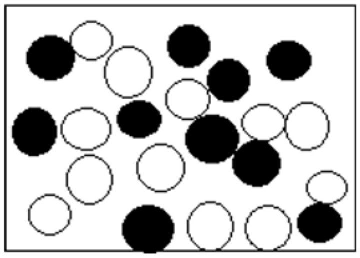
- Similar atomic radii (15% or less difference)
- Same crystal structure
- Similar electronegativities
- Similar valency

Types of solid solutions

a) Substitutional solid solution
    - Disordered
    - Ordered

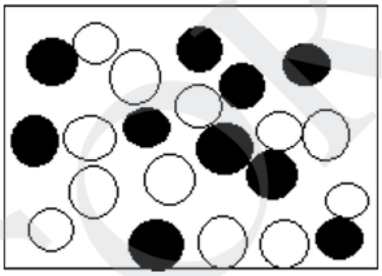
b) Interstitial solid solution

Substitutional solid solution:-



- There is a direct substitution of one type of atom for another so that solute atoms enter the crystal to take positions of solvent atoms
- It forms when solute and solvent atoms possess equal or approximately equal diameters. For eg: atomic diameter of cu = 2.551 Å and that of nickel is 2.487 Å and the two form substitutional solid solution

Disordered substitutional solid solution:-



- The solute atoms do not occupy any specific position but are distributed at random in the lattice structure of the solvent in the substitutional solid solution. This condition is called disordered.
- When this type of solution crystallizes, the core contains more atoms of higher melting point compared to outer fringes having more atoms of lower melting points

Ordered substitutional solid solution:-

- The alloy in the disordered condition when cooled slowly undergoes re arrangement of atoms
- It produces uniform distribution of solute and solvent atoms. They move to definte orderly positions in the lattice.

Interstitial Solid solutions:-

- It forms when solute atoms are very small as compared to solvent atoms and they are unable to substitute due to large diameter differences. They fit into interstices or spaces in the lattice

- Atomic size factor is not the only reason. Small interstitial solute atoms dissolve much more readily in transition metals (Fe, Ni,Mn,Mo,Cr,W,etc.,) than in other metals

What kinds of phases exist

Based on state → Gas, Liquid, Solid

Based on atomic order → Amorphous, Quasi-crystalline, Crystalline

Based on band structure → Insulating, Semi-conducting, Semi-metallic, Metallic Based on Property → Para-electric, Ferromagnetic, Superconducting

Based on stability → Stable, Metastable, Unstable

Also sometimes- Based on size/geometry of an entity → Nanocrystalline, mesoporous, layered.

Phase transformation

Phase transformation is the change of one phase into another. For example

- Water → Ice and α-Fe (BCC) → γ-Fe (FCC)

Grain

The single crystalline part of polycrystalline metal separated by similar entities by a grain boundary

Solute

The component of either a liquid or solid solution that is present to a lesser or minor extent; the component that is dissolved in the solvent.

Solvent

The component of either a liquid or solid solution that is present to a greater or major extent; the component that dissolves the solute.

System

System has two meanings. First, ‘‘system’’ may refer to a specific body of material or object. Or, it may relate to the series of possible alloys consisting of the same components, but without regard to alloy composition.

Solubility Limit

For many alloy systems and at some specific temperature, there is a maximum concentration of solute atoms that may dissolve in the solvent to form a solid solution; this is called a Solubility Limit.

Microstructure

(Phases + defects + residual stress) & their distributions

Structures requiring magnifications in the region of 100 to 1000 times. (or) The distribution of phases and defects in a material.

Phase diagram

Map that gives relationship between phases in equilibrium in a system as a function of T, P and composition. Map demarcating regions of stability of various phases

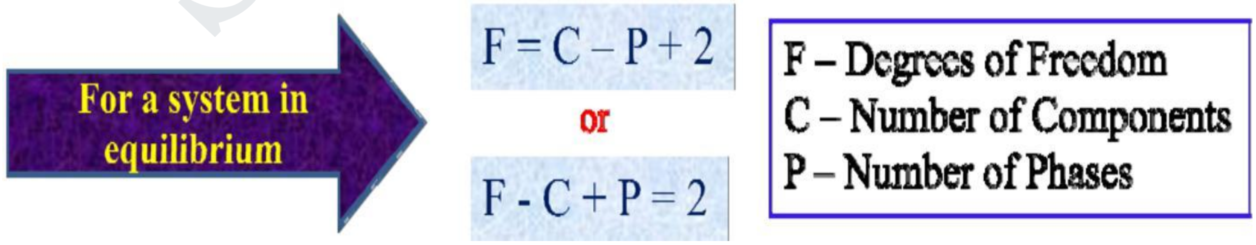
GIBBS PHASE RULE

The phase rule connects the Degrees of Freedom, the number of components in a system and the number of phases present in a system via a simple equation.

To understand the phase rule one must understand the variables in the system along with the degrees of freedom.

We start with a general definition of the phrase "degrees of freedom".

Degrees of Freedom: The degree of freedom, F, are those externally controllable conditions of temperature, pressure, and composition, which are independently variable and which must be specified in order to completely define the equilibrium state of the system



For a system in equilibrium

$$F = C - P + 2$$

or

$$F - C + P = 2$$

F – Degrees of Freedom
C – Number of Components
P – Number of Phases

The degrees of freedom cannot be less than zero so that we have an upper limit to the number of phases that can exist in equilibrium for a given system.

Variables in a phase diagram

C – No. of components

P – No. of phases

F – No. of degrees of freedom

Variables in the system = Composition variables + Thermodynamic variables

Composition of a phase specified by (C – 1) variables (If the composition is expressed in %ages then the total is 100% → there is one equation connecting the composition variables and we need to specify only (C - 1) composition variables)

No. of variables required to specify the composition of all phases: P(C – 1) (as there are P phases and each phase needs the specification of (C – 1) variables)

Thermodynamic variables = P + T (usually considered) = 2 (at constant pressure (e.g. atmospheric pressure) the thermodynamic variable becomes 1)

Total no. of variables in the system = P (C – 1) + 2

F < no. of variables → F < P (C – 1) + 2For a system in equilibrium the chemical potential of each species is same in all the phases

If α, β, γ… are phases, then: $\mu A(\alpha) = \mu A(\beta) = \mu A(\gamma)$…..

Suppose there are 2 phases (α and β phases) and 3 components (A, B, C) in each phase then : $\mu A(\alpha) = \mu A(\beta)$, $\mu B(\alpha) = \mu B(\beta)$, $\mu C(\alpha) = \mu C(\beta)$ → i.e. there are three equations. For each component there are (P – 1) equations and for C components the total number of equations is C(P – 1). In the above example the number of equations is 3(2 – 1) = 3 equations.

F = (Total number of variables) – (number of relations between variables)

$= P(C - 1) + 2] - [C(P - 1)] = C - P + 2$

In a single phase system F = Number of variables

P↑ → F↓ (For a system with fixed number of components as the number phases increases the degrees of freedom decreases.

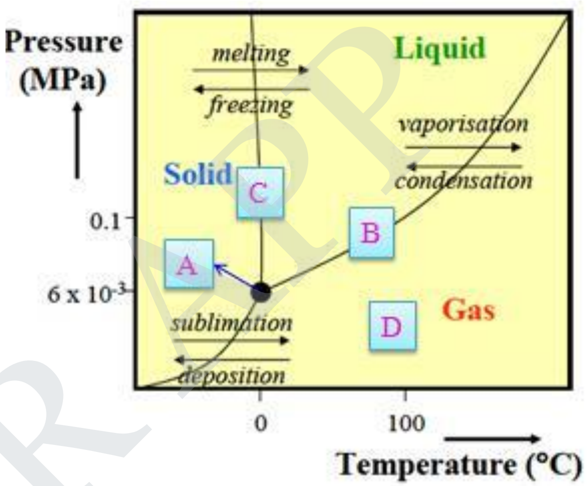
UNARY PHASE DIAGRAM

Let us start with the simplest system possible: the unary system wherein there is just one component.

Though there are many possibilities even in unary phase diagram (in terms of the axis and phases), we shall only consider a T-P unary phase diagram.

Let us consider the water (H2O) unary phase diagram

The Gibbs phase rule here is: F=C-P+2 (2 is for T&P) (no composition variables here)



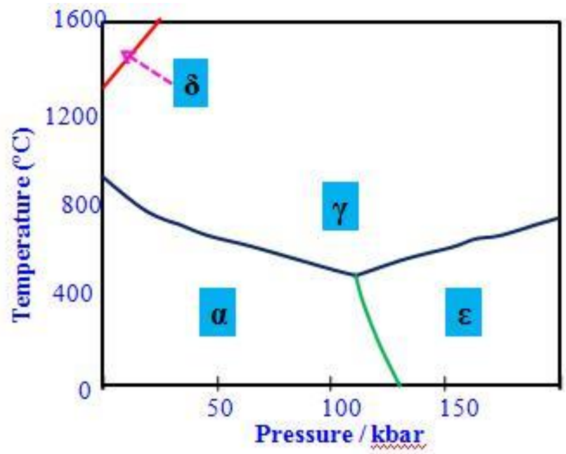
Along the 2 phase co-existence (at B & C) lines the degree of freedom (F) is 1 → i.e. we can chose either T or P and the other will be automatically fixed

The 3 phase co-existence points (at A) are invariant points with F=0. (Invariant point implies they are fixed for a given system).

The single phase region at point D, T and P can both be varied while still being in the single phase region with F = 2.

The above figure represents the phase diagram for pure iron. The triple point temperature and pressure are 490ºC and 110 kbars, respectively. α, γ and ε refer to

ferrite, austenite and ε-iron, respectively. δ is simply the higher temperature designation of α.



BINARY PHASE DIAGRAM

Binary implies that there are two components.

Pressure changes often have little effect on the equilibrium of solid phases (unless of course we apply ‘huge’ pressures).

Hence, binary phase diagrams are usually drawn at 1 atmosphere pressure. The Gibbs phase rule is reduced to:

Variables are reduced to : $F = C - P + 1$ (1 is for T).

T & Composition (these are the usual variables in materials phase diagrams)

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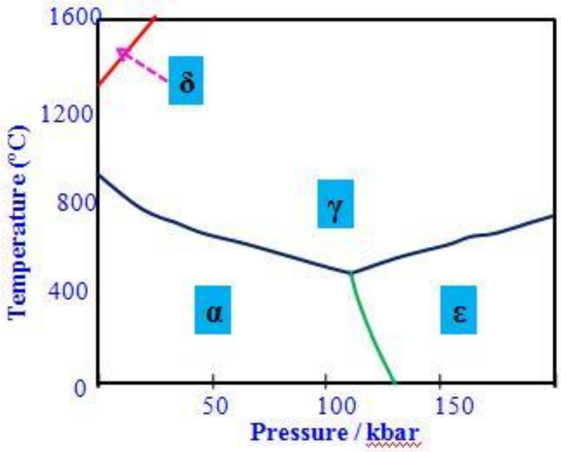

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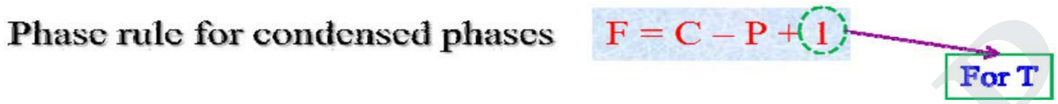
T & Composition (these are the usual variables in materials phase diagrams)

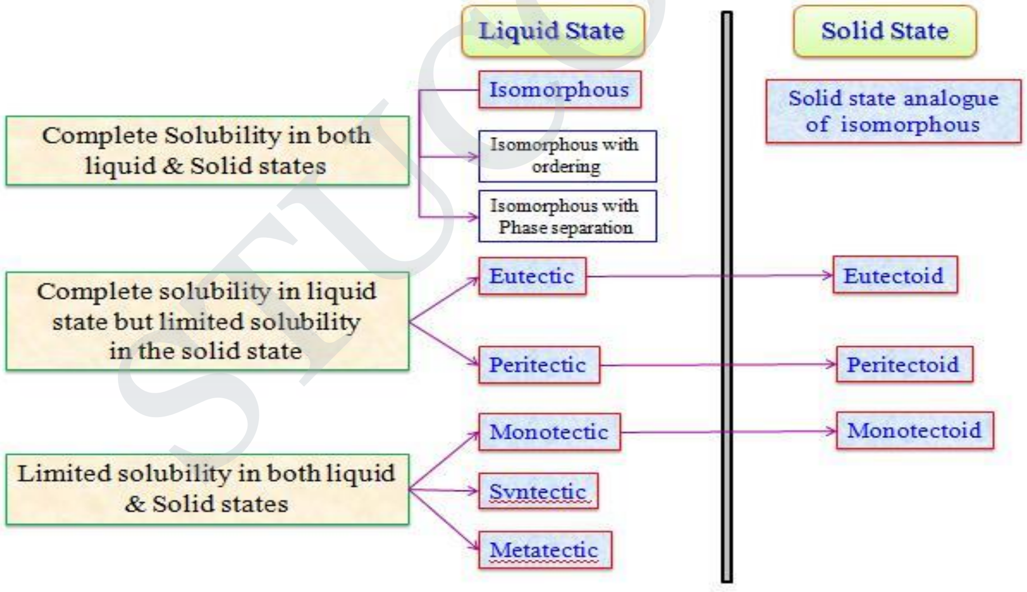


In the next page we consider the possible binary phase diagrams. These have been classified based on:

Complete solubility in both liquid & solid states

Complete solubility in both liquid state, but limited solubility in the solid state

Limited solubility in both liquid & solid states



Isomorphous Phase Diagram

Isomorphous phase diagrams form when there is complete solid and liquid solubility.

Complete solid solubility implies that the crystal structure of the two components have to be same and Hume-Rothery rules to be followed.

Examples of systems forming isomorphous systems: Cu-Ni, Ag-Au, Ge-Si, Al2O3-Cr2O3

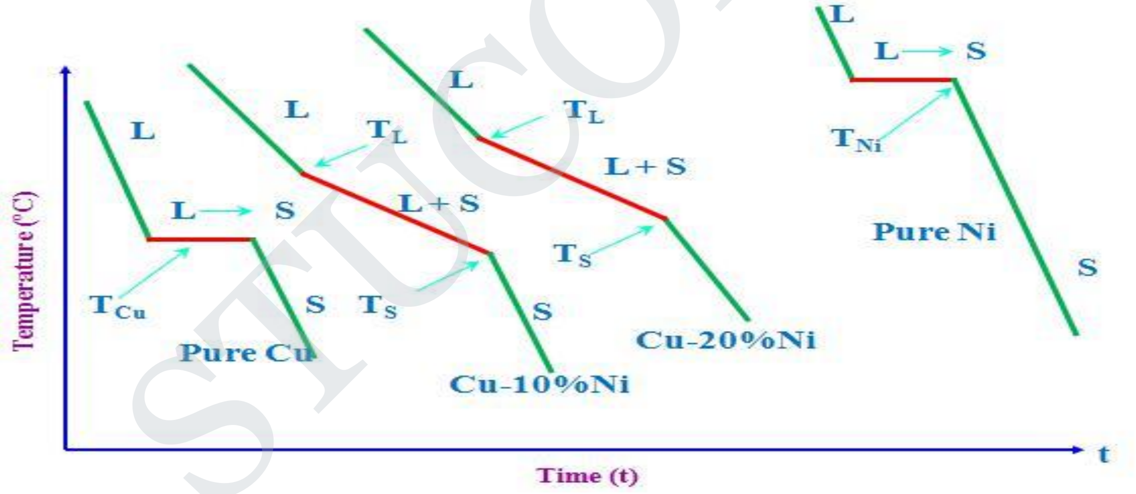
Both the liquid and solid contain the components A and B.

In binary phase diagrams between two single phase regions there will be a two phase region → In the isomorphous diagram between the liquid and solid state there is the (Liquid + Solid) state.

The Liquid + Solid state is NOT a semi-solid state → it is a solid of fixed composition and structure, in equilibrium with a liquid of fixed composition.

In some systems (e.g. Au-Ni system) there might be phase separation in the solid state (i.e.,the complete solid solubility criterion may not be followed) → these will be considered as a variation of the isomorphous system (with complete solubility in the solid and the liquid state.

Cooling curves: Isomorphous system



Isomorphous Phase Diagram

This very simple case is one complete liquid and solid solubility, an isomorphous system.

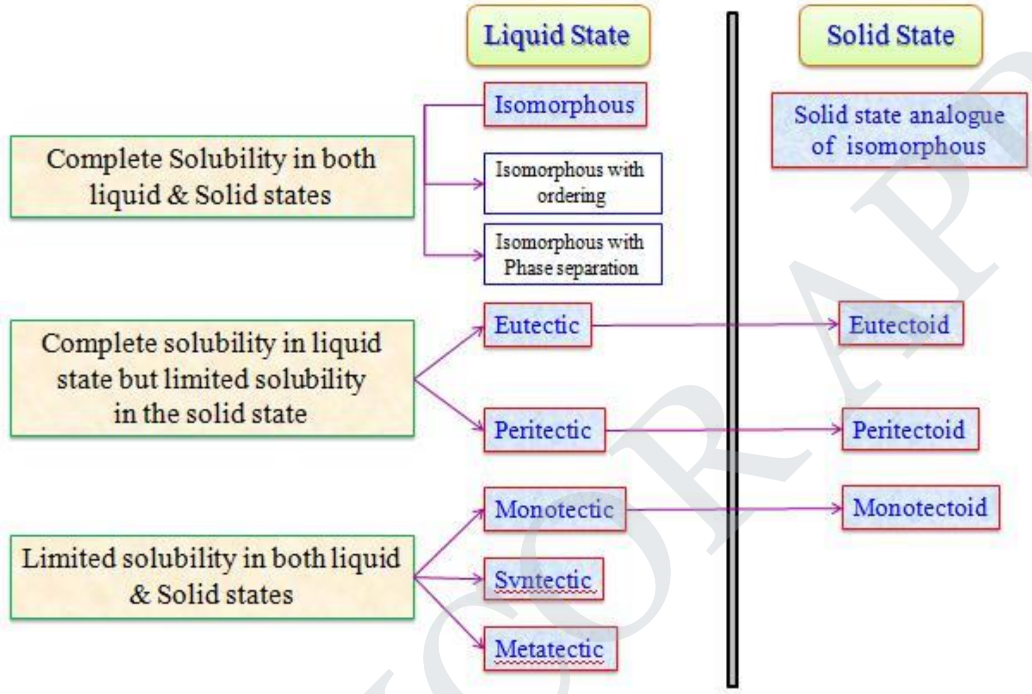
The example is the Cu-Ni alloy of Fig. 3.1.

The complete solubility occurs because both Cu and Ni have the same crystal structure (FCC), near the same radii, electronegativity and valence.The liquidus line separates the liquid phase from solid or solid + liquid phases. That is, the solution is liquid above the liquidus line.

Complete solubility in both liquid & solid states

Complete solubility in both liquid state, but limited solubility in the solid state

Limited solubility in both liquid & solid states



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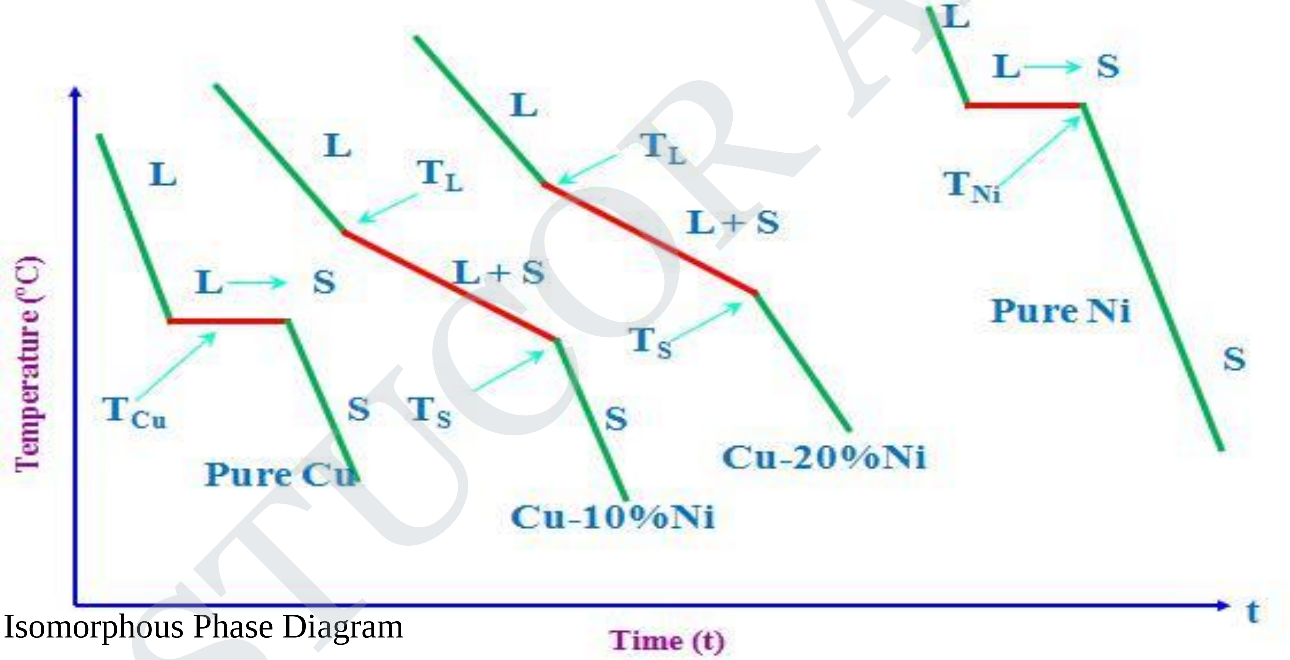

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The solidus line is that below which the solution is completely solid (does not contain a liquid phase

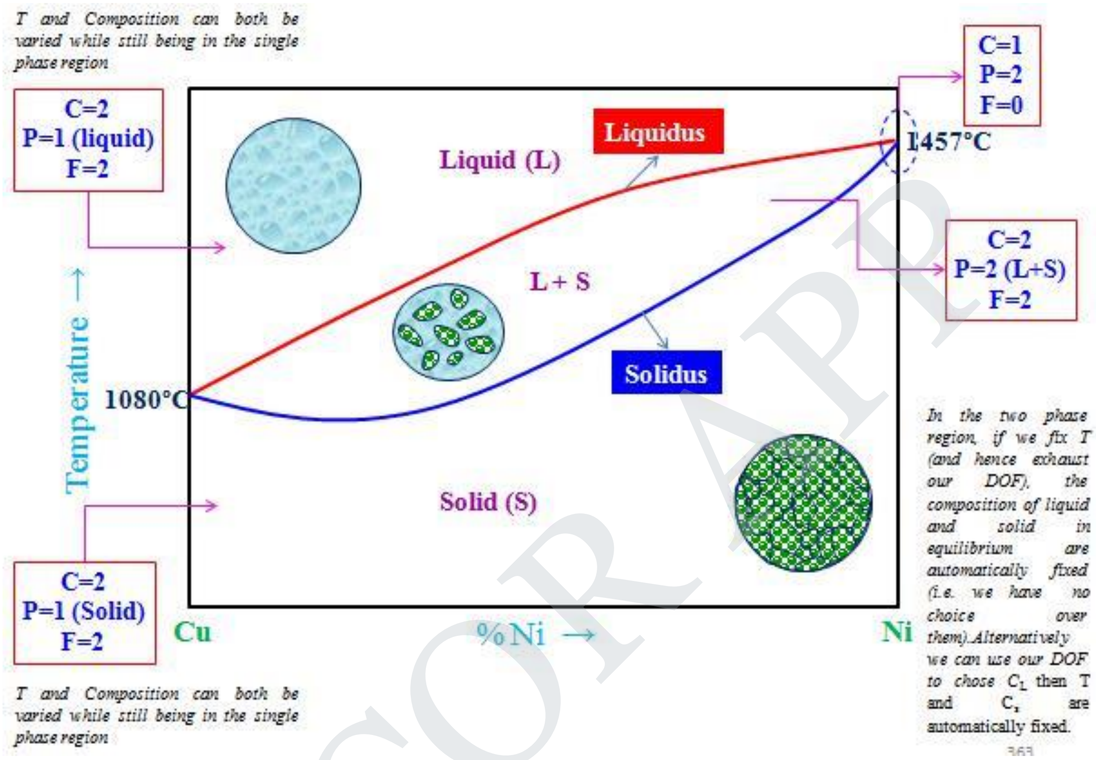


Figure 3.1: The copper–nickel phase diagram.

