

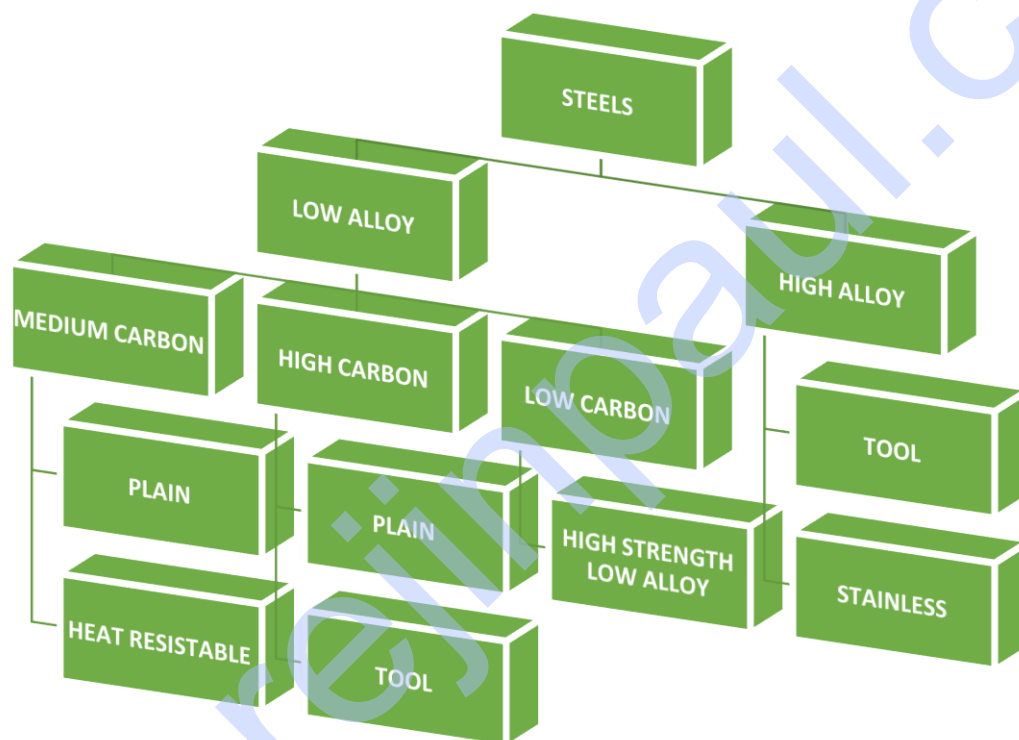
## UNIT – I

### PART-A

1. Define the term solid solution. (APRIL MAY 2019)

A number of metals dissolve in each other forming solid solutions. Solid solutions are analogous to liquid solutions. The mixing of the elements in the solid is on the atomic scale. When a solute atom is much smaller than the solvent atom it may dissolve interstitially occupying a void space in the parent structure.

2. How will you classify steels? (APRIL MAY 2019)



3. What is the equilibrium phase diagram(Apr/May 2018)

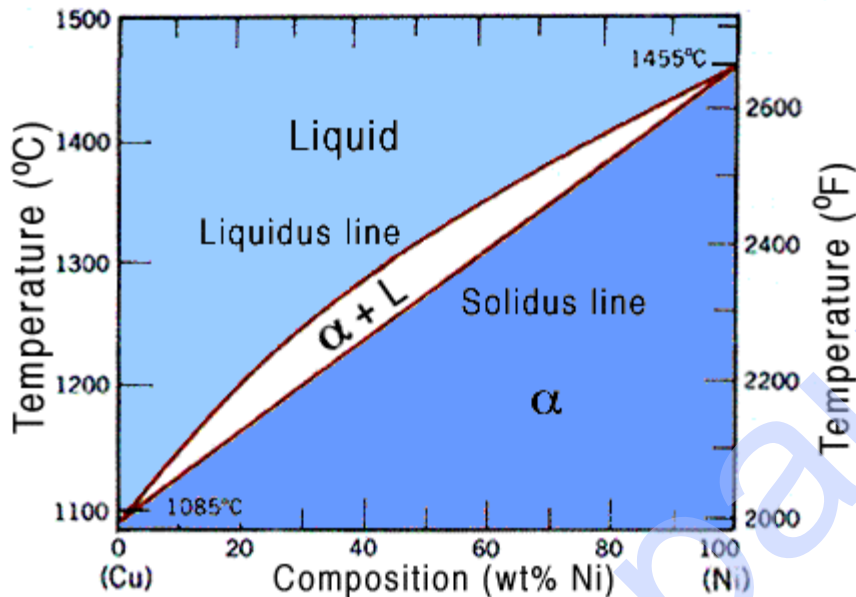
Give the relationship of composition of a solution as a function of temperatures and the quantities of phases in equilibrium. These diagrams do not indicate the dynamics when one phase transforms into another.

4. Define Cementite and Pearlite in Fe-C alloys.(Apr/May 2018)

Cementite (or iron carbide) is a compound of iron and carbon, more precisely an intermediate transition metal carbide with the formula  $\text{Fe}_3\text{C}$ . By weight, it is 6.67% carbon and 93.3% iron. It has an orthorhombic crystal structure. It is a hard, brittle material, normally classified as a ceramic in its pure form, and is a frequently found and important constituent in ferrous metallurgy. While cementite is present in most steels and cast irons.

Pearlite is a two-phased, lamellar (or layered) structure composed of alternating layers of ferrite (87.5 wt%) and Cementite (12.5 wt%) that occurs in some steels and cast irons. During slow cooling of an iron-carbon alloy, pearlite forms by a eutectoid reaction as austenite cools below 727 °C (1,341 °F) (the eutectoid temperature). Pearlite is a microstructure occurring in many common grades of steels.

5. Draw the typical phase diagram of isomorphous alloy system.(Nov/Dec 2018)

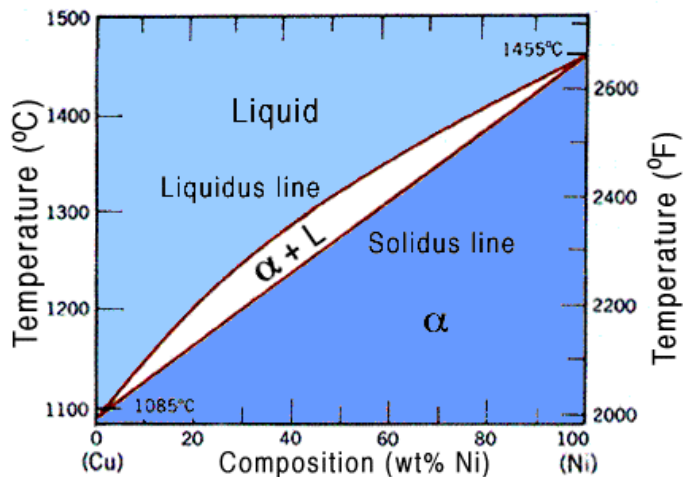


6. Write a typical peritectoid reaction.(Nov/Dec 2018)

Peritectoid	$\alpha + \gamma \xrightarrow{\text{Cool}} \beta$	Ni-Zn, Cu-Sn, Ni-Mn, Fe-Cb, Cu-Sb, Cu-Si	$\alpha \text{---} \beta \text{---} \gamma$
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7. What are the types of solid solutions? (Apr/May 2017)  
Interstitial and substitutional are the types of solid solutions.
8. Why is carbon solubility more in austenite? (Apr/May 2017)  
Inter atomic space for FCC is larger when compared to BCC. So, in FCC more carbon atom can occupy the larger space between atoms. That is why solubility in austenite is higher.

9. Draw a typical Isomorphous phase diagram (Nov/Dec 2017)



10. Why carbon content in Austenite is higher than ferrite (Nov/Dec 2017)

Austenite has face centered cubic (FCC) crystal structure and ferrite has body centered cubic (BCC) crystal structure. Due to its larger size, carbon atoms occupy octahedral interstitial sites in these crystals. Octahedral interstitial site of BCC ferrite is much smaller for carbon than that of FCC austenite. This is why solubility of carbon in ferrite is much smaller than solubility of carbon in austenite.

11. State Gibbs phase rule

Gibbs phase rule describes the relationship between the number of phases and the effect of variables such as pressure, temperature and composition.

Gibbs phase rule is given by  $P + F = C + 2$

Where P = number of phases in the system

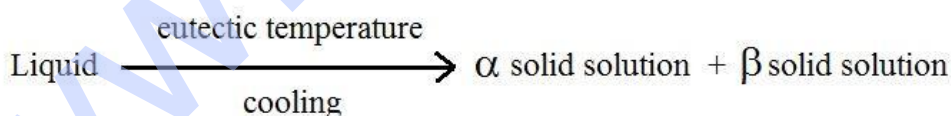
F = number of variables that can be changed independently without affecting the number of phases.

2 = Degrees of freedom.

12. Give the typical eutectic and eutectoid reactions.

Eutectic

reaction



Eutectoid reaction :



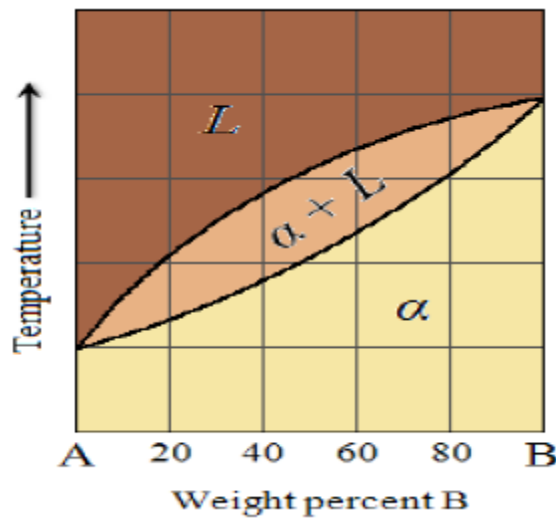
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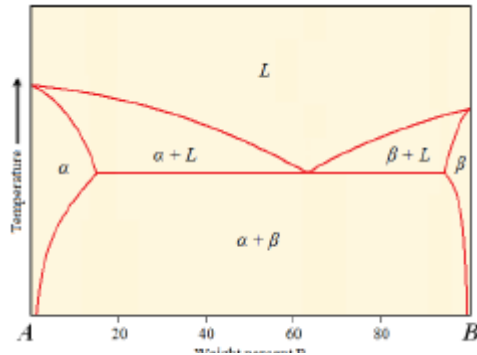
17. Name and explain the standard rule for the formation of substitutional type of solid solution. (April/May 2015)

The Hume-Rothery rules, named after William Hume-Rothery, are a set of basic rules that describe the conditions under which an element could dissolve in a metal, forming a solid solution. There are two sets of rules, one refers to substitutional solid solutions, and the other refers to interstitial solid solutions. For substitutional solid solutions, the Hume-Rothery rules are follows: The atomic radius of the solute and solvent atoms must differ by no more than 15%. 
$$\left| \frac{r_{\text{solute}} - r_{\text{solvent}}}{r_{\text{solvent}}} \right| \times 100\% \leq 15\%$$
 The crystal structures of solute and solvent must be similar. Complete solubility occurs when the solvent and solute have the same valency. A metal dissolves a metal of higher valency to a greater extent than one of lower valency. The solute and solvent should have similar electronegativity. If the electronegativity difference is too great, the metals tend to form intermetallic compounds instead of solid solutions.

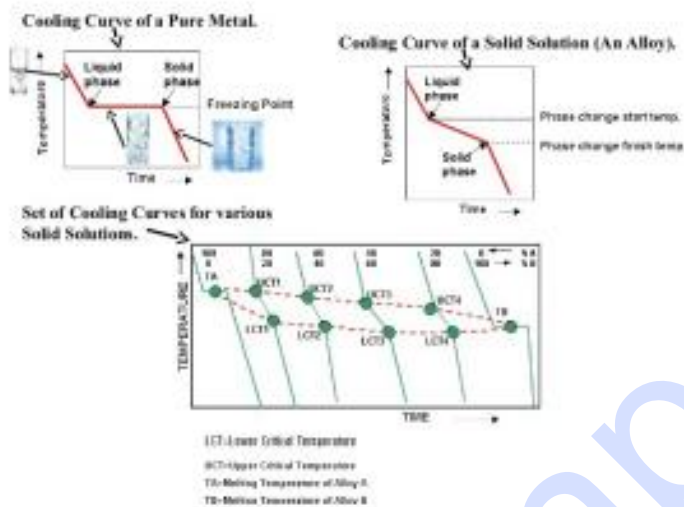
18. Name the system and sketch the labeled ideal binary phase diagrams for the system where the components are completely soluble in liquid and partially soluble in solid states. (April/May 2015)

The system is eutectic system and diagram is shown below.





19. Draw a typical cooling curve of pure metal and solid solution. (Nov/Dec 2015)



20. What do you mean by invariant reaction (Nov/Dec 2015)

This type of reaction is an invariant reaction, because it is in thermal equilibrium; another way to define this is the Gibbs free energy equals zero. Tangibly, this means the liquid and two solid solutions all coexist at the same time and are in chemical equilibrium.

21. State Gibb's phase rule (May/June 2014)

$$F = C - P + 2$$

Where F = number of degrees of freedom

C = number of components

P = number of phases in thermodynamic equilibrium.

22. Define Eutectoid reaction (May/June 2014)

Mixture of two or more components in such proportion that their combined melting point is the lowest attainable in some cases as low as 60°C (140°F). Eutectic alloys are fusible: upon cooling they convert from liquids to intimately mixed solids.

23. What is Peritectoid reaction (Nov/Dec 2014)

Peritectoid transformations are a comparatively rare type of invariant reaction where in the solid state of a material, a phase *A* decomposes on heating into a mixture of two other phases *B* and *C*.

**24. What is substitutional solid solution? Give two examples (Nov/Dec 2014)**

In substitutional solid solution, the atoms of alloying elements occupy the atomic sites of the base metal. They are classified as

**Regular or ordered substitutional solid solution :** In this type, the substitution of atoms of alloying elements is in a definite order in the base metal matrix. Examples: Ag-Cu solid solution.

**Random or disordered solid solution :** In this type, the substitution of atoms of alloying elements is in any random order in the base metal matrix. Example :  $\alpha$ - Brass.

**25. State Gibbs phase rule**

Gibbs phase rule describes the relationship between the number of phases and the effect of variables such as pressure, temperature and composition.

Gibbs phase rule is given by  $P + F = C + 2$

Where *P* = number of phases in the system

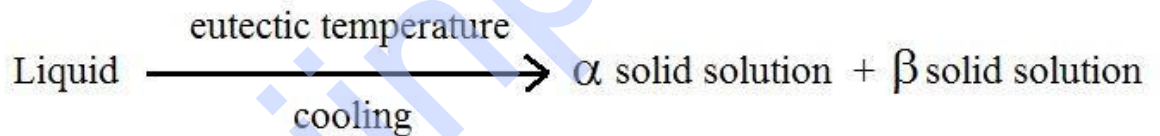
*F* = number of variables that can be changed independently without affecting the number of phases.

2 = Degrees of freedom.

**26. Give the typical eutectic and eutectoid reactions.**

Eutectic

reaction



Eutectoid reaction :



**27. What is austempering**

**Austempering** is heat treatment that is applied to ferrous metals, most notably steel and ductile iron. In steel it produces a bainite microstructure whereas in cast irons it produces a structure of acicular ferrite and high carbon, stabilized austenite known as ausferite. It is primarily used to improve mechanical properties or reduce / eliminate distortion.

**28. Name any two shallow hardening processes**

- (i) Carburizing
- (ii) Nitriding

**29. Give the effects of silicon on steel**

- It is a ferrite solid solution strengthener
- It improves oxidation resistance
- It reduces hysteresis losses
- It increases toughness.

30. What are bearing alloys? Give an example

Bearing alloys are anti-friction materials used as rotating shaft holders or supporters. These shaft holders or supporters transmits load to a shaft rotating relative to the bearing. Examples: White metal alloys (Babbitts).

31. What is Polymerization?

Polymerization is defined as the process of forming a large polymer by linking together of monomers. Examples of Polymers are wood, resin, starch, nylon, etc.

32. State the advantages of fiber reinforced composites?

- (i) The fiber reinforced composite has better stiffness, strength and toughness.
- (ii) The function of fibres is to withstand the load, while the matrix ensures uniform distribution of the applied load.

33. List the applications of engineering ceramics?

- Used as an abrasive material in grinding wheels,
- Used in medical, dental and orthopedic implants.
- Used as a die material for hot extrusion.
- Used as a wear resistant coating s for metals and composites.

34. Distinguish between elasticity and Plasticity

Elasticity is a property of objects or systems that allows them to deform reversibly. Elastic deformations can be caused by forces and impacts.

Plasticity is the property that causes irreversible deformations on an object or a system. Such deformations can be caused by forces and impact.

### **PART-B**

1. Draw the iron carbon equilibrium phase diagram and discuss the different phases that take place in it. (Apr/May 2018)

Refer Question number: 10.

2. Discuss the classification, properties and application of steel. (Apr/May 2018)

**Steel :** Steels are alloys of iron and carbon. However steels contain other elements like silicon , manganese, sulphur, phosphorus, nickel etc. The alloying elements are either intentionally added or retained during the refining process.

**Specification of steels:**

The American Iron and steel institute the society of Automotive Engineers. American society for testing and materials are responsible for the classification and specification of steels as well as other alloys. The AISI / SAE designation for the steels is s four digit number: First two digit indicate the alloy content, and last two digit indicate the carbon concentration.

### Classification of steel:

Steel can be classified as follows

#### 1. Plain carbon ( or) non alloy steels

- (i) Low carbon steels
- (ii) Medium carbon steels
- (iii) High carbon steels

#### 2, Alloy steels

- (i) Low alloy steels
- (ii) High alloy steels

### Plain carbon steels:

Plain carbon steels are those in which carbon is the alloying element that essentially controls the properties of the alloys and in which the amount of manganese cannot exceed 1.65% and the copper and silicon contents each must be less than 0.6%. Composition of plain carbon steels: Carbon upto 1.5% Manganese upto 1.65% Copper upto 0.6% Silicon upto 0.6% Other names: the plain carbon steels are also known by many terms such as carbon steels, non alloy steels and straight carbon steels.

Characteristics of plain carbon steels: - Plain carbon steels are the moderately priced steels due to the absence of large amount of alloying elements. - They are sufficiently ductile to readily formed. - Plain carbon steels are available in almost all product forms: sheet , strip, bar , plated, pipe, wire.

### Applications of plain carbon steels

Plain carbon steels are used for mass production products such as automobiles and appliances. They also find applications in the production of ball bearings base plates housing, chutes , structural member etc.

### Classification of plain carbon steels:

Low –carbon steel: those containing between 0.25 and 0.6 % carbon.

Medium – carbon steels: those containing between 0.25 and 0.60% carbon.

High-carbon steels: those containing more than 0.6% carbon.

### Low carbon steels:

The low carbon steels represent the largest tonnage of all the steel produced.

The low-carbon steels are those steels that contain less than about 0.25% carbon. The low-carbon steels are also known as mild steels.

Characteristics of low carbon steels:

Low carbon steels are relatively soft and weak.

They cannot be hardened appreciably by heat treatment.

They possess good formability and weldability.

Strengthening of low carbon steels is accomplished by cold work.

They have outstanding ductility and toughness.

The micro structure of low carbon steels consists of ferrite and pearlite constituents.

Of all steels, the low carbon steels are the least expensive to produce.

Medium carbon steels:

Medium carbon steels are those steels that have between 0.25 and 0.60% carbon.

The medium carbon steels may be heat treated, quenched and then tempered to improve their mechanical properties.

Characteristics of medium carbon steels:

The main properties of medium carbon steels are:

1. The plain medium-carbon steels have low hardenability.
2. In plain medium carbon steels the high strength and hardness properties are achieved.