Tie line and Lever rule

Chemical Composition of Phases: To determine the actual chemical composition of the phases of an alloy, in equilibrium at any specified temperature in a two phase region, draw a horizontal temperature line, called a tie line, to the boundaries of the field . These points of intersection are dropped to the base line, and the composition is read directly.

Relative Amounts of Each Phase:

To determine the relative amounts of the two phases in equilibrium at any specified temperature in a two phase region, draw a vertical line representing the alloy and a horizontal temperature line to the boundaries of the field.

The vertical line will divide the horizontal line into two parts whose lengths are inversely proportional to the amount of the phases present. This is also known as Lever rule.

The point where the vertical line intersects the horizontal line may be considered as the fulcrum of a lever system.

The relative lengths of the lever arms multiplied by the amounts of the phases present must balance.

Tie line and Lever rule

We draw a horizontal line (called the Tie Line)at the temperature of interest (say T0). Let Tie line is XY.

Solid (crystal) of composition C 1 coexists with liquid of composition C 2

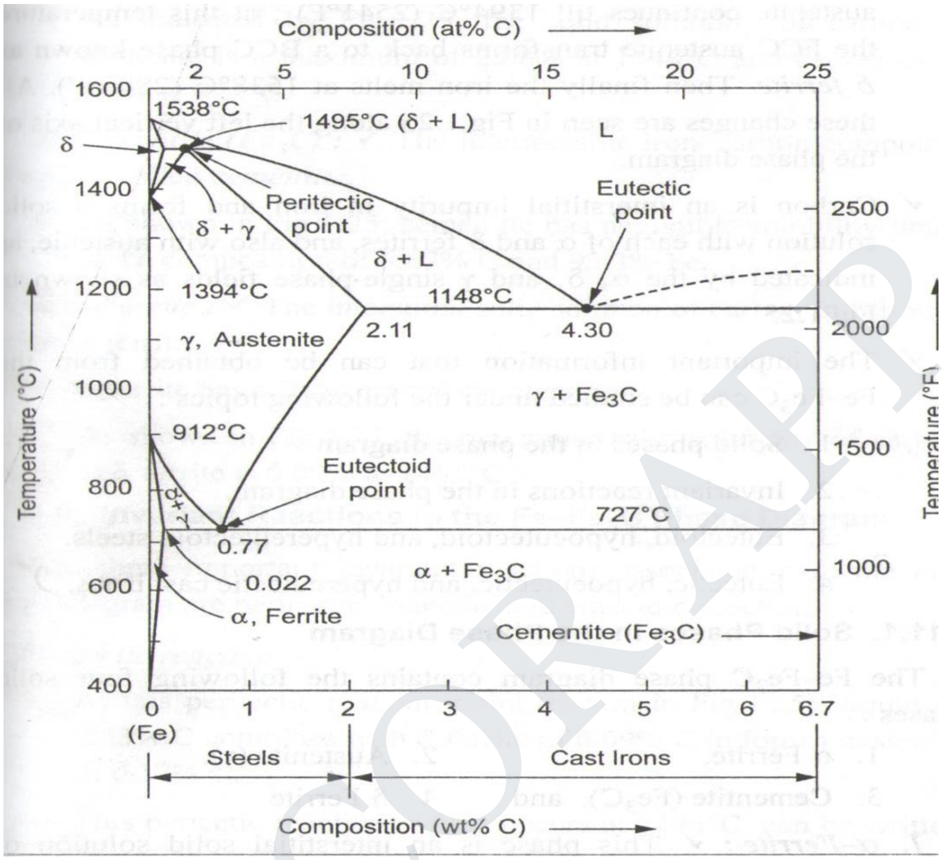
Note that tie lines can be drawn only in the two phase coexistence regions (fields). Though they may be extended to mark the temperature.

To find the fractions of solid and liquid we use the lever rule.

The portion of the horizontal line in the two phase region is akin to ‘lever’ with the fulcrum at the nominal composition (C0)

The opposite arms of the lever are proportional to the fraction of the solid and liquid phase present (this is lever rule).

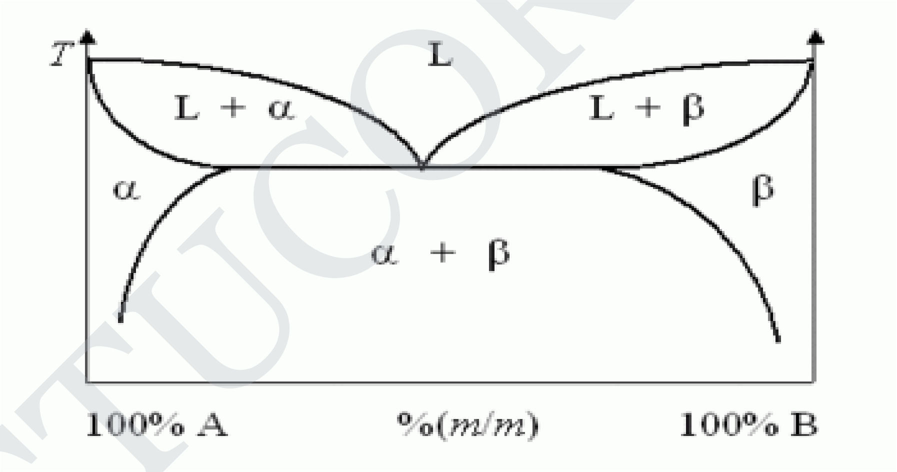
IRON-IRON CARBIDE EQUILIBRIUM DIAGRAM



- It is used to show conditions at which thermodynamically distinct phases can occur at equilibrium.
- Common components of a phase diagram are lines of equilibrium or phase boundaries, which refer to lines that mark conditions under which multiple phases can coexist at equilibrium.
- Phase transitions occur along lines of equilibrium.
- Triple points are points on phase diagrams where lines of equilibrium intersect.
- The water phase diagram has a triple point corresponding to the single temperature and pressure at which solid, liquid, and gaseous water can coexist in a stable equilibrium.
- Solidus Line: the temperature below which the substance is stable in the solid state.

- Liquidus Line: the temperature above which the substance is stable in a liquid state.
- There may be a gap between the solidus and Liquidus within the gap, the substance consists of a mixture of crystals and liquid
- The Possible phases are:
  - α- Ferrite(B.C.C)
  - γ- Austenite(F.C.C)
  - δ- Ferrite(B.C.C)
  - Liquid Fe-C
  - Fe_3C (or) Cementite

EUTECTIC REACTION

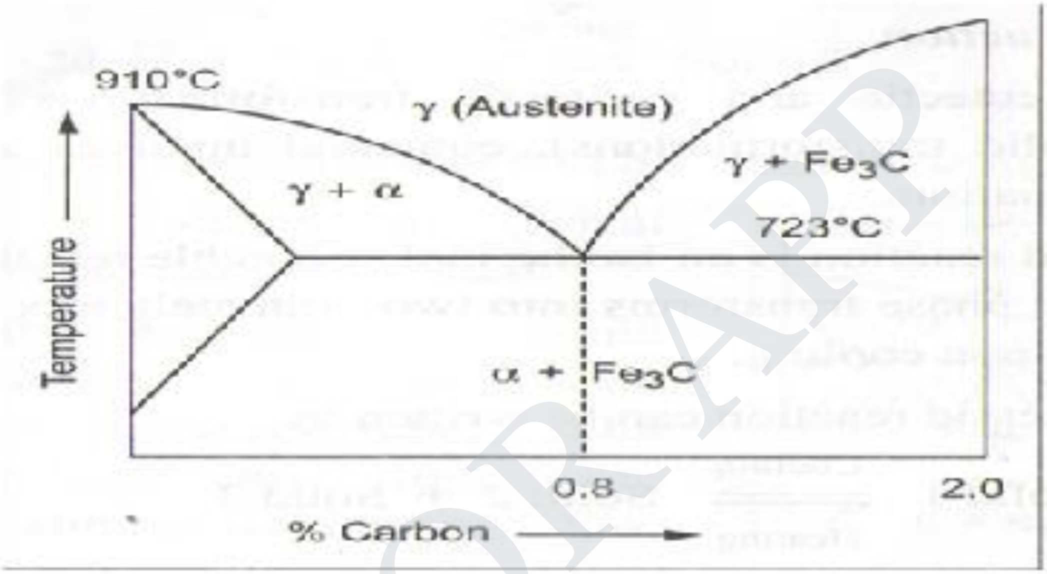


$$\text{Liquid} \underset{\text{Heating}}{\overset{\text{Cooling}}{\rightleftharpoons}} \text{Solid 1} + \text{Solid 2}$$

- In a eutectic reaction liquid phase is directly converted in to solid phase having two different structures when cooling.
- The eutectic temperature and composition determine a point on the phase diagram called the eutectic point.

- In a eutectic reaction the solid phase having two different structures converted into single liquid phase while heating.
- The two different structures such as Austenite and Cementite at 4.3% carbo

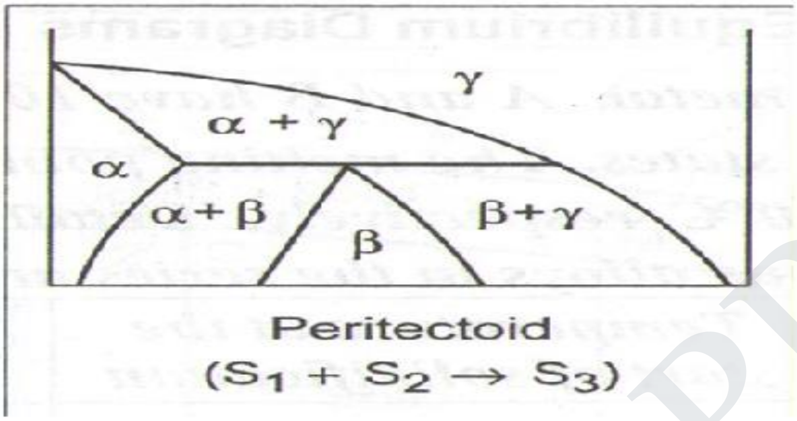
ECTECTOID REACTION



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

- In a eutectoid reaction the single solid phase having one structures converted into two different structure solid phase while cooling.
- In a eutectoid reaction two different structure solid phases is directly converted in to single structure solid phase while when cooling.
- The eutectoid temperature and composition determine a point on the phase diagram called the eutectoid point.
- That is Austenite is a single structure and two different structures such as Ferrite and Cementite .
- This reaction occurs in a 0.8% of carbon at 723°C.

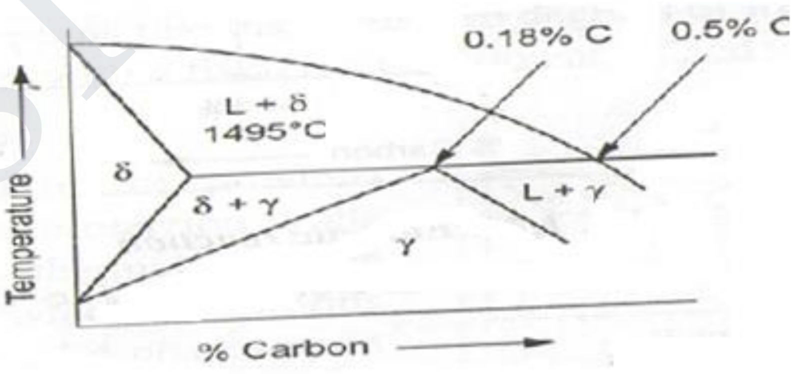
PERITECTOID REACTION



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

- Theperitectoid reaction is an isothermal reversible reaction in which two solid phases transform into a third solid phase upon cooling.
- Theperitectoid reaction is an isothermal reversible reaction in which single solid phases transform into a two solid phase upon heating.
- It is reversible reaction of eutectic reaction

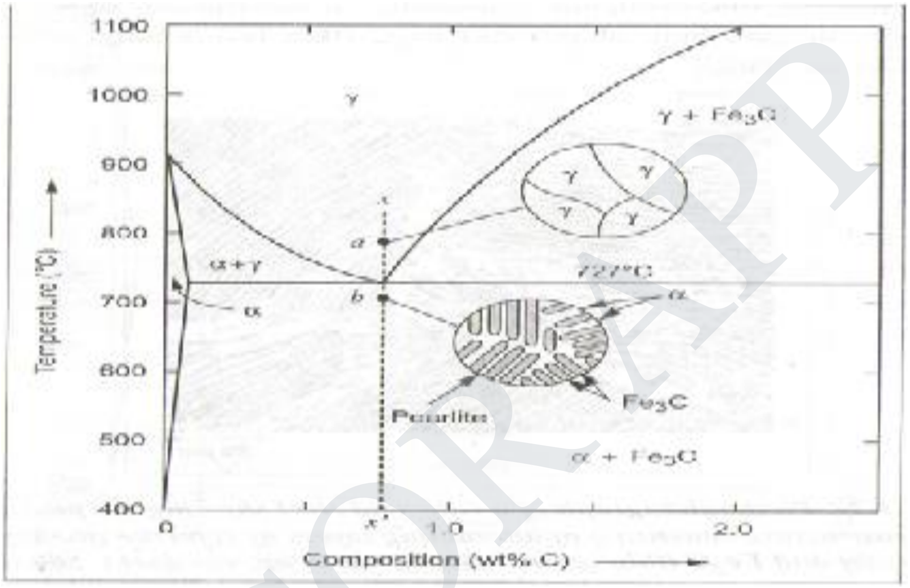
PERITECTIC REACTION



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

- In the pertectic reaction a solid and liquid phases combine to from another solid phase while cooling and reversible while heating.
- It is reversible reaction of eutectoidreaction.
- This reaction occurs in a 0.18% of carbon at 1495°C.

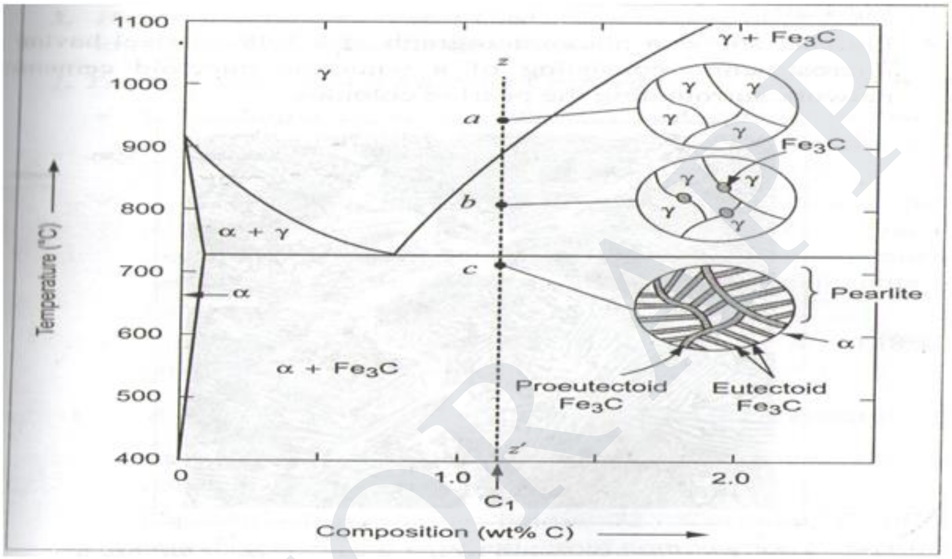
TRANSFORMATION OF EUTECTOID STEEL



- A sample of a 0.8% eitecotid steel is heated to above 700°C and maintained for sufficient period of time.
- It converted in to homogeneous austenite. This process is called as austenitizing.

- On further cooling the entire structure to transform austenite to a lamellar structure that is ferrite and cementite.
- The a lamellar structure nothing but ferrite and cementite.

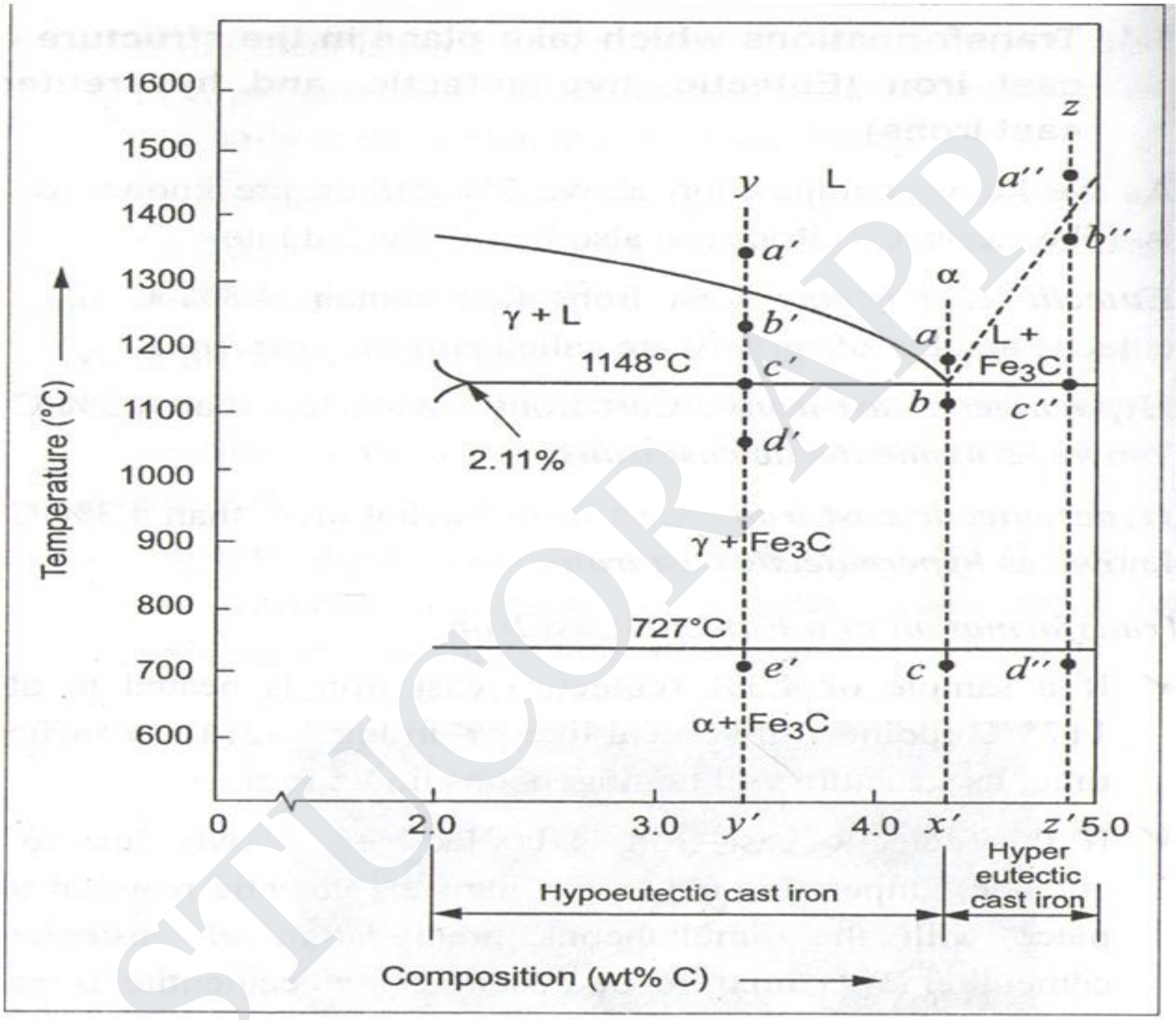
TRANSFORMATION OF HYPEREUTECTOID STEEL



- To the right of the eutectoid reaction between 0.8% to 2.11% of cabon hyper eutectoid takes places.
- Hence three stages a, b,c are marked depend upon curves are draw.
- The sample of 1.2% C is taken.
- At the point C the proeutectoid that is cementite an pearlite structure.
- At the point B cementite and austenite is present.
- At the point A fully austenite is present.

TRANSFORMATION OF EUTECTIC (4.3%C) show in xx’, HYPOEUTECTIC(2.0% to 4.3%C) show in yy’,

HYPEREUTECTIC(4.3% to 5.0%C) show in yy’,



UNIT-II

HEAT TREATMENT

Heat Treatment Is the Process Of Giving The Controlled Heating And Cooling To Derive Different Properties In The Materials.

PURPOSE OF HEAT TREATMENT:-

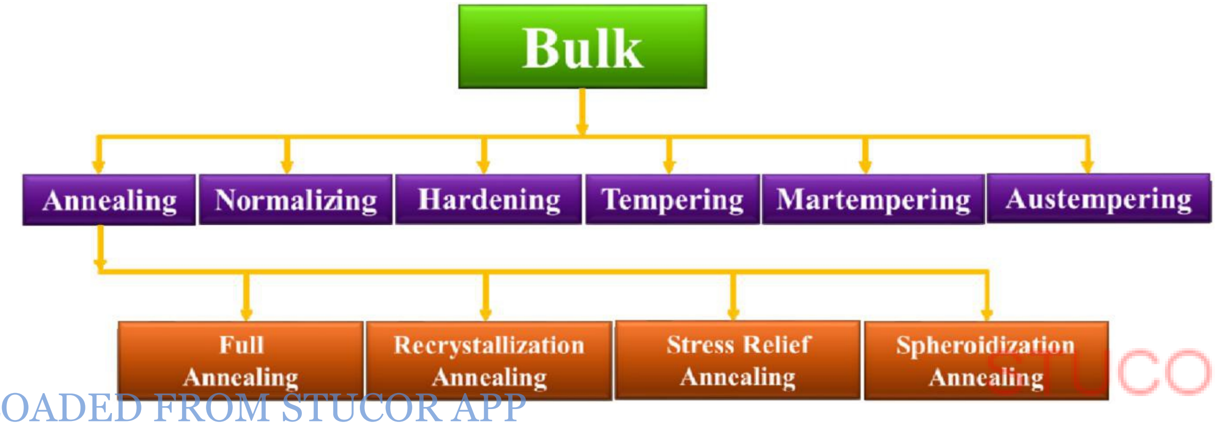
- To Relive Internal Stress
- To Improve Machine Ability.
- To Improve Refine Grain Size.
- To Improve Mechanical Properties.
- To Improve resistance to wear etc.

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 required rate to obtain the desired properties.



ANNEALLING

- The Process of Slow Cooling Is Knows As Annealing.
- The Materials Are Heated Above Critical Temperature.
- Then The Temperature maintain For a Period Of Time.
- Then allow it to cool slowly to room temperature In Side the Furnace It Self..
- Cooling is usually done in the furnace itself by decreasing the temperature 10°C to 30°C per hour.

Types Of Annealing:-

- full annealing
- process annealing
- stress relief annealing
- recrystallisation annealing

Full Annealing:-

- The Material Is Heated Above 723°C To 910°C.
- Hence The Structure is converting into homogeneous single phase austenite.
- Then The Temperature maintains For a Period of Time.
- Then allow it to cool slowly to room temperature In Side the Furnace It Self..
- Cooling is usually done in the furnace itself by decreasing the temperature 10°C to 30°C per hour.

Process annealing:-

- The Material Is Heated Above 550°C To 650°C.
- Then The Temperature maintains For a Period of Time.
- Then allow it to cool slowly to room temperature.
- The method is very cheaper more rapidly used.

Stress relief annealing:-

- The Material Is Heated Above 500°C To 650°C.
- Then The Temperature maintains For a Period of Time.
- Then allow it to cool slowly to room temperature In Side the Furnace It Self.
- The method is very cheaper more rapidly used.
- Hence Internal Stress Are Removed**.**
-

Recrystallisation annealing:-

- The Material Is Heated Above 500°C To 650°C.
- Then The Temperature maintains For a Period of Time.
- Then allow it to cool slowly to room temperature In Side the Furnace It Self.
- Hence Distorted Grains Of Cold Worked Metals Are Replaced By New Grains.

NORMALIZING

Normalizing is similar to full annealing but cooling is done by still air rather then furnace.

Purpose of Normalizing:-

- To Improve Refine Grain Size.
- To Improve Mechanical Properties.
- To Increase The Strength Of The Steel.

Operation:-

- Material Is Heated Above 40°C - 50°C Above Its Upper Critical Temperature. .
- Then The Temperature maintains For a Period of Time.
- Then allow it to cool slowly to room temperature.
  - But cooling is done in still air.
  - The Normalizing process consisting of ferrite and pearlite for hypoeucetoid steels. and pearlite and cementite for hyper eutectoid steel.

QUENCHING

- The Process of fast or instant Cooling Is Knows as Annealing.
- Cooling is done by contact the material with quenching medium.
- Quenching medium as solid liquid and gas.