Application of medium carbon steels:

The medium carbon steels include railway wheels, railway tracks, gears, crank shafts, and other machine parts.

**HIGH-CARBON STEELS:**

High carbon steels are those steels that have more than 0.6%. Characteristics of high carbon steels:

High carbon steels are the hardest, and strongest of the carbon steels.

They are the least ductile of the carbon steels.

They are more wear resistant.

They are capable of holding a sharp cutting edge (which is a very important property for making tools).

Application of high carbon steels:

The plain high carbon steels include cutting tools and dies (for forming and shaping materials) knives, razors, hack saw blades, springs and high strength wire.

### Compositions:

Dead mild steel – 0.05 Mild steel - 0.08 – 0.15 Mild steel – 0.5 Mild steel – 0.1-0.3

Alloy steels: In general terms, alloy steels mean any steels other than carbon steels.

The steels products manual defines alloy steels as steels that steels. Manganese -1.65, silicon – 0.6%, copper – 0.6%

### Alloying elements:

The most commonly used alloying elements are chromium, nickel, molybdenum, vanadium, tungsten, cobalt, boron, copper and others.

### Purpose of Alloying:

To increase its strength

To improve hardness

To improve toughness

To improve resistance to abrasion and wear

To improve Machinability

To improve ductility

To achieve better electrical and magnetic properties

### Classification of Alloy steels:

Alloy steels can be divided into two main groups.

1. Low alloy steels: these contain up to 3 to 4% of alloying elements.
2. High alloy steels: These contain more than 5% of alloying elements.

### Low Alloy Steels:

Low alloy steels are steels which contain up to 3% to 4% of one or more alloying elements.

They have similar microstructure and require similar heat treatments to that of the plain carbon steel.

They are also referred as pearlitic alloy steels as the normalised structure contains the eutectoid pearlite.

### Types of low alloy steel:

AISI steels and HSLA steels.

### AISI steels:

American Iron and steel institute are steels that are generally used in machine construction.

AISI steels are sometimes also referred as construction steels or structural steels.

AISI steel normally have less than about 5% total addition of elements such as cr, Ni, Cu, n, Mo, V etc.

HSLA steels:

HSLA (high strength low, alloy) steels, also known as micro alloyed steels, have been developed by making micro alloying additions of the elements Al, Nb and V either singly or in combination to give a major grain refinement.

High Alloy steels:

High alloy steels are steels which contain more than 5% of one or more alloying elements.

They have different microstructure and require different heat treatment than that of the plain carbon steels.

The room temperature structures after normalizing may be austenitic, martensitic or contain precipitated carbides.

Types of high alloy steels:

Tool and die steels-high quality

Stainless steel to improve corrosion resistance.

3. Draw iron-iron carbide phase diagram, name the various fields, lines and reactions. (NOV/DEC 2018)

Refer: page: 5. Question number: 1. April/May 2015.

4. Draw the room temperature microstructure of eutectic steel. (NOV/DEC 2018)

Refer: page no. 9. Question no. 6-b. Nov/Dec 2017.

5. Discuss on substitutional solid solution with an example. (NOV/DEC 2018)

Refer: page no. 3. Question number: 3-ii. Nov/Dec 2015 and Refer: page: 5. Question number: 1. April/May 2015.

6. What type of solid solution is Fe<sub>3</sub>C, interstitial or substitutional? where do C atoms occupy in Ferrite? (NOV/DEC 2018)

Fe<sub>3</sub>C is interstitial type solid solution. Refer: page no. 3. Question number: 3-ii. Nov/Dec 2015

7. Explain the following invariant reactions with reference to a phase diagram: Eutectic reaction and eutectoid reaction. (Apr/May 2019)



**11. (a) (i) EUTECTIC SYSTEM:** In a eutectic reaction, when a liquid solution of fixed composition, solidifies at a constant temperature, forms a mixture of two or more solid phases without an intermediate pasty stage. This process reverses on heating. In a eutectic system, there is always a specific alloy, known as 'eutectic composition', that freezes at a lower temperature than all other compositions. At eutectic temperature two solids form simultaneously from a single liquid.

3 Marks

phase. The eutectic temperature and composition determine a point on the phase diagram known as 'eutectic point'.

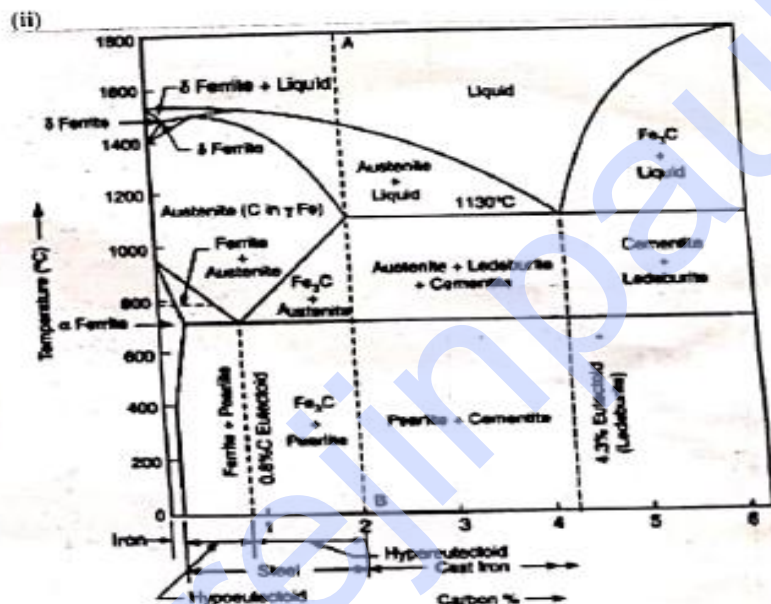
Binary alloy eutectic system may be classed as follows.

1. One in which, two metals are completely soluble in the liquid state but are insoluble in each other, in the solid state.

2. The other in which two metals are completely soluble in the liquid state but are partly soluble in each other in the solid state.

**EUTECTOID:** When the solution above the transformation point is solid, rather than liquid, an analogous eutectoid transformation can occur. For instance, in the iron-carbon system, the austenite phase can undergo a eutectoid transformation to produce ferrite and cementite (iron carbide), often in lamellar structures such as pearlite and bainite. This eutectoid point occurs at 727°C (1340.6 °F) and about 0.83% carbon; alloys of nearly this composition are called high-carbon steel, while those which have less carbon are termed mild steel. The process analogous to glass formation in this system is the martensitic transformation.

3 Marks



7 Marks

8. Draw the iron-iron carbide phase diagram and mark on it all salient temperatures and composition fields. (Apr/May 2019)

Refer: page: 5. Question number: 1. April/May 2015.

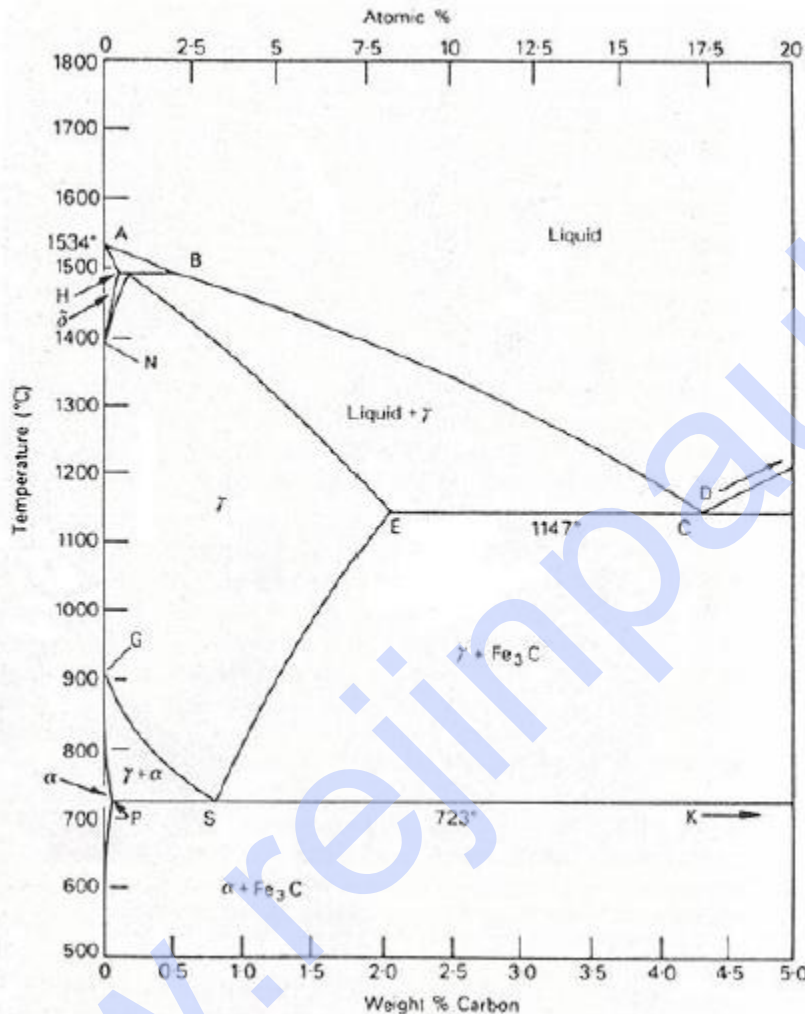
9. What are the micro-constituents of iron-carbon alloys? Explain the general characteristics of each.

Refer: page no. 4. Question no. 5. April/May 2017.

10. Neatly sketch labeled iron carbon equilibrium diagram. Name, write and explain the reactions involved. (April/May 2015)

A study of the constitution and structure of all steels and irons must first start with the iron-carbon equilibrium diagram. Many of the basic features of this system influence the behavior

of even the most complex alloy steels. For example, the phases found in the simple binary Fe-C system persist in complex steels, but it is necessary to examine the effects alloying elements have on the formation and properties of these phases. The iron-carbon diagram provides a valuable foundation on which to build knowledge of both plain carbon and alloy steels in their immense variety. It should first be pointed out that the normal equilibrium diagram really represents the meta stable equilibrium between iron and iron carbide (cementite). Cementite is meta stable, and the true equilibrium should be between



iron and graphite. Although graphite occurs extensively in cast irons (2-4 wt % C), it is usually difficult to obtain this equilibrium phase in steels (0.03-1.5 wt% C). Therefore, the meta stable equilibrium between iron and iron carbide should be considered, because it is relevant to the behavior of most steels in practice. The much larger phase field of  $\gamma$ -iron (austenite) compared with that of  $\alpha$ -iron (ferrite) reflects the much greater solubility of carbon in  $\gamma$ -iron, with a maximum value of just over 2 wt % at 1147°C (E, Fig. 1). This high solubility of carbon in  $\gamma$ -iron is of extreme importance in heat treatment, when solution treatment in the  $\gamma$ -region followed by rapid quenching to room temperature allows a supersaturated solid solution of carbon in iron to be formed. The  $\alpha$ -iron phase field is severely restricted, with a maximum carbon solubility of 0.02 wt% at 723°C (P), so over the carbon range encountered in steels from 0.05 to 1.5 wt%,  $\alpha$ -iron is normally associated with iron carbide in one form or another. Similarly, the  $\delta$ -phase field is very restricted between 1390 and 1534°C and disappears completely when the carbon content reaches 0.5 wt% (B). There are several

temperatures or critical points in the diagram, which are important, both from the basic and from the practical point of view. Firstly, there is the A1, temperature, at which the eutectoid reaction occurs (P-S-K), which is 723°C in the binary diagram. Secondly, there is the A3, temperature when  $\alpha$ -iron transforms to  $\gamma$ -iron. For pure iron this occurs at 910°C, but the transformation temperature is progressively lowered along the line GS by the addition of carbon. The third point is A4 at which  $\gamma$ -iron transforms to  $\delta$ -iron, 1390°C in pure iron, but this is raised as carbon is added. The A2, point is the Curie point when iron changes from the ferro to the paramagnetic condition. This temperature is 769°C for pure iron, but no change in crystal structure is involved. The A1, A3 and A4 points are easily detected by thermal analysis or dilatometry during cooling or heating cycles, and some hysteresis is observed. Consequently, three values for each point can be obtained. Ac for heating, Ar for cooling and Ae (equilibrium), but it should be emphasized that the Ac and Ar values will be sensitive to the rates of heating and cooling, as well as to the presence of alloying elements. The great difference in carbon solubility between  $\gamma$ - and  $\alpha$ -iron leads normally to the rejection of carbon as iron carbide at the boundaries of the  $\gamma$  phase field. The transformation of  $\gamma$  to  $\alpha$  – iron occurs via a eutectoid reaction, which plays a dominant role in heat treatment. The eutectoid temperature is 723°C while the eutectoid composition is 0.80% C(s). On cooling alloys containing less than 0.80% C slowly, hypo-eutectoid ferrite is formed from austenite in the range 910-723°C with enrichment of the residual austenite in carbon, until at 723°C the remaining austenite, now containing 0.8% carbon transforms to pearlite, a lamellar mixture of ferrite and iron carbide (cementite). In austenite with 0.80 to 2.06% carbon, on cooling slowly in the temperature interval 1147°C to 723°C, cementite first forms progressively depleting the austenite in carbon, until at 723°C, the austenite contains 0.8% carbon and transforms to pearlite. Steels with less than about 0.8% carbon are thus hypo-eutectoid alloys with ferrite and pearlite as the prime constituents, the relative volume fractions being determined by the lever rule which states that as the carbon content is increased, the volume percentage of pearlite increases, until it is 100% at the eutectoid composition. Above 0.8% C, cementite becomes the hyper-eutectoid phase, and a similar variation in volume fraction of cementite and pearlite occurs on this side of the eutectoid composition. The three phases, ferrite, cementite and pearlite are thus the principle constituents of the infrastructure of plain carbon steels, provided they have been subjected to relatively slow cooling rates to avoid the formation of meta stable phases.

#### **The austenite- ferrite transformation:**

Under equilibrium conditions, pro-eutectoid ferrite will form in iron-carbon alloys containing up to 0.8 % carbon. The reaction occurs at 910°C in pure iron, but takes place between 910°C and 723°C in iron-carbon alloys. However, by quenching from the austenitic state to temperatures below the eutectoid temperature A<sub>e1</sub>, ferrite can be formed down to temperatures as low as 600°C. There are pronounced morphological changes as the transformation temperature is lowered, which it should be emphasized apply in general to hypo- and hyper-eutectoid phases, although in each case there will be variations due to the precise crystallography of the phases involved. For example, the same principles apply to the formation of cementite from austenite, but it is not difficult to distinguish ferrite from cementite morphologically. **The austenite-cementite transformation:**

The Dube classification applies equally well to the various morphologies of cementite formed at progressively lower transformation temperatures. The initial development of grain boundary allotriomorphs is very similar to that of ferrite, and the growth of side plates or Widmanstätten cementite follows the same pattern. The cementite plates are more rigorously crystallographic in form, despite the fact that the orientation relationship with austenite is a more complex one. As in the case of ferrite, most of the side plates originate from grain

boundary allotriomorphs, but in the cementite reaction more side plates nucleate at twin boundaries in austenite.

### The austenite-pearlite reaction:

Pearlite is probably the most familiar micro structural feature in the whole science of metallography. It was discovered by Sorby over 100 years ago, who correctly assumed it to be a lamellar mixture of iron and iron carbide. Pearlite is a very common constituent of a wide variety of steels, where it provides a substantial contribution to strength. Lamellar eutectoid structures of this type are widespread in metallurgy and frequently pearlite is used as a generic term to describe them.

11. **Explain the procedural steps for constructing the binary phase diagram where the components show complete liquid and solid solubility. Draw the labeled diagram and name the system. Give one example for the alloy system showing above mentioned behavior. (April/May 2015)**

Let the two metals in a binary system be A & B. They are soluble in each other in all proportion in both solid and liquid states. Both A & B have definite melting points. Since the two are soluble in all proportion in solid state they must have similar crystal structures, nearly the same atomic diameters and identical valence. Let us assume that the melting point of A is higher than that of B. If you monitor and later plot the temperature of molten pure metal as it cools you get cooling curves similar to that in fig 1 when the cooling rate is slow. In this case the number of component (C) is equal to one. As long as there is only one phase (P) the degree of freedom (F) as predicted by Gibb's phase rule ( $P + F = C + 1$ ) is one. It means liquid or solid state may exist over a range of temperatures. However as solidification sets in both liquid and solid must coexist. In such a situation  $F = 0$ . This means two phases (liquid & solid) in a single component system at one atmosphere pressure can coexist only at a fixed temperature. This is why the temperature in fig 1 remains constant until the entire liquid gets transformed into solid at its freezing (or melting) point.

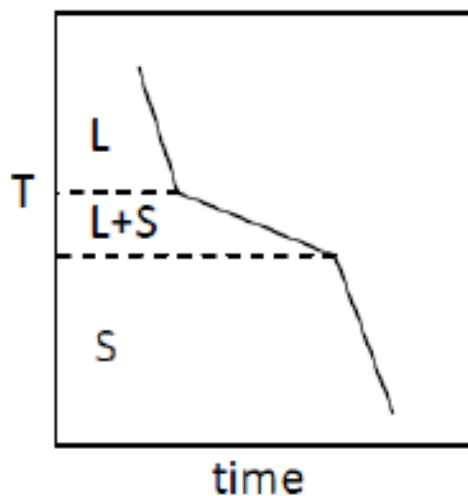
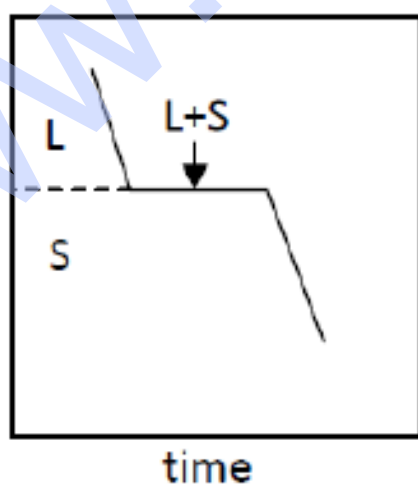
Fig 1: Shows a typical cooling curve of a pure metal. Note that liquid is stable above its melting point where as below its melting point it is solid. In this case  $P=1$ . Therefore  $F = 1$ . This is why both L & S exist over a range of temperature. Whereas both liquid (L) & solid (S) can coexist only at the melting (or freezing) point. Under an equilibrium rate of cooling both the melting & the freezing points are the same. What should the cooling curve look like if the molten alloy were made of two components A & B? Since the two components are miscible in all proportions the liquid must be homogeneous. Its composition is the same at every location. Apply Gibb's phase rule. Note that  $C = 2$ ,  $P = 1$ , therefore  $F = 2$ . This denotes the number of independent variables. These are the temperature and the composition. It means at a fixed temperature the alloy can have a range of composition or an alloy can exist over a range of temperature. During solidification it must pass through a stage when both liquid and solid could coexist. In such a situation  $P = 2$ . Therefore  $F = 1$ . It means that two phases can coexist over a range of temperature. The cooling curve of such an alloy should be similar to the one given in fig 2. Fig 2: Shows a typical cooling curve of a binary isomorphous alloy. Note that liquid is stable above a temperature where solidification starts and solid is stable below a temperature where solidification ends. Whereas both liquid (L) & solid (S) can coexist over a range of temperatures. Unlike pure metal an alloy solidifies over a range of temperature. An isomorphous alloy does not have a definite melting or freezing point. Such an alloy is characterized by a temperature where solidification begins and a temperature where it ends. Between the two temperatures both liquid and solid can coexist. If you find these two temperatures for a set of alloy having different compositions and plot these as a function of composition you would get a pair of lines as shown in fig 3. These are known as

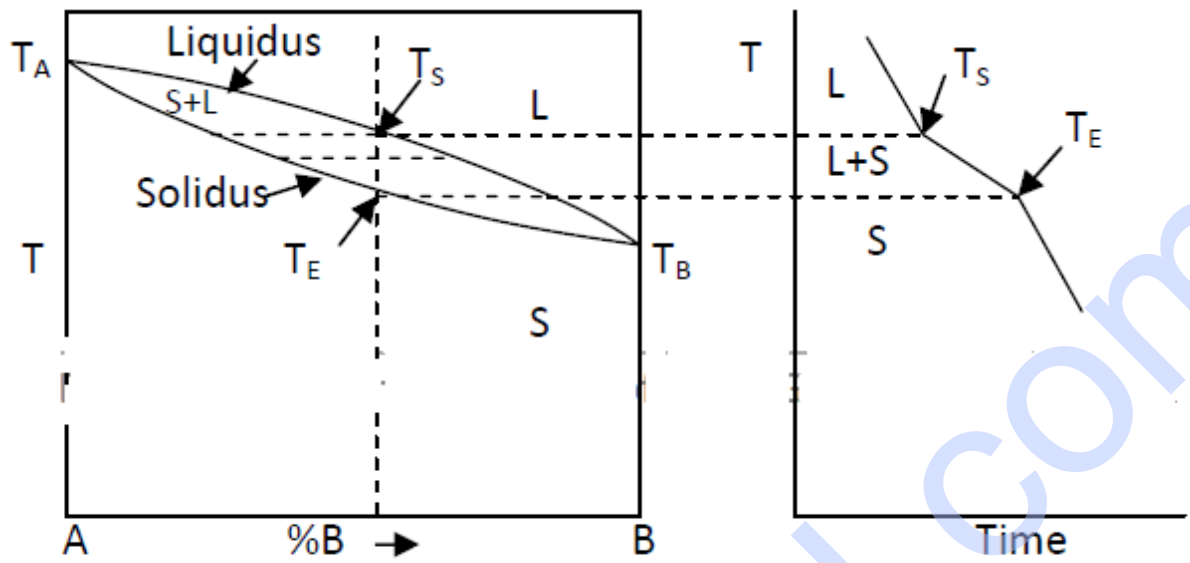


the liquidus and the solidus. Such a graph is known as the phase diagram of a binary isomorphous alloy. In the temperature region between the liquidus & the solidus the alloy is partly liquid and partly solid.

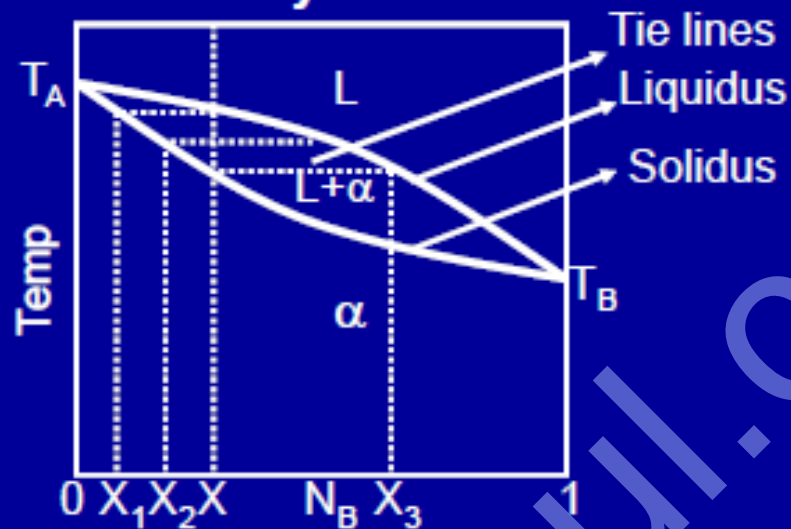
Let us analyze the process of solidification of an alloy of a given composition  $X$  as illustrated in slide 1. Draw a vertical line at  $NB = X$  as shown. Solidification begins at a temperature where it intersects the liquidus. Draw a horizontal line through this point. Extend the same to intersect the solidus line. This gives the composition of the first solid to form. In this case it is  $X_1$ . As the temperature drops the amount of solid keeps increasing. During the process the composition of the solid that forms keeps changing. At the same time composition of the existing solid should also change. The compositions of the liquid and the solid that can coexist at a particular temperature are given by the points of intersections of the horizontal line called tie line at this temperature with the liquidus & the solidus as shown in slide 1. How can the composition of the solid that has already formed change during solidification? The initial solid is rich in A whereas the new solid is rich in B. The composition of the old solid can change only if B atoms could diffuse through the solid. Diffusion in solid is a relatively slow process in comparison to that in the liquid. In addition convection current also helps the composition of the liquid to change as expected by the diagram. However for the composition of the solid to change sufficient time must be allowed during cooling. Therefore the alloy must be cooled very slowly so that at every stage there is an equilibrium between the solid and the liquid. Such a cooling rate is called equilibrium cooling rate. This is why often phase diagrams are called equilibrium diagrams.

Slide 1: The sketch shows a typical phase diagram of a binary isomorphous system. The composition can be denoted either as weight fraction (or %) or atom fraction. Let  $NB$  denote the atom fraction of B in the alloy and  $X_i$  be the corresponding weight fraction. Alpha represents solid solution of B in A (or A in B). The line called liquidus gives the temperature at which solidification begins. It also gives the composition of the liquid. The solidus denotes the temperature & composition of solid during solidification. Slide 2: Shows an equilibrium diagram of a binary isomorphous system made of two metals A & B. It gives the temperature range over which solidification takes place. Consider an alloy having a composition  $X$ . Let this denote either atom fraction or weight fraction B ( $NB$ ). Draw a vertical line at  $NB = X$ . It intersects the liquidus & solidus. These are the temperatures at which the solidification begins or ends. Draw a tie line at a temperature  $T$ . It intersects solidus & liquidus at  $X_1$  &  $X_2$ .





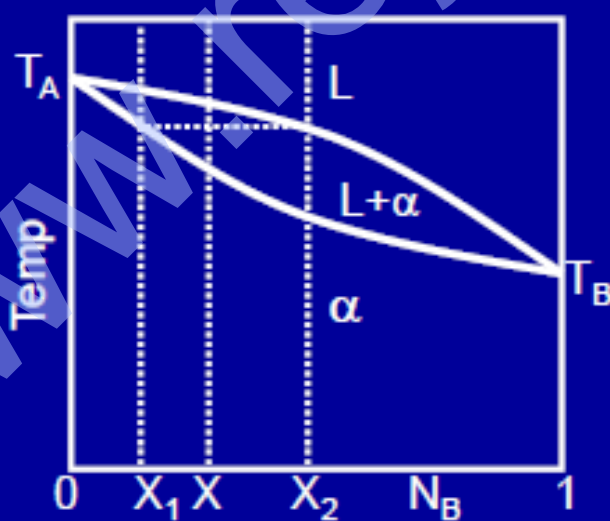
## Phase diagram of a Binary Isomorphous system



Liquidus: onset of solidification / liquid composition

Solidus: completion of solidification / solid composition

## Estimation of phase percent (wt fraction)



$a$ : wt fraction  $\alpha$

$b$ : wt fraction liquid

$X_i$ : atom fraction B

$$a X_1 + b X_2 = X$$

$$a + b = 1$$

$$a = (X_2 - X) / (X_2 - X_1)$$



- i) Draw iron-iron carbide phase diagram, name the various field, line and reactions. (Nov/Dec 2015)

12. Discuss on substitutional solid solution. (Nov/Dec 2015)

If the atoms of the solvent or parent metal are replaced in the crystal lattice by atoms of the solute metal then the solid solution is known as substitutional solid solution. For example, copper atoms may substitute for nickel atoms without disturbing the F.C.C. structure of nickel. In the substitutional solid solutions, the substitution can be either disordered or ordered. (a) shows disordered substitutional solid solution. Here the solute atoms have substituted disorderly for the solvent atoms on their lattice site. (b) shows an ordered substitutional solid solution. Here the solute atoms have substituted in an orderly manner for the solvent atoms on their lattice site.

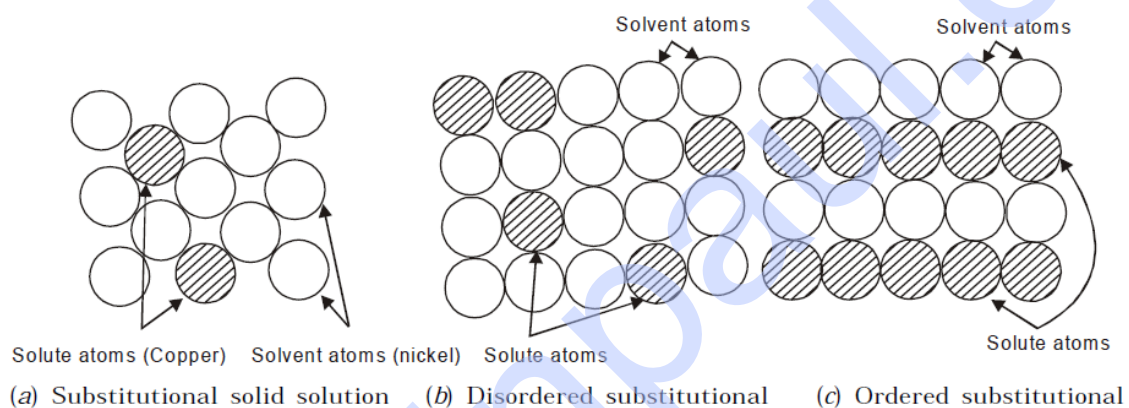
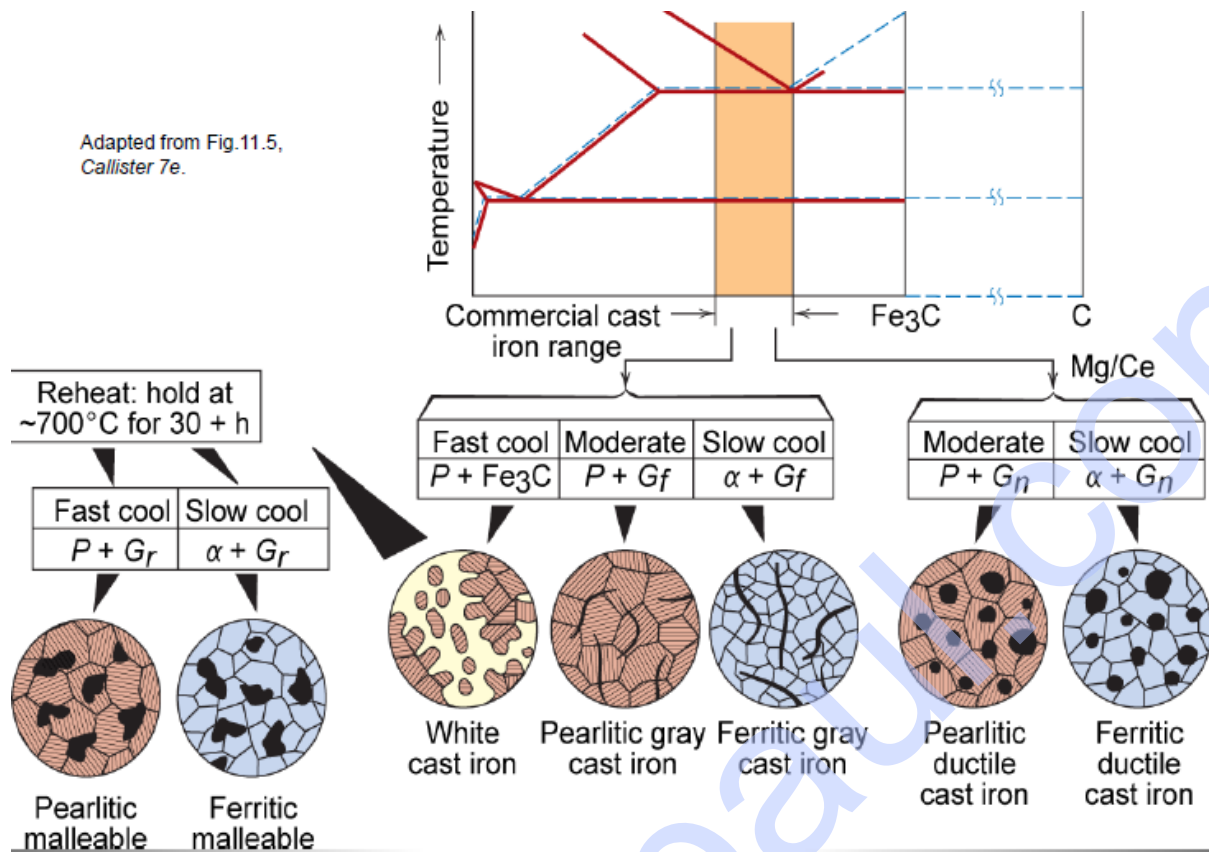


Fig. 5.1 Solid solutions

13. Compare the microstructure, properties and application of any two kind of cast iron. (Nov/Dec 2015)

Adapted from Fig.11.5,  
Callister 7e.



### White cast iron:

Very hard but brittle.

High wear and abrasion resistance

Extremely difficult to machine

Is used to produce malleable cast iron

Heat treatment to 800-900 deg C causes decomposition of Fe<sub>3</sub>C to graphite clusters.

Application: rollers in rolling mills, brake shoes, extrusion nozzles.



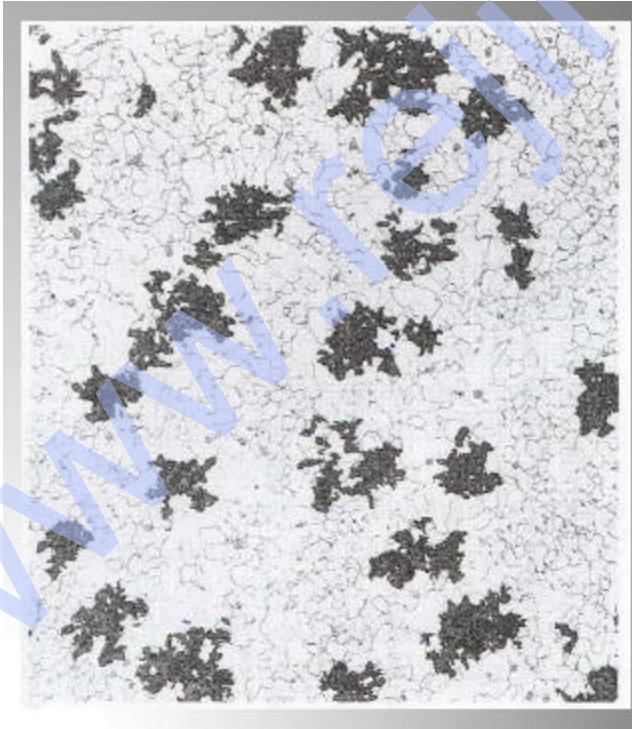
**Malleable cast iron:**

Produced by annealing white cast iron at 900-1060 deg C for 50- 70hrs.

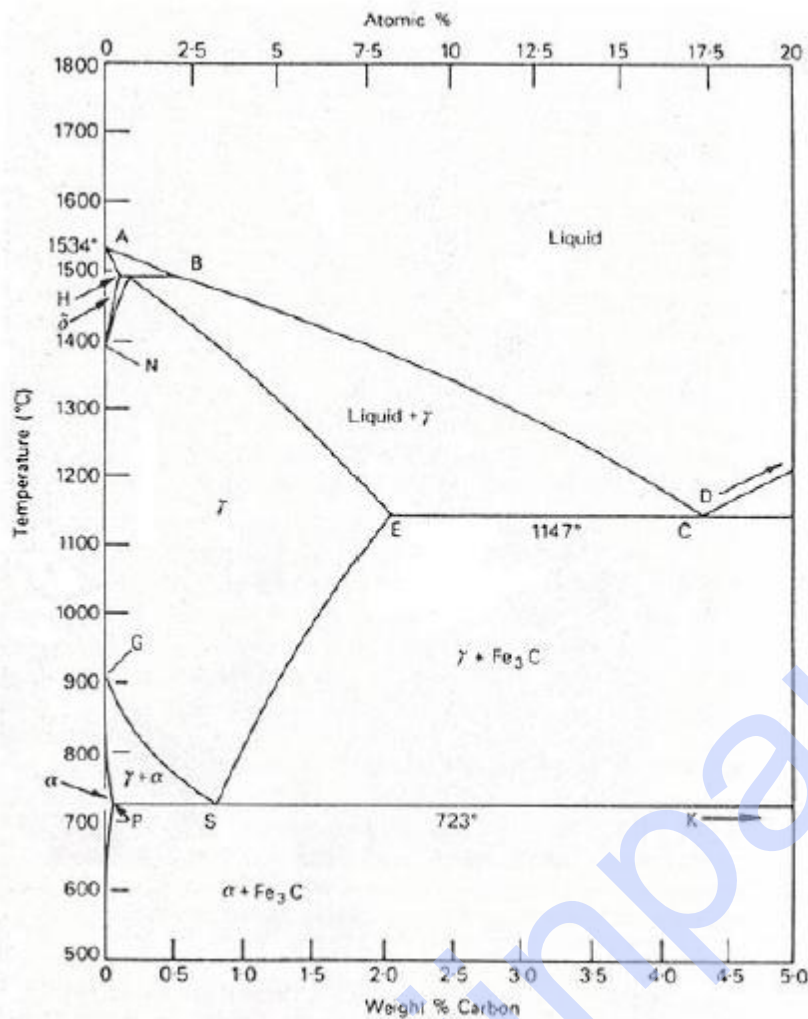
C is in the form of irregular spheroid.

**Application:**

Casting mould, railroad, pipe fittings and bridges, connecting rods.



14. Explain in detail about the Iron carbon diagram:(April/May 2014)



A study of the constitution and structure of all steels and irons must first start with the iron-carbon equilibrium diagram. Many of the basic features of this system influence the behavior of even the most complex alloy steels. For example, the phases found in the simple binary Fe-C system persist in complex steels, but it is necessary to examine the effects alloying elements have on the formation and properties of these phases. The iron-carbon diagram provides a valuable foundation on which to build knowledge of both plain carbon and alloy steels in their immense variety. It should first be pointed out that the normal equilibrium diagram really represents the meta stable equilibrium between iron and iron carbide (cementite). Cementite is meta stable, and the true equilibrium should be between iron and graphite. Although graphite occurs extensively in cast irons (2-4 wt % C), it is usually difficult to obtain this equilibrium phase in steels (0.03-1.5 wt% C). Therefore, the meta stable equilibrium between iron and iron carbide should be considered, because it is relevant to the behavior of most steels in practice. The much larger phase field of  $\gamma$ -iron (austenite) compared with that of  $\alpha$ -iron (ferrite) reflects the much greater solubility of carbon in  $\gamma$ -iron, with a maximum value of just over 2 wt % at 1147°C (E, Fig. 1). This high solubility of carbon in  $\gamma$ -iron is of extreme importance in heat treatment, when solution treatment in the  $\gamma$ -region followed by rapid quenching to room temperature allows a supersaturated solid solution of carbon in iron to be formed. The  $\alpha$ -iron phase field is severely restricted, with a maximum carbon solubility of 0.02 wt% at 723°C (P), so over the carbon range encountered in steels from 0.05 to 1.5 wt%,  $\alpha$ -iron is normally associated with iron carbide in one form or another. Similarly, the  $\delta$ -phase field is very restricted between 1390 and 1534°C and disappears completely when the carbon content reaches 0.5 wt% (B). There are several



temperatures or critical points in the diagram, which are important, both from the basic and from the practical point of view. Firstly, there is the A1, temperature, at which the eutectoid reaction occurs (P-S-K), which is 723°C in the binary diagram. Secondly, there is the A3, temperature when  $\alpha$ -iron transforms to  $\gamma$ -iron. For pure iron this occurs at 910°C, but the transformation temperature is progressively lowered along the line GS by the addition of carbon. The third point is A4 at which  $\gamma$ -iron transforms to  $\delta$ -iron, 1390°C in pure iron, but this is raised as carbon is added. The A2, point is the Curie point when iron changes from the ferro to the paramagnetic condition. This temperature is 769°C for pure iron, but no change in crystal structure is involved. The A1, A3 and A4 points are easily detected by thermal analysis or dilatometry during cooling or heating cycles, and some hysteresis is observed. Consequently, three values for each point can be obtained. Ac for heating, Ar for cooling and Ae (equilibrium), but it should be emphasized that the Ac and Ar values will be sensitive to the rates of heating and cooling, as well as to the presence of alloying elements. The great difference in carbon solubility between  $\gamma$ - and  $\alpha$ -iron leads normally to the rejection of carbon as iron carbide at the boundaries of the  $\gamma$  phase field. The transformation of  $\gamma$  to  $\alpha$  – iron occurs via a eutectoid reaction, which plays a dominant role in heat treatment. The eutectoid temperature is 723°C while the eutectoid composition is 0.80% C(s). On cooling alloys containing less than 0.80% C slowly, hypo-eutectoid ferrite is formed from austenite in the range 910-723°C with enrichment of the residual austenite in carbon, until at 723°C the remaining austenite, now containing 0.8% carbon transforms to pearlite, a lamellar mixture of ferrite and iron carbide (cementite). In austenite with 0.80 to 2.06% carbon, on cooling slowly in the temperature interval 1147°C to 723°C, cementite first forms progressively depleting the austenite in carbon, until at 723°C, the austenite contains 0.8% carbon and transforms to pearlite. Steels with less than about 0.8% carbon are thus hypo-eutectoid alloys with ferrite and pearlite as the prime constituents, the relative volume fractions being determined by the lever rule which states that as the carbon content is increased, the volume percentage of pearlite increases, until it is 100% at the eutectoid composition. Above 0.8% C, cementite becomes the hyper-eutectoid phase, and a similar variation in volume fraction of cementite and pearlite occurs on this side of the eutectoid composition. The three phases, ferrite, cementite and pearlite are thus the principle constituents of the infrastructure of plain carbon steels, provided they have been subjected to relatively slow cooling rates to avoid the formation of meta stable phases.