Selection of Quenching medium:-

- Boiling point.
- Viscosity.
- Desired rate of cooling.

Stages of Quenching:-

Stages 1: vapour-jacket stages.

- The work piece of hot metal is first inserted into tank having quench medium.
- The vaporizes and forms a gaseous layer separating the metal and liquid
- In this stage cooling is very slow.

Stages 2: vapour-transport cooling stage.

- The hot metal is cooled to a temperature.
- In this stage bubbles nucleate and remove the gaseous layer.
- In this stage cooling rate more.

Stages 3: liquid cooling stage.

- The metal cools below the boiling point of quenchant.
- In this stage all heat transfer occurs through conduction across the solid and liquid interface.
- In this stage is the slowest cooling rate is obtained.

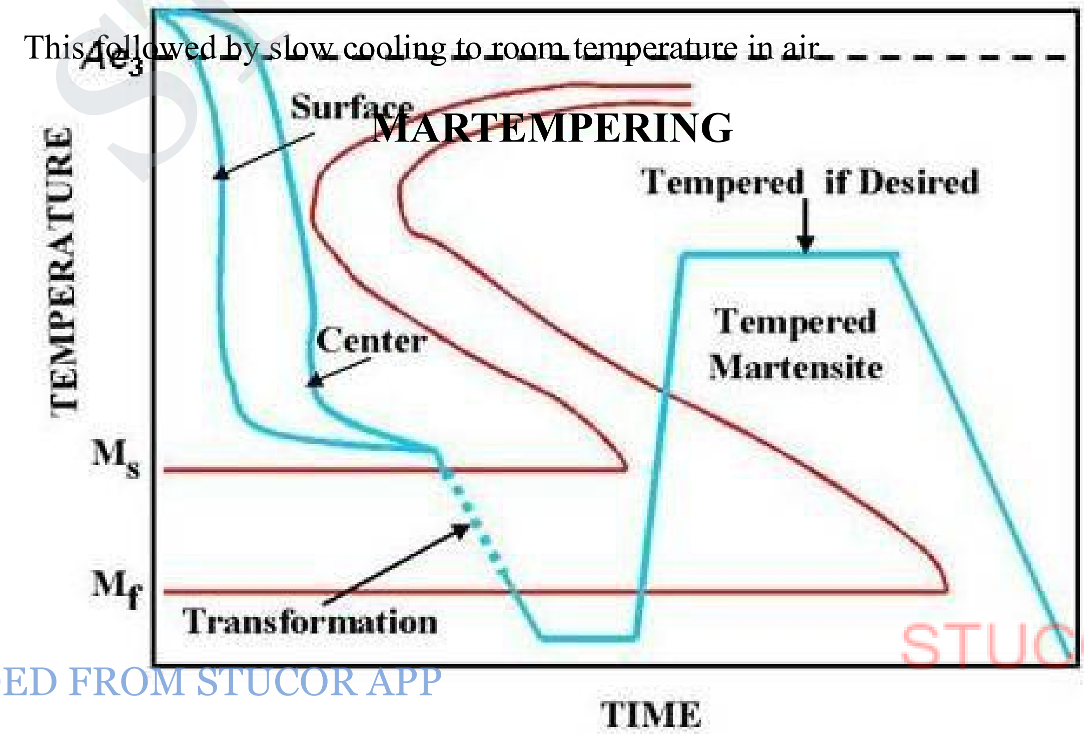
TEMPERING

- The tempering is done to reduce hardness of steel and improve ductility and toughness.
- In this process the heating is done for the metals which are already hardened steel.

Operation:-

- The hardened metal is heated to a temperature between 250°C To 650°C.
- Then The Temperature maintains For a Period of Time (1-2 hours)
- This followed by slow cooling to room temperature in air.

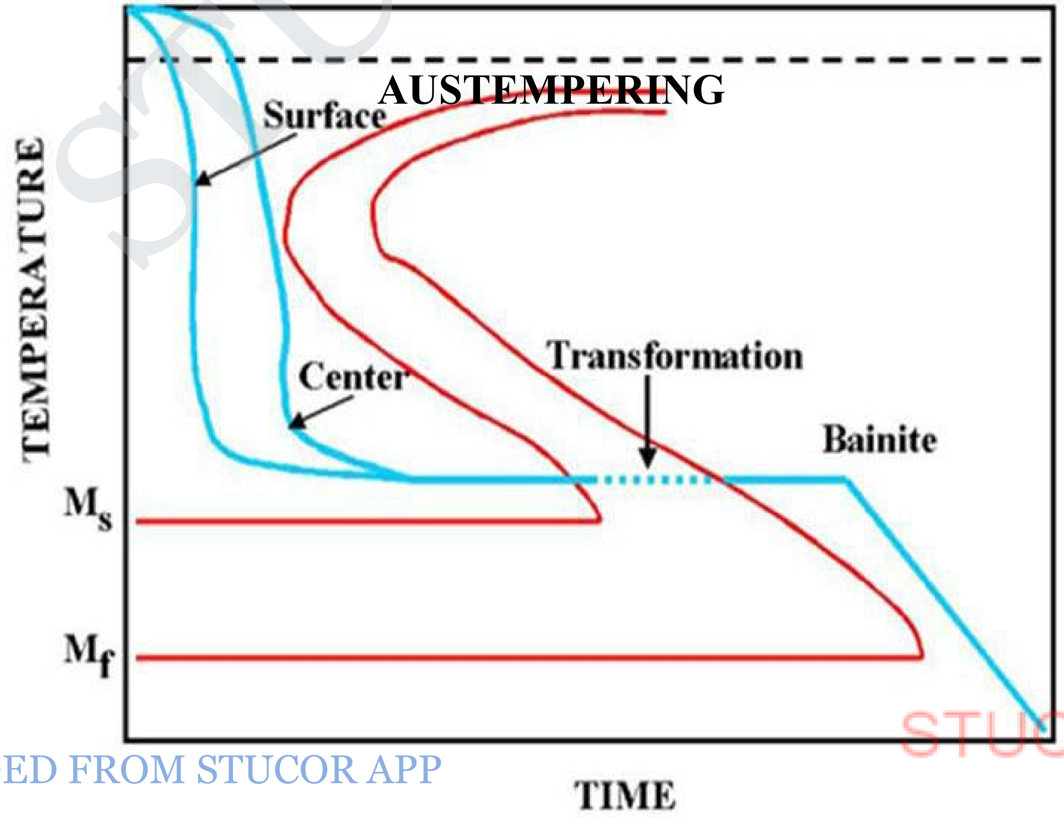
MARTEMPERING



Martempering is a heat treatment for steel involving austenitisation followed by step quenching, at a rate fast enough to avoid the formation of ferrite, pearlite or bainite to a temperature slightly above the martensite start (Ms) point. A schematic of above the process is shown in Fig.4 7.

The advantage of martempering lies in the reduced thermal gradient between surface and center as the part is quenched to the isothermal temperature and then is air cooled to room temperature.

Residual stresses developed during martempering are lower than those developed during conventional quenching because the greatest thermal variations occur while the steel is in the relatively plastic austenitic condition and because final transformation and thermal changes occur throughout the part at approximately the same time. Martempering also reduces or eliminate susceptibility to cracking.



Austempering process is similar to the Martempering process except that the sample after the homogenization of temperature from surface and temperature, instead of quenching,

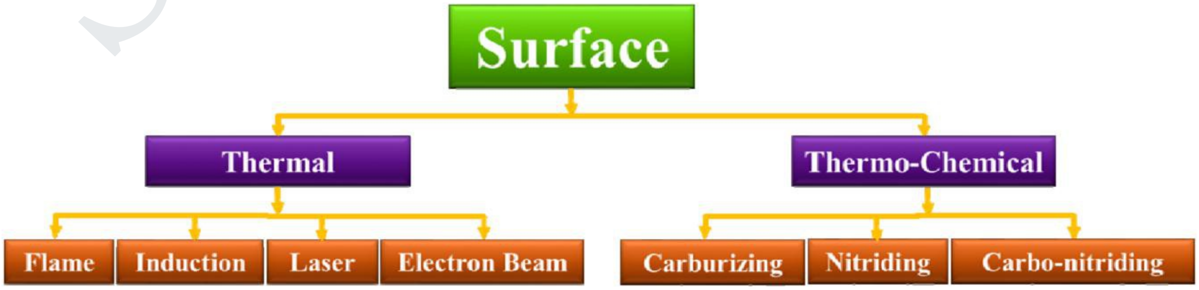
held at that temperature above Ms for sufficient time (in the bainite transformation range) to produce banitic microstructure.A schematic of this process is shown in Fig. An advantage of this process over Martempering is that the tempering can be avoided. Other advantages include, Higher ductility, Resistance to shock, Uniform hardness, Tougher and more wear restiance, Higher impact and Fatigue Strengths.

SURFACE HARDENING

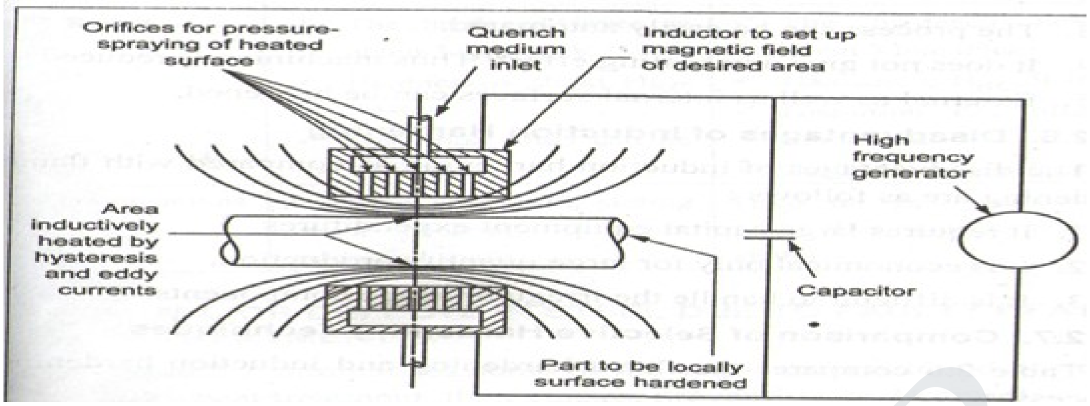
Numerous industrial applications require a hard wear resistant surface called the *case*, and a relatively soft, tough inside called the *core*. Example: Gears

They are two different categories. They are thermo chemical and thermo mechanical treatments. Thermo chemical treatment is related to change in chemical composition and In Thermo mechanical treatment, there is no change of chemical composition of the steel and are essentially shallow- hardening methods.

A detailed flow chart is given below related to surface hardening treatments.

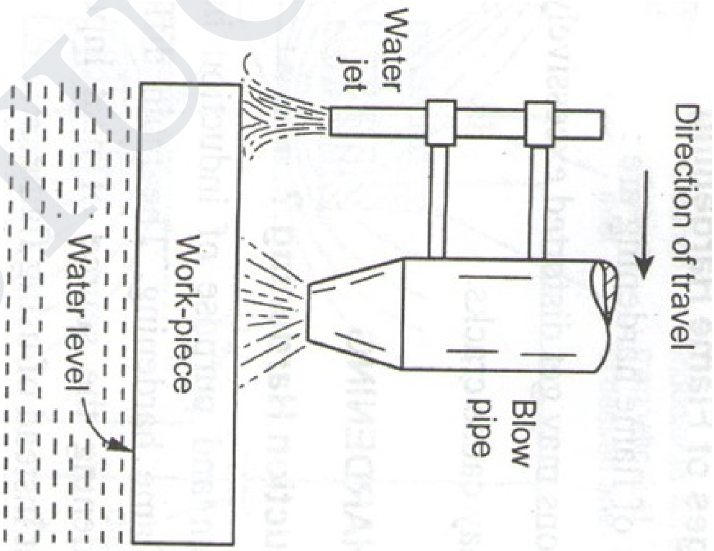


INDUCTION HARDENING



- Material Is Heated Above Its Upper Critical Temperature.
- Heating IS Done By Passing High Frequency Alternating Current Current
- Cyclic Magnetic Field That Is Generated Induces By Alternating Current That Heats The Work Piece.
- Hence Surface Is Quenches By Water Spray That Follows The Flame.

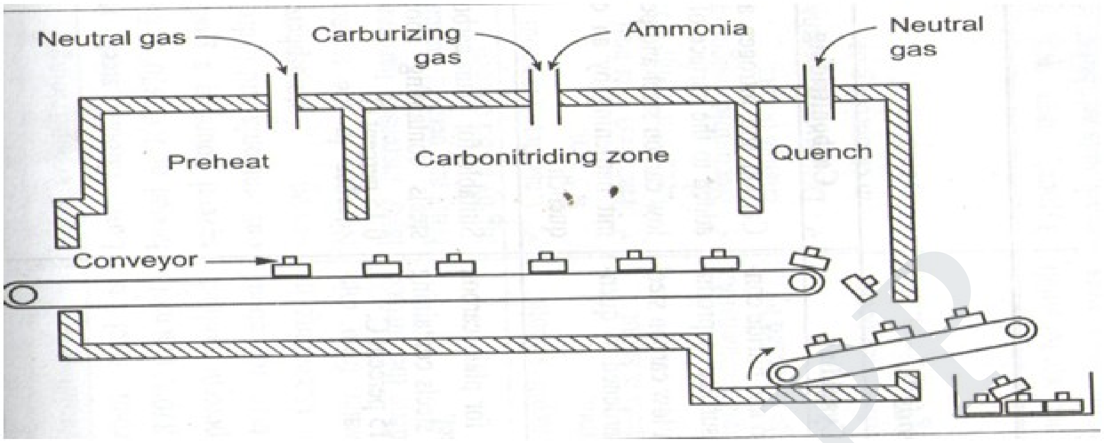
FLAME HARDENING



- Material Is Heated Above Its Upper Critical Temperature.
- Oxy-Acetylene Tourch Is Used As A Heating Source.

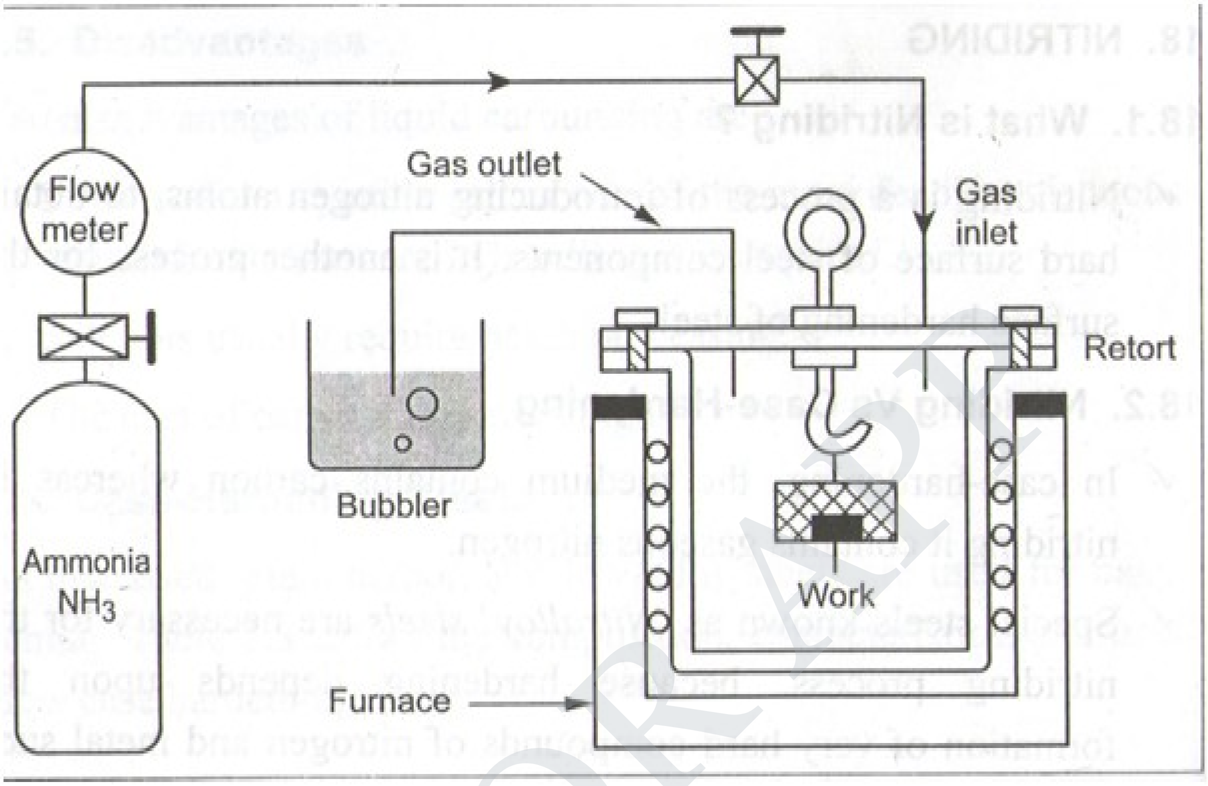
- Hence Surface Is Quenches By Water Spray That Follows The Flame.
- Steels Having 0.3% To 0.6% Carbon Are Hardened By Flame Hardened.

CARBONITRIDING



- It is carried out in a gas- atmosphere furnace.
- Hence propane (or) methane mixed with the ammonia.
- The organic gas serves as the source of carbon and the ammonia gas serves of nitrogen.
- The work piece is heated to 850°C at 2 to 10 hours. This is followed by quenching and then tempering is employed at 180°C.
- Case Depth Is About 0.5mm.
- Hardness after heat treatment Rc65
- Typical uses:-
  - Gears.
  - Nuts.
  - Bolts.

NITRIDING SYSTEM



- First The Work piece are heat treated to produce the required properties in the core.
- The steel part are heated and maintained at about 500°C for between 40 to and 100 hrs.
- The treatment takes place in gas-tight chamber.
- Hence ammonia gas is allowed to circulate
- The ammonia decomposes and releasing single atoms of nitrogen.
- The atomic from of nitrogen(N) is absorbed on the surface of steel components.
- Hence harden surface can obtained.

CYANIDING

- Nitrogen And Carbon Is Used To Obtain Hard Surface

e Is Immersing in the Cyanide Bath.

- Hence hard surface is obtained .

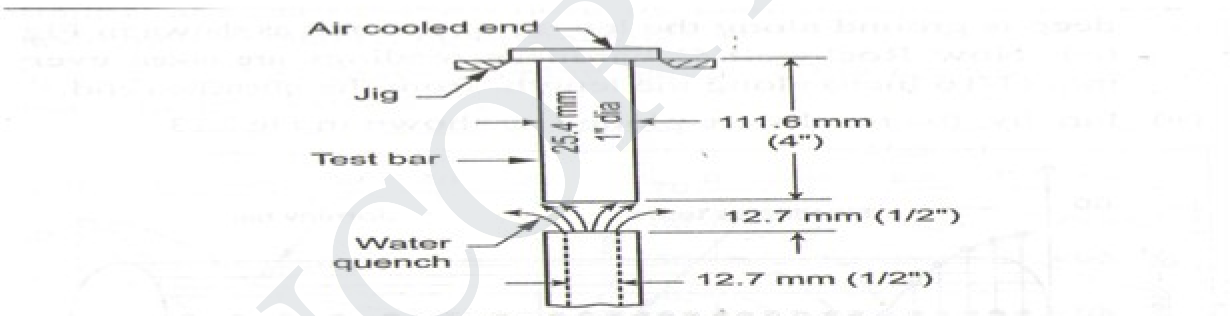
Operation:-

- The Steel Components Are Heated Above A Temperature Of 950°C
- Here Sodium Cyanide And Sodium Carbonate Is Used As Molten Bath.
- During this treatment both carbon and nitrogen diffuse into the surface of the steel.
- Hence hard iron nitrides contribute to the surface to be hardened.

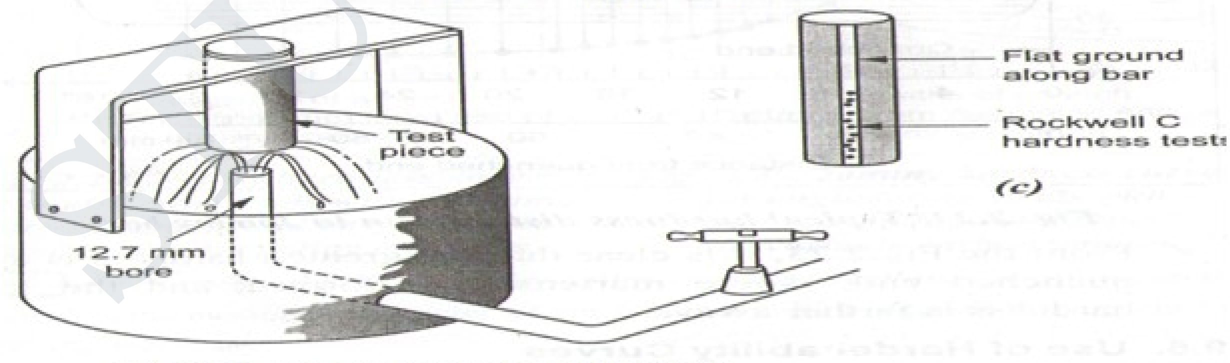
Applications:-

Gear. Shafts, pins, braked, cams, sleeves , springs,

END-QUENCH SPECIMEN& JOMINY END QUENCH APPARATUS



(a) End-quench specimen



(b) Jominy end-quench apparatus

TESTING PROCEDURE:-

- The standard test piece is heated to above upper critical temperature until it become completely austenitic.

enched at one end only by standard jet of water at 25°C.

- Thus Different Rates Of Cooling Are Obtained Along The Length Of The Test-Piece.
- Hence Now Rockwell C Hardness Reading Are Taken Every 1.5mm (1/16 Inch) Along The Length From The Quenched End.
- Hence hardened is more on quenched end and lower on the other end.

UNIT-III

FERROUS AND NON FERROUS METALS

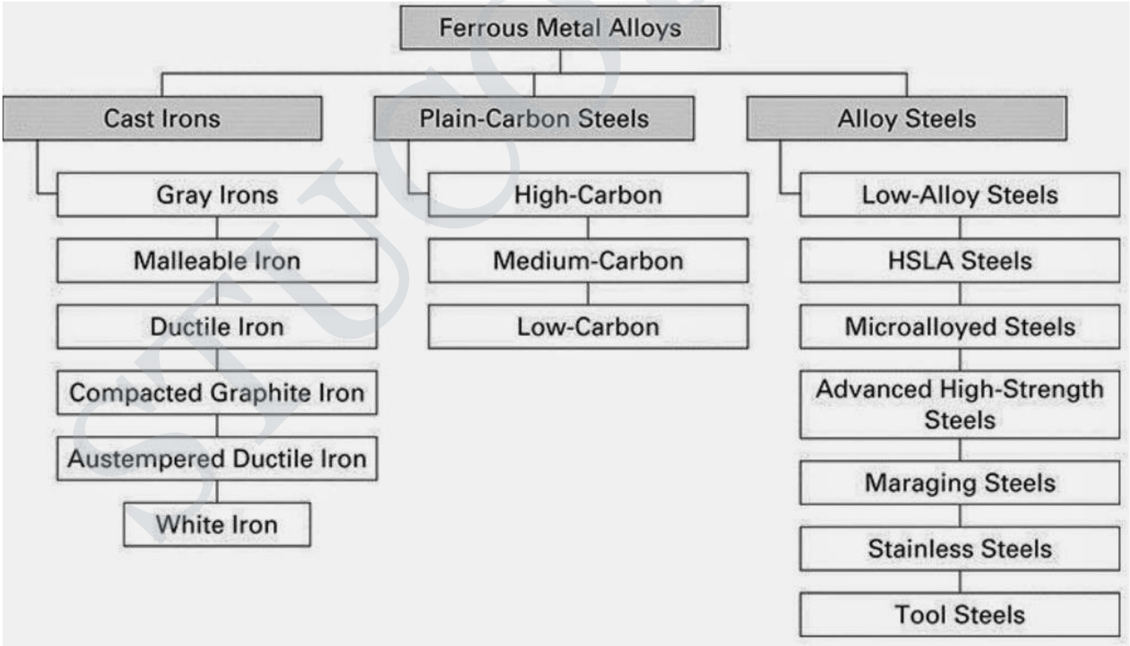
Materials are made up of elements. Materials are anything that have weight and occupy some space. An every increasing variety of materials is available, each having its own characteristics application, advantages and limitations.