#### **The austenite- ferrite transformation:**

Under equilibrium conditions, pro-eutectoid ferrite will form in iron-carbon alloys containing up to 0.8 % carbon. The reaction occurs at 910°C in pure iron, but takes place between 910°C and 723°C in iron-carbon alloys. However, by quenching from the austenitic state to temperatures below the eutectoid temperature Ae1, ferrite can be formed down to temperatures as low as 600°C. There are pronounced morphological changes as the transformation temperature is lowered, which it should be emphasized apply in general to hypo- and hyper-eutectoid phases, although in each case there will be variations due to the precise crystallography of the phases involved. For example, the same principles apply to the formation of cementite from austenite, but it is not difficult to distinguish ferrite from cementite morphologically.

#### **The austenite-cementite transformation:**

The Dube classification applies equally well to the various morphologies of cementite formed at progressively lower transformation temperatures. The initial development of grain boundary allotriomorphs is very similar to that of ferrite, and the growth of side plates or Widmanstätten cementite follows the same pattern. The cementite plates are more rigorously crystallographic in form, despite the fact that the orientation relationship with austenite is a

more complex one. As in the case of ferrite, most of the side plates originate from grain boundary allotriomorphs, but in the cementite reaction more side plates nucleate at twin boundaries in austenite.

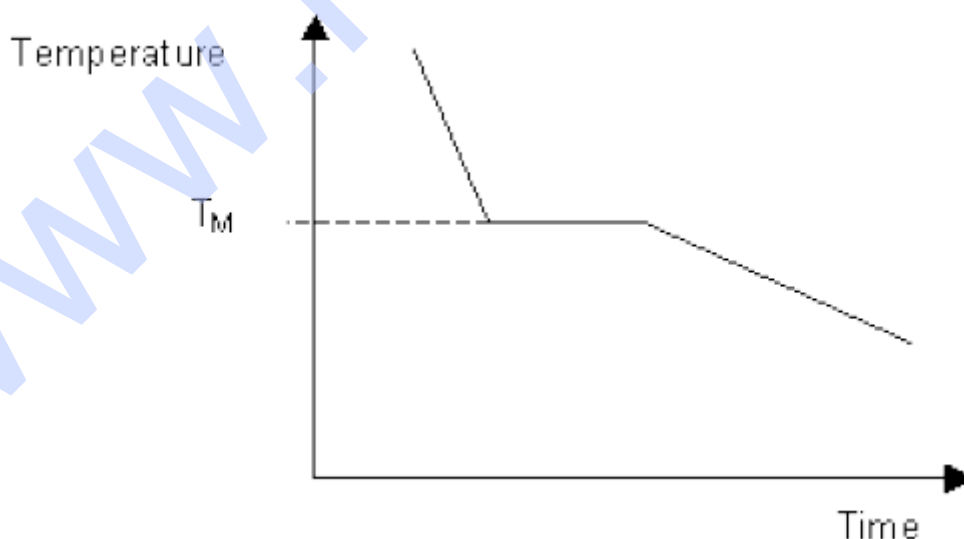
#### The austenite-pearlite reaction:

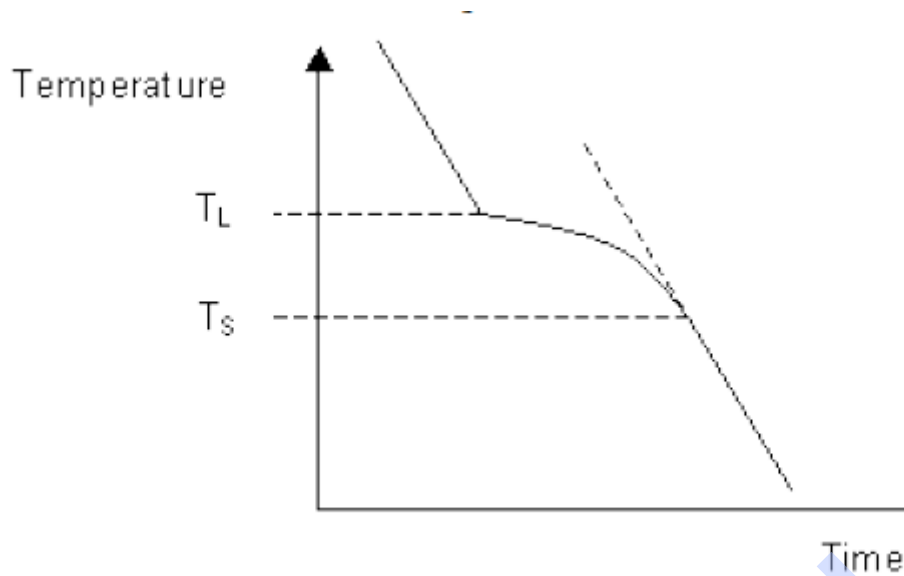
Pearlite is probably the most familiar micro structural feature in the whole science of metallography. It was discovered by Sorby over 100 years ago, who correctly assumed it to be a lamellar mixture of iron and iron carbide. Pearlite is a very common constituent of a wide variety of steels, where it provides a substantial contribution to strength. Lamellar eutectoid structures of this type are widespread in metallurgy and frequently pearlite is used as a generic term to describe them.

#### 15. Explain about the cooling curve of off-eutectic binary alloys

(April/May 2014)

The melting temperature of any pure material (a one-component system) at constant pressure is a single unique temperature. The liquid and solid phases exist together in equilibrium only at this temperature. When cooled, the temperature of the molten material will steadily decrease until the melting point is reached. At this point the material will start to crystallise, leading to the evolution of latent heat at the solid liquid interface, maintaining a constant temperature across the material. Once solidification is complete, steady cooling resumes. The arrest in cooling during solidification allows the melting point of the material to be identified on a time-temperature curve. temperature range over which the solid and liquid phases are in equilibrium. Instead of a single melting temperature, the system now has two different temperatures, the liquidus temperature and the solidus temperature which are needed to describe the change from liquid to solid. The liquidus temperature is the temperature above which the system is entirely liquid, and the solidus is the temperature below which the system is completely solid. Between these two points the liquid and solid phases are in equilibrium. When the liquidus temperature is reached, solidification begins and there is a reduction in cooling rate caused by latent heat evolution and a consequent reduction in the gradient of the cooling curve. Upon the completion of solidification the cooling rate alters again allowing the temperature of the solidus to be determined. As can be seen on the diagram below, these changes in gradient allow the liquidus temperature  $T_L$ , and the solidus temperature  $T_S$  to be identified.

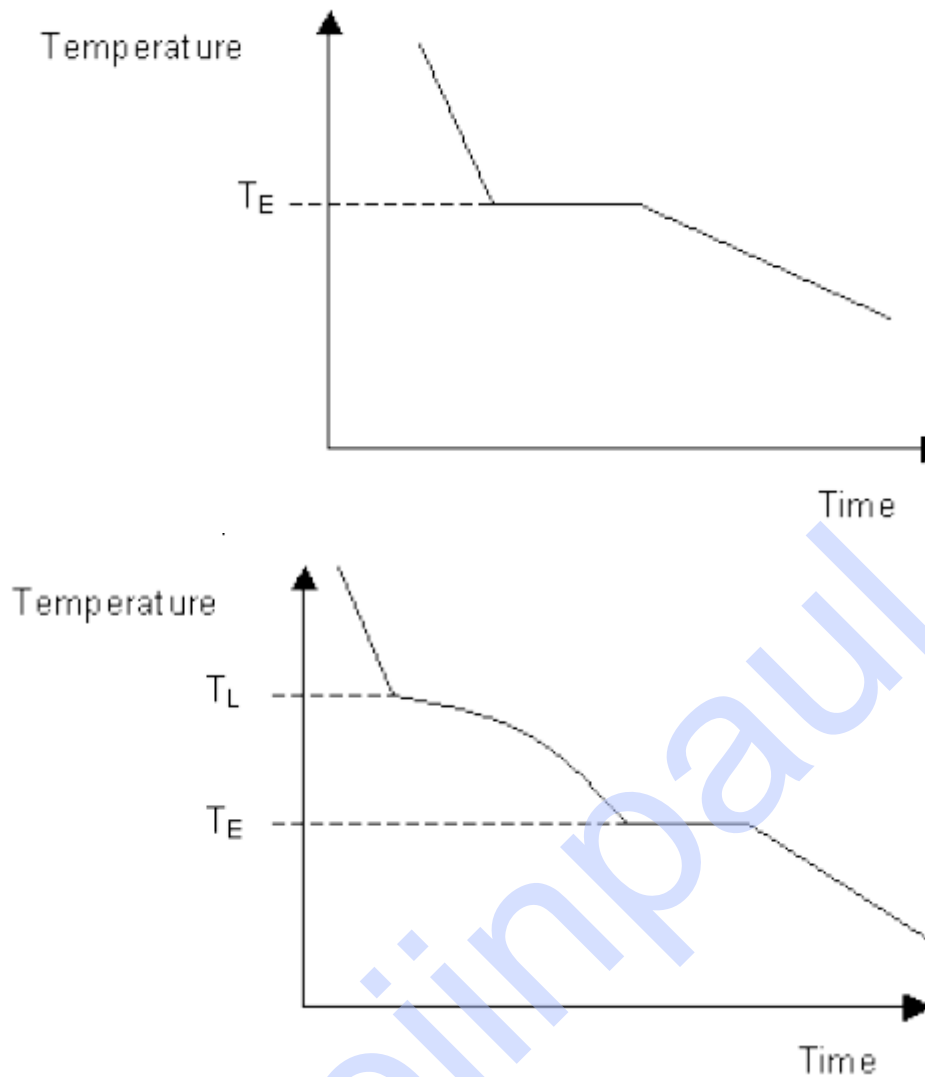




When cooling a material of eutectic composition, solidification of the whole sample takes place at a single temperature. This results in a cooling curve similar in shape to that of a single-component system with the system solidifying at its eutectic temperature.

When solidifying hypoeutectic or hypereutectic alloys, the first solid to form is a single phase which has a composition different to that of the liquid. This causes the liquid composition to approach that of the eutectic as cooling occurs. Once the liquid reaches the eutectic temperature it will have the eutectic composition and will freeze at that temperature to form a solid eutectic mixture of two phases. Formation of the eutectic causes the system to cease cooling until solidification is complete. The resulting cooling curve shows the two stages of solidification with a section of reduced gradient where a single phase is solidifying and a plateau where eutectic is solidifying.





By taking a series of cooling curves for the same system over a range of compositions the liquidus and solidus temperatures for each composition can be determined allowing the solidus and liquidus to be mapped to determine the phase diagram.

Below are cooling curves for the same system recorded for different compositions and then displaced along the time axis. The red regions indicate where the material is liquid, the blue regions indicate where the material is solid and the green regions indicate where the solid and liquid phases are in equilibrium.

By removing the time axis from the curves and replacing it with composition, the cooling curves indicate the temperatures of the solidus and liquidus for a given composition. By removing the time axis from the curves and replacing it with composition, the cooling curves indicate the temperatures of the solidus and liquidus for a given composition.

16. Explain with a neat sketch of iron-iron carbide equilibrium diagram and indicate all the phases. Also write the three important invariant reactions.

Refer: NOV/DEC 2015

17. Explain the various classifications of steels and cast Iron with microstructure, properties and applications.

Steel is composed of iron and carbon, although it is the amount of carbon, as well as the level of impurities and additional alloying elements that determine the properties of each steel grade. The carbon content in steel can range from 0.1-1.5%, but the most widely used grades of steel contain only 0.1-0.25% carbon. Elements such as manganese, phosphorus and sulphur are found in all grades of steel, but, whereas manganese provides beneficial effects, phosphorus and sulphur are deleterious to steel's strength and durability. Different types of steel are produced according to the properties required for their application, and various grading systems are used to distinguish steels based on these properties. According to the American Iron and Steel Institute (AISI), steel can be broadly categorized into four groups based on their chemical compositions.

## 1. Carbon Steels:

Carbon steels contain trace amounts of alloying elements and account for 90% of total steel production. Carbon steels can be further categorized into three groups depending on their carbon content:

- Low Carbon Steels/Mild Steels contain up to 0.3% carbon
- Medium Carbon Steels contain 0.3 – 0.6% carbon
- High Carbon Steels contain more than 0.6% carbon

## 2. Alloy Steels:

Alloy steels contain alloying elements (e.g. manganese, silicon, nickel, titanium, copper, chromium and aluminum) in varying proportions in order to manipulate the steel's properties, such as its hardenability, corrosion resistance, strength, formability, weldability or ductility.

- Applications for alloy steel include pipelines, auto parts, transformers, power generators and electric motors

## 3. Stainless Steels:

Stainless steels generally contain between 10-20% chromium as the main alloying element and are valued for high corrosion resistance. With over 11% chromium, steel is about 200 times more resistant to corrosion than mild steel. These steels can be divided into three groups based on their crystalline structure:

- *Austenitic*: Austenitic steels are non-magnetic and non heat-treatable, and generally contain 18% chromium, 8% nickel and less than 0.8% carbon. Austenitic steels form the largest portion of the global stainless steel market and are often used in food processing equipment, kitchen utensils and piping.
- *Ferritic*: Ferritic steels contain trace amounts of nickel, 12-17% chromium, less than 0.1% carbon, along with other alloying elements, such as molybdenum, aluminum or titanium. These magnetic steels cannot be hardened with heat treatment, but can be strengthened by cold working.
- *Martensitic*: Martensitic steels contain 11-17% chromium, less than 0.4% nickel and up to 1.2% carbon. These magnetic and heat-treatable steels are used in knives, cutting tools, as well as dental and surgical equipment.

## 18. Classifications of Cast Iron: Ref Nov/Dec 2015

19. What is hardenability? How is Jominy end quench test used to measure hardenability?

**Ref : April/May 2015 and Nov/Dec 2015.**

(b) Explain TTT diagram with neat sketch and indicate all the phases with microstructure?

**Ref : April/May 2015**

20. Discuss the properties and the applications of the following:

(i) Tool steels (ii) HSLA

(i) Tool steels:  
Tool steels contain tungsten, molybdenum, cobalt and vanadium in varying quantities to increase heat resistance and durability, making them ideal for cutting and drilling equipment.

Steel products can also be divided by their shapes and related applications:

- *Long/Tubular Products* include bars and rods, rails, wires, angles, pipes, and shapes and sections. These products are commonly used in the automotive and construction sectors.
- *Flat Products* include plates, sheets, coils and strips. These materials are mainly used in automotive parts, appliances, packaging, shipbuilding, and construction.
- *Other Products* include valves, fittings, and flanges and are mainly used as piping materials.

(ii) HSLA

**Ref: April/May 2015**

(b) Explain age hardening of Al/-Cu with the help of phase diagram?

**Ref: May/June 2014, April/May 2015.**

21. What is polymerization? Explain addition polymerization and condensation polymerization with examples.

**Ref: May/June 2014.**

22. What is strengthening mechanism? Explain the strengthening mechanism of fibre-reinforced composites.

23. Define hardness. Explain Brinell and Rockwell hardness test with neat sketches.

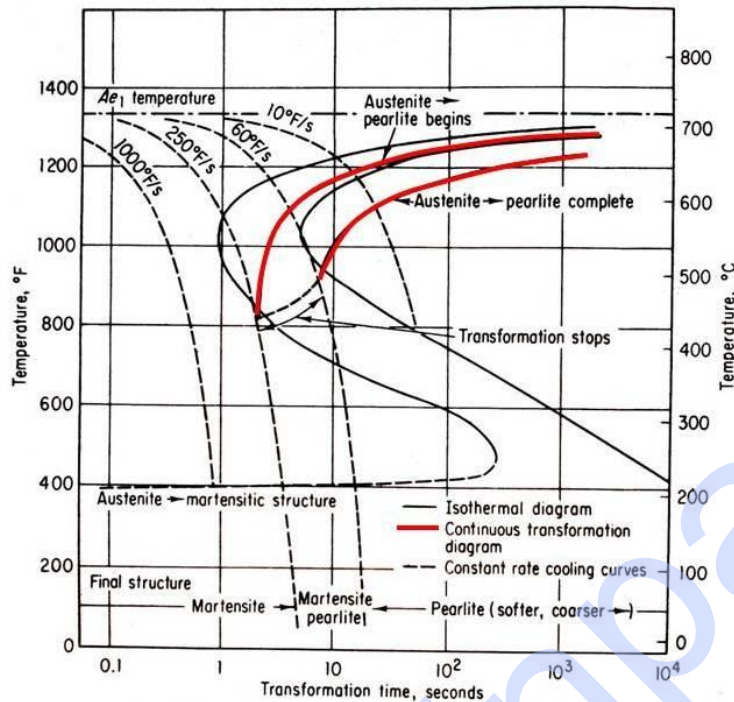
Hardenability refers to its ability to be hardened to a particular depth under a particular set of conditions.

Brinell and Rockwell Hardness test : **Ref: April/May 2015 (Q,No 15(a))**

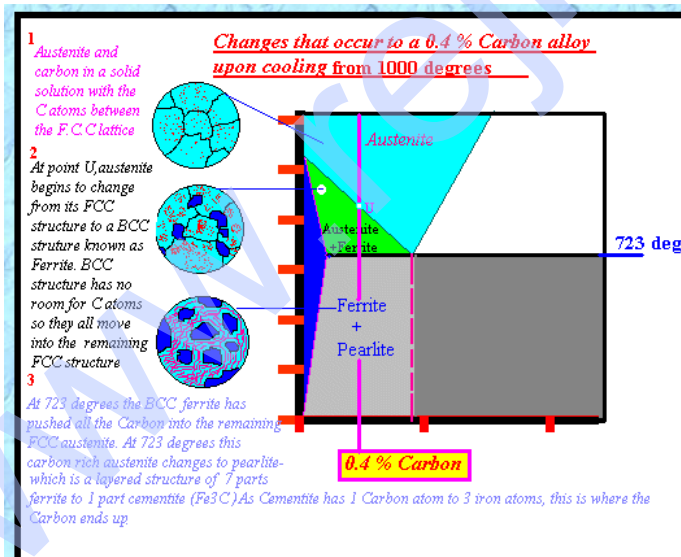
(b) Explain the mechanism of plastic deformation by slip and twinning with neat sketches.