Classification of metals:-

Ferrous and non-ferrous

Ferrous:-

- The metals, which contain iron as their main constituent, are called ferrous metals
- Ferrous materials are the most important metals/alloys in the metallurgical and mechanical industries because of their very extensive use.



CAST IRON

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

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

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

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

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

The varieties of cast iron in common use are:

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

Grey Cast Iron

It is the iron which is most commonly used in foundry work. If this iron is machined or broken, its fractured section shows the greyish colour, hence the name “grey” cast iron. The grey colour is due to the fact that carbon is present in the form of free graphite. A very good characteristic of grey cast iron is that the free graphite in its structure acts as a lubricant. This is suitable for those components/products where sliding action is desired. machinability, high compressive strength, low tensile

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

White Cast Iron

It is so called due to the whitish colour shown by its fracture. White cast iron contains carbon exclusively in the form of iron carbide Fe_3C (cementite). From engineering point of view, white cast iron has limited applications. This is because of poor machinability

and possessing, in general, relatively poor mechanical properties. It is used for inferior castings and places where hard coating is required as in outer surface of car wheels. Only crushing rolls are made of white cast iron. But it is used as raw material for production of malleable cast ir

Malleable Cast Iron

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

The malleable cast iron is ductile and may be bent without rupture or breaking the

section. Its tensile strength is usually higher than that of grey cast iron and has excellent machining qualities. Malleable cast iron components are mainly utilized in place of forged steel or parts where intricate shape of these parts creates forging problem. This material is principally employed in rail, road automotive and pipe fittings etc.

Nodular Cast Iron

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

Outstanding characteristics of nodular cast iron are high fluidity which allows the castings of intricate shape. This cast iron is widely used in castings where density as well as pressure tightness is a highly desirable quality. The applications include hydraulic

etc.

Chilled Cast Iron

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

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

STAINLESS STEELS

The only material known to engineers which possesses a combination of various properties such as: wide range of strength and hardness, high ductility and formability, high corrosion resistance, good creep resistance, good thermal conductivity, good machinability, high hot & cold workability and excellent surface finish is stainless steel. Alloy steels have been developed for a specific purpose. We shall study them as follows: They are known as stainless since they do not corrode or rust easily in most of environment and media. Stainless steels can be further divided into the following three

Ferritic stainless steel:

It is that steel when properly heat treated and finished, resists oxidation and corrosive attacks from corrosive media. Ferritic stainless steels contain 12–18% chromium, 0.15 to 0.2% carbon besides iron and usual amounts of manganese and silicon. The steels are stainless and relatively cheap. They are magnetic in nature. Structure of these steels consist of ferrite phase which cannot be hardened by he treatment. These steels are actually iron-chromium alloys and cannot be hardened by heat treatment. Such type of steel is utilized in manufacture of dairy equipment food processing plants, etc.

Martensitic stainless steel:

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

Austentic stainless steels:

These are the most costliest among all stainless steels. In these steels besides chromium, strong austenitic stabilizer and therefore the microstructure of these steels is austentic at room temperature. These steels contain 12 to 21% chromium and 8 to

15% nickel and carbon less than 0.2%. The most familiar alloy of this group is known as 18:8 stainless steel i.e. 18% chromium and 8% nickel plus other. Other elements like carbon, manganese and silicon in very small quantities.

TOOL STEELS

Tool steels are specially alloyed steels designed for high strength, impact toughness and wear resistance at room and elevated temperatures. They are normally used in forming and machining of metals. So the requirements in a tool steel are that it should be capable of becoming very hard and further that it should be able to retain its hardness at high temperatures normally developed during cutting of materials. This property is known as “red hardness”. Further, tool steel should not be brittle for smooth working.

High Speed Steel (H.S.S.)

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

0.9% and rest iron.

Molybdenum High Speed Steel

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

NON-FERROUS METALS AND ALLOYS

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

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

in industry are: copper, aluminium, tin, lead, zinc, and

Copper

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

Properties and Uses

(1) **High Thermal Conductivity:** Used in heat exchangers, heating vessels and appliances, etc.
(2) **High Electrical Conductivity:** Used as electrical conductor in various shapes and forms for various applications.
(3) **Good Corrosion Resistance:** Used for providing coating on steel prior to nickel and chromium plating
(4) **High Ductility:** Can be easily cold worked, folded and spun. Requires annealing

After cold working as it loses its ductility.

Aluminium

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

Properties and Uses

- Like copper it is also corrosion resistant.
- It is very good conductor of heat and electricity although not as good as copper.
- Possesses high ductility and light weight so widely utilized in aircraft industry.
- Needs frequent annealing if cold worked since it becomes hard after cold working.
- In view of its ductility and malleability it has replaced copper in electrical transmission and appliances to some extent.
- It is used in manufacturing of household utensils including pressure cookers.

Zinc

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

Properties and Uses

e: Widely used as protective coating on iron and steel.

Coating may be provided by dip galvanizing or electroplating.

(2) **High fluidity and low melting point:** Most suitable metal for pressure die casting generally in the form of alloy.

(3) **When rolled into sheets**, zinc is utilized for roof covering and for providing a damp proof non-corrosive lining to containers.

(4) **The galvanized wires, nails, etc.** are produced by galvanizing technique and zinc is also used in manufacture of brasses.

Nickel

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

Properties and Uses

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

Magnesium

Principal ores of magnesium are **magnesite**, **carnallite** and **dolomite**. Magnesium is extracted by electrolytic process.

Properties and Uses:

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

Vanadium

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

Properties and Uses:

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

Antimony

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

Properties and Uses

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

ALLOYS OF COPPER

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

Brass

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

(1) Alfa brass: Contains upto 36% Zn and rest copper for cold working.

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

The tensile strength and ductility of brass both increase with increase in content of Zn upto 30% zinc. With further increase in zinc content beyond 30%, the tensile strength continues to increase upto 45% of Zn, but ductility of brasses drops significantly. β-phase is less ductile than α-phase but it is harder and stronger.

Thus, there are various types of brasses depending upon proportion of copper and zinc. Fundamentally brass is a binary alloy of copper with as much as 50% zinc. Various classes of brasses such as cartridge brass, Muntzmetal leaded brass, Admirality brass, naval brass and nickel brass depending upon the proportion of copper and zinc plus third alloying metal are available for various uses. Suitable type of brasses can undergo the processes of casting, hot forging, cold forging, cold rolling into sheets, drawing into wires and extrusion for obtaining requisite special cross-section bars. The melting point of brass varies according to its composition but most of the brasses in the common range liquefy between temperatures of 840°C to 960°C. By adding small quantities of other elements, the properties of brass may be greatly affected. For example, addition of 1 to 2% zinc improves the machinability of brass. Brass has a greater strength than that of copper but has a lower thermal and electrical conductivity. Brasses possess very good corrosion resistance and can be easily soldered. Brasses are used in hydraulic fittings, pump linings, utensils, bearings and bushes, etc.

Bronze

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

Phosphor_bronze:

When bronze contains phosphorus, it is known as phosphor bronze. Phosphorus present in such alloy increases the strength, ductility and soundness of castings. Various compositions of this alloy are available for different applications. The composition of the alloy varies according to whether it is to be forged, wrought or cast. A common type of phosphor bronze has the following composition as per Indian standards. Copper = 93.6%, tin = 9%, and phosphorus = 0.1 to 0.3%. The alloy possesses good wearing qualities and high elasticity. The alloy is resistant to salt water corrosion. Cast phosphor bronze is utilized for production of bearings and **gears**. Bearings of bronze contain 10% tin and small addition of lead. This is also used in making gears, nuts, for machine lead screws, springs, pump parts, linings and many other such applications.

Gun metal:

Gun metal contains 2% zinc, 10% tin and 88% copper. It is a very famous composition. Sometimes very small amount of lead is also added to improve cast ability and machinability. The presence of zinc improve its fluidity. This bronze is used for bearing bushes, glands, pump valves and boiler fittings, etc.

Silicon bronze:

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

Bell metal:

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

Manganese Bronze:

It is an alloy of copper, zinc and manganese. It contains 55 to 60% copper, 40% zinc, with 3.5% manganese. This alloy is highly resistant to corrosion. It is stronger and harder than phosphor bronze. It has poor response to cold working but can be easily hot worked. It is generally utilized for producing bushes, plungers, feed pumps and rods, etc. Worm gears are frequently made of manganese bronze.

Muntz Metal:

The composition of this alloy is 60 percent copper and 40 per cent zinc. Sometimes a small quantity of lead is also added. This alloy is stronger, harder and more ductile than normal brass. While hot working between 700°C to 750, it responds excellently for process but does not respond to cold working. This alloy is utilized for a wide variety of small components of machines, bolts, rods, tubes, electrical equipment as well as ordinance works. It is widely employed in producing such articles which are required to resist wear.

Alloys of Aluminium

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

Duralumin:

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

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

Y-Alloy:

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

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

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

Alloys of Nickel

German silver:

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

Monel metal:

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

Nichrome:

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

Inconel and incolony:

These alloys principally contain, Ni, Cr, Fe, Mo, Ti and very small proportions of carbon. These are used as high temperature alloys. Inconel does not respond to heat treatment.

UNIT IV

NON METALLIC MATERIALS

Typical Commodity and Engineering Polymers/Plastics-Properties and Applications

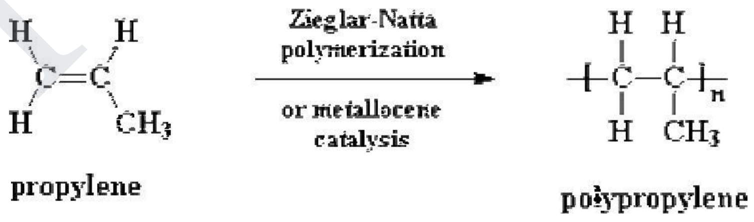
Polymers such as polyethylene, polypropylene, PVC etc which does not have excellent mechanical and thermal properties are used in high volume in non-structural applications are termed commodity polymers. Polymers which possess properties such as

i) Excellent mechanical properties over temperatures from below -40°C (-40°F) to above 148°C (300°F), ii) Self-extinguishing, non-dripping characteristics, iii) Excellent durability, dimensional stability and low water absorption, iv) Resistance to aqueous chemical environments and v) Excellent impact strength, are classified as engineering polymers/plastics . Ex., polyphenylene oxide, PEEK, polyethylene terephthalate, polyphenylene sulphide, Teflon, Kevlar, polyimide, polyeterimide, ABS etc.

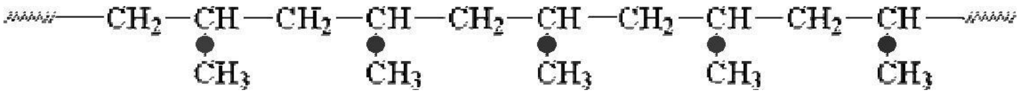
4.1 Polypropylene

Polypropylene(thermoplastic, melting temperature: 174^{O}C; glass transition temperature: -17^{O}C) is a versatile commodity polymer. It serves double duty, both as a plastic and as a fiber. As a plastic it's used to make things like dishwasher-safe food containers. It can do this because it doesn't melt below 160^{O}C, or 320^{O}F. Polyethylene, a more common plastic, will anneal at around 100^{O}C, which means that polyethylene dishes will warp in the dishwasher. As a fiber, polypropylene is used to make indoor-outdoor carpeting, used around swimming pools and miniature golf courses. It works well for outdoor carpet because it is easy to make colored polypropylene, and because polypropylene doesn't absorb water, like nylon does.

It is slightly more susceptible than polyethylene to strong oxidizing agents. It offers the best stress-crack resistance of the polyolefins. Products made of polypropylene are brittle at 0°C and may crack or break if dropped from benchtop height. Polypropylene can be made from the monomer propylene by Ziegler-Natta polymerization and by metallocene catalysis polymerization.



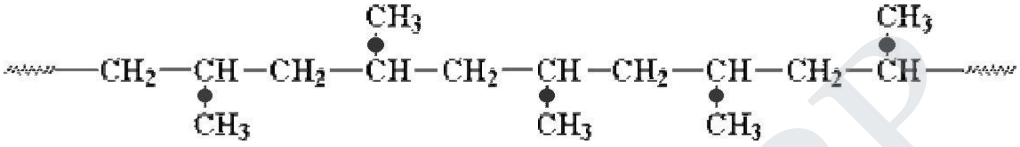
In Isotactic polypropylene all the methyl groups are on the same side of the chain, like this:



$$\sim\!\!\sim CH_2-\underset{CH_3}{CH}-CH_2-\underset{CH_3}{CH}-CH_2-\underset{CH_3}{CH}-CH_2-\underset{CH_3}{CH}-CH_2-\underset{CH_3}{CH}-\sim\!\!\sim$$

isotactic polypropylene

Atactic means that the methyl groups are placed randomly on both sides of the chain like this:

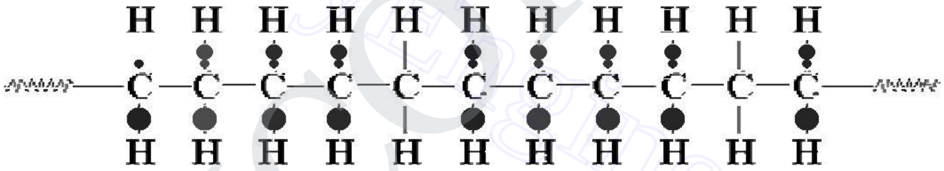


$$\sim\!\!\sim CH_2-\underset{CH_3}{CH}-CH_2-\overset{CH_3}{CH}-CH_2-\underset{CH_3}{CH}-CH_2-\underset{CH_3}{CH}-CH_2-\overset{CH_3}{CH}-\sim\!\!\sim$$

atactic polypropylene

4.2 Polyethylene

Polyethylene is probably the polymer seen mostly in daily life. Polyethylene is the most popular plastic in the world. This is the polymer that makes grocery bags, shampoo bottles, children's toys, and even bullet proof vests. For such a versatile material, it has a very simple structure, the simplest of all commercial polymers. A molecule of polyethylene is nothing more than a long chain of carbon atoms, with two hydrogen atoms attached to each carbon atom.



$$\sim\!\!\sim \underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\sim\!\!\sim$$

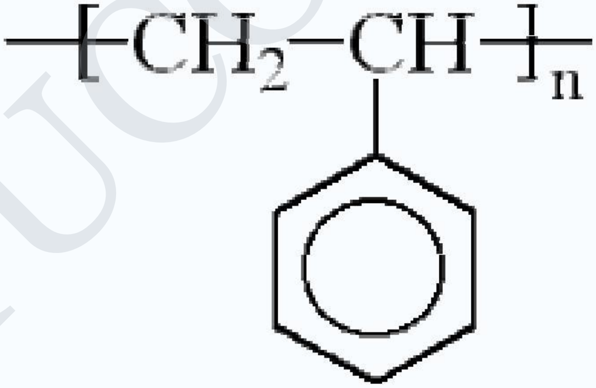
Sometimes it's a little more complicated. That is some of the carbons, instead of having hydrogens attached to them, will have long chains of polyethylene attached to them. This is called branched, or low-density polyethylene, or LDPE. When there is no branching, it is called linear polyethylene, or HDPE. Linear polyethylene is much stronger the branched polyethylene, but branched polyethylene is cheaper and easier to make. Linear polyethylene is normally produced with molecular weights in the range of 200,000 to 500,000, but it can be made even higher. Polyethylene with molecular weights of three to six million is referred to as ultra-high molecular weight polyethylene, or UHMWPE. UHMWPE can be used to make fibers which are so strong they replaced Kevlar for use in bullet proof vests. Large sheets of it can be used instead of ice for skating rinks. Branched polyethylene is often made by free radical vinyl polymerization. Linear polyethylene is made by a more complicated procedure called Ziegler-Natta polymerization. UHMWPE is made using metallocene catalysis polymerization. But Ziegler-Natta polymerization can be used to make LDPE, too. By copolymerizing ethylene monomer with a alkyl-branched comonomer such as one gets a copolymer which has short hydrocarbon branches. Copolymers like this are called linear low-density polyethylene, or LLDPE. LLDPE is often used to make things like plastic films.

Linear low-density polyethylene (LLDPE) combines the toughness of low-density polyethylene with the rigidity of high-density polyethylene.

Cross-linked high-density polyethylene (XLPE) is a form of high-density polyethylene wherein the individual molecular chains are bonded to each other (using heat, plus chemicals or radiation) to form a three-dimensional polymer of extremely high molecular weight. This structure provides superior stress-crack resistance and somewhat improves the toughness, stiffness and chemical resistance of HDPE. XLPE is a superior material for moulding very large storage tanks.

4.3 Polystyrene

Polystyrene is normally a solid thermoplastic, but can be melted at higher temperature for molding or extrusion, then resolidified. It is an amorphous and its glass transition temperature is 100^{o}C. Polystyrene is an aromatic polymer. Polystyrene is also used as a building material, with electrical appliances (light switches and plates), and in other household items. Polystyrene can be transparent or can be made to take on various colors. It is economical and is used for producing plastic model assembly kits, plastic cutlery, CD "jewel" cases, and many other objects where a fairly rigid, economical plastic of various colors is desired. For architectural and engineering modelling, polystyrene is extruded into forms of standard modelling scale with the cross-sections of a miniature I-beam as well as rods and tubes. It is also formed into sheets with various patterns for this purpose as well. The blank sheets of polystyrene are referred to as "plasticard". Polystyrene fabricated into a sheet can be stamped (formed) into economic, disposable cups, glasses, bowls, lids, and other items, especially when high strength, durability, and heat resistance are not essential. A thin layer of transparent polystyrene is often used as an infra-red spectroscopy standard.

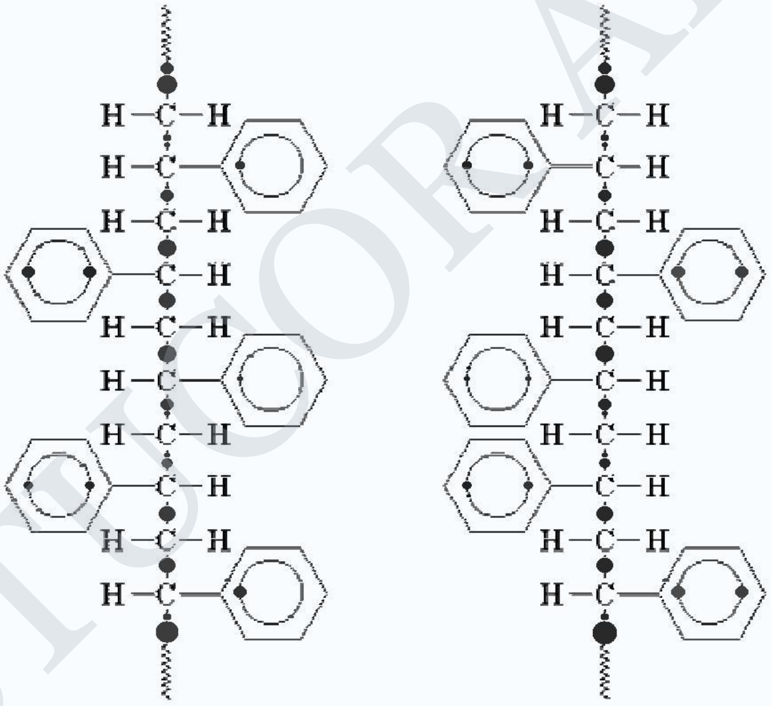


Polystyrene

The outside housing of the computer is probably made of polystyrene. Model cars and airplanes are made from polystyrene, and it also is made in the form of foam packaging and insulation (Styrofoam™ is one brand of polystyrene foam). Clear plastic drinking cups are made of polystyrene. So are a lot of the molded parts on the inside of car, like the radio knobs. Polystyrene is also used in toys, and the housings of things like hairdryers, computers, and kitchen appliances.

Expanded polystyrene is very easily cut with a hot -wire foam cutter, which is easily made by a heated and taut length wire, usually nichrome due to its thermal conductance. Hot wire foam cutters work by heating special wire (usually nichrome or stainless steel) to the point where it can vaporize foam immediately adjacent to it. The foam gets vaporized before actually touching the heated wire, which yields exceptionally smooth cuts. Polystyrene, shaped and cut with hot wire foam cutters, is used in architecture models, actual signage, amusement park and movie sets, airplane construction, and much more.

Polystyrene's most common use, however, is as expanded polystyrene, which is a mixture of about 5% polystyrene and 95% gaseous blowing agent. This is the lightweight material of which coffee cups and takeaway food containers are made. The voids filled with trapped air give expanded polystyrene low thermal conductivity. This makes it ideal as a construction material and is used in structural insulated panel building systems. It is also used as insulation in building structures, as packing material for cushioning inside boxes, as non-weight bearing architectural structures (such as pillars) and also in crafts.



syndiotactic polystyrene

atactic polystyrene

Syndiotactic polystyrene has a regular structure, so it can pack into crystal structures. The irregular atactic polystyrene can't.

and model building, particularly architectural models. Foamed between two sheets of paper, it makes a more-uniform substitute for corrugated cardboard tradenamedFoamcore. Expanded polystyrene used to contain CFCs but other, more environmentally-safe blowing agents are now used. Because it is an aromatic hydrocarbon, polystyrene is flammable and burns with an orange-yellow flame giving off soot, as opposed to non-aromatic hydrocarbon polymers such as polyethylene, which burn with a light yellow flame (often with a blue tinge) and no soot. Production methods include sheet stamping (PS) and injection molding (both PS and HIPS).

Toughening of Polystyrene

Pure polystyrene is brittle, but hard enough that a fairly high-performance product can be made by giving it some of the properties of a stretchier material, such as polybutadiene rubber. The two materials cannot normally be mixed due to the amplified effect of intermolecular forces on polymer solubility (see plastic recycling), but if polybutadiene is added during polymerization it can become chemically bonded to the polystyrene, forming a graft copolymer which helps to incorporate normal polybutadiene into the final mix, resulting in high-impact polystyrene or HIPS, often called "high-impact plastic" in advertisements. Common applications include use in toys and product casings. HIPS is usually injection molded in production.

4.4 Polyvinyl chloride(PVC)(VINYL Plastic)

$$\text{- -[-CH}_2\text{-CH(Cl)-]}_n\text{--}$$

Polyvinyl chloride is obtained by suspension or bulk free radical polymerization of vinyl chloride. . It is an amorphous polymer(thermo plastic) having glass transition temperature around 87^{o}C. It is an unstable polymer compared to the other commodity polymers like PE, PP etc. Its commercial success is attributed to the discovery of suitable stabilizers and other additives. Lead compounds (lead stearate etc), organo tin compounds(dibutyl tin dilaurate etc) etc are used as stabilizers. About 50% of produced PVC is used as rigid resins (ex in PVC pipes etc). Flexible PVC is made via plasticization using plasticizers such as dioctyl phthalate, dioctyl adipate, tricresyl phosphate etc. Building construction market account for 30 % of its production. which include pipe and fittings, siding, carpet backing, windows gutters, wall coverings etc . Bottles and packaging sheet are also major rigid markets. Flexible vinyl is used in wire and cable insulation, film and sheet, floor coverings, synthetic leather products, coatings, blood bags, medical tubing and many other applications. Plasticized PVC is melt processed. PVC has a good resistance to hydrocarbons. Its application is widened using fillers, pigments, impact modifiers etc.

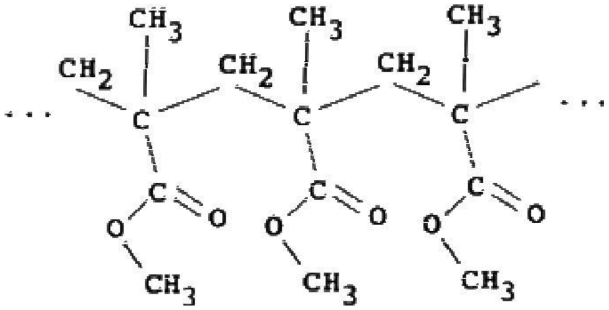
4.5 Poly(methyl methacrylate) (Diakon, Lucite, Oroglas, Perspex, Plexiglas)

PMMA is an amorphous(glass transition 105^{o}C), transparent and colourless thermoplastic that is hard and stiff but brittle and notch-sensitive. It has good abrasion and UV resistance and excellent optical clarity but poor low temperature, fatigue and solvent and scratch resistances. Though flammable, it has low smoke emission. General purpose grades can be extruded and injection moulded. Monomer casting is also used to achieve much higher molecular weights - which are not melt processable because of their extremely high melt viscosity - with somewhat improved properties. The monomer cast items most commonly encountered are sheets and novelty displays in which e.g. insects or watch parts are embedded. Thin films are normally made from impact modified grades, which incorporate a small proportion of elastomer(s), in order to improve their flexibility. Perspex CQ is a particular example of monomer cast sheet which was, until recently, made for intra-ocular use and they are additive-free and the purest (and probably the highest molecular weight) grade of PMMA available. Applications include sinks, baths, displays, signs, glazing (especially aircraft), lenses and light covers. Cast sheet is also used for guards and the like.

PMMA is used for instance in the rear lights of cars. The spectator protection in ice hockey stadiums is made of PMMA as are the very largest windows and fish tanks in the world. The material is used to produce laserdiscs, and sometimes also for DVDs, but the more expensive polycarbonate (also used for CDs) has better properties when exposed to moisture. PMMA has a good degree of compatibilty with human tissue, and can be used for replacement intraocular lenses in the eye when the original lens has been removed in the treatment of cataracts. Hard contact lenses are frequently made of this material; soft contact lenses are often made of a related polymer, in which acrylate monomers are used that contain one or more hydroxyl groups to make them hydrophilic.

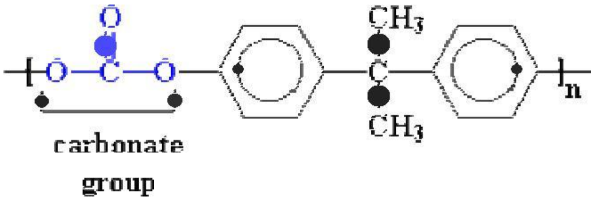
It is a rigid, transparent material and better at transmitting light than inorganic glass. PMMA is more transparent than glass. When glass windows are made too thick, they become difficult to see through. But PMMA windows can be made as much as 13 inches (33 cm) thick, and they're still perfectly transparent. This makes PMMA ideal in the construction of large aquariums where windows must be thick in order to withstand the pressure of millions of gallons of water. The material is often used in place of glass. These optical qualities are the basis for its principal applications: from building to furniture, road signs, the car industry, navy, electrical appliances, laboratory equipment. Unlike glass, PMMA does not filter UV light. Some manufacturers coat their PMMA with UV films to add this property. Up to wavelengths of 2800 nm, PMMA allows most IR (infrared) light to pass. Longer wavelengths of IR energy, up to 25,000 nm are essentially blocked. Special formulations of colored PMMA exist to allow specific IR wavelengths to pass while blocking visible light (for remote control or heat sensor applications, for example). PMMA can be joined using cyanoacrylate cement (so-called "Superglue"), or by using liquid dichloromethane to dissolve the plastic at the join which then fuses and sets, forming an almost invisible weld. PMMA can also be easily polished, by which method cut edges (which turn opaque) can be returned to transparency.

In orthopedics, PMMA bone cement is used to affix implants and to remodel lost bone. It is supplied as a powder and a liquid; when mixed, they yield a dough which then hardens. Dentures are often made of PMMA. In cosmetic surgery, tiny PMMA microspheres suspended in some biological fluid are injected under the skin to permanently reduce wrinkles or scars.



4.6 POLYCARBONATE

It is an amorphous engineering thermoplastic with excellent combination of properties. It is one of the engineering plastic to compete with die cast metals. Polycarbonate, or specifically polycarbonate of bisphenol A, is a clear plastic used to make shatterproof windows, lightweight eyeglass lenses



Polycarbonate of bisphenol A is a thermoplastic. This means it can be molded when it is hot. But the polycarbonate used in eye glasses is a thermoset. Polycarbonate plastic is used to make bullet-proof windows, greenhouse walls, automobile headlamps, and rugged housings for cell phones, pagers, and laptop computers. It is a tough, shatter- and heat-resistant material, and is now being used in as many aesthetic applications as in traditional functional applications. From fashionable designer houseware to eye-catching transparent housing for electronics, polycarbonate plastic has bridged the gap between functionality and style. It has become sought after not only for its outstanding physical properties, but also for its ability to be molded into amazingly intricate shapes and dyed with an imagination's worth of brilliant and transparent colors. Like new clothing material that takes the catwalks of Milan by storm, polycarbonate plastic has become fashionable-it has become chic.

Polycarbonate is a tough, dimensionally stable, transparent thermoplastic that has many applications which demand high performance properties. This versatile thermoplastic maintains its properties over a wide range of temperatures, from -40"F to 280"F. It is available in three types: machine grade; window and glass-filled. It has the highest impact of any Thermoplastic, transparent up to 2" in special grades, outstanding dimensional and thermal stability, and exceptional machinability, stain resistant and non-toxic with low water absorption. Machine Grade is relatively stress free to permit the most demanding machining. It is also available in glass- filled. This polycarbonate is perfect for high performance uses in tough applications over a broad temperature range. Window Grade is optically clear, providing total luminous transmittance and very low haze factor. The high impact strength makes it resistant to repeated blows, shattering and spalling. Polycarbonate is excellent for electrical applications, because of its high dielectric strength and high volume resistivity which decreases only slightly as temperature or humidity is increased

Polycarbonate is unusually tough, due to the nature of its chemical bonding. It is also transparent and almost self extinguishing, with a relatively high continuous use temperature of around 115°C. Chemical resistance is not outstanding and it needs the addition of light stabilizers for any UV resistance. Glass fibers enhance the stiffness but reduce toughness, as might be anticipated. Polycarbonate is a versatile blending material, with blends of PC/PET and PC/ABS available commercially. Applications of polycarbonate include: glazing panels, light fittings, safety helmets and medical components.

Glass Filled

Glass-reinforced polycarbonate is finding principal applications in designs where metals, particularly die-cast aluminum and zinc, are commonly used. The coefficient of thermal expansion is reduced by nearly 75%, thus equaling that of some metals. While glass-reinforced has less impact strength than standard grades, it is still tougher and more impact resistant than most other plastics and die cast aluminum.

Machinability

Parts can be easily machined from standard metal working tools. No special tools are needed, and finished parts can be polished to a high gloss. Water or water-soluble cutting oils should be used when machining polycarbonate, since some standard cutting oils will attack the material. Polycarbonate can be machined on standard metalworking or woodworking equipment. Its unique properties permit it to be machined without chipping, splitting or breaking.

Annealing

Polycarbonate slab (Zelux) has been stressed relieved using Liquo-Temp annealing process. In some instances where extensive machining is required, a secondary annealing of semi-finished parts is highly recommended. Secondary annealing can be accomplished by heating parts at 250"F in a desiccated air circulating oven for one hour per one inch of thickness. After heating, the oven should be turned off and allowed to cool to room temperature spontaneously.

Bonding

Polycarbonate can be mechanically bonded by standard methods. It can also be cemented by using a solvent such as methylene chloride or adhesives such as epoxy, urethane and silicone. Polycarbonate and also be ultrasonically or vibrationally welded.

Applications

Appliances

Coffee filters, shaver housings, chocolate moulds, blenders, table wares, kitchen mixer bowls, grinder bowls, housings for ball point and fountain pens, rim heater grills, motor bracket and housing, camera, binocular casings and parts, flash lights, lenses and casings, water tank for steam iron, fruit juicer parts, high impact vacuum sweeper housings, mixers and power tools, bobbins for textile industries, baby feeding bottles and cutlery.
Automotive

Wind screen wiper brackets, car interior moulded trims, instrument glazing, indicator lamps, wind shield for two wheelers, door handles, head lamp support, traffic light housings and signal lenses, battery cases, helmets, wheel cover, body panels, components for sewing machine, chassis, levers, valves, control cams, directional signs, ventilation and radiator grills, housing for automobile and aerial motors etc.

Electrical & electronics

Wiring devices, insulator panels, plug and socket terminal blocks, coil formers, starter enclosures, electric meter covers, breaker boxes, gears, fuses, telephone housing for mining operations, dials, sight windows, housing for computers, calculators, magnetic disk packs etc.

Food contact articles

Mineral water bottles, microwave oven wares, food storage containers etc

Medical equipment components

Blood bottles, dispensers for inhalers, sterilisable lab wares and containers, tissue culture dishes, surgical disposables, diagnostic cardio-vascular and intravenous devices, housing for blood cleaning filters

Other uses

High temperature and pressure windows , face shields , industrial equipment and housing components, instrument components, electrical insulators and connectors, aircraft & missile components, portholes in pressure chambers, jet pump impellers and diffusers, card guides, assembly line cogs, sporting goods, slide rule components vacuum metallised reflectors, housing for street lamps, lenses and safety glasses, sun glasses, face protective waresaudio compact discs, film and slide cassettes,(the astronauts stepped onto the moon in polycarbonate helmets), windows, bank screens, police shields etc.

Typical physical properties

Specific gravity : 1.2, Tensile strength MPa : 62, Tensile modulus MPa : 2379, Flexural modulus MPa : 2344, Elongation at break (%): 110, Impact strength izod, notched, J/m : 123, Hardness : M70, Deflection temperature under load (1.82 MPa): 132 ^{0}C, Coefficient of linear expansion(mm/mm/^{0}C) 122 X 10^{-6}, Water absorption 24 hrs (%) : 0.15, Refractive index: 1.58-1.59, Dielectric strength (KV/mm): 15 Dielectric constant (10^{6} Hz): 2.97, Power factor: 0.0021, Volume resistivity(Ohm.m): 2.1 x 10^{16}, Melting point,(^{o}C): 220-230, Glass transition temperature (^{o}C): 140, Mould shrinkage(%): 0.4 - 0.7.

4.7 ABS Plastics

It is a tercopolymer containing styrene, acrylonitrile and butadiene comonomers. The earliest materials were the physical blends of styrene -acrylonitrile copolymer(SAN) and acrylonitrile-butadiene copolymers. Today the ABS referes to a product consisting of discrete cross-linked polybutadiene rubber particles that are grafted with SAN and embedded in a SAN matrix. ABS materials are important for their wide spread use as quality housings for equipments. It possesses the following important properties such as, high impact resistance, good stiffness, excellent surface quality, high dimensional stability at elevated temperatures & good heat distortion temperature, good chemical and stress cracking resistance, good low temperature properties etc. It can be electroplated

Eventhough polypropylene is cheaper than ABS, ABS is preferred where the extreme toughness and superior heat distortion resistance is required. But its main disadvantages are i) lack transparency, ii) poor weathering resistance and iii) poor flame resistance

ABS is used in vehicle construction industry(automotive instrument panels, and other interior components such as fascia panels, door covers, door handles, radiator grilles, ventilation system components, heater housings, seat belt fastenings, console panels, loud speaker housings, interior trim and other uses). ABS is also alloyed with polycarbonate to have enhanced heat resistance and surface hardness in conjuction with good impact strength. Molded ABS products are used in both protective and decorative applications. Examples include safety helmets, camper tops, pipe fittings, home-security devices and housings for small appliances, communications equipment, and business machines.

Chrome-plated ABS has replaced die-cast metals in plumbing hardware and automobile grilles, wheel covers, and mirror housings. Typical products vacuum-formed from extruded ABS sheet are refrigerator liners, luggage shells, tote trays, mower shrouds, boat hulls, and large components for recreational vehicles. Extruded shapes include weather seals, glass beading, refrigerator breaker strips, conduit, and pipe for drain-waste-vent (DWV) systems. Pipe and fittings comprise one of the largest single application areas for ABS.

Based on the property requirement ABS can be categorized into different grades such as General purpose , Fire retardant, Improved heat resistant, Enhanced chemical resistant, static dissipation grade, Extrusion grade, Fire retardant- extrusion etc. ABS is more hygroscopic than polystyrene and absorbs moisture upto 0.3%. It can be processed at 250-260^{o}C. It has low heat resistance compared to polystyrene. I t is an amorphous material and show low moulding shrinkage. ABS resins are hard, rigid, and tough, even at low temperatures. They consist of particles of a rubberlike toughener suspended in a continuous phase of styrene-acrylonitrile (SAN) copolymer. Various grades of these amorphous, medium-priced thermoplastics are available offering different levels of impact strength, heat resistance, flame retardance, and platability. Most natural ABS resins are translucent to opaque, and they can be pigmented to almost any color. Grades are available for injection molding, extrusion, blow molding, foam molding, and thermoforming. Molding and extrusion grades provide surface finishes ranging from satin to high gloss. Some ABS grades are designed specifically for electroplating. Their molecular structure is such that the plating process is rapid, easily controlled, and economical.

Compounding of some ABS grades with other resins produces special properties. For example, ABS is alloyed with polycarbonate to provide a better balance of heat resistance and impact properties at an intermediate cost. Deflection temperature is improved by the polycarbonate; molding ease, by the ABS. Other ABS resins are used to modify rigid PVC for use in pipe, sheeting, and molded parts. Reinforced grades containing glass fibers, to 40%, are also available.

Properties: ABS plastics offer a good balance of tensile strength, impact and abrasion resistance, dimensional stability, surface hardness, rigidity, heat resistance, low-temperature properties, chemical resistance, and electrical characteristics. These materials yield plastically at high stresses, so ultimate elongation is seldom significant in design; a part usually can be bent beyond its elastic limit without breaking, although it does stress-whiten. While not generally considered flexible, ABS parts have enough spring to accommodate snap-fit assembly requirements.

Impact properties of ABS are exceptionally good at room temperature and, with special grades, at temperatures as low as -40°F. Because of its plastic yield at high strain rates, impact failure of ABS is ductile rather than brittle. A long-term tensile design stress of 1,000 to 1,500 psi (at 73°F) is recommended for most grades.

General-purpose ABS grades may be adequate for some outdoor applications, but prolonged exposure to sunlight causes color change and reduces surface gloss, impact strength, and ductility. Less affected are tensile strength, flexural strength, hardness, and elastic modulus. Pigmenting the resins black, laminating with opaque acrylic sheet, and applying certain coating systems provide weathering resistance. For maximum color and gloss retention, a compatible coating of opaque, weather-resistant polyurethane can be used on molded parts. For weather able sheet applications, ABS resins can be coextruded with a compatible weather-resistant polymer on the outside surface.

ABS resins are stable in warm environments and can be decorated with durable coatings that require baking at temperatures to 160°F for 30 to 60 min. Heat-resistant grades can be used for short periods at temperatures to 230°F in light load applications. Low moisture absorption contributes to the dimensional stability of molded ABS parts.. Molded ABS parts are almost completely unaffected by water, salts, most inorganic acids, food acids, and alkalies, but much depends on time, temperature, and especially stress level. FDA acceptance depends to some extent on the pigmentation system used. The resins are soluble in esters and ketones, and they soften or swell in some chlorinated hydrocarbons, aromatics, and aldehydes.

4.8 POLY ETHER ETHER KETONE(PEEK)

Figure 1. Chemical formula of polyether ether ketone (PEEK) from I.C.I.

PEEK (Tg : 145°C) is an abbreviation for PolyEtherEther-Ketone, a high performance engineering thermoplastic and is an excellent material for a wide spectrum of applications where thermal, chemical, and combustion properties are critical to performance. The tensile properties of PEEK™ exceed those of most engineering plastics and can be reinforced with carbon fiber resulting in a tensile strength of over 29,000 psi (200 MPa) with excellent properties being retained up to 570°F(300°C). The exceptional stiffness of PEEK™ is reflected in its flexural modulus which is among the best of any thermoplastic. Glass or carbon fiber reinforcement gives further improvement up to very high temperatures.

These semi-crystalline polymers have excellent mechanical properties, good thermal stability and good chemical resistance. Despite a Tg of 145°C, the continuous service rating of PEEK is 250°C. PEEK is inherently fire retardant. It is easier to burn a hole through an aluminium sheet than through one made from PEEK. These materials are, however, very expensive and difficult to process. They find application in high temperature wire covering and printed circuit boards. Fibre reinforced grades are used in demanding applications that include valves, pumps and missile nose cones

PEEK combines excellent tribological properties with moldability and outstanding performance at high temperatures. Carbon fiber-reinforced PEEK is probably the only injection moldable bearing material that has a measurable wear factor at over 500°F (260°C), all the thermoplastics fail at or below this temperature. PEEK can retain its flexural and tensile properties at very high temperatures -- in excess of 250"C (482"F). The addition of glass fiber and carbon fiber reinforcements enhances the mechanical and thermal properties of the basic PEEK material. Superior chemical resistance has allowed them to work effectively as a metal replacement in harsh environments. They are inert to all common solvents and resist a wide range of organic and inorganic liquids. When extensive machining is required, a secondary annealing process should be considered.

MECHANICAL

At room temperature, PEEK™ functions as a typical engineering thermoplastic. It is tough, strong, rigid, has good load bearing properties over long periods, and it is resistance to both abrasion and dynamic fatigue.

THERMAL

PEEK™'S continuous service UV rating is 482°F (250°C) for unfilled and 500°F (260°C) for glass filled grades. PEEK™ also offers high temperature mechanical properties making it suitable for some application up to 600°F (315^{o}C).

FLAMMABILITY

PEEK™ has a high "Oxygen Index" and meets UL 94 -VO requirements, and demonstrates extremely low smoke emission. It contains no flame-retardant additives or halogens.

CHEMICAL RESISTANCE

PEEK™ has good resistance to aqueous reagents and long-term performance in superheated water at 500°F. (260°C.). Its resistance to attack is good over a wide pH range from 60% sulfuric acid to 40% sodium hydroxide at elevated temperatures. Attack can occur with some concentrated acids.

HYDROLYSIS RESISTANCE

PEEK can be used for thousands of hours at temperatures in excess of 480°F(250°C). in steam or high-pressure water environments without significant degradation in properties.

RADIATION RESISTANCE

Preliminary tests suggest that radiation resistance is extremely good.

Two of the highest performance areas of PEEK are in oil exploration and chemical processing industry.

Oil Exploration

Geologists use data logging equipment to analyze the nature and structure of rock in an attempt to locate oil bearing strata. This may involve sample removal or the use of a probe (acoustic, radiation, electrical) to evaluate the rock. Although all downhole materials must have good wear resistance and mechanical strength, the specific geometries involved and the function of the probe exclude most conventional materials. Therefore, an easily processable material which can withstand temperatures in excess of 392°F (200°C), pressures up to 580 psi, and has excellent resistance to chemically aggressive environments, electricity and radiation is required. Natural PEEK™ polymer and GL30 PEEK™ polymer composite grades are chosen by the oil industry as they are the only materials able to perform well in such a demanding environment.

The GL30 PEEK™ polymer is specially formulated to contain an optimum amount of short glass fiber reinforcement. The mechanical properties of the material are greatly enhanced with little reduction in processability.

Chemical Processing Industry

PEEK polymer composites are becoming increasingly used in the chemical processing industry due to a combination of excellent mechanical properties, processability, a high continuous operating temperature (500°F (260°C), UL746B) and outstanding chemical resistance. Conventional processing methods (injection molding, compression molding) are often used to form compressor plates, seals and pump components used in gas and fluid transport systems. The excellent fatigue resistance and general mechanical properties have been shown to outperform fluoropolymers, while the chemical resistance is vastly superior to metal components for such applications. The ability to form thin films on complex 3-dimensional objects means that PEEK™ polymer is often used to coat metallic parts which operate in chemically aggressive environments. The formation of these thin films is achieved by either electrostatic or plasma spray coating techniques. The chemical processing industry strives for purity of product. The contamination introduced by materials used to handle the substances during production is a selection criteria. PEEK™ polymer is inherently pure, and therefore can be used in long service applications with extremely low levels of contamination introduced to the chemical streams being processed.

PEEK Polymer for the Automotive Industry

The automotive industry constantly strives to increase the performance level and minimize the weight of in-engine components. Therefore, thermoplastic materials are often used to replace parts of the engine which are traditionally constructed from metals. PEEK™ polymer, a polyaryletherketone resin, is the leading high performance thermoplastic for automotive applications. It combines outstanding tribological performance with excellent mechanical properties over a wide temperature range.

Most automotive applications are required to operate at temperatures in excess of 248°F (120°C). Therefore, a high continuous operating temperature (500°F (260°C), UL746B) and excellent mechanical properties at this temperature make PEEK™ polymer the natural choice

Tribological performance may be defined as the friction and wear of interacting surfaces in relative motion. Therefore, the tribology of dry and lubricated contacts is critical for the operation of internal combustion engines. PEEK™ polymer has excellent friction and wear properties which are optimized in the specially formulated tribological grades, namely, 450FC30 and 150FC30 PEEK™ polymer.

ADVANTAGES OF PEEK

Excellent flexural, impact and tensile characteristics.

Very high continuous working temperature.

PEEK's excellent mechanical properties are retained even at temperatures in excess of 250"C (482"F).

Very high heat distortion temperature.

For unreinforced PEEK, the HDT is 160"C (320"F). The addition of 30% glass or carbon fiber reinforcement results in a dramatic increase to 315"C (599"F).

Exceptional chemical resistance.

PEEK is insoluble in all common solvents and, being crystalline, is extremely resistant to attack by a very wide range of organic and inorganic chemicals. A superior dielectric with low loss even at high temperatures and frequencies.

Excellent hydrolysis resistance.

PEEK has an excellent resistance to hydrolysis in boiling water and superheated steam (sterilizationin/ autoclavabiiity) at temperatures in excess of 250"C (482"F).

Good radiation resistance.

Absorbing more than 1000 M rads of irradiation with no significant reduction in mechanical properties, PEEK exhibits exceptional resistance to high doses of gamma radiation.

Outstanding wear and abrasion resistance.

PEEK and reinforced PEEK have excellent wear and abrasion resistance characteristics with low coefficient of friction and high limiting PV properties.

Low smoke and toxic gas emissions.

Levels of smoke and toxic gas released during combustion are among the lowest of any thermoplastic material.

APPLICATIONS

PEEK's exceptional property profile enables it to be utilized in many of the most critical areas in general industry, such as, automotive, marine, oilwell, electronics, medical, aero-space etc

FEATURES

- Excellent chemical resistance
- Very low moisture absorption
- Inherently good wear and abrasion resistance
- Unaffected by continuous exposure to hot water or steam

4.9 Polytetrafluoroethylene(PTFE)

Polytetrafluoroethylene [Teflon, $–(CF_2-CF_2)_n$ -] is obtained by polymerizing (emulsion polymerization) tetrafloroethylene (ie., When all the hydrogen atoms in polyethylene have been replaced by fluorine, polytetrafluoroethylene (PTFE) is obtained). It is a tough, flexible, non-resilient material of moderate tensile strength but with excellent resistance to heat, chemicals and to the passage of electric current. It is resistant to many chemicals, including acetic acid, ammonia, sulfuric acid, and hydrochloric acid It remains ductile in compression at temperatures as low as 4K(-269oC). The coefficient of friction is low and is reported to be lower than that of any other solid.

PTFE is an outstanding insulator over a wide range of temperature and frequency. Its volume resistively exceeds 10 20 ohm meter. Any current measured is a polarization current rather than a conduction current. It has a low dielectric constant (2.1 at 60 Hz). A melt viscosity of 10 10-1011 poises has been measured at about 350oC. A slow rate of decomposition has been detected at the melting point and this increases with increase in temperature. There are no solvent for PTFE and it is attacked by molten alkali metal at room temperature and in some cases by fluorine. Treatment with solution of sodium metal in liquid ammonia will sufficiently alter the surface of PTFE so that it can be cemented to other materials using epoxy adhesives. Although it has good weathering resistance, it is degraded by high energy radiation. The polymer is not wetted by water and does not absorb measurably. The permeability to gases is very low and water vapour transmission is only half that of low density polyethylene.

It has a high bulk density and exceptional chemical properties.. It can temporarily withstand temperatures of 260oC and still have the same chemical properties. Teflon also retains its chemical properties in cryogenic temperatures of -240oC . It is a chemical inert material, making it relatively safe to use and handle.

Nonpolarity

The carbon backbone of the linear polymer is completely sheathed by the electron cloud of fluorine atoms, much like a wire core is protected by insulation coating. This ensheathment, and the angles at which the carbon-fluorine bonds are disposed, causes the centers of electronegativity and electropositivity to be perfectly balanced across the polymer chain cross section. As a result, no net charge difference prevails. This nonpolarity of the polymer is partly responsible for its lack of chemical reactivity.

Low inter chain forces

The bond forces between two adjacent polymer chains are significantly lower than the forces within one chain. High C-F and C-C bond strengths are among the strongest in single bond organic chemistry. The polymer must absorb considerable energy to disrupt these bonds.

Crystallinity

The high degree of crystallinity in these semicrystalline polymers results in high melting points(327°C), mechanical properties, and an integral barrier to migrating, small, nonpolar molecules. Under certain conditions, these molecules penetrate the plastics. The melting point of Teflon PTFE is one of the highest in organic polymer chemistry.