Ref: Nov/Dec 2015.

24. draw iron-iron carbide phase diagram, name the various field, line and reactions.



ii) draw the typical microstructure of 0.5% C steel at 920C, 780 C and 200 C.



b) i) discuss on substitutional solid solution.

If the atoms of the solvent or parent metal are replaced in the crystal lattice by atoms of the solute metal then the solid solution is known as substitutional solid solution. For example, copper atoms may substitute for nickel atoms without disturbing the F.C.C. structure of

nickel. In the substitutional solid solutions, the substitution can be either disordered or ordered. (a) shows disordered substitutional solid solution. Here the solute atoms have substituted disorderly for the solvent atoms on their lattice site. (b) shows an ordered substitutional solid solution. Here the solute atoms have substituted in an orderly manner for the solvent atoms on their lattice site.

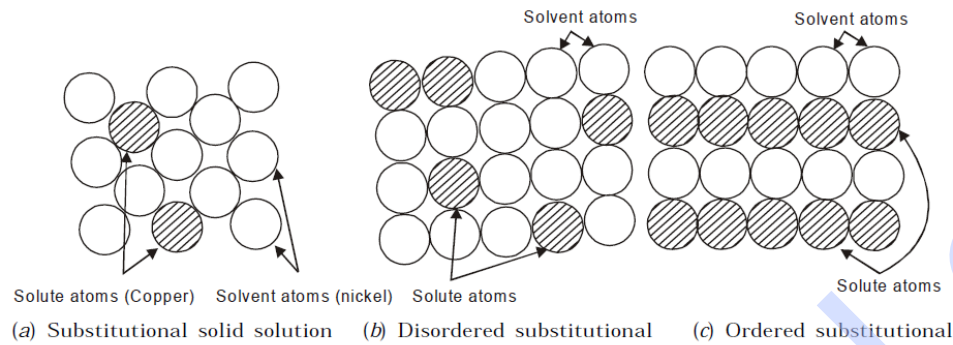
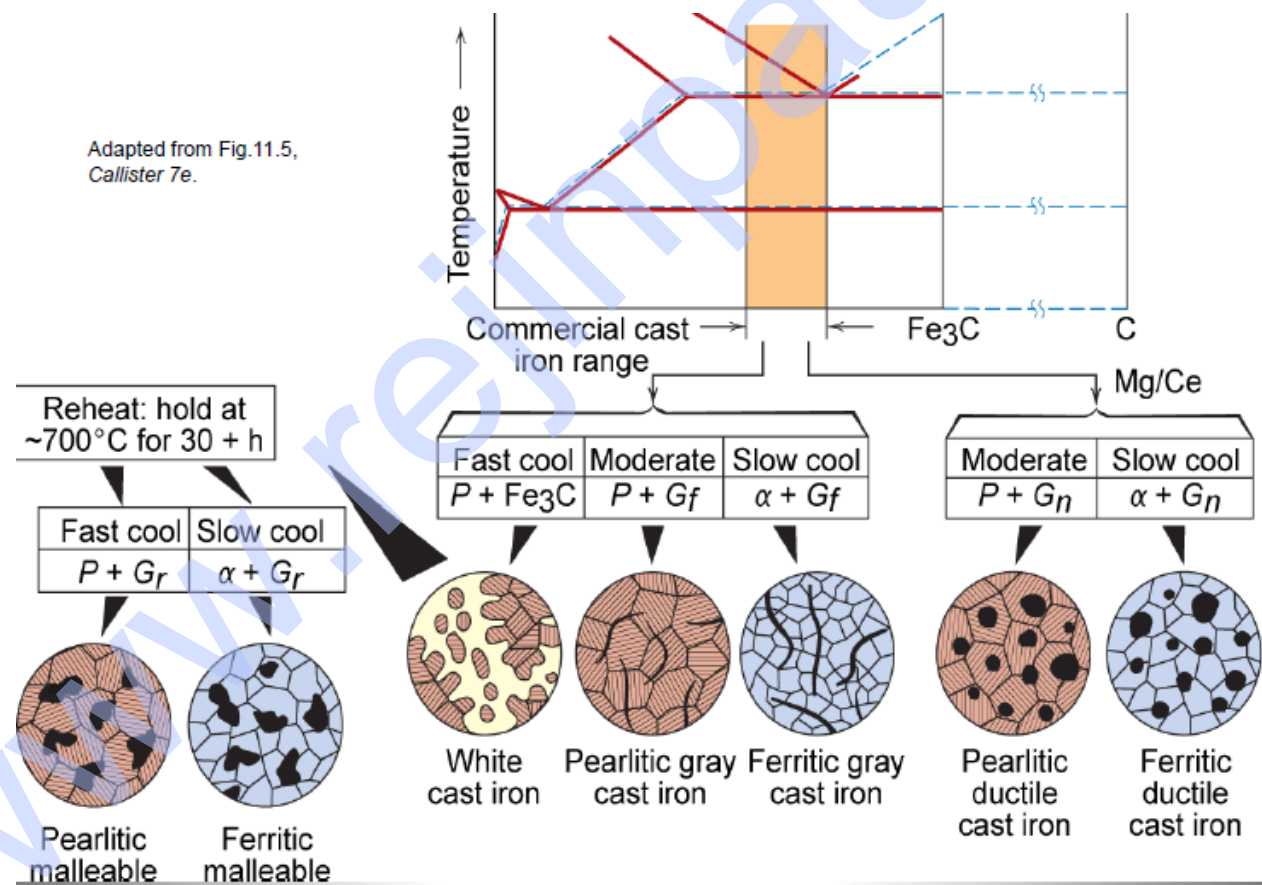


Fig. 5.1 Solid solutions

ii) Compare the microstructure, properties and application of any two kind of cast iron.



#### White cast iron:

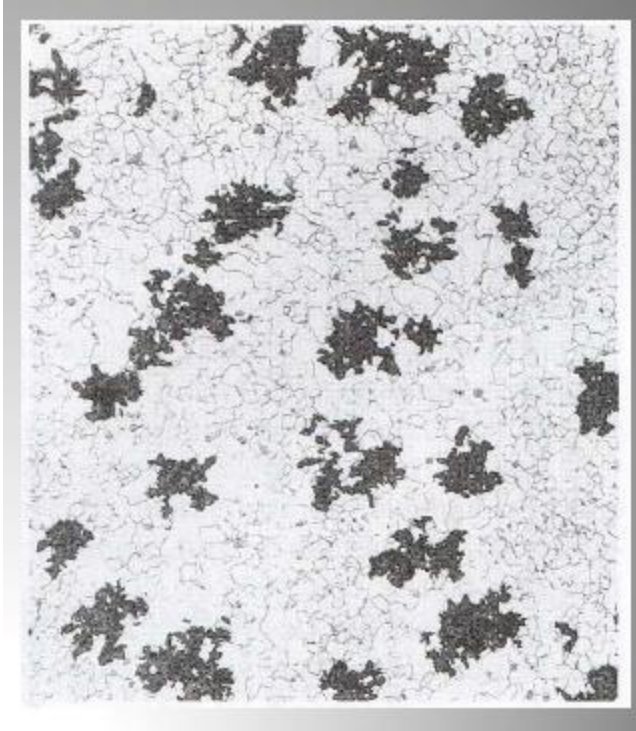
- Very hard but brittle.
- High wear and abrasion resistance
- Extremely difficult to machine
- Is used to produce malleable cast iron
- Heat treatment to 800-900 deg C causes decomposition of  $\text{Fe}_3\text{C}$  to graphite clusters.
- Application: rollers in rolling mills, brake shoes, extrusion nozzles.



#### Malleable cast iron:

- Produced by annealing white cast iron at 900-1060 deg C for 50-70hrs.
- C is in the form of irregular spheroid.
- Application: casting mould, railroad, pipe fittings and bridges, connecting rods.





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## UNIT-II

### PART A

1. What is the difference between stress relief and recrystallisation?

Stress relief	Recrystallisation
To neutralize residual stress and work stress	To refine crystal structure
To induce softness	To improve toughness
Material will be kept at high temperature at prolonged time and cooled in air.	Heated above

2. What makes nitriding different from rest of case hardening process, besides composition?

Nitriding will be performed in nitrogen atmosphere unlike other hardening process. Nitriding will form carbo nitride which is a very hard compound, which will prove wear resistance.

3. What are the needs of annealing process?

Stress relieving, grains refinement, residual stress removal and induce ductility.

4. What are the factors should be considered while selecting a quenching medium?

Thermal conductivity, flash point, fire point, heat capacity and density.

5. What is austempering?

It refers to quenching steel to a temperature below the nose and holding it isothermally to produce bainite.

6. State any two surface hardening process.

Case hardening, flame hardening and induction hardening.

7. What is quenching. List some of the quenching medium generally used in industries? (Nov/Dec 2014)

It is sudden and drastic cooling of material for the critical temperature. Water, oil and sand are the quenching medium used normally.

8. What is the significance of TTT diagram in the heat treatment of steel? (Nov/Dec 2014)

TTT diagram used to find the properties and microstructure of the material with various cooling rate.

9. Define recrystallization ? (May/June 2014)

Original grains size of the parent material will be restructured and reoriented to form a new grains of different size by heat treatment is called recrystallization.

10. What are the types of heat Treatment? (May/June 2014) Annealing

Normalizing

Hardening

Tempering

11. Differentiate annealing and normalizing treatment? (April/May 2015)

S.No	Annealing	Normalizing
1	Main purpose of annealing is to relieve internal stresses	Main purpose of normalizing is to improve mechanical properties of steel.
2	Less hardness, more tensile strength and toughness	Slightly more hardness, less tensile strength and toughness
3	Pearlite is coarse.	Pearlite is fine.
4	Grain size distribution is more	Grain size distribution is less.

12. Austempering is different from other hardening treatments. Explain the statement. (April/May 2015)

Austempering is heat treatment that is applied to ferrous metals, most notably steel and ductile iron. In steel it produces a bainite microstructure whereas in cast irons it produces a structure of acicular ferrite and high carbon, stabilized austenite known as ausferrite. It is primarily used to improve mechanical properties or reduce / eliminate distortion. Austempering is defined by both the process and the resultant microstructure. Typical austempering process parameters applied to an unsuitable material will not result in the formation of bainite or ausferrite and thus the final product will not be called austempered. Other hardening process will lead to some microstructure element other than austenized product.

13. What do you mean by Hardenability?

Hardenability refers to its ability to be hardened to a particular depth under a particular set of conditions.

14. Which type of surface hardening process that does not involve composition change?

Induction hardening, forging, quenching. Shot peening.

15. What is austempering

Austempering is heat treatment that is applied to ferrous metals, most notably steel and ductile iron. In steel it produces a bainite microstructure whereas in cast irons it produces a structure of acicular ferrite and high carbon, stabilized austenite known as ausferrite. It is primarily used to improve mechanical properties or reduce / eliminate distortion.

16. Name any two shallow hardening processes

(i) Carburizing

(ii) Nitriding

17. What is quenching. List some of the quenching medium generally used in industries? It is sudden and drastic cooling of material for the critical temperature. Water, oil and sand are the quenching medium used normally.

18. What is the significance of TTT diagram in the heat treatment of steel?

TTT diagram used to find the properties and microstructure of the material with various cooling rate.

19. Define recrystallization ?

Original grains size of the parent material will be restructured and reoriented to form a new grains of different size by heat treatment is called recrystallization.

20. What are the types of heat Treatment? (May/June 2014) Annealing  
Normalizing, Hardening and Tempering .

**21. What are the principal advantages of austempering over conventional quenching and temper method? (Apr/May 2017)**

Less distortion, greater ductility, uniform/ consistent hardness, good wear resistance and resistance to hydrogen embrittlement.

**22. Mention few applications of induction hardening system? (Apr/May 2017)**

Surface hardening of railway suspension springs, metallic conveyers, earth moves parts and slurry pumps.

**23. What is the difference between stress relief and recrystallization heat treatment process (Nov/Dec 2017)**

Stress Relieving consists of heating the steel to a temperature below the critical range to relieve the stresses resulting from cold working, shearing, or gas cutting. It is not intended to alter the micro-structure or mechanical properties significantly also a process for making material softer.

However stress relieving does not change the material properties as does annealing and normalizing. On the other hand, recrystallization heat treatment is the process that alters the physical and sometimes chemical properties of a material to increase its ductility and to make it more workable. It involves heating a material to above its recrystallization temperature, maintaining a suitable temperature, and then cooling.

**24. Which has higher critical cooling rate: eutectoid steel or hypereutectoid steel? (Nov/Dec 2017)**

As hypereutectoid steel has higher carbon content than the eutectoid steel, hypereutectoid steel will have higher critical cooling rate.

**PART B**

1. Brief on various phase transformation with continuous cooling transformation diagram super imposed on TTT diagram.

Refer question 12.

2. Brief on jominy end quench test and interpretation of results.

Refer question 13.

3. Brief on the tempering process.  
refer question no 10.
4. What is hardenability? Describe a test that is used for determination of hardenability of steel.  
Refer question 13
5. What is case hardening? Explain in details the carburizing processes.
6. Brief on hardening and tempering of steel with respect to rate of cooling and tempering temperature respectively.
7. Define hardenability? Explain Jominy end quench test. Explain carburization.

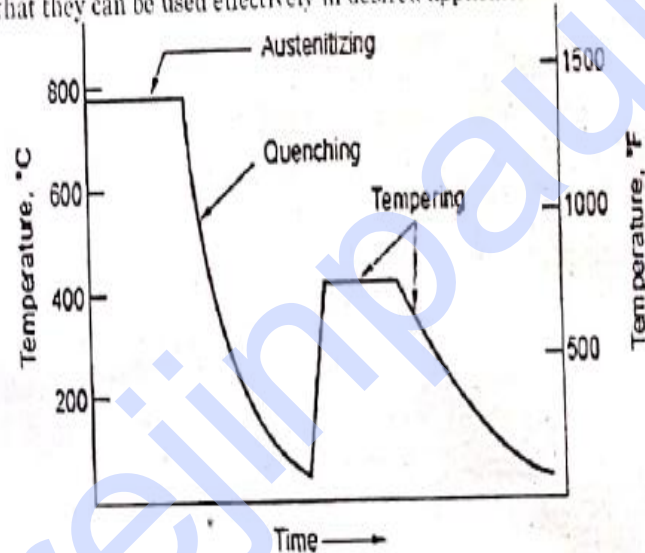
Refer question 11

8. Brief on hardening and tempering of steel with respect to rate of cooling and tempering temperature respectively.

**Hardening** involves heating of steel, keeping it at an appropriate temperature until all pearlite is transformed into austenite, and then quenching it rapidly in water or oil. The temperature at which austenitizing rapidly takes place depends upon the carbon content in the steel used. The heating time should be increased ensuring that the core will also be fully transformed into austenite. The microstructure of a hardened steel part is ferrite, martensite, or cementite.

**Tempering** involves heating steel that has been quenched and hardened for an adequate period of time so that the metal can be equilibrated. The hardness and strength obtained depend upon the temperature at which tempering is carried out. Higher temperatures will result into high ductility, but low strength and hardness. Low tempering temperatures will produce low ductility, but high strength and hardness. In practice, appropriate tempering temperatures are selected that will produce the desired level of hardness and strength. This operation is performed on all carbon steels that have been hardened, in order to reduce their brittleness, so that they can be used effectively in desired applications.

5 Marks



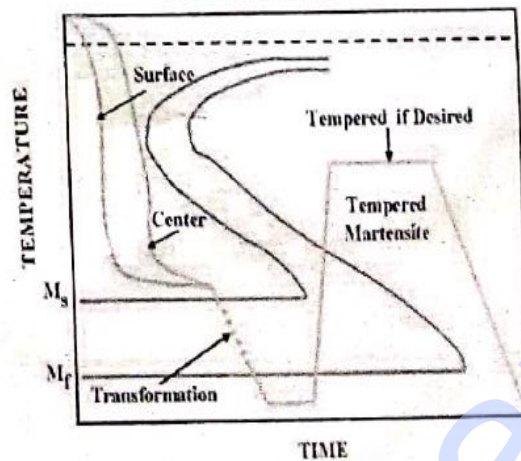
3 Marks

9. Discuss the concept involved in martempering

- (ii) 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 ( $M_s$ ) point

3 Marks

#### MARTEMPERING



2 Marks

Page 4 of 13

10. Brief on Jominy end quench test and interpretation of results.
11. Brief on the types of carburizing and need for post carburizing heat treatments.

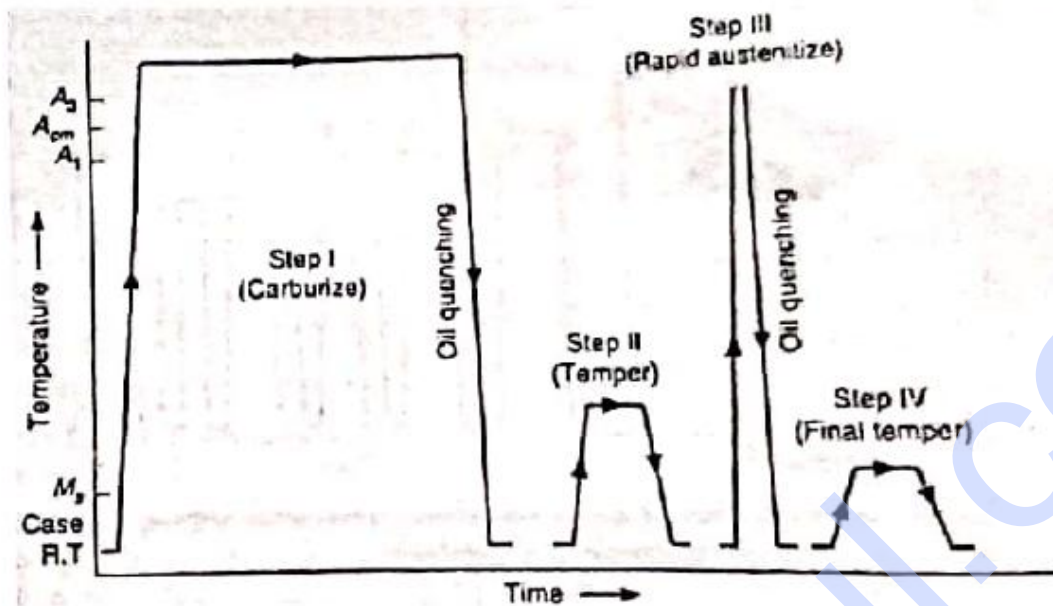
There are plots in the literature that we can use that will give us the cooling rates experienced for any point in a steel specimen of a particular size, geometry and quench. (The standard quenches are water or oil. Once the cooling rate is known, the hardness can be determined from the Hardenability curve.

(ii) **carburization** is a heat treatment process in which iron or steel absorbs carbon while the metal is heated in the presence of a carbon-bearing material, such as charcoal or carbon monoxide. The intent is to make the metal harder. Depending on the amount of time and temperature, the affected area can vary in carbon content. Longer carburizing times and higher temperatures typically increase the depth of carbon diffusion.