Insolubility

There is no known solvent for Teflon fluorocarbon resins under ordinary conditions.

Low coefficient of friction

The low coefficient of friction of Teflon results from low interfacial forces between its surface and another material and the comparatively low force to deform.

Low dielectric constant and dissipation factor: Teflon provides low, if not the lowest, values for these parameters. These low values arise from the polymer's nonpolarity as well as the tight electron hold in the ultrapolymer bonds.

Low water absorptivity

For Teflon to absorb water, the surface must remain wet for a long enough time for water to become physico-chemically associated with the polymer chains, and then it must become included in the polymer bulk structure. Water is a very high energy material and Teflon has a very low surface energy. Therefore, these events are energetically incompatible and only occur under special circumstances and to a small extent.

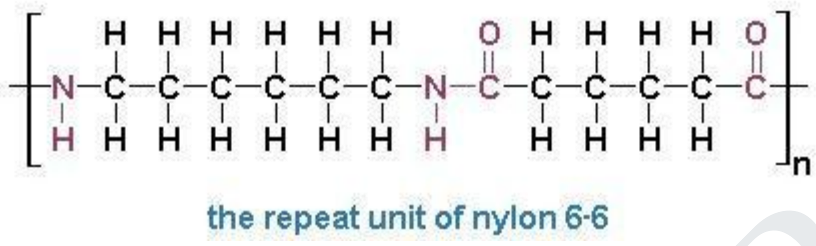
Excellent weatherability

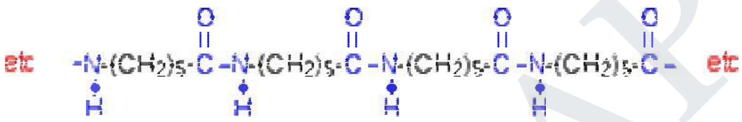
Weather includes light of various wavelengths (IR, visible, UV), water (liquid or gas), other gases, and normal temperatures and pressure. The physical and chemical makeup of Teflon makes it inert to these influences.

Flame resistant

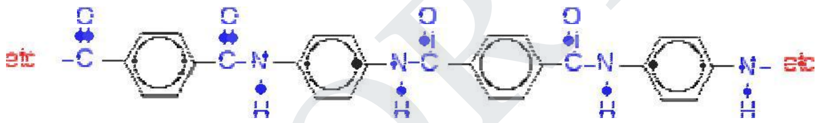
Teflon will burn when exposed to flame, but will not continue to burn when the flame is removed.

Polyamides(NYLONS)





Nylon-6



Kevlar(aromatic nylon)

Polyamides are a group of thermoplastic polymers containing amide groups in the main chain. They are popularly known as nylons. They may be aliphatic (nylon 66, nylon6 etc) or aromatic(Kevlar, nomex etc). Commercially important polyamides are PA-66, PA-6, PA-11, PA-12, PA-610, PA-612 etc. Polyamides have good strength and toughness with excellent fatigue resistance. However, they are prone to absorb moisture, ranging from 8 - 10% for PA6 and PA66 to 2 - 3% for PA11 and PA12 at saturation. Mechanical properties are affected by moisture, with toughness improving with the absorption of moisture whereas modulus is reduced. Polyamides are resistant to hydrocarbons, esters and glycols, but swell and dissolve in alcohols. They are also attacked by acids but generally stable to alkalis. PA6 and PA66 are mainly used in textiles, but they also find application where toughness is a requirement, for example, zip fastener teeth, gears, wheels and fan blades. PA11 is more flexible than PA66 and is typically used for petrol and hydraulic hose as well as powder coatings for metals. Strength and rigidity of these materials can be dramatically enhanced by the addition of glass or carbon fibre reinforcement; the level of saturation water absorption is also reduced. However, the designer needs to be aware of the anisotropic properties that can result in mouldings due to the flow and alignment of the reinforcing phase that occurs during moulding.

Polyamides are fairly readily attacked by strong acids, but are much more resistant to alkaline hydrolysis. Hydrolysis is faster at higher temperatures. Hydrolysis by water alone is so slow as to be completely unimportant. Kevlar is rather more resistant to hydrolysis than nylon .

Properties

Hard and tough thermoplastic, good abrasion resistance, low coefficient of friction, high tensile strength, good dimensional stability, low tendency to warp, smooth appearance of surface, average to high surface gloss, resistant to lubricants, engine fuels, grease etc, good resistance to coolants, refrigerants, paint solvent cleaners, resistant to aqueous solution of many inorganic chemicals.
Uses

Nylon fibres are used in textiles, fishing line and carpets. Nylon films is used for food packaging, offering toughness and low gas permeability, and coupled with its temperature resistance, for boil-in-the-bag food packaging. Moulding and extrusion compounds find many applications as replacements for metal parts, for instance in car engine components. Intake manifolds in nylon are tough, corrosion resistant, lighter and cheaper than aluminium (once tooling costs are covered) and offer better air flow due to a smooth internal bore instead of a rough cast one. Its self-lubricating properties make it useful for gears and bearings.

Electrical insulation, corrosion resistance and toughness make nylon a good choice for high load parts in electrical applications as insulators, switch housings and the ubiquitous cable ties. Another major application is for power tool housings. Glass reinforced polyamides are the material of choice for applications such as power tool housings. Transparent amorphous polyamides are available and find application in sterilisable medical components and sight glasses.

Polyethylene terephthalate(PET)

Polyethylene terephthalate (PET) and polybutylene terephthalate (PBT) are the most common thermoplastic polyesters. They are similar to PA6 and PA66 in many respects but with much lower water absorption. However, they are prone to hydrolysis, and prolonged contact with water at temperatures as low as 50°C has a detrimental effect on properties. Polyethylene terephthalate (PET) is often called just “polyester”. Polybutylene terephthalate (PBT) also a (thermoplastic) polyester, the most common resin system used in glass reinforced plastic (GRP) is also a polyester system.

General Properties

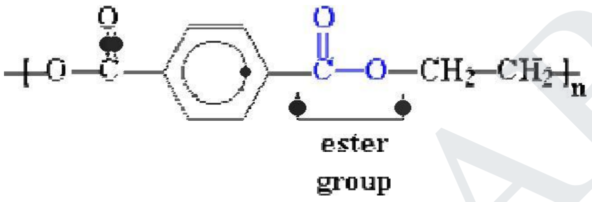
Polyethylene terephthalate (PET) is a hard, stiff, strong, dimensionally stable material that absorbs very little water. It has good gas barrier properties and good chemical resistance except to alkalis (which hydrolyse it). Its crystallinity varies from amorphous to fairly high crystalline. It can be highly transparent and colourless but thicker sections are usually opaque and off-white.

Polyethylene Terephthalate Films

It is widely known in the form of biaxially oriented and thermally stabilised films usually referred to by their main brand names Mylar, Melinex or Hostaphan. Strictly speaking, these names should be used only for this type of film whose properties are different from, and in several respects superior to, those of "ordinary" polyethylene terephthalate (PET) film(Mylar)

Applications

The "Mylar®-type" films are used for capacitators, graphics, film base and recording tapes etc. PET is also used for fibres for a very wide range of textile and industrial uses (Dacron®, Trevira®, Terylene®). Other applications include bottles and electrical components.



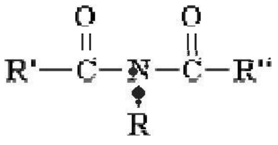
Its melting and glass transition temperature are 265^{o}C and 74^{o}C respectively. PET is used in the manufacture of biaxially oriented film and bottles, the latter suitable for carbonated drinks. The purpose of the orientation is to enhance rigidity, strength and toughness and also to improve barrier properties, which allows thinner bottles to be made.

PBT displays a good combination of stiffness and toughness and can withstand continuous service at 120°C. The most important grades are those reinforced with glass. Applications for PBT include electrical connectors, pump components, and gears, as well as under bonnet and exterior parts for cars.

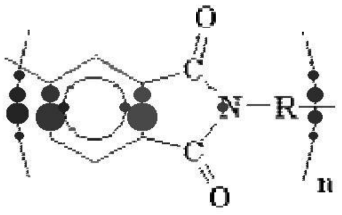
4.10 Thermoplastic Polyimides (PI, PAI, PEI)

Polyimide(Vespel-Dupont)(PI)

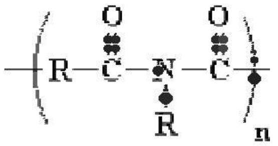
Polymeric compounds containing multiple imides, ie, NH groups derived from ammonia (NH3) by replacement of two hydrogen atoms by metals or equivalents of acid groups.



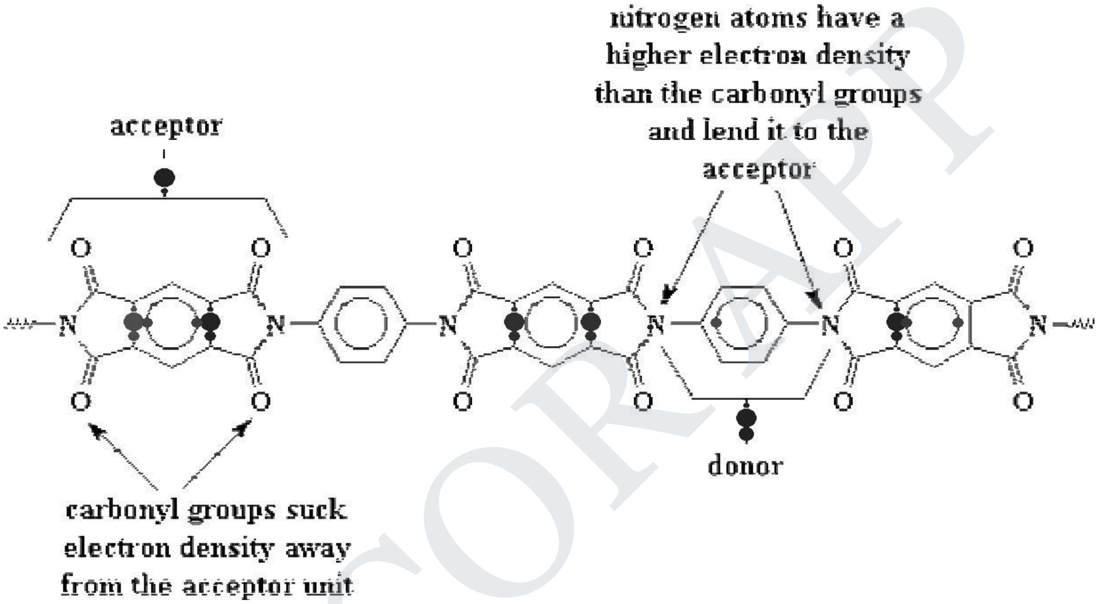
an imide



aromatic heterocyclic polyimide



linear polyimide



Polyimides (PI) are noted for their high temperature performance, retaining their mechanical properties to 250°C. They exhibit low flammability and smoke emission characteristics and offer the lowest minimum service temperature of thermoplastics. They are relatively expensive and can be difficult to process. Thermoplastic polyimide requires high temperatures and pressures and is usually processed by autoclave or compression moulding. They are susceptible to attack by halogenated solvents

Polyimides are a very interesting group of incredibly strong and astoundingly heat and chemical resistant polymers. Their strength and heat and chemical resistance are so great that these materials often replace glass and metals, such as steel, in many demanding industrial applications. Polyimides are even used in many everyday applications. They are used for the struts and chassis in some cars as well as some parts under-the-hood because they can withstand the intense heat and corrosive lubricants, fuels, and coolants cars require. They are also used in the construction of many appliances as well as microwave cookware and food packaging because of their thermal stability, resistance to oils, greases, and fats and their transparency to microwave radiation. They can also be used in circuit boards, insulation, fibers for protective clothing, composites, and adhesives. These polymers have excellent resistant to oxidative degradation, chemicals, strong bases and high energy radiation. It possesses good flame and abrasion resistances. But unfortunately these polymers cannot be moulded by conventional thermoplastic techniques. They are used as wire enamels, insulating varnishes, as coatings for glass cloth etc. Polyimide foams have been used for sound deadening of jet engines. They are used in space craft construction, rockets and weapons technology.

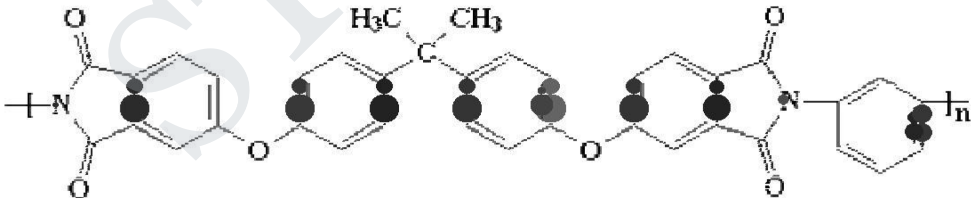
These polymers consists predominantly of ring structures and hence possesses high softening point. They are used in the manufacture of seals, gaskets, piston rings and as a binder in the diamond grinding wheels. Glass and carbon fibre reinforced polyimides are used in aircraft industry. It is also used in soldering and welding equipments. Kapton is a polyimide film made from pyromelltic anhydride and aromatic ether amine. Polyesterimides and polybismaleinimides are modified polyimides.

4.11 Polyamide- imide (PAI)

Polyamide-imides are amorphous thermoplastic materials with excellent mechanical properties, especially at elevated temperatures. Trimellitic anhydrides react with aromatic diamines to produce polyamide -imides. Polyamide-imides are applied in demanding engineering applications. Solvay Advanced Polymer's Torlon® is a well-known example of a polyamide-imide engineering resin that is also used to molded, extruded or machined plastic parts or shape stock.

Polyamide-imides are thermoplastic amorphous polymers which enjoy exceptional mechanical, thermal and chemical resistant properties. These properties put polyamide-imides at the top of the price and performance pyramid. Other high performance polymers in this same realm are polyetheretherketones and polyimides. Polyamide-imides hold, as the name suggests, a positive synergy of properties from both polyamides and polyimides, such as high strength, melt processabilty, exceptional high heat capability, and broad chemical resistance. Polyamide-imide polymers can be processed into a wide variety of forms, -from injection or compression molded parts and ingots, -to coatings, films, fibers and adhesives. Properties approaching those of Polyimide, yet melt processable. Highest strength of any unreinforced thermoplastic. Good wear resistance. Low smoke emission. Good radiation resistance.

4.12 Polyetherimides(PEI)



Polyetherimides are thermally stable at high temperatures and exhibit good optical properties making them useful in high temperature processing applications, in the fabrication of optoelectronics devices, and in optical applications. Polyetherimides (PEI) are amorphous, high performance thermoplastics with a continuous use temperature of around 170° C. PEI resins can also be melt processed using typical equipment for high volume production.

The strength, creep and impact properties of PEIs make them ideal for under bonnet components. They are also used in high temperature switchgear and electrical connectors. A number of medical equipment components are manufactured using PEIs, taking advantage of their excellent resistance to repeated sterilisation using steam, autoclave, gamma radiation or ethylene oxide. Microwave cookware is another application. They exhibit very high tensile strength without reinforcement, high glass transition(215^{o}C), deflection(200^{o}C) and softening (219^{o}C) temperatures. PEI are competitive with PAI, polysulphones, polycarbonates, polyphenylene sulphides etc. It is used in microwave equipment, printed circuit boards, wire insulation etc.

4.13 Polyphenylene Oxide (PP0)

PPO is prepared by oxidative coupling of phenylene oxide monomer.
PPO is a high strength, tough and heat resistant polymer, but in the unmodified state it is extremely difficult to process. It is also relatively expensive. Fortunately, it is miscible with polystyrene, and the resulting amorphous blends are easily processed and cheaper than PPO, with little loss in mechanical properties. Stiffness and strength are approximately 50% higher than high impact ABS, with similar creep behaviour. Modified PPO grades are also self extinguishing when ignited. Resistance to solvents is poor, a characteristic of styrene-based polymers. As well as glass fibre reinforced grades, these materials are available in structural foam grades.

Although unmodified polyphenylene oxide (PPO) is a semi-crystalline thermoplastic, all commercially available grades are blended with (high impact) polystyrene in order to improve melt processability. A wide range of proportions, together with the use of other modifiers, results in a good range of grades with differing properties tailored to the needs of individual end-uses. These blends are amorphous, opaque, pale grey engineering thermoplastics with a balance of properties (and cost) not unlike nylon but without nylon's high water absorption and consequent dimensional instability. However they have poor fatigue characteristics and poor solvent, though good hydrolysis, resistance.

Thermal properties

PPO has a higher heat deformation resistance than many general purpose thermoplastics at a lower price than the more expensive 'engineering thermoplastics'. One of the main reasons for using the PPO blends is the outstanding dimensional stability at elevated temperatures and the broad temperature use range.

Fire behavior

Conventional grades are non-self-extinguishing but self-extinguishing grades (generally made by including phosphorous based additives) are available with a slightly lower heat distortion temperature and impact strength. As a general rule the materials are difficult to ignite and burn with a sooty luminous flame and a pungent odour but do not drip. The flammability ranges from UL 94 HB to V-0 depending on the grade tested.

Electrical properties

Moisture absorption is low over a wide range of humidity levels and therefore dielectric properties are excellent over a wide range of moisture and temperature conditions.

Machining

PPO blends can be machined without difficulty using standard machine conditions for polymers. The products are difficult to cut and machining needs to be slow (feeds and speeds).

Surface treatment

PPO blends can be painted with good coatability. A primer and a polyurethane type of paint is recommended.

Welding

PPO can be solvent welded using commercially available solvents and solvent solutions containing 1 to 7% PPO resin.

Bonding

PPO blends can be bonded using a wide range of commercially available adhesives including epoxy adhesives. Mechanical: Machine housings, pump housings and impellers

Applications

Consumer goods: Power tool housings, portable mixers, hairdryers.
Automotive: Instrument panels and seat backs, spoilers, wheel trims, external mirror housings. Electrical: Electrical terminal housings, cable connectors, bulb sockets, coil formers. Miscellaneous: Plastic parts in central heating systems.

Injection moulding

Typical melt temperatures of 250 to 300^{o}C are needed with a die head temperature of around 250^{o}C for injection moulding of PPO. The injection pressure should be 1000 to 1200 bar and the follow-up pressure should be 50 - 70% of the injection pressure. The back pressure should be set at 30 - 50 bar. The mould temperature should be in the region of 80 to 105^{o}C. Injection speed is generally high but moulds with a long flow path should have adequate mould venting. Mould shrinkage is low (0.005 - 0.01 m/m).

Extrusion

PPO is relatively easy to extrude and can be processed on single or twin screw extruders and on vented or unvented extruders.

4.15 UREA-FARMALDEHYDE RESIN

It is a thermosetting resin prepared by heating urea and formaldehyde in the presence of mild alkalies, such as pyridine or ammonia. The urea and formaldehyde undergo a condensation reaction in which they combine to form a water-soluble polymer. This polymer is used to formulate adhesives and coating agents or is mixed.

Physical properties

Relative Vapour Density (air = 1): (at 20°C)1.07(Foe formaldehyde), Specific Gravity (20°C): 1.2–1.4, % Volatile by Volume: 25–50 (water), Solubility in Water (g/L @ 25°C) 50, Water dilutability (mls): 100 minimum, pH (25°C): 7.8–8.2, Viscosity @ 25°C (cps): 150–250, Solids content (%): 64–66. Values may be slightly different depending upon the specific grade of resin. Urea formaldehyde resin is a colourless to milky viscous liquid, with faint formaldehyde odour. It is soluble in water and alcohol. The free formaldehyde content of UF resins is less than 5 per cent and usually less than 0.5 per cent depending on grade.

End uses

It is most commonly used for commercially produced interior and exterior particle boards. UF polymers have proven to be very good adhesives for wooden materials. Due to their high reactivity and cost efficiency, they are the most popular binders for interior products. Adhesives based on formaldehyde are used as binders in the production of reconstituted wood panels such as particleboard, plywood, medium density fibreboard, laminated veneer lumber, finger joints and laminated beams. UF resins and other related formaldehyde resins are also used in resin impregnated decorative paper laminates, glass fibre insulation binders, foundry cores, pulp and papers processing aids, paper sizing, textile treatments, paints and enamels, and miscellaneous joinery applications.

4.16 PF RESIN (Phenol-formaldehyde resin, phenolic resin, Bakelite)

It is a thermoset resin prepared by condensation polymerization of phenol and formaldehyde. If acid catalyst is used the resin is called Novolac and if base catalyst is employed the resulting resin is termed as resol. PF is mainly used in mouldings and laminates. Phenolics have poor tracking resistance under conditions of high humidity.

4.17 Ceramics materials

Ceramic materials are inorganic, nonmetallic materials. Most ceramics are compounds between metallic and nonmetallic elements for which the interatomic bonds are either totally ionic or predominantly ionic but having some covalent character. The term ceramic comes from the Greek word keramikos, which means burnt stuff, indicating that desirable properties of these materials are normally achieved through a high-temperature heat treatment process called firing.

Ceramic materials are important in today's society. Consider the ceramic engine and what advantages it offers in terms of fuel economy, efficiency, weight savings and performance. Below are three gif's showing a montage of a prototype ceramic engine and some of the internal automotive components made from ceramics.

Aluminum Oxide, Al2O3

Alumina is the most cost effective and widely used material in the family of engineering ceramics. The raw materials from which this high performance technical grade ceramic is made are readily available and reasonably priced, resulting in good value for the cost in fabricated alumina shapes. With an excellent combination of properties and an attractive price, it is no surprise that fine grain technical grade alumina has a very wide range of applications.

Key Properties

Hard, wear-resistant

Excellent dielectric properties from DC to GHz frequencies

Resists strong acid and alkali attack at elevated temperatures Good thermal conductivity

Excellent size and shape capability

High strength and stiffness

Available in purity ranges from 94%, an easily metallizable composition, to 99.5% for the most demanding high temperature applications.

General Information

Aluminum oxide, commonly referred to as alumina, possesses strong ionic interatomic bonding giving rise to it's desirable material characteristics. It can exist in several crystalline phases which all revert to the most stable hexagonal alpha phase at elevated temperatures. This is the phase of particular interest for structural applications and the material available from Accuratus.

Alpha phase alumina is the strongest and stiffest of the oxide ceramics. Its high hardness, excellent dielectric properties, refractoriness and good thermal properties make it the material of choice for a wide range of applications.

High purity alumina is usable in both oxidizing and reducing atmospheres to 1925°C. Weight loss in vacuum ranges from 10^{-7} to 10^{-6} g/cm^2.sec over a temperature range of 1700° to 2000°C. It resists attack by all gases except wet fluorine and is resistant to all common reagents except hydrofluoric acid and phosphoric acid. Elevated temperature attack occurs in the presence of alkali metal vapors particularly at lower purity levels.

The composition of the ceramic body can be changed to enhance particular desirable material characteristics. An example would be additions of chrome oxide or manganese oxide to improve hardness and change color. Other additions can be made to improve the ease and consistency of metal films fired to the ceramic for subsequent brazed and soldered assembly.

Key Properties

The major properties of sintered silicon carbide of interest to the engineer or designer, are as follows:

High hardness (second only to diamond)

Low density 40% the density of steel – approximately the same as aluminium Low porosity

Good wear resistance in sliding and abrasive environments

Excellent corrosion resistance in most chemical environments

Low thermal expansion and high thermal conductivity leading to excellent thermal shock resistance.

Applications

Automotive Components and Seal Faces
Due to their greater resistance to both wear and thermal shock, sintered silicon carbide seal faces for automotive water pumps are replacing seal faces made of materials such as aluminium oxide. In many cases the material has proven more suitable in meeting the performance demands of U.S. and European vehicles – i.e. lasting the lifetime of the vehicle without leaking. These components are manufactured by conventional high volume pressing and injection moulding methods to meet the economic constraints of the application.

Armour

Sintered Silicon Carbide has demonstrated an excellent performance record as ceramic material in composite armour protection systems. The properties of sintered silicon carbide, such as its high hardness, compressive strength and elastic modulus, provide superior ballistic capability when confronted with high-velocity projectiles. The low specific density of the material makes it suitable in applications where weight requirements are critical.

Heat Exchanger Tubes

Sintered Silicon Carbide tubes are used in shell and tube heat exchangers in the chemical process industry. The tubes used in these applications are often over 4 m in length.

Mechanical Seals

Pumps must operate in an infinite variety of demanding environments. Sintered Silicon Carbide offers a high performance seal face material that has proven successful in such diverse pumping applications as chemical processing, refining, mining and pulp and paper processing. The material provides superior corrosion and abrasion resistance; shock resistance; and low sliding friction against a wide range of mating materials.