The objectives of the post-carburizing heat treatment are to (i) Improve the microstructure and refine coarser grains of core and case of carburized steel (ii) Achieve high hardness at the surface; and (iii) break the carbide network in the carburized case, which may be formed due to higher carbon content (1.0%)

3 Marks





12. (a) Compare and contrast the process of full annealing, stress relief annealing, recrystallization annealing and spheroidise annealing. (Apr/May 2017)

Annealing is one of the heat treatment processes, which is done to steels for obtaining some properties. Annealing plays a predominant role in deciding the strength toughness and various other physical factors of the steel produced. In general annealing is of different types. Each type plays a significant role in forming the steel with the required properties. Some of the annealing processes are

- 1) Full annealing
- 2) Bright annealing
- 3) Box annealing
- 4) Isothermal annealing
- 5) Spherodize annealing
- 6) Sub critical annealing
  - a. Stress relief annealing
  - b. Re crystallization annealing
  - c. Process annealing

**Full annealing**

In general full annealing is one of the most commonly used annealing process. The purpose behind employing this heat treatment process is

- 1) To relieve internal stresses
- 2) To reduce hardness and increase ductility
- 3) For refining of grain size
- 4) To make isotropic in nature in mechanical aspects
- 5) For making the material having homogeneous chemical composition

- 6) For making the material suitable for high machining processes
- 7) To make steel suitable for undergoing other heat treatment processes like hardening, normalizing etc.

Full annealing is done by heating the steels to  $A_3$  temperature for hypo eutectoid steels and  $A_1$  for hyper eutectoid steels and then allowed to stay there for a time period and then subjected to slow cooling.

### **Bright annealing**

In some cases surface brightness of the component is highly desired in such cases this process is used. In this process the heating process is done in the presence of inert media so as to prevent oxidation of the surface metal. In general the materials used to provide inert environment around the body are either argon, nitrogen. In addition to these any reducing media acts as a protective shield around the object. In this process even the color of the surface is retained.

### **Box annealing**

This annealing process can be called by various names such as black annealing, pot annealing, close annealing. In this process keeping the steel to be annealed in a closed medium carries the annealing process. The surroundings of the steel material are covered with cast iron chips, sand, and charcoal. The final annealing process is same as that of full annealing but the only difference is the medium used for doing this process. The background of this process is to prevent oxidation of the steel metal.

### **Isothermal annealing**

This process is other wise called as cycle annealing. In this process the material is heated to just above the temperature of  $A_3$  and then faster cooling rates are adopted than that of a normal annealing processes till the temperature reaches just below  $A_1$  temperature. The steel material is kept at that temperature for obtaining uniformity and then cooled to normal room temperature.

Isothermal annealing seems to be more advantageous over the conventional annealing processes some of the advantages of this process are

- 1) When slower cooling required materials are to be annealed then this process seems to be advantageous than the normal process. This process is even effective when the reduction of hardness is required.
- 2) Due to the generation of intermediate equalization of temperature homogeneity is more comparatively
- 3) The parts, which are annealed by this process, have high machinability and improved surface finish of the machined part can be obtained.

In general this process is used for low and medium carbon steels. This process is even used for some of the alloy steels for obtaining improved machinability. This improvement in the machinability is due to the formation of spheroidized structure.

### **Spheroidized annealing**

Any methods through which spheroids are formed are called as spheroidized annealing. If an annealed product contains globules of cementite in the matrix of ferrite in the microstructure then it is termed as a spheroid. In general this microstructure is formed by various ways some of them are

- 1) Hardening and high temperature tempering



- 2) Holding the product at the temperature just below the  $A_1$  temperature
- 3) Thermal cycling around  $A_1$

### **Subcritical annealing**

This process is done over cold worked steels. In this process the cold worked steel is heated to a temperature just above the lower critical temperature. Due to the heating of the steel to lower critical temperature this process is named as sub critical temperature. In general this process is done to

- 1) To relieve internal stresses developed due to cold working process
- 2) To refine the grain structure
- 3) To reduce hardness and to improve ductility of the material

Sub critical annealing is done by three processes for obtaining various varieties of properties on cold worked steels.

- 1) Stress relief annealing
- 2) Recrystallization annealing
- 3) Process annealing (intermediate annealing)

### **Stress relief annealing**

In this process the cold worked steel is heated to a temperature around 525°C i.e. just below the recrystallization temperature. So due to this heating there arises no change in the microstructure of the material. The body is kept at that temperature for around two to three hours and then subjected to air-cooling. As there is no change in the microstructure this heating process has no adverse effect on the hardness and strength of the material. This annealing process reduces the risk of deformation of the product during machining.

### **Recrystallization annealing**

In this annealing process the cold worked steel material is heated to a temperature above  $A_1$  i.e. around 625 to 650°C. During this annealing process the cementite present in the microstructure starts converting into spheroids and hence high machining ability is obtained. Due to heating of temperature up to  $A_1$  the grain structure changes and not only these internal stresses developed in the cold working process are removed.

13. Define Hardenability. Describe the test procedure to determine **hardenability of steel.** (Apr/May 2017)

Refer Question Bank Page No.40, Question No.2.

14. **Brief of hardening and tempering of steel** (Nov/Dec 2017)

The term hardened steel is often used for a medium or high carbon steel that has been given heat treatment and then quenching followed by tempering. The quenching results in the formation of metastable martensite, the fraction of which is reduced to the desired amount during tempering.

This is the most common state for finished articles such as tools and machine parts. In contrast, the same steel composition in annealed state is softer, as required for forming and machining. Depending on the temperature and composition of the steel, it can be hardened or softened. To make steel harder, it must be heated to very high temperatures. The final result of exactly how hard the steel becomes depends on the amount of carbon present in the metal.

Only steel that is high in carbon can be hardened and tempered. If a metal does not contain the necessary quantity of carbon, then its crystalline structure cannot be broken, and therefore the physical makeup of the steel cannot be altered. Frequently, the term “hardening” is associated with tempered steel. Both processes are used hand in hand when hardening steel.

The two part process begins with hardening the steel so that it becomes hard and does not wear over time. However, very often, this process leaves the steel very brittle and susceptible to breaking during use. Tempering reduces the hardness of the forged steel very slightly but improves the overall product as it results in steel that is much less brittle.

The two major processes of hardening and tempering can be classified into four major steps. First, a piece of carbon steel is heated gradually until it reaches a temperature above the alloy's critical temperature.

The steel is then quenched, usually in water or oil (though other quenches, such as brine or sodium hydroxide solutions, are sometimes used to achieve a particular result). The steel is now at that given alloy's maximum hardness, but as discussed above, also brittle. At this point, tempering is usually performed to achieve a more useful balance of hardness and toughness. The steel is gradually heated until the desired temper colours are drawn, generally at a temperature significantly lower than the alloy's critical point.

Different colours in the temper spectrum reflect different balances of hardness to toughness, so different temper levels are appropriate for different applications. The steel is then re-quenched to ‘fix’ the temper at the desired level. A talented smith or metalworker can fine-tune the performance of a steel tool or item to precisely what is required based solely on careful observation of temper colours.

### **Tempering**

Tempering is a process of heat treating, which is used to increase the toughness of iron-based alloys. Tempering is usually performed after hardening, to reduce some of the excess hardness, and is done by heating the metal to some temperature below the critical point for a certain period of time, then allowing it to cool in still air. The exact temperature determines the amount of hardness removed, and depends on both the specific composition of the alloy and on the desired properties in the finished product.

For instance, very hard tools are often tempered at low temperatures, while springs are tempered to much higher temperatures. Tempering is applied to ferrous alloys, such as steel or cast iron, to achieve greater toughness by decreasing the hardness of the alloy. The reduction in hardness is usually accompanied by an increase in ductility, thereby decreasing the brittleness of the metal.

Tempering is usually performed after quenching, which is rapid cooling of the metal to put it in its hardest state. Tempering is accomplished by controlled heating of the quenched work-piece to a temperature below its “lower critical temperature”. This is also called the lower transformation temperature or lower arrest (A1) temperature; the temperature at which the crystalline phases of the alloy, called ferrite and cementite, begin combining to form a single-phase solid solution referred to as austenite.

Heating above this temperature is avoided, so as not to destroy the very-hard, quenched microstructure, called martensite.

Precise control of time and temperature during the tempering process is crucial to achieve the desired balance of physical properties. Low tempering temperatures may only relieve the

internal stresses, decreasing brittleness while maintaining a majority of the hardness. Higher tempering temperatures tend to produce a greater reduction in the hardness, sacrificing some yield strength and tensile strength for an increase in elasticity and plasticity.

However, in some low alloy steels, containing other elements like chromium and molybdenum, tempering at low temperatures may produce an increase in hardness, while at higher temperatures the hardness will decrease. Many steels with high concentrations of these alloying elements behave like precipitation hardening alloys, which produces the opposite effects under the conditions found in quenching and tempering, and are referred to as maraging steels.

In carbon steels, tempering alters the size and distribution of carbides in the martensite, forming a microstructure called «tempered martensite». Tempering is also performed on normalized steels and cast irons, to increase ductility, machinability, and impact strength. Steel is usually tempered evenly, called «through tempering,» producing a nearly uniform hardness, but it is sometimes heated unevenly, referred to as «differential tempering,» producing a variation in hardness

#### 15. Compare different types of case hardening process (Nov/Dec 2017)

##### **Nitriding :**

Nitriding is a heat treating process that diffuses nitrogen into the surface of a metal to create a case-hardened surface. These processes are most commonly used on low-carbon, low-alloy steels. They are also used on medium and high-carbon steels, titanium, aluminium and molybdenum.

Typical applications include gears, crankshafts, camshafts, cam followers, valve parts, extruder screws, die-casting tools, forging dies, extrusion dies, firearm components, injectors and plastic mold tools.

##### **Carburizing:**

Carburizing is a heat treatment process in which iron or steel absorbs carbon while the metal is heated in the presence of a carbon-bearing material, such as charcoal or carbon monoxide. The intent is to make the metal harder. Depending on the amount of time and temperature, the affected area can vary in carbon content.

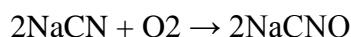
Longer carburizing times and higher temperatures typically increase the depth of carbon diffusion. When the iron or steel is cooled rapidly by quenching, the higher carbon content on the outer surface becomes hard due to the transformation from austenite to martensite, while the core remains soft and tough as a ferritic and/or pearlite microstructure.

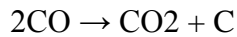
This manufacturing process can be characterized by the following key points: It is applied to low-carbon work pieces; work pieces are in contact with a high-carbon gas, liquid or solid; it produces a hard work piece surface; work piece cores largely retain their toughness and ductility; and it produces case hardness depths of up to 0.25 inches (6.4 mm).

In some cases it serves as a remedy for undesired decarburization that happened earlier in a manufacturing process.

##### **Cyaniding:**

Cyaniding is a case-hardening process that is fast and efficient; it is mainly used on low-carbon steels. The part is heated to 871-954 °C (1600- 1750 °F) in a bath of sodium cyanide and then is quenched and rinsed, in water or oil, to remove any residual cyanide.





This process produces a thin, hard shell (between 0.25 - 0.75 mm, 0.01 and 0.03 inches) that is harder than the one produced by carburizing, and can be completed in 20 to 30 minutes compared to several hours so the parts have less opportunity to become distorted. It is typically used on small parts such as bolts, nuts, screws and small gears. The major drawback of cyaniding is that cyanide salts are poisonous.

### **Carbonitriding:**

Carbonitriding is a metallurgical surface modification technique that is used to increase the surface hardness of a metal, thereby reducing wear.

During the process, atoms of carbon and nitrogen diffuse interstitially into the metal, creating barriers to slip, increasing the hardness and modulus near the surface. Carbonitriding is often applied to inexpensive, easily machined low carbon steel to impart the surface properties of more expensive and difficult to work grades of steel. Surface hardness of carbonitrided parts ranges from 55 to 62 HRC.

Certain pre-industrial case hardening processes include not only carbon-rich materials such as charcoal, but nitrogen-rich materials such as urea, which implies that traditional surface hardening techniques were a form of carbonitriding.

### **Flame or Induction Hardening:**

Flame or induction hardening are processes in which the surface of the steel is heated very rapidly to high temperatures (by direct application of an oxy-gas flame, or by induction heating) then cooled rapidly, generally using water; this creates a “case” of martensite on the surface. A carbon content of 0.3–0.6 wt% C is needed for this type of hardening.

Typical uses are for the shackle of a lock, where the outer layer is hardened to be file resistant, and mechanical gears, where hard gear mesh surfaces are needed to maintain a long service life while toughness is required to maintain durability and resistance to catastrophic failure.

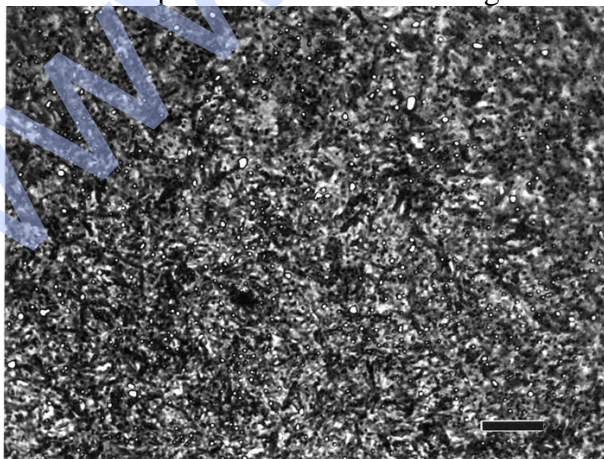
Flame hardening uses direct impingement of an oxy-gas flame onto a defined surface area. The result of the hardening process is controlled by four factors:

Design of the flame head.

Duration of heating.

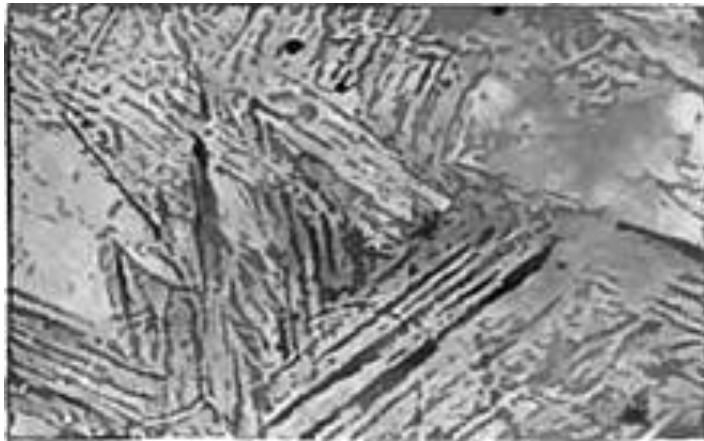
Target temperature to be reached.

Composition of the metal being treated.





Hardened steel



Tempered steel

- 16. Draw a neat sketch of the isothermal transformation diagram for eutectoid steel and explain the construction procedure. Label all the salient features on it. Superimpose on it a cooling curve to obtain bainitic phase. (April/May 2015)**

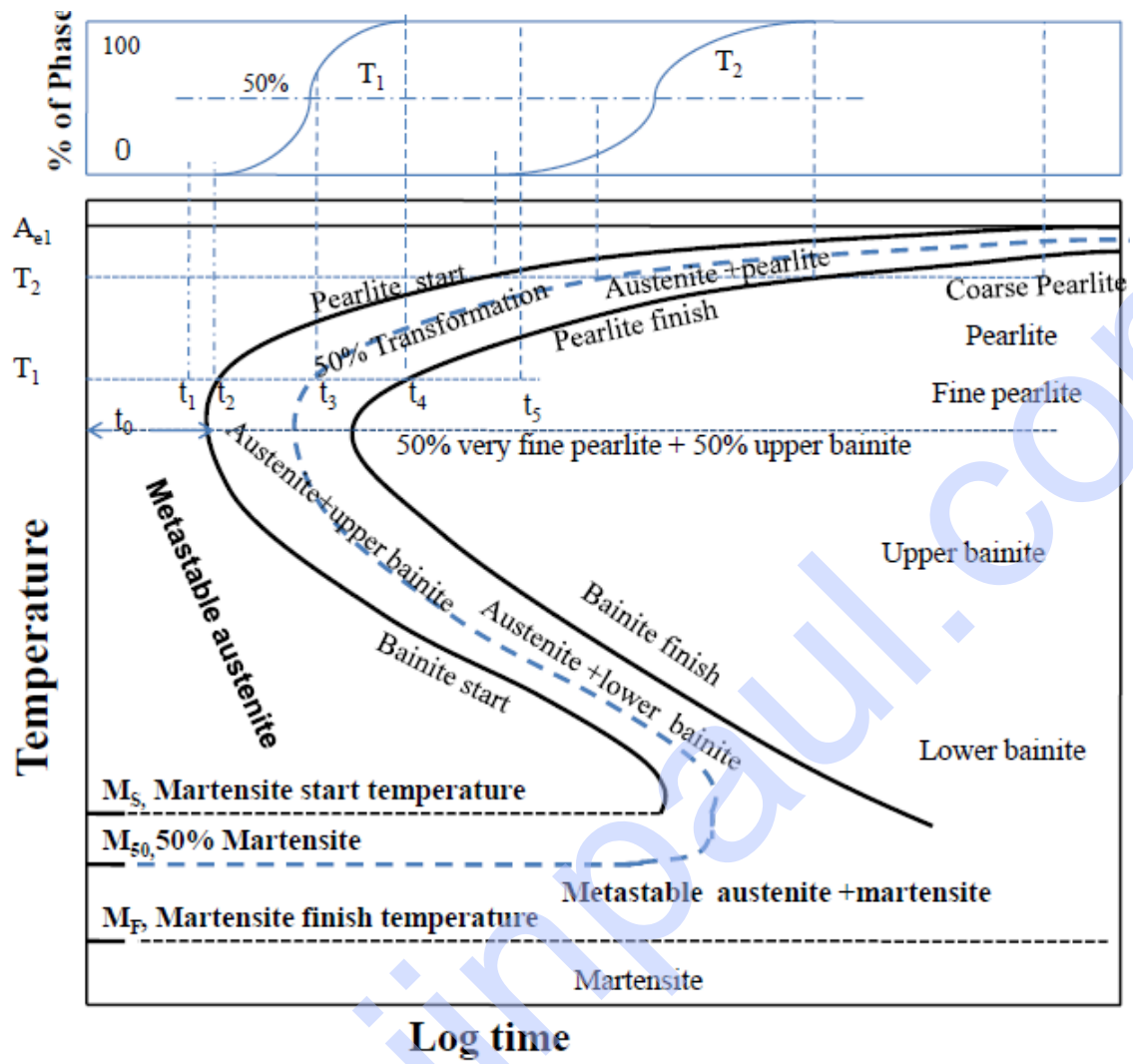
Isothermal transformation diagrams (also known as time-temperature-transformation (TTT) diagrams) are plots of temperature versus time (usually on a logarithmic scale). They are generated from percentage transformation-vs logarithm of time measurements, and are useful for understanding the transformations of an alloy steel that is cooled isothermally. An isothermal transformation diagram is only valid for one specific composition of material, and only if the temperature is held constant during the transformation, and strictly with rapid cooling to that temperature. Though usually used to represent transformation kinetics for steels, they also can be used to describe the kinetics of crystallization in ceramic or other materials. Time-temperature-precipitation diagrams and time-temperature-embrittlement diagrams have also been used to represent kinetic changes in steels.

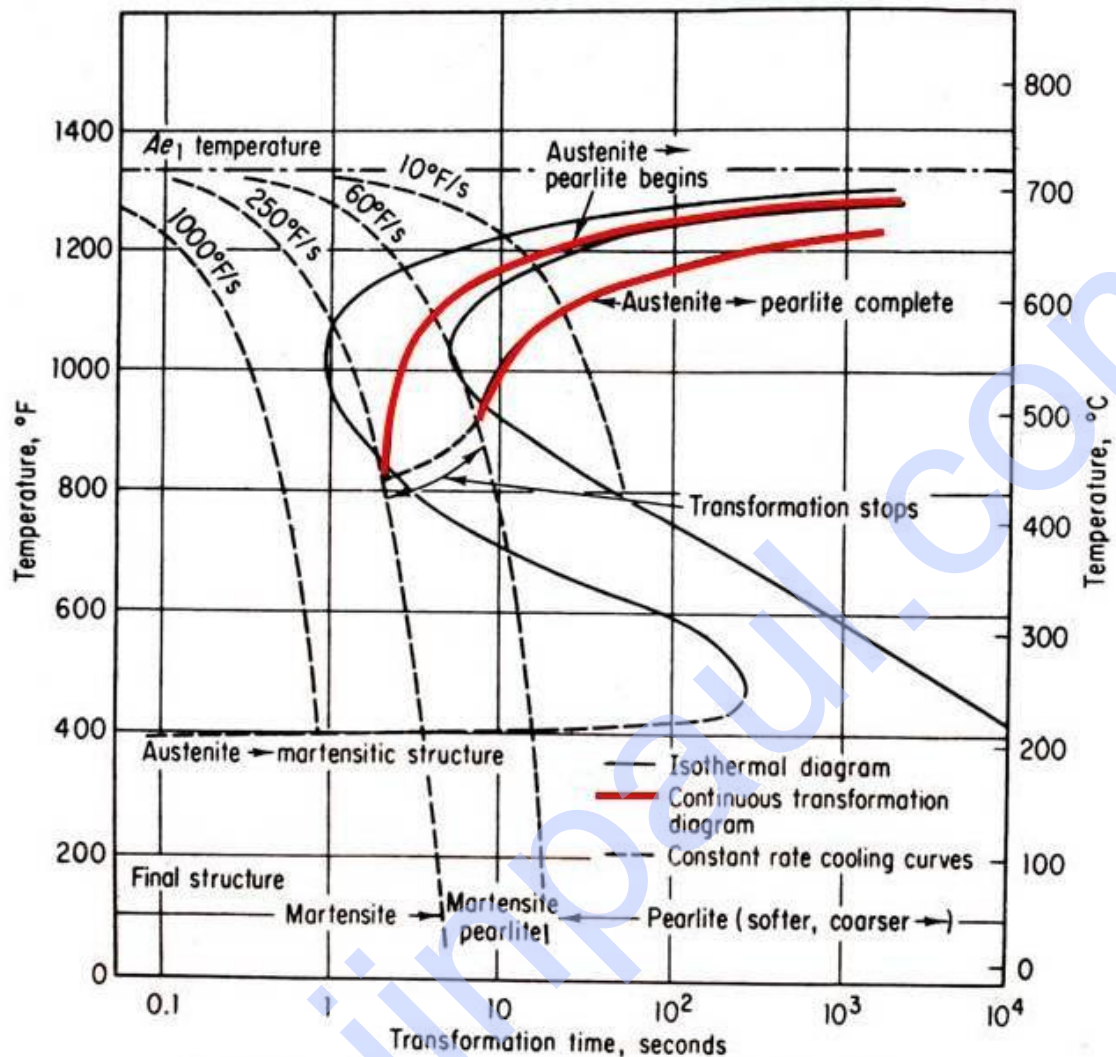
Isothermal transformation (IT) diagram or the C-curve is associated with mechanical properties, micro constituents/microstructures, and heat treatments in carbon steels. Diffusional transformations like austenite transforming to a cementite and ferrite mixture can be explained using the sigmoidal curve; For example the beginning of pearlitic transformation is represented by the pearlite start (Ps) curve. This transformation is complete at Pf curve. Nucleation requires an incubation time. The rate of nucleation increases and the rate of micro constituent growth decreases as the temperature decreases from the liquidus temperature reaching a maximum at the bay or nose of the curve. Thereafter, the decrease in diffusion rate due to low temperature offsets the effect of increased driving force due to greater difference in free energy. As a result of the transformation, the micro constituents, Pearlite and Bainite, form; Pearlite forms at higher temperatures and bainite at lower.

Austenite is slightly under cooled when quenched below Eutectoid temperature. When given more time, stable micro constituents can form: ferrite and cementite. Coarse pearlite is produced when atoms diffuse rapidly after phases that form pearlite nucleate. This transformation is complete at the pearlite finish time (Pf). However, greater under cooling by rapid quenching results in formation of martensite or bainite instead of pearlite. This is possible provided the cooling rate is such that the cooling curve intersects the martensite start temperature or the bainite start curve before intersecting the Ps curve. The martensite transformation being a diffusionless shear transformation is represented by a straight line to signify the martensite start temperature.

1. The kinetic aspects of phase transformations are as important as the equilibrium diagrams for the heat treatment of steels. The metastable phase martensite and the morphologically metastable micro constituent bainite, which are of extreme importance to the properties of steels, can generally form with comparatively rapid cooling to ambient temperature. That is when the diffusion of carbon and alloying elements is suppressed or limited to a very short range. Bainite is a eutectoid decomposition that is a mixture of ferrite and cementite. Martensite, the hardest constituent, forms during severe quenches from supersaturated austenite by a shear transformation. Its hardness increases monotonically with carbon content up to about 0.7 wt%. If these unstable metastable products are subsequently heated to a moderately elevated temperature, they decompose to more stable distributions of ferrite and carbide. The reheating process is sometimes known as tempering or annealing. The transformation of an ambient temperature structure like ferrite-pearlite or tempered martensite to the elevated-temperature structure of austenite or austenite-carbide is also of importance in the heat treatment of steel. One can conveniently describe what is happening during transformation with transformation diagrams. Four different types of such diagrams can be distinguished. These include: Isothermal transformation diagrams describing the formation of austenite, which will be referred to as IT diagrams. Isothermal transformation (IT) diagrams, also referred to as time-temperature-transformation (TTT) diagrams, describing the decomposition of austenite, Continuous heating transformation (CHT) diagrams, Continuous cooling transformation (CCT) diagrams. Isothermal Transformation Diagrams. This type of diagram shows what happens when a steel is held at a constant temperature for a prolonged period. The development of the microstructure with time can be followed by holding small specimens in a lead or salt bath and quenching them one at a time after increasing holding times and measuring the amount of phases formed in the microstructure with the aid of a microscope. During the formation of austenite from an original microstructure of ferrite and pearlite or tempered martensite, the volume decreases with the formation of the dense austenite phase. From the elongation curves, the start and finish times for austenite formation, usually defined as 1% and 99% transformation, respectively, can be derived. IT Diagrams (Decomposition of Austenite). The procedure starts at a high temperature, normally in the austenitic range after holding there long enough to obtain homogeneous austenite without undissolved carbides, followed by rapid cooling to the desired hold temperature. The cooling was started from 850°C (1560°F). The A<sub>1</sub> and A<sub>3</sub> temperatures are indicated as well as the hardness. Above A<sub>3</sub> no transformation can occur. Between A<sub>1</sub> and A<sub>3</sub> only ferrite can form from austenite.







Continuous Cooling-Transformation (C-T) Diagram

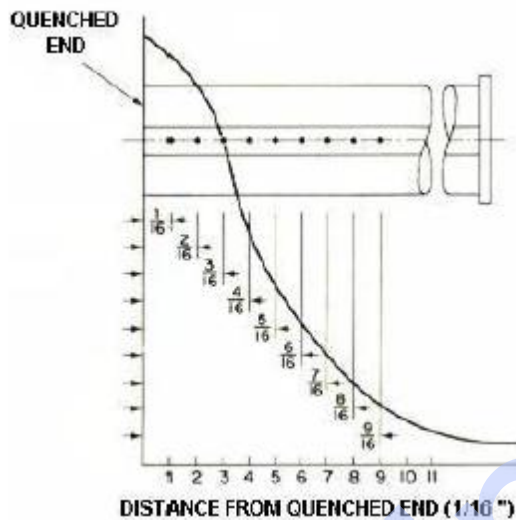
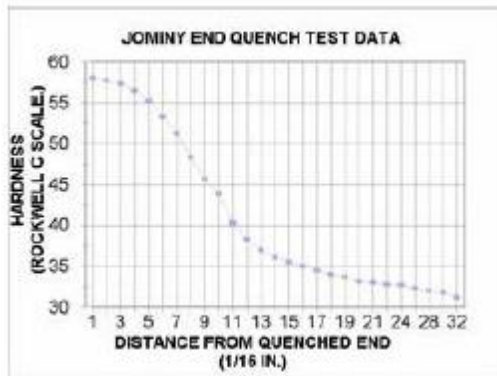
(Derived from the isothermal-transformation diagram for a plain-carbon eutectoid steel)

17. Differentiate hardness and hardenability. Explain with a neat sketch, the procedure to plot the hardenability curves for eutectoid steel in Jominy End Quench Test. (April/May 2015)

HARDENABILITY	HARDNESS
The hardness of a steel is a measure of a sample's resistance to indentation or scratching.	Hardenability refers to its ability to be hardened to a particular depth under a particular set of conditions.

The influence of alloy composition on the ability of a steel alloy to transform to martensite for a particular quenching treatment is related to a parameter called hardenability. For every different steel alloy there is a specific relationship between the mechanical properties and the cooling rate. Hardenability is used to describe the ability of an alloy to be hardened by the formation of martensite as a result of a given heat treatment. One standard procedure that is widely utilized to determine hardenability is the Jominy end quench test.





#### 18. Brief on hardening and tempering of steel with respect to rate of cooling and tempering temperature respectively. (Nov/Dec 2015)

The use of this treatment will result in an improvement of the mechanical properties, as well as an increase in the level of hardness, producing a tougher, more durable item. Alloys are heated above the critical transformation temperature for the material, then cooled rapidly enough to cause the soft initial material to transform to a much harder, stronger structure. Alloys may be air cooled, or cooled by quenching in oil, water, or another liquid, depending upon the amount of alloying elements in the material. Hardened materials are usually tempered or stress relieved to improve their dimensional stability and toughness.

Steel parts often require a heat treatment to obtain improved mechanical properties, such as increasing hardness or strength. The hardening process consists of heating the components above the critical (normalizing) temperature, holding at this temperature for one hour per inch of thickness cooling at a rate fast enough to allow the material to transform to a much harder, stronger structure, and then tempering. Steel is essentially an alloy of iron and carbon; other steel alloys have other metal elements in solution. Heating the material above the critical temperature causes carbon and the other elements to go into solid solution. Quenching “freezes” the microstructure, inducing stresses. Parts are subsequently tempered to transform the microstructure, achieve the appropriate hardness and eliminate the stresses. Material is heated up to the suitable temperature and then quenched in water or oil to harden to full hardness according to the kind of steels. Material is heated to the suitable temperature for hardening, then cooled rapidly by immersing the hot part in water, oil or another suitable

liquid to transform the material to a fully hardened structure. Parts which are quenched usually must be aged, tempered or stress relieved to achieve the proper toughness, final hardness and dimensional stability.

Tempering is a process of heat treating, which is used to increase the toughness of iron-based alloys. Tempering is usually performed after hardening, to reduce some of the excess hardness, and is done by heating the metal to some temperature below the critical point for a certain period of time, then allowing it to cool in still air. The exact temperature determines the amount of hardness removed, and depends on both the specific composition of the alloy and on the desired properties in the finished product. For instance, very hard tools are often tempered at low temperatures, while springs are tempered to much higher temperatures.

Alloys may be air cooled, or cooled by quenching in oil, water, or another liquid, depending upon the amount of alloying elements in the material and final mechanical properties to be achieved. Hardened materials are tempered to improve their dimensional stability and toughness.

Tempering is a heat treatment technique applied to ferrous alloys, such as steel or cast iron, to achieve greater toughness by decreasing the hardness of the alloy. The reduction in hardness is usually accompanied by an increase in ductility, thereby decreasing the brittleness of the metal. Tempering is usually performed after quenching, which is rapid cooling of the metal to put it in its hardest state. Tempering is accomplished by controlled heating of the quenched work-piece to a temperature below its "lower critical temperature". This is also called the lower transformation temperature or lower arrest (A<sub>1</sub>) temperature; the temperature at which the crystalline phases of the alloy, called ferrite and cementite, begin combining to form a single-phase solid solution referred to as austenite. Heating above this temperature is avoided, so as not to destroy the very-hard, quenched microstructure, called martensite.

Precise control of time and temperature during the tempering process is crucial to achieve the desired balance of physical properties. Low tempering temperatures may only relieve the internal stresses, decreasing brittleness while maintaining a majority of the hardness. Higher tempering temperatures tend to produce a greater reduction in the hardness, sacrificing some yield strength and tensile strength for an increase in elasticity and plasticity. However, in some low alloy steels, containing other elements like chromium and molybdenum, tempering at low temperatures may produce an increase in hardness, while at higher temperatures the hardness will decrease. Many steels with high concentrations of these alloying elements behave like precipitation hardening alloys, which produces the opposite effects under the conditions found in quenching and tempering, and are referred to as maraging steels.

#### **19. Compare Austempering and martempering: (Nov/Dec 2015)**

martensite, forming a microstructure called "tempered martensite". Tempering is also performed on normalized steels and cast irons, to increase ductility, machinability, and impact strength. Steel is usually tempered evenly, called "through tempering," producing a nearly uniform hardness, but it is sometimes heated unevenly, referred to as "differential tempering," producing a variation in hardness.

Austempering forms bainite instead of martensite. Bainite is a slow isothermal transformation from austenite.

Bainite has increased ductility and toughness at the same strength levels as martensite.

Bainite has reduced distortion and residual stress which lowers subsequent processing costs.



Austempering provides the shortest cycle time to through –harden within the hardness range of Rockwell C 35-55 HRC. Not all steels can be austempered.

Austempering consists of the following processing steps. Heating to a temperature above A3 to transform the microstructure to austenite.

Quenching to a temperature above the Ms temperature and holding for a period of time to transform the austenite to bainite.

No tempering is required.

Steels for austempering: Plain carbon steels with carbon between 0.50 – 1.00% and manganese  $\geq 0.60\%$

Carbon steels with manganese  $\geq 1.00\%$  and carbon slightly less than 0.50%.

Alloy steels with carbon  $\geq 0.30\%$  such as 5100 series.

Alloy steels with carbon  $\geq 0.40\%$  such as 1300 to 4000 series and 4140, 6145, 9440.

### **Martempering**

To avoid residual stresses generated during quenching

Austenized steel is quenched above Ms (20-30°C above Ms i.e. 180 - 250°C)

Holding in salt bath for homogenization of temperature across the sample (large holding time is avoided to avoid forming bainite)

The steel is then quenched in air and the entire sample transforms simultaneously

Tempering follows

The process is called Martempering

The process is beneficial as: Steep temperature gradient is minimized

Thermal and structural stresses are minimal

More retained austenite – lesser volume change

### **20. Brief on the types of carburizing and need for post carburizing heat treatment? (Nov/Dec 2015)**

Carburizing or carburization is a heat treatment process in which iron or steel absorbs carbon while the metal is heated in the presence of a carbon-bearing material, such as charcoal or carbon monoxide. The intent is to make the metal harder. Depending on the amount of time and temperature, the affected area can vary in carbon content. Longer carburizing times and higher temperatures typically increase the depth of carbon diffusion. When the iron or steel is cooled rapidly by quenching, the higher carbon content on the outer surface becomes hard due to the transformation from austenite to martensite, while the core remains soft and tough as a ferritic and/or pearlite microstructure. This manufacturing process can be characterized by the following key points: It is applied to low-carbon work pieces are in contact with a high-carbon gas, liquid or solid; it produces a hard work piece surface; work piece cores largely retain their toughness and ductility; and it produces case hardness depths of up to 0.25 inches (6.4 mm). In some cases it serves as a remedy for undesired decarburization that happened earlier in a manufacturing process.

Carburization of steel involves a heat treatment of the metallic surface using a source of carbon. Carburization can be used to increase the surface hardness of low carbon steel. Early carburization used a direct application of charcoal packed around the sample to be treated



(initially referred to as case hardening), but modern techniques use carbon-bearing gases or plasmas (such as carbon dioxide or methane). The process depends primarily upon ambient gas composition and furnace temperature, which must be carefully controlled, as the heat may also impact the microstructure of the remainder of the material. For applications where great control over gas composition is desired, carburization may take place under very low pressures in a vacuum chamber.

Plasma carburization is increasingly used to improve the surface characteristics (such as wear, corrosion resistance, hardness, load-bearing capacity, in addition to quality-based variables) of various metals, notably stainless steels. The process is environmentally friendly (in comparison to gaseous or solid carburizing). It also provides an even treatment of components with complex geometry (the plasma can penetrate into holes and tight gaps), making it very flexible in terms of component treatment.

The process of carburization works via the diffusion of carbon atoms into the surface layers of a metal. As metals are made up of atoms bound tightly into a metallic crystalline lattice, the carbon atoms diffuse into the crystal structure of the metal and either remain in solution (dissolved within the metal crystalline matrix — this normally occurs at lower temperatures) or react with elements in the host metal to form carbides (normally at higher temperatures, due to the higher mobility of the host metal's atoms). If the carbon remains in solid solution, the steel is then heat treated to harden it. Both of these mechanisms strengthen the surface of the metal, the former by forming pearlite or martensite, and the latter via the formation of carbides. Both of these materials are hard and resist abrasion. Gas carburizing is normally carried out at a temperature within the range of 900 to 950 °C. In oxy-acetylene welding, a carburizing flame is one with little oxygen, which produces a sooty, lower-temperature flame. It is often used to anneal metal, making it more malleable and flexible during the welding process. A main goal when producing carburized work pieces is to ensure maximum contact between the work piece surface and the carbon-rich elements. In gas and liquid carburizing, the work pieces are often supported in mesh baskets or suspended by wire. In pack carburizing, the work piece and carbon are enclosed in a container to ensure that contact is maintained over as much surface area as possible. Pack carburizing containers are usually made of carbon steel coated with aluminum or heat-resisting nickel-chromium alloy and sealed at all openings with fire clay.

**21. Distinguish 'hardness and hardenability'. With suitable sketches, explain the Jominy hardness test for hardenability:**

**Refer : Question No.2 (April/May 2015)**

**22. Discuss different types of annealing processes? (Nov/Dec 2015)**

### **Purpose of Annealing:**

The purpose of annealing may involve one or more of the following aims:

1. To soften the steel and to improve machinability.
2. To relieve internal stresses induced by some previous treatment (rolling, forging, uneven cooling).
3. To remove coarseness of grain.