Bearings

For state-of-the-art magnetically driven pumps, sintered silicon carbide is particularly suited for thrust and journal bearing components. Excellent corrosion resistance provides optimum performance in many chemical environments. High thermal conductivity minimizes the likelihood of failure due to thermal shock, and its specific strength makes it safe to use at high rotational speeds. Bearing components are usually produced as tight tolerance precision ground parts.

Blast and Atomisation Nozzles

Sintered Silicon Carbide is probably the most popular ceramic alternative to tungsten carbide for blast nozzle applications. Typically providing long life (50% over WC) due to excellent wear and corrosion resistance. The low wear rate maintains the internal nozzle geometry and provides maximum blasting effectiveness, minimum compressor requirements and reduced downtime due to replacement. Sintered silicon carbide is also about one fifth the weight of Tungsten Carbide, so the blasting operation is also easier for the operator.

Process Industry Valve Applications

The outstanding corrosion resistance of sintered silicon carbide, particularly in acids, makes it an ideal candidate for valve and valve trim applications. Typical demanding applications such as slurry flashing, HF acid handling and rare earth processing use sintered silicon carbide valve components.

Paper Industry Applications

The excellent corrosion and wear resistance of sintered silicon carbide provides hard surfaces that can be machined to smooth, highly polished finishes. These finishes offer low coefficients of friction and compatibility with forming fabrics. Tiles, inserts and palm guides are available in finished and semi-finished forms.

Centrifuge Tiles and Wear Parts

Often used in applications where tungsten carbide and alumina fail to provide optimum lifetime performance.

Semiconductor Production

The benefit of using silicon carbide for semiconductor components includes; the thermal expansion match to silicon, the resistance to wear and chemical corrosion which leads to reduced maintenance and component recycling. The material is well suited as a structural material for low mass silicon wafer handling components and rigid, dimensionally stable platforms due to its lightness in weight and high elastic modulus. Typical applications include vacuum chucks, chemical mechanical polishing blocks, wafer carriers, and thermocouple protection tubes.

Fused Silica, SiO_2

Fused silica is a noncrystalline (glass) form of silicon dioxide (quartz, sand). Typical of glasses, it lacks long range order in its atomic structure. It's highly cross linked three dimensional structure gives rise to it's high use temperature and low thermal expansion coefficient.

.**Key Properties**

- ✓ Near zero thermal expansion
- ✓ Exceptionally good thermal shock resistance
- ✓ Very good chemical inertness
- ✓ Can be lapped and polished to fine finishes
- ✓ Low dielectric constant
- ✓ Low dielectric loss
- ✓ Good UV transparency

.

Typical Uses

- ✓ High temperature lamp envelopes
- ✓ Temperature insensitive optical component supports
- ✓ Lenses, mirrors in highly variable temperature regimes
- ✓ Microwave and millimeter wave components
- ✓ Aeronautical radar windows

Silicon Nitride, $Si_3 N_4$

Silicon nitride is a man made compound synthesized through several different chemical reaction methods. Parts are pressed and sintered by well developed methods to produce a ceramic with a unique set of outstanding properties. The material is dark gray to black in color and can be polished to a very smooth reflective surface, giving parts with a striking appearance. High performance silicon nitride materials were developed for automotive engine wear parts, such as valves and cam followers and proven effective. The cost of the ceramic parts never dropped enough to make the ceramics feasible in engines and turbochargers. The very high quality bodies developed for these demanding high reliability applications are available today and can be used in many severe mechanical, thermal and wear applications.

.Key Properties

- ✓ High strength over a wide temperature range
- ✓ High fracture toughness
- ✓ High hardness
- ✓ Outstanding wear resistance, both impingement and frictional modes
- ✓ Good thermal shock resistance
- ✓ Good chemical resistance

.

Typical Uses

- ✓ Rotating bearing balls and rollers
- ✓ Cutting tools
- ✓ Engine moving parts — valves, turbocharger rotors
- ✓ Engine wear parts — cam followers, tappet shims
- ✓ Turbine blades, vanes, buckets
- ✓ Metal tube forming rolls and dies
- ✓ Precision shafts and axles in high wear environments
- ✓ Weld positioners

General Information

The material is an electrical insulator and is not wet by nonferrous alloys. Silicon nitride is a rather expensive material, but it’s performance to cost benefit ratio is excellent in the applications where it can outperform the normally utilized materials with long life and very reliable low maintenance operation.

Zirconium Oxide, $ZrO2$

Zirconia is an extremely refractory material. It offers chemical and corrosion inertness to temperatures well above the melting point of alumina. The material has low thermal conductivity. It is electrically conductive above 600°C and is used in oxygen sensor cells and as the susceptor (heater) in high temperature induction furnaces. With the attachment of platinum leads, nernst glowers used in spectrometers can be made as a light emitting filament which operates in air.

Key Properties

- Use temperatures up to 2400°C
- High density
- Low thermal conductivity (20% that of alumina)
- Chemical inertness
- Resistance to molten metals
- Ionic electrical conduction
- Wear resistance
- High fracture toughness
- High hardness

.

Typical Uses

- Precision ball valve balls and seats
- High density ball and pebble mill grinding media
- Rollers and guides for metal tube forming
- Thread and wire guides
- Hot metal extrusion dies
- Deep well down-hole valves and seats
- Powder compacting dies
- Marine pump seals and shaft guides
- Oxygen sensors
- High temperature induction furnace susceptors
- Fuel cell membranes
- Electric furnace heaters over 2000°C in oxidizing atmospheres

Sialon

Sialon, a fine grain nonporous technical grade engineering material, is a silicon nitride ceramic with a small percentage of aluminum oxide added.

Sialon is outstanding in nonferrous metal contact. It is highly thermal shock resistant, strong, and is not wet or corroded by aluminum, brass, bronze, and other common industrial metals.

Key Properties

- Excellent thermal shock resistance
- Not wetted or corroded by nonferrous metals
- High strength
- Good fracture toughness
- Good high temperature strength
- Low thermal expansion

.

Typical Uses

- ✓ Thermocouple protection tubes for nonferrous metal melting
- ✓ Immersion heater and burner tubes
- ✓ Degassing and injector tubes in nonferrous metals
- ✓ Metal feed tubes in aluminum die casting
- ✓ Welding and brazing fixtures and pins

Key Properties

SiAlONs exploit the following properties:

low density,

high strength

superior thermal shock resistance,

moderate wear resistance

fracture toughness,

mechanical fatigue and creep resistance,

oxidation resistance.

In pressureless sintered materials, the high temperature properties are limited by the glassy phases that form at grain boundaries during sintering. These materials are only suitable to long term use at temperatures of less than 1000 ° C.

Applications

Cutting Tools

Wear Components

Metal Forming Tools

4.18 Composite Materials

Man's evolution has been tied to his progress in materials. Yesterday it was the Stone, Bronze and Iron Ages. Today it is the Age of Composites. However, even in these earlier ages man experimented with and learned to use composite materials.

A composite material is a multiphase material, which is composed of at least two basic elements working together to produce material properties that are different to the properties of those elements on their own. In practice, most composites consist of a bulk material (the 'matrix'), and a reinforcement of some kind, added primarily to increase the strength and stiffness of the matrix. This reinforcement is usually in fibre form. Composites maintain an interface between components and act in concert to provide improved specific or synergistic characteristics not obtainable by any of the original components acting alone.

The definition will allow the inclusion of natural materials such as wood which consists of cellulose fibers bonded together with lignin and other carbohydrate constituents, as well as the silk fiber spun by a spider which is as strong as steel on a weight basis consisting of a gel core encased in a solid protein structure as composite materials.

Composites include:

(1) Fibrous (composed of fibers, and usually in a matrix),
(2) Laminar (layers of materials),
(3) Particulate (composed of particles or flakes, usually in a matrix),
(4) Hybrid (combinations of any of the above).

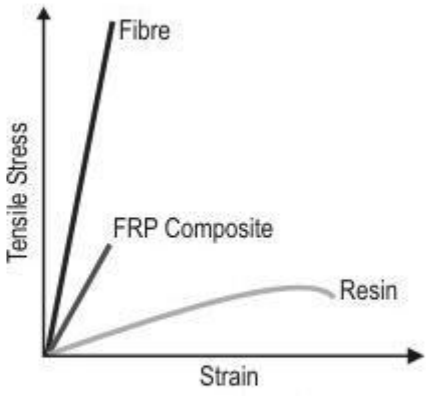
Today, the most common man-made composites can be divided into three main groups:

1. **Polymer Matrix Composites (PMC's)** – These are the most common and will be discussed here. Also known as FRP - Fibre Reinforced Polymers (or Plastics) – these materials use a polymer-based resin as the matrix, and a variety of fibres such as glass, carbon and aramid as the reinforcement.

2. **Metal Matrix Composites (MMC's)** - Increasingly found in the automotive industry, these materials use a metal such as aluminium as the matrix, and reinforce it with fibres such as silicon carbide.

3. **Ceramic Matrix Composites (CMC's)** - Used in very high temperature environments, these materials use a ceramic as the matrix and reinforce it with short fibres, or whiskers such as those made from silicon carbide and boron nitride.

It is when the resin systems are combined with reinforcing fibres such as glass, carbon and aramid that exceptional properties can be obtained. The resin matrix spreads the load applied to the composite between each of the individual fibres and also protects the fibres from damage caused by abrasion and impact. High strengths and stiffnesses, ease of moulding complex shapes, high environmental resistance all coupled with low densities, make the resultant composite superior to metals for many applications. Since PMC's combine a resin system and reinforcing fibres, the properties of the resulting composite material will combine something of the properties of the resin on its own with that of the fibres on their own, as surmised in Figure .4.1



Overall, the properties of the composite are determined by the ,
1) properties of the fibre,
2) properties of the resin,
3) ratio of fibre to resin in the composite (Fibre Volume Fraction (FVF)
4) geometry and orientation of the fibres in the composite

The ratio of the fibre to resin derives largely from the manufacturing process used to combine resin with fibre. However, it is also influenced by the type of resin system used, and the form in which the fibres are incorporated. In general, since the mechanical properties of fibres are much higher than those of resins, the higher the fibre volume fraction (FVF) the higher will be the mechanical properties of the resultant composite. In practice there are limits to this, since the fibres need to be fully coated in resin to be effective, and there will be an optimum packing of the generally circular cross-section fibres. In addition, the manufacturing process used to combine fibre with resin leads to varying amounts of imperfections and air inclusions. Typically, with a common hand lay-up process as widely used in the boat-building industry, a limit for FVF is approximately 30-40%. With the higher quality, more sophisticated and precise processes used in the aerospace industry, FVF's approaching 70% can be successfully obtained.

Loads on composites

There are four main direct loads that any material in a structure has to withstand: tension, compression, shear and flexure.

Tension

Figure 4.2 shows a tensile load applied to a composite. The response of a composite to tensile loads is very dependent on the tensile stiffness and strength properties of the reinforcement fibres, since these are far higher than the resin system on its own.

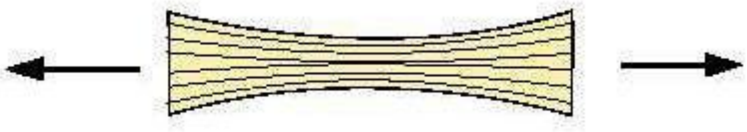


Figure 4.2 Tensile load applied to a composite body

Compression

Figure 4.3 shows a composite under a compressive load. Here, the adhesive and stiffness properties of the resin system are crucial, as it is the role of the resin to maintain the fibres as straight columns and to prevent them from buckling

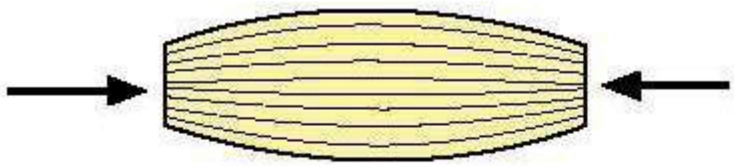


Figure 4.3 - Illustrates the compression load applied to a composite body.

Shear

Figure 4.4 shows a composite experiencing a shear load. This load is trying to slide adjacent layers of fibres over each other. Under shear loads the resin plays the major role, transferring the stresses across the composite. For the composite to perform well under shear loads the resin element must not only exhibit good mechanical properties but must also have high adhesion to the reinforcement fibre. The interlaminar shear strength (ILSS) of a composite is often used to indicate this property in a multiplayer composite ('laminate').

Figure 4.4 - Illustrates the shear load applied to a composite body.

Flexure

Flexural loads are really a combination of tensile, compression and shear loads. When loaded as shown (Figure 4.5), the upper face is put into compression, the lower face into tension and the central portion of the laminate experiences shear

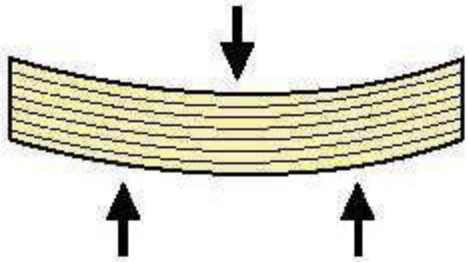


Figure 4.5 - Illustrates the loading due to flexure on a composite body.

A range of strength and stiffness (modulus) figures for different materials are given in Figure 4.6 to compare the spread of properties associated with composites and other structural materials

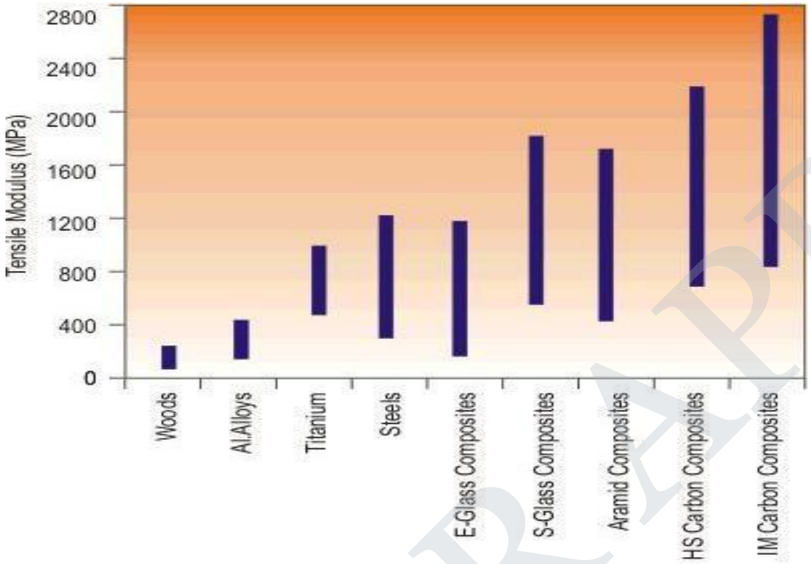


Figure 4.6 – Tensile Strength of Common Structural Materials

Particulate Composites

Particle-reinforced composites are candidate materials for a wide variety of aerospace and nonaerospace applications. The high costs and technical difficulties involved with the use of many fiber-reinforced composites often limit their use in many applications. Consequently, particulate composites have emerged as viable alternatives to conventional fiber-reinforced composites. Particulate composites can be processed to near net shape potentially reducing the manufacturing costs.

They are candidate materials where shock or impact properties are important. For example, particle-reinforced metal matrix composites have shown great potential for many automotive applications. Typically, these materials are aluminum matrix reinforced with SiC or TiC particles.

Reinforced concrete can also be thought of as a particle-reinforced composite. In situ ceramics can be modeled as particulate composites and are candidate materials for many high-temperature applications. The characterization of these materials is fundamental to their reliable use. It has been observed that the overall properties of these composites exhibit scatter because of the uncertainty in the constituent material properties, and fabrication-related parameters.

The observed scatter in the global composite behavior or "response" is usually caused by the existence of uncertainties in the basic or "primitive" variables. Primitive variables are properties or parameters that participate at the lowest or micromechanics level in defining a global or homogenized property. Volume fractions and individual constituent properties such as moduli, thermal expansion coefficients, thermal conductivities, and strengths are examples of primitive

variables.
They are assumed to be independent and have their own statistical distributions. Response variables are those that characterize such composite behavior as the composite moduli, thermal properties, and strengths.

UNIT –V

MECHANICAL PROPERTIES AND TESTING MECHANISMS

5.1 Plastic Deformation

When a material is stressed below its elastic limit, the resulting deformation or strain is temporary. Removal of stress results in a gradual return of the object to its original dimensions. When a material is stressed beyond its elastic limit, plastic or permanent deformation takes place, and it will not return to its original shape by the application of force alone. The ability of a metal to undergo plastic deformation is probably its most outstanding characteristic in comparison with other materials. All shaping operations such as stamping, pressing, spinning, rolling, forging, drawing, and extruding involve plastic deformation of metals. Various machining operations such as milling, turning, sawing, and punching also involve plastic deformation.

Plastic deformation may take place by :

Slip

Twinning

Combination of slip and twinning

Deformation by Slip:

If a single crystal of a metal is stressed in tension beyond its elastic limit, it elongates slightly, a step appears on the surface indicating relative displacement of one part of the crystal with respect to the rest, and the elongation stops. Increasing the load will cause another step. It is as if neighboring thin sections of the crystal had slipped past one another like a sliding cards on a deck. Each successive elongation requires a higher stress and results in the appearance of another step, which is actually the intersection of a slip plane with the surface of the crystal. Progressive increase of the load eventually causes the material to fracture.

Slip occurs in directions in which the atoms are most closely packed, since this requires the least amount of energy.

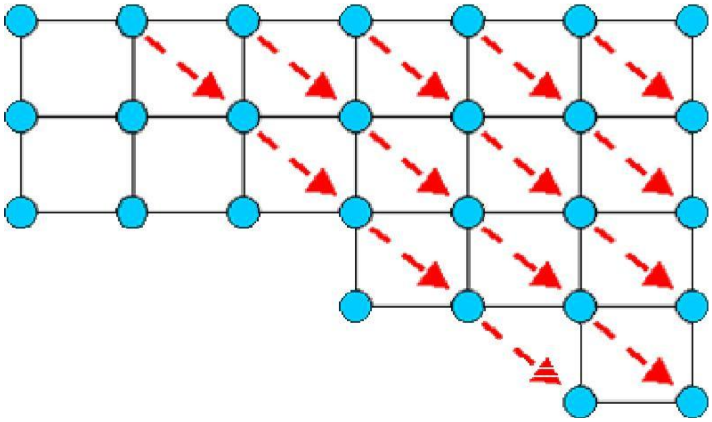


Figure 5.1 The effect of slip on the lattice structure.

Figure 1 shows that when the plastic deformation is due to slip, the atoms move a whole interatomic space (moving from one corner to another corner of the unit cell). This means that overall lattice structure remains the same. Slip is observed as thin lines under the microscopes and these lines can be removed by polishing.

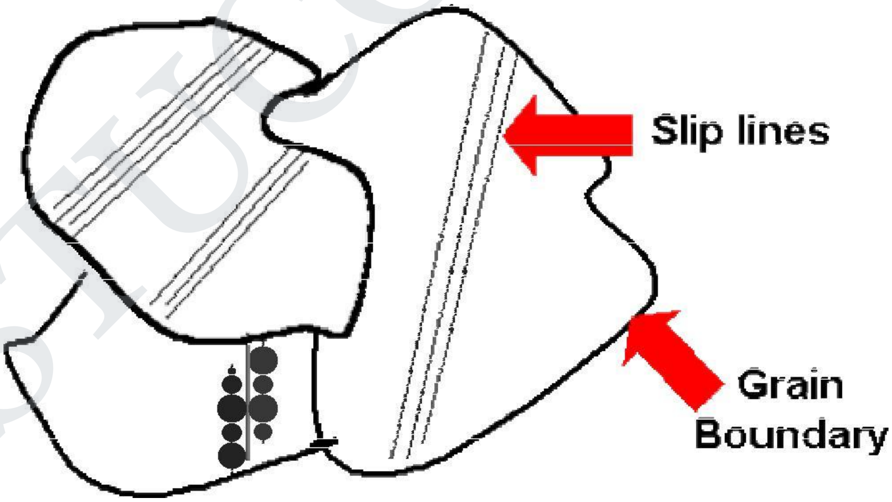


Figure 5.2 Slip appears as thin lines under the microscope.

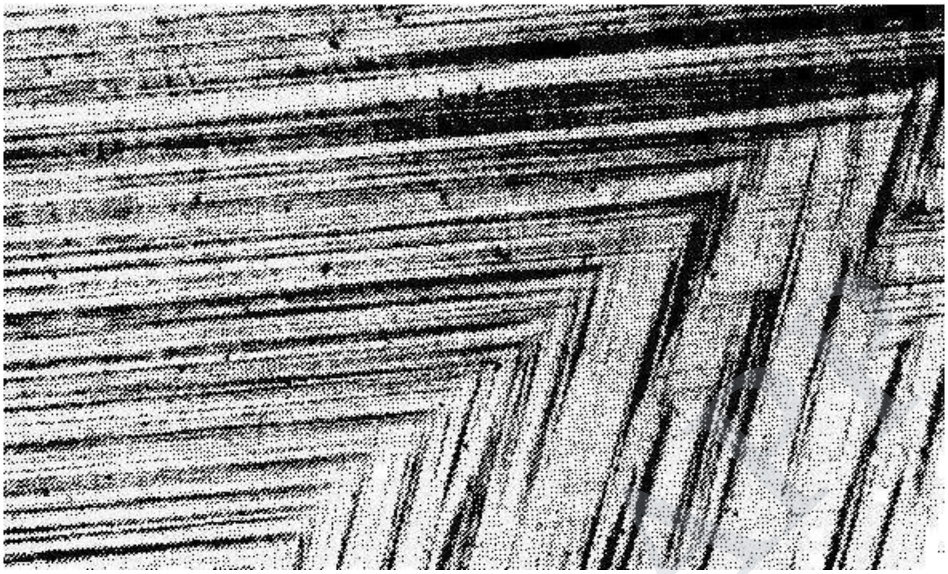


Figure 5.3 Slip lines in copper.

Deformation by Twinning:

When mechanical deformation is created by twinning, the lattice structure changes. The atoms move only a fraction of an interatomic space and this leads to a rearrangement of the lattice structure. Twinning is observed as wide bands under the microscope. These wide bands cannot be removed by polishing.

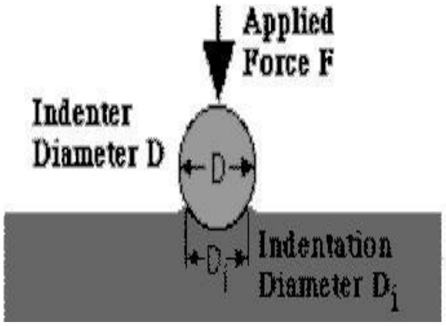
Two kinds of twins are of interest to the metallurgists:

1. Deformation or mechanical twins, most prevalent in close packed hexagonal metals (magnesium, zinc, iron with large amount of ferrite)

2. Annealing twins, most prevalent in F.C.C. (Face centered cubic) metals (aluminum, copper, brass, iron with austenite).These metals have been previously worked and heat treated. The twins are formed because of a change in the normal growth mechanism.

The Brinell Hardness Test

The Brinell hardness test method consists of indenting the test material with a 10 mm diameter hardened steel or carbide ball subjected to a load of 3000 kg. For softer materials the load can be reduced to 1500 kg or 500 kg to avoid excessive indentation. The full load is normally applied for 10 to 15 seconds in the case of iron and steel and for at least 30 seconds in the case of other metals. The diameter of the indentation left in the test material is measured with a low powered microscope. The Brinell harness number is calculated by dividing the load applied by the surface area of the indentation.



$$BHN = \frac{F}{\frac{\pi}{2} D \cdot \left(D - \sqrt{D^2 - D_i^2}\right)}$$

The diameter of the impression is the average of two readings at right angles and the use of a Brinell hardness number table can simplify the determination of the Brinell hardness. A well structured Brinell hardness number reveals the test conditions, and looks like this, "75 HB 10/500/30" which means that a Brinell Hardness of 75 was obtained using a 10mm diameter hardened steel with a 500 kilogram load applied for a period of 30 seconds. On tests of extremely hard metals a tungsten carbide ball is substituted for the steel ball. Compared to the other hardness test methods, the Brinell ball makes the deepest and widest indentation, so the test averages the hardness over a wider amount of material, which will more accurately account for multiple grain structures and any irregularities in the uniformity of the material. This method is the best for achieving the bulk or macro-hardness of a material, particularly those materials with heterogeneous structures.

VICKERS HARDNESS TEST

The Vickers hardness test was developed in 1924 by Smith and Sandland at Vickers Ltd as an alternative to the Brinell method to measure the hardness of materials.[1] The Vickers test is often easier to use than other hardness tests since
the required calculations are independent of the size of the indenter, and the indenter can be used for all materials irrespective of hardness. The basic principle, as with all common measures of hardness, is to observe the questioned material's ability to resist plastic deformation from a standard source. The Vickers test can be used for all metals and has one of the widest scales among hardness tests. The unit of hardness given by the test is known as the Vickers Pyramid Number (HV) or Diamond Pyramid Hardness (DPH). The hardness number can be converted into units of pascals, but should not be confused with a pressure, which also has units of pascals. The hardness number is determined by the load over the surface area of the indentation and not the area normal to the force, and is therefore not a pressure.

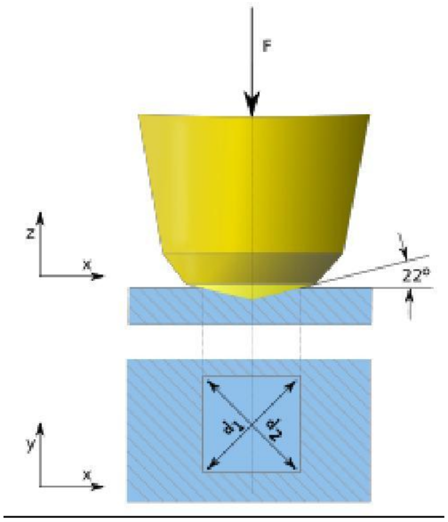
The hardness number is not really a true property of the material and is an empirical value that should be seen in conjunction with the experimental methods and hardness scale used. When doing the hardness tests the distance between indentations must be more than 2.5 indentation diameters apart to avoid interaction between the work-hardened regions.

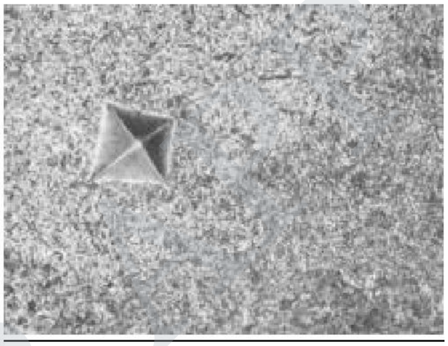
If HV is expressed in SI units the yield strength of the material can be approximated as:

$$\sigma_y = \frac{H_V}{c} \approx \frac{H_V}{3}$$

where c is a constant determined by geometrical factors usually ranging between 2 and 4.

[edit] Implementation





Vickers test scheme

An indentation left in case-hardened steel after a Vickers hardness test.

It was decided that the indenter shape should be capable of producing geometrically similar impressions, irrespective of size; the impression should have well-defined points of measurement; and the indenter should have high resistance to self-deformation. A diamond in the form of a square-based pyramid satisfied these conditions. It had been established that the ideal size of a Brinell impression was 3/8 of the ball diameter. As two tangents to the circle at the ends of a chord 3d/8 long intersect at 136°, it was decided to use this as the included angle of the indenter. The angle was varied experimentally and it was found that the hardness value obtained on a homogeneous piece of material remained constant, irrespective of load. Accordingly, loads of various magnitudes are applied to a flat surface, depending on the hardness of the material to be measured. The HV number is then determined by the ratio F/A where F is the force applied to the diamond in kilograms-force and A is the surface area of the resulting indentation in square millimetres. A can be determined by the formula

$$A = \frac{d^2}{2\sin(136^\circ/2)}$$

which can be approximated by evaluating the sine term to give

$$A \approx \frac{d^2}{1.8544}$$

where d is the average length of the diagonal left by the indenter. Hence,[3]

$$HV = \frac{F}{A} \approx \frac{1.8544F}{d^2}$$

where F is kgf and d is millimetres.

The corresponding units of HV are then kilograms-force per square millimetre (kgf/mm²). To calculate Vickers hardness number using SI units one needs to convert the force applied from kilogram-force to newtons by multiplying by 9.806 65 (standard gravity) and convert mm to m. To do the calculation directly, the following equation can be used:

$$HV = \frac{F}{A} \approx \frac{0.1891F}{d^2}$$

where F is newtons and d is millimetres.

Vickers hardness numbers are reported as xxxHVyy, e.g. 440HV30, or xxxHVyy/zz if duration of force differs from 10 s to 15 s, e.g. 440Hv30/20, where:
440 is the hardness number,

HV gives the hardness scale (Vickers), 30 indicates the load used in kg.

20 indicates the loading time if it differs from 10 s to 15 s

Vickers values are generally independent of the test force: they will come out the same for 500 gf and 50 kgf, as long as the force is at least 200 gf.[5]

Examples of HV values for various materials

Material	Value
316L stainless steel	140HV30
347L stainless steel	180HV30
Carbon steel	55–120HV5
Iron	30–80HV5

ROCKWELL HARDNESS TEST

The differential depth hardness measurement was conceived in 1908 by a Viennese professor Paul Ludwik in his book Die Kegelprobe (crudely, "the cone trial").[3] The differential-depth method subtracted out the errors associated with the mechanical imperfections of the system, such as backlash and surface imperfections. The Brinell hardness test, invented in Sweden, was developed earlier—in 1900—but it was slow, not useful on fully hardened steel, and left too large an impression to be considered nondestructive.

The Rockwell hardness tester, a differential-depth machine, was co-invented by Connecticut natives Hugh M. Rockwell (1890–1957) and Stanley P. Rockwell (1886–1940). A patent was applied for on July 15, 1914.[4] The requirement for this tester was to quickly determine the effects of heat treatment on steel bearing races. The application was subsequently approved on February 11, 1919, and holds patent number #1,294,171. At the time of invention, both Hugh and Stanley Rockwell (not direct relations) worked for the New Departure Manufacturing Co. of Bristol, CT. New Departure was a major ball bearing manufacturer that, in 1916, became part of United Motors and, shortly thereafter, General Motors Corp. After leaving the Connecticut company, Stanley Rockwell, then in Syracuse, NY, applied for an improvement to the original invention on September 11, 1919, which was approved on November 18, 1924. The new tester holds patent #1,516,207.[5][6] Rockwell moved to West Hartford, CT, and made an additional improvement in 1921. Stanley collaborated with instrument manufacturer Charles H. Wilson of the Wilson-Mauelen Company in 1920 to commercialize his invention and develop standardized testing machines. Stanley started a heat-treating firm circa 1923, the Stanley P. Rockwell Company, which still exists in Hartford, CT. The later-named Wilson Mechanical Instrument Company has changed ownership over the years, and was most recently acquired by Instron Corp. in 1993.

Operation

The determination of the Rockwell hardness of a material involves the application of a minor load followed by a major load, and then noting the depth of penetration, vis a vis, hardness value directly from a dial, in which a harder material gives a higher number. The chief advantage of Rockwell hardness is its ability to display hardness values directly, thus obviating tedious calculations involved in other hardness measurement techniques.

It is typically used in engineering and metallurgy. Its commercial popularity arises from its speed, reliability, robustness, resolution and small area of indentation.

In order to get a reliable reading the thickness of the test-piece should be at least 10 times the depth of the indentation. Also, readings should be taken from a flat perpendicular surface, because round surfaces give lower readings. A correction factor can be used if the hardness must be measured on a round surface.

Stanley P. Rockwell invented the Rockwell hardness test. He was a metallurgist for a large ball bearing company and he wanted a fast non-destructive way to determine if the heat treatment process they were doing on the bearing races was successful. The only hardness tests he had available at time were Vickers, Brinell and Scleroscope. The Vickers test was too time consuming, Brinell indents were too big for his parts and the Scleroscope was difficult to use, especially on his small parts.

To satisfy his needs he invented the Rockwell test method. This simple sequence of test force application proved to be a major advance in the world of hardness testing. It enabled the user to perform an accurate hardness test on a variety of sized parts in just a few seconds.

Rockwell test methods are defined in the following standards: ASTM E18 Metals

Types of the Rockwell Test

There are two types of Rockwell tests:

Rockwell:
The minor load is 10 kgf, the major load is 60, 100, or 150 kgf.

Superficial Rockwell:
The minor load is 3 kgf and major loads are 15, 30, or 45 kgf.

In both tests, the indenter may be either a diamond cone or steel ball, depending upon the characteristics of the material being tested.

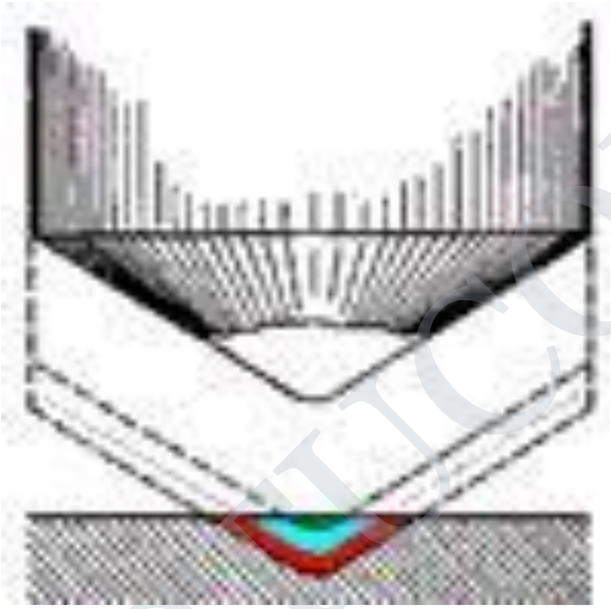
Rockwell Scales

Rockwell hardness values are expressed as a combination of a hardness number and a scale symbol representing the indenter and the minor and major loads. The hardness number is expressed by the symbol HR and the scale designation.

There are 30 different scales. The majority of applications are covered by the Rockwell C and B scales for testing steel, brass, and other metals. However, the increasing use of materials other than steel and brass as well as thin materials necessitates a basic knowledge of the factors that must be considered in choosing the correct scale to ensure an accurate Rockwell test. The choice is not only between the regular hardness test and superficial hardness test, with three different major loads for each, but also between the diamond indenter and the 1/16, 1/8, 1/4 and 1/2 in. diameter steel ball indenters.

If no specification exists or there is doubt about the suitability of the specified scale, an analysis should be made of the following factors that control scale selection:

Scale limitations
Principal of the Rockwell Test



The major load is applied for a specified time period (dwell time) beyond zero The major load is released leaving the minor load applied

The resulting Rockwell number represents the difference in depth from the zero reference position as a result of the application of the major load.

CREEP TEST

Method for determining creep or stress relaxation behavior. To determine creep properties, material is subjected to prolonged constant tension or compression loading at constant temperature. Deformation is recorded at specified time intervals and a creep vs. time diagram is plotted. Slope of curve at any point is creep rate. If failure occurs, it terminates test and time for rupture is recorded. If

specimen does not fracture within test period, creep recovery may be measured. To determine stress relaxation of material, specimen is deformed a given amount and decrease in stress over prolonged period of exposure at constant temperature is recorded

Viscoplasticity is a theory in continuum mechanics that describes the rate-dependent inelastic behavior of solids. Rate-dependence in this context means that the deformation of the material depends on the rate at which loads are applied. The inelastic behavior that is the subject of viscoplasticity is plastic deformation which means that the material undergoes unrecoverable deformations when a load level is reached. Rate-dependent plasticity is important for transient plasticity calculations. The main difference between rate-independent plastic and viscoplastic material models is that the latter exhibit not only permanent deformations after the application of loads but continue to undergo a creep flow as a function of time under the influence of the applied load.

The elastic response of viscoplastic materials can be represented in one-dimension by Hookean spring elements. Rate-dependence can be represented by nonlinear dashpot elements in a manner similar to viscoelasticity. Plasticity can be accounted for by adding sliding frictional elements as shown in Figure 1. In the figure E is the modulus of elasticity, λ is the viscosity parameter and N is a power-law type parameter that represents non-linear dashpot [$\sigma(d\varepsilon/dt)= \sigma = \lambda(d\varepsilon/dt)(1/N)$]. The sliding element can have a yield stress (σy) that is strain rate dependent, or even constant, as shown in Figure 1c.

Viscoplasticity is usually modeled in three-dimensions using overstress models of the Perzyna or Duvaut-Lions types. In these models, the stress is allowed to increase beyond the rate-independent yield surface upon application of a load and then allowed to relax back to the yield surface over time. The yield surface is usually assumed not to be rate-dependent in such models. An alternative approach is to add a strain rate dependence to the yield stress and use the techniques of rate independent plasticity to calculate the response of a material For metals and alloys, viscoplasticity is the macroscopic behavior caused by a mechanism linked to the movement of dislocations in grains, with superposed effects of inter-crystalline gliding. The mechanism usually becomes dominant at temperatures greater than approximately one third of the absolute melting temperature. However, certain alloys exhibit viscoplasticity at room temperature (300K). For polymers, wood, and bitumen, the theory of viscoplasticity is required to describe behavior beyond the limit of elasticity or viscoelasticity.

Creep is the tendency of a solid material to slowly move or deform permanently under constant stresses. Creep tests measure the strain response due to a constant stress as shown in Figure 3. The classical creep curve represents the evolution of strain as a function of time in a material subjected to uniaxial stress at a constant temperature. The creep test, for instance, is performed by applying a constant force/stress and analyzing the strain response of the system. In general, as shown in Figure 3b this curve usually shows three phases or periods of behavior

A primary creep stage, also known as transient creep, is the starting stage during which hardening of the material leads to a decrease in the rate of flow which is initially very high. $(0 \leq \varepsilon \leq \varepsilon_1)$.

The secondary creep stage, also known as the steady state, is where the strain rate is constant. $(\varepsilon_1 \leq \varepsilon \leq \varepsilon_2)$.

A tertiary creep phase in which there is an increase in the strain rate up to the

fracture strain.
$(\epsilon_2 \leq \epsilon \leq \epsilon_R)$. [edit]

Relaxation test

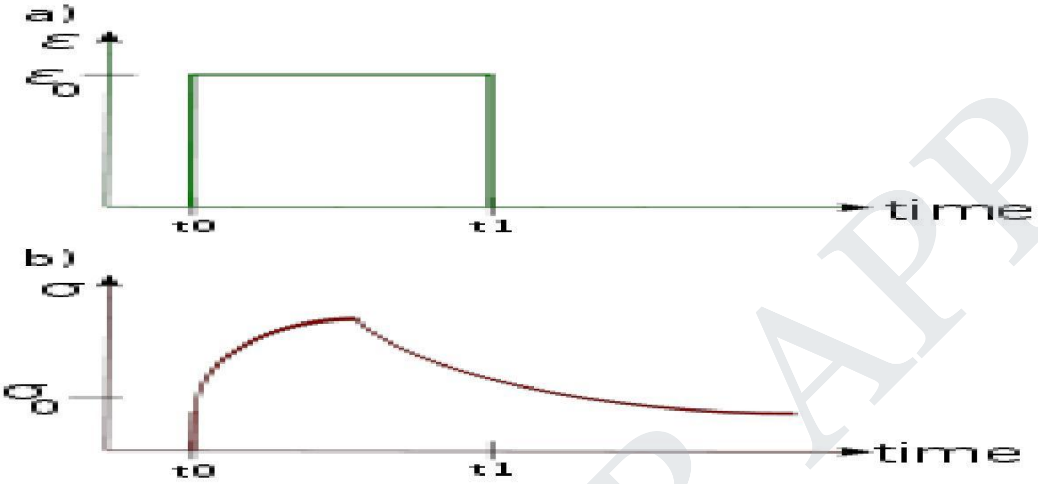


Figure 4. a) Applied strain in a relaxation test and b) induced stress as functions of time over a short period for a viscoplastic material.

As shown in Figure 4, the relaxation test is defined as the stress response due to a constant strain for a period of time. In viscoplastic materials, relaxation tests demonstrate the stress relaxation in uniaxial loading at a constant strain. In fact, these tests characterize the viscosity and can be used to determine the relation which exists between the stress and the rate of viscoplastic strain. The decompositon of strain rate is

$$\frac{d\boldsymbol{\varepsilon}}{dt} = \frac{d\boldsymbol{\varepsilon}_e}{dt} + \frac{d\boldsymbol{\varepsilon}_{vp}}{dt} \, .$$

The elastic part of the strain rate is given by

$$\frac{d\boldsymbol{\varepsilon}_e}{dt} = \mathsf{E}^{-1} \frac{d\boldsymbol{\sigma}}{dt}$$

For the flat region of the strain-time curve, the total strain rate is zero. Hence we have,

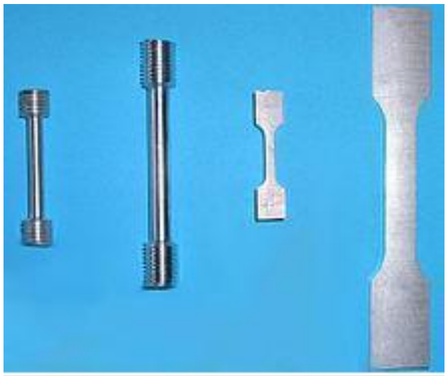
$$\frac{d\varepsilon_{vp}}{dt} = -E^{-1}\frac{d\sigma}{dt}$$

Therefore the relaxation curve can be used to determine rate of viscoplastic strain and hence the viscosity of the dashpot in a one-dimensional viscoplastic material model. The residual value that is reached when the stress has plateaued at the end of a relaxation test corresponds to the upper limit of elasticity. For some materials such as rock salt such an upper limit of elasticity occurs at a very small value of stress and relaxation tests can be continued for more than a year without any observable plateau in the stress.

It is important to note that relaxation tests are extremely difficult to perform because maintaining the condition $\frac{d\varepsilon}{dt} = 0$ in a test requires considerable delicacy

Tensile testing, also known as tension testing, is a fundamental materials science test in which a sample is subjected to uniaxial tension until failure. The results from the test are commonly used to select a material for an application, for quality control, and to predict how a material will react under other types of forces. Properties that are directly measured via a tensile test are ultimate tensile strength, maximum elongation and reduction in area. From these measurements the following properties can also be determined: Young's modulus, Poisson's ratio, yield strength, and strain-hardening characteristics.

Tensile specimen



Tensile specimens made from an aluminum alloy. The left two specimens have a round cross-section and threaded shoulders. The right two are flat specimen designed to be used with serrated grips.

A tensile specimen is a standardized sample cross-section. It has two shoulders and a gage section in between. The shoulders are large so they can be readily gripped, where as the gage section has a smaller cross-section so that the deformation and failure can occur in this area.

The shoulders of the test specimen can be manufactured in various ways to mate to various grips in the testing machine (see the image below). Each system has advantages and disadvantages; for example, shoulders designed for serrated grips are easy and cheap to manufacture, but the alignment of the specimen is dependent on the skill of the technician. On the other hand, a pinned grip assures good alignment. Threaded shoulders and grips also assure good alignment, but the technician must know to thread each shoulder into the grip at least one diameter's length, otherwise the threads can strip before the specimen fractures.

In large castings and forgings it is common to add extra material, which is designed to be removed from the casting so that test specimens can be made from it. These specimen not be exact representation of the whole workpiece because the grain structure may be different throughout. In smaller workpieces or when critical parts of the casting must be tested, a workpiece may be sacrificed to make the test specimens. For workpieces that are machined from bar stock, the test specimen can be made from the same piece as the bar stock.

The repeatability of a testing machine can be found by using special test specimens meticulously made to be as similar as possible.

The following tables give the test specimen dimensions and tolerances per standard ASTM E8.

A universal testing machine

The most common testing machine used in tensile testing is the universal testing machine. This type of machine has two crossheads; one is adjusted for the length of the specimen and the other is driven to apply tension to the test specimen. There are two types: hydraulic powered and electromagnetically powered machines.

The machine must have the proper capabilities for the test specimen being tested. There are three main parameters: force capacity, speed, and precision and accuracy. Force capacity refers to the fact that the machine must be able to generate enough force to fracture the specimen. The machine must be able to apply the force quickly or slowly enough to properly mimic the actual application. Finally, the machine must be able to accurately and precisely measure the gage length and forces applied; for instance, a large machine that is designed to measure long elongations may not work with a brittle material that experiences short elongations prior to fracturing.

Alignment of the test specimen in the testing machine is critical, because if the specimen is misaligned, either at an angle or offset to one side, the machine will exert a bending force on the specimen. This is especially bad for brittle materials, because it will dramatically skew the results. This situation can be minimized by using spherical seats or U-joints between the grips and the test machine. A misalignment is indicated when running the test if the initial portion of the stress-strain curve is curved and not linear.

The strain measurements are most commonly measured with an extensometer, but strain gauges are also frequently used on small test specimen or when Poisson's ratio is being measured. Newer test machines have digital time, force, and elongation measurement systems consisting of electronic sensors connected to a data collection device (often a computer) and software to manipulate and output the data. However, analog machines continue to meet and exceed ASTM, NIST, and ASM metal tensile testing accuracy requirements, continuing to be used today.[citation needed]

Process

The test process involves placing the test specimen in the testing machine and applying tension to it until it fractures. During the application of tension, the elongation of the gage section is recorded against the applied force. The data is manipulated so that it is not specific to the geometry of the test sample. The elongation measurement is used to calculate the engineering strain, ε, using the following equation:[4]

$$\varepsilon = \frac{\Delta L}{L_0} = \frac{L - L_0}{L_0}$$

where ΔL is the change in gage length, L0 is the initial gage length, and L is the final length. The force measurement is used to calculate the engineering stress, σ, using the following equation:

$$\sigma = \frac{F_n}{A}$$

where F is the force and A is the cross-section of the gage section. The machine does these calculations as the force is increase so that the data points can be graphed into a stress-strain curve.

Standards
Metals

ASTM E8 Standard Test Methods for Tension Testing of Metallic Materials ISO 6892 Metallic materials—Tensile testing at ambient temperature
JIS Z2241 Method of tensile test for metallic materials

COMPRESSION TEST

The box compression test (bct) measures the compressive strength of boxes made of corrugated fiberboard as well as wooden boxes and crates. It provides a plot of deformation vs compressive force. Containers other than boxes can also be subjected to compression testing: drum, pail, etc.

Compression tester for shipping containers

A BCT plot is a measure of the strength of a shipping container and is measured in kN .deflection or deformation is measured in mm or inches.

Test Procedures

A common method of conducting the test, as described in several published standard test methods, is to compress a box at a constant rate of 1/2 inch (12.5 mm) per minute between two rigid platens. The platens can be fixed so that they remain parallel or one can be pivoted or "floating". The test can be conducted on empty or filled boxes, with or without a box closure. Conditioning to standard temperature and humidity is important.

The dynamic loads have some relationship with expected field loads.: often factors of 4 or 5 are used to estimate the allowable working load on boxes.

A test can also be conducted with platens that are not mechanically driven but are free to move with a fixed mass (or fixed force) loaded upon them. The results of static load testing can be:

The time to failure

The time to a critical deformation

The ability of a box to protect the contents from compression damage etc

As with any laboratory testing field validation is necessary to determine suitability.

Factors potentially affecting test results

Size and construction of the specific shipping container under test Grade and flute structure of corrugated fiberboard

moisture content of the corrugated board (based on relative humidity) Orientation of the box during the test

Inner supports, if used during testing (wood, corrugated board, cushioning) Contents (when box is tested with contents)

Box closure

Whether the compression machine has "fixed" or "floating" (swiveled) platens. Previous handling or testing of box.

Estimations

Corrugated fiberboard can be evaluated by many material test methods including an Edge Crush Test (ECT). There have been efforts to estimate the peak compression strength of a box (usually empty, regular singelwall slotted containers, top-to-bottom) based on various board properties. Some have involved finite element analysis. One of the commonly referenced empirical estimations was puplished by McKee in 1963. This used the board ECT, the MD and CD flexural stiffness, the box perimeter, and the box depth. Simplifications have used a formula involving the board ECT, the board thickness, and the box perimeter. Most estimations do not relate well to other box orientations, box styles, or to filled boxes. Physical testing of filled and closed boxes remains necessary.

Relevant Standards

ASTM Standard D642 Test Method for Determining Compressive Resistance of Shipping Containers, Components, and Unit Loads.

ASTM Standard D4577 Test Method for Compression Resistance of a Container Under Constant Load

ASTM Standard D7030 Test Method for Short Term Creep Performance of Corrrugated Fiberboard Containers Under Constant Load Using a Compression Test Machine

German Standard DIN 55440-1 Packaging Test; compression test; test with a constant conveyance-speed

ISO 12048 Packaging -- Complete, filled transport packages -- Compression etc.