The treatment is applied to forgings, cold-worked sheets and wire, and castings. The operation consists of:

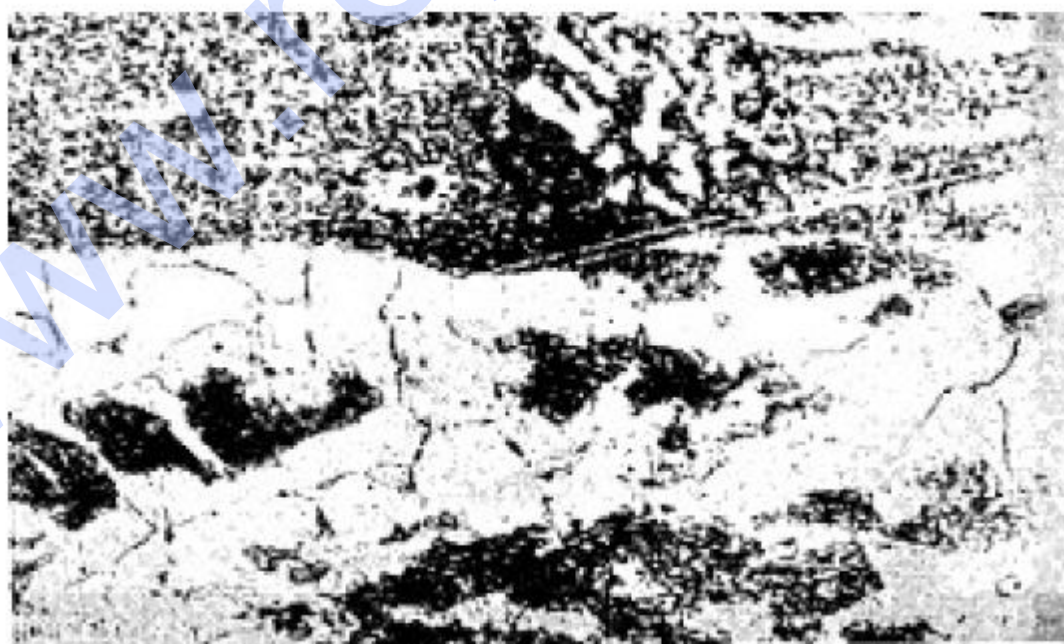
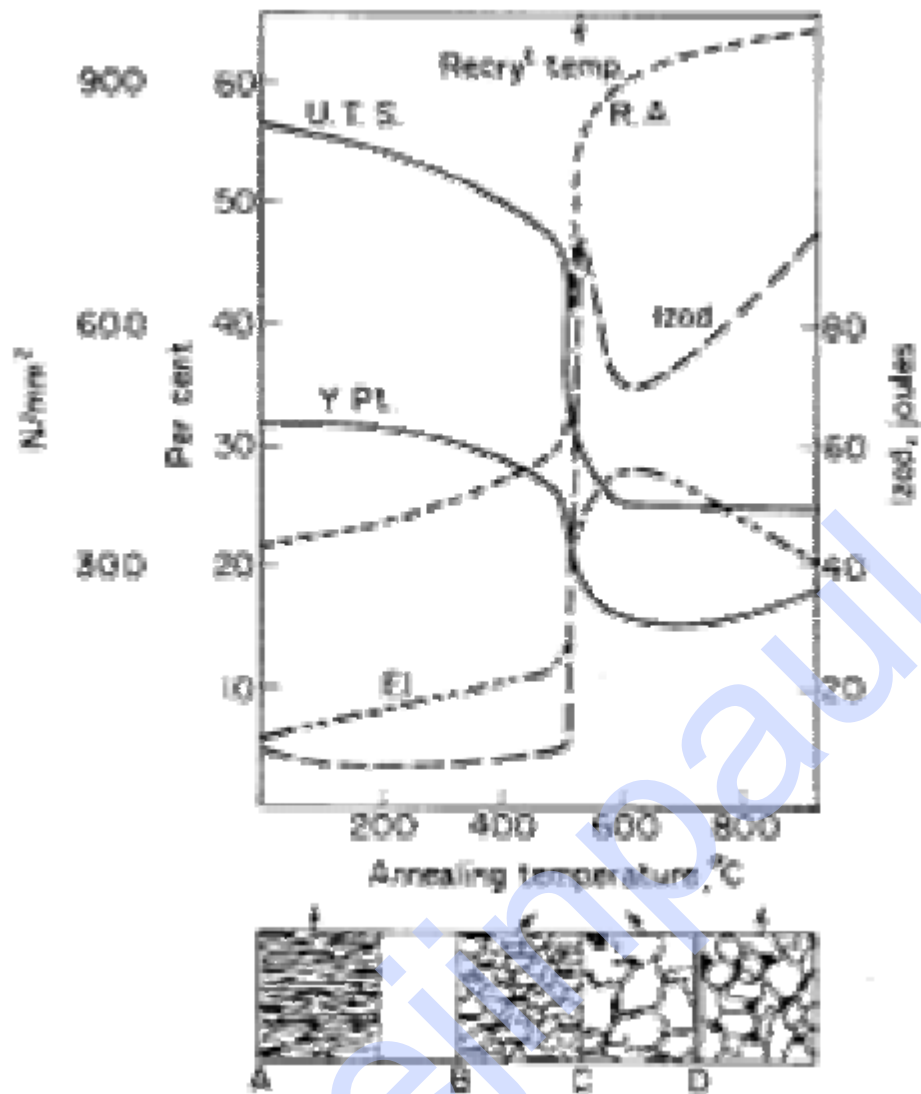
- a. Heating the steel to a certain temperature,

- b. "Soaking" at this temperature for a time sufficient to allow the necessary changes to occur,
- c. Cooling at a predetermined rate.

### **Sub-critical Annealing:**

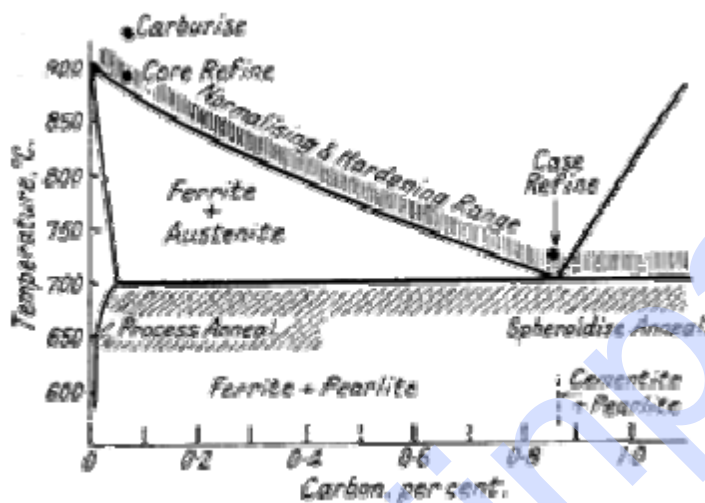
It is not always necessary to heat the steel into the critical range. Mild steel products which have to be repeatedly cold worked in the processes of manufacture are softened by annealing at 500° to 650°C for several hours. This is known as "process" or "close" annealing, and is commonly employed for wire and sheets. The recrystallisation temperature of pure iron is in the region of 500°C consequently the higher temperature of 650°C brings about rapid recrystallisation of the distorted ferrite since mild steel contains only a small volume of strained pearlite a high degree of softening is induced. As shown, Fig. 1b illustrates the structure formed consisting of the polyhedral ferrite with elongated pearlite. Prolonged annealing induces greater ductility at the expense of strength, owing to the tendency of the cementite in the strained pearlite to "ball-up" or spheroidise, as illustrated in figure. This is known as "divorced pearlite". The ferrite grains also become larger, particularly if the metal has been cold worked a critical amount. A serious embrittlement sometimes arises after prolonged treatment owing to the formation of cementite films at the ferrite boundaries. With severe forming operations, cracks are liable to start at these cementite membranes. The modern tendency is to use batch or continuous annealing furnaces with an inert purging gas. Batch annealing usually consists of 24-30 hrs 670°C, soak 12 hrs, and slow cool it for 4-5 days. Open coil annealing consists in recoiling loosely with controlled space between wraps and it reduces sticker and discoloration. Continuous annealing is used for thin strip (85% Red) running at about 400 m/min. The cycle is approximately up to 660°C 20 sec, soak and cool 30-40 sec. There is little chance for grain growth and it produces harder and stiffer strip; useful for cans and paneling. "Double reduced" steel is formed by heavy reduction (~50%) after annealing but it suffers from directionality. This can be eliminated by heating between 700- 920°C and rapidly quenching.

**23. Explain normalizing and induction hardening. (Nov/Dec 2015)**



## Full Annealing and Normalizing Treatments

For steels with less than 0.9% carbon both treatments consist in heating to about 25-50°C above the upper critical point indicated by the Fe-Fe<sub>3</sub>C equilibrium diagram (Fig. 2.1). For higher carbon steels the temperature is 50°C above the lower critical point. These temperatures allow for the effects of slight variations in the impurities present and also the thermal lag associated with the critical changes. After soaking at the temperature for a time dependent on the thickness of the article, the steel is very slowly cooled. This treatment is known as full annealing, and is used for removing strains from forgings and castings, improving machinability and also when softening and refinement of structure are both required. Normalizing differs from the full annealing in that the metal is allowed to cool in still air. The structure and properties produced, however, varying with the thickness of metal treated. The tensile strength, yield point, reduction of area and impact value are higher than the figures obtained by annealing.



### Changes on Annealing:

Consider the heating of a 0.3% carbon steel. At the lower critical point (Ac1) each "grain" of pearlite changes to several minute austenite crystals and as the temperature is raised the excess ferrite is dissolved, finally disappearing at the upper critical point (Ac3), still with the production of fine austenite crystals. Time is necessary for the carbon to become uniformly distributed in this austenite. The properties obtained subsequently depend on the coarseness of the pearlite and ferrite and their relative distribution. These depend on:

- the size of the austenite grains; the smaller their size the better the distribution of the ferrite and pearlite.
- the rate of cooling through the critical range, which affects both the ferrite and the pearlite.

As the temperature is raised above Ac3 the crystals increase in size. On a certain temperature the growth, which is rapid at first, diminishes. Treatment just above the upper critical point should be aimed at, since the austenite crystals are then small.

By cooling slowly through the critical range, ferrite commences to deposit on a few nuclei at the austenite boundaries. Large rounded ferrite crystals are formed, evenly distributed among the relatively coarse pearlite. With a higher rate of cooling, many ferrite crystals are formed at the austenite boundaries and a network structure of small ferrite crystals is produced with fine pearlite in the centre. Overheated, Burnt and Under annealed structures when the steel is heated well above the upper critical temperature large austenite crystals form. Slow cooling gives rise to the Widmanstatten type of structure, with its characteristic lack of both ductility and resistance to shock. This is known as an overheated structure, and it can be refined by reheating the steel to just above the upper critical point. Surface decarburization usually

occurs during the overheating. During the Second World War, aircraft engine makers were troubled with overheating (above 1250°C) in drop-stampings made from alloy steels. In the hardened and tempered condition the fractured surface shows dull facets. The minimum overheating temperature depends on the “purity” of the steel and is substantially lower in general for electric steel than for open-hearth steel. The overheated structure in these alloy steels occurs when they are cooled at an intermediate rate from the high temperature. At faster or slower rates the overheated structure may be eliminated. This, together with the fact that the overheating temperature is significantly raised in the presence of high contents of MnS and inclusions, suggests that this overheating is connected in some way with a diffusion and precipitation process, involving MnS. This type of overheating can occur in an atmosphere free from oxygen, thus emphasizing the difference between overheating and burning. As the steel approaches the solids temperature, incipient fusion and oxidation take place at the grain boundaries. Such steel is said to be burnt and it is characterized by the presence of brittle iron oxide films, which render the steel unfit for service, except as scrap for remelting.

**24. Explain in detail about spheroidizing. What is tempering of steel. Explain?**  
(Nov/Dec 2014)

Spheroidizing is a form of heat treatment for iron-based alloys, commonly carbon steels, in order to convert them into ductile and machinable alloys. It is conducted at temperatures that are slightly below the eutectoid temperature (temperature at which the solution is a solid solution rather than liquid), followed by a slow cooling process. The resulting spheroidite structure is a microstructure that contains sphere-like cementite particles. Spheroidite is known as the most ductile and machinable form of steel. This article will look into the technique and applications of spheroidizing process.

Spheroidizing of high carbon steel is a method of prolonged heating at a temperature below the eutectoid temperature. By heating at this temperature pearlite, which is the lowest energy arrangement of steel, gets converted to ferrite and cementite. The graphite content of steel assumes a spheroidal shape after spheroidizing and after prolonged heating the pearlite layers are broken down and spherical lumps of cementite, or spheroidite, are formed.

The structures in spheroidite are one thousand times larger than those of pearlite and are spaced further apart. This means the spheroidite steel is extremely ductile. However, the process of spheroidizing does consume a lot of energy.

**Advantages of Spheroidizing**

Some of the advantages of spheroidizing are mentioned below:

- Increases ductility of high carbon steel
- Spheroidite structure reduces energy needed for subsequent operations
- Machinability is increased.

**Industrial Applications**

Some of the industrial applications of spheroidizing are listed below:

- Machinable steel
- Rail road tracks
- Tyre cords
- Bridge cables.

Tempering is a process of heat treating, which is used to increase the toughness of iron-based alloys. Tempering is usually performed after hardening, to reduce some of the excess hardness, and is done by heating the metal to some temperature below the critical



point for a certain period of time, then allowing it to cool in still air. The exact temperature determines the amount of hardness removed, and depends on both the specific composition of the alloy and on the desired properties in the finished product. For instance, very hard tools are often tempered at low temperatures, while springs are tempered to much higher temperatures.

Tempering is a heat treatment technique applied to ferrous alloys, such as steel or cast iron, to achieve greater toughness by decreasing the hardness of the alloy. The reduction in hardness is usually accompanied by an increase in ductility, thereby decreasing the brittleness of the metal. Tempering is usually performed after quenching, which is rapid cooling of the metal to put it in its hardest state. Tempering is accomplished by controlled heating of the quenched work-piece to a temperature below its "lower critical temperature". This is also called the lower transformation temperature or lower arrest (A<sub>1</sub>) temperature; the temperature at which the crystalline phases of the alloy, called ferrite and cementite, begin combining to form a single-phase solid solution referred to as austenite. Heating above this temperature is avoided, so as not to destroy the very-hard, quenched microstructure, called martensite.

Precise control of time and temperature during the tempering process is crucial to achieve the desired balance of physical properties. Low tempering temperatures may only relieve the internal stresses, decreasing brittleness while maintaining a majority of the hardness. Higher tempering temperatures tend to produce a greater reduction in the hardness, sacrificing some yield strength and tensile strength for an increase in elasticity and plasticity. However, in some low alloy steels, containing other elements like chromium and molybdenum, tempering at low temperatures may produce an increase in hardness, while at higher temperatures the hardness will decrease. Many steels with high concentrations of these alloying elements behave like precipitation hardening alloys, which produces the opposite effects under the conditions found in quenching and tempering, and are referred to as maraging steels.

In carbon steels, tempering alters the size and distribution of carbides in the martensite, forming a microstructure called "tempered martensite". Tempering is also performed on normalized steels and cast irons, to increase ductility, machinability, and impact strength. Steel is usually tempered evenly, called "through tempering," producing a nearly uniform hardness, but it is sometimes heated unevenly, referred to as "differential tempering," producing a variation in hardness.

**25. What is CCR. Write difference between normalizing and tempering? (Nov/Dec 2014)**

Annealing and Normalizing are the primary processes which come under the category of heat treatment of steels.

Tempering is a secondary treatment which is done after the primary processes of heat treatment.

Quenching is the cooling of the material from the higher temperature of the room temperature.

When you take a untreated piece of steel and put it in a furnace to raise its temperature to around 723°C i.e to a single phase and after that turn off the furnace and let the piece of steel to cool inside a furnace, this process is known as annealing (Furnace cooling or slow cooling)

When you take a untreated piece of steel and put it in a furnace and raise the temp. to the around 723°C i.e to a single phase and take the piece out of the furnace and allow it to cool in air, this process is known as normalizing (air cooling).



After ant primary treatment especially after hardening(water or oil cooled),the material incurs such properties which are unfit for certain application ,in those cases we can in order to improve the property we need to heat the metal to a temp. less than 723oC temp. This is known as tempering.

Quenching is the cooling process generally, faster cooling like dipping in water, brine solution, oil etc.

## UNIT-III

### PART A

1. What makes nitriding different from rest of case hardening process, besides composition?

Nitriding will be performed in nitrogen atmosphere unlike other hardening process. Nitriding will form carbo nitride which is a very hard compound, which will prove wear resistance.

2. What is the difference between malleable and spheroidal cast iron?

Malleable cast irons are used for hot rolling and forging. Spheroidal cast iron are used for machining operations like turning and milling.

3. What are the primary groups of plain carbon steels?

Low carbon steel, mild steel and high carbon steel.

4. What is meant by precipitation hardening?

Precipitation hardening, also called age or particle hardening, is a heat treatment process that helps make metals stronger. The process does this by producing uniformly dispersed particles within a metal's grain structure that help hinder motion and thereby strengthen it—particularly if the metal is malleable.

5. What is effect of Si in steel?

It increases strength without limiting grain size. Used to promote large grain sizes used in magnetic applications. Used in spring steels.

6. What are brasses and bronze?

Brasses are alloys of copper and zinc and may contain small amount of other alloying elements. Traditional bronze is a copper alloy with with up to 10% tin. The tin in bronze makes it more resistant to wear than unalloyed copper. Bronzes today are usually stronger and more resistant to corrosion than brass.

7. What are the effects of adding Si in steels? (Apr/May 2017)

Deoxidize, fine grain size, increases fatigue strength and increase wear properties.

8. Differentiate brass from bronze?

Alloy	Composition	Uses	Advantages
Brass	70% Cu, 30% Zn	House hold and nautical fittings, musical instrument	Appearance, limited corrosion, harder than pure copper
Bronze	95% Cu, 5% Sn	Status, ornaments, bells	Appearance, little corrosion, harder than brass, sonorous (rings well when struck)

9. Which type of stainless steel is non magnetic? (Nov/Dec 2017)  
Austenitic steels are non magnetic in nature
10. What is the role of boron in steel alloying? (Nov/Dec 2017)  
The role of boron in steel is to enhance the hardness level through enhancing the hardenability.
11. What is HSLA? Explain with respect to composition, properties and application.  
High-strength low-alloy steel (HSLA) is a type of alloy steel that provides better mechanical properties or greater resistance to corrosion than carbon steel. HSLA steels vary from other steels in that they are **not** made to meet a specific chemical composition but rather to specific mechanical properties. They have carbon content between 0.05–0.25% to retain formability and weldability. Other alloying elements include up to 2.0% manganese, small quantities of copper, nickel, niobium, nitrogen, vanadium, chromium, molybdenum, titanium, calcium, rare earth elements, or zirconium. They are used in cars, trucks, cranes, bridges, roller coasters and other structures that are designed to handle large amounts of stress or need a good strength-to-weight ratio. HSLA steel cross-sections and structures are usually 20 to 30% lighter than carbon steel with the same strength.
12. Explain briefly the effect of ferrite stabilizer on the eutectoid temperature and composition.  
Stabilizing ferrite decreasing the temperature range, in which austenite exists. The elements having the same crystal structure as the ferrite lower the A<sub>4</sub> point and increases A<sub>3</sub> point. These elements lower the solubility of carbon in austenite, causing increase of amount of carbides in the steel. Ferrite stabilizers are chromium, tungsten, molybdenum, vanadium, aluminum and silicon.
13. Which type of stainless steel is used for surgical instruments.  
Martensitic stainless steel is used to make surgical instruments.
14. What is the typical constituent microstructure of bearing alloy  
The alloy mentioned in the patent was 89% Tin, 9% Antimony and 2% Copper, which is amazingly close to today's very popular ASTM B-23 Grade 2 "Babbitt" was originally applied to Tin-base alloys, it is now used to describe bearing metals with Lead or other metals as the major element.

15. What are the primary effects of chromium and copper as alloying elements in steel  
Chromium stabilizes ferrite, increases corrosion resistance and increases hardness.  
Copper will increase the ductility and increases fracture toughness.
16. What are super alloys  
Super alloys are the alloys of Nickel and tungsten which is used in high temperature application.
17. What are the effects of alloying additions on steel?  
To increase Strength, Hardness, Toughness, Properties
18. What are the various types of Tool steels? Plain carbon  
Low alloy  
High speed  
High Chromium High Carbon steels
19. Write short notes on types of stainless steels. (May 2009) Austenite Stainless steel: They have austenite structure retained at room temperature.  
Ferrite stainless steel: They have ferrite structure at all room temperatures up to their melting points. Martensitic stainless steels.
20. How Bearing alloys classified?  
White metal  
Copper base  
Aluminium base

## **PART B**

1. Brief on the influence of alloying elements: Co, Ni, Mo and V
- Co:
- Increases hardness
  - Increases hardenability
  - Increases wear resistance
  - Increases high temperature hardness
  - Increases creep resistance
- Ni:
- Increases hardness
  - Increases hardenability
  - Increases wear resistance
  - Increases high temperature hardness

- Increases creep resistance

Mo:

- Increases work hardenability
- Decreases critical cooling rate
- Induces ductility.
- Reduced cold cracking

V:

- Increases the critical cooling rate
- Increase hardenability
- Increases wear resistance
- Improves surface hardness depth.

2. List the types and their typical applications of tool steel.

Refer question no. 8

3. Brief the precipitation hardening and ageing treatment of Al-Cu alloy.

Refer question no. 9

4. Write a short notes on : HSLA steel, maraging steel, stainless steel.

Refer question no. 8 and 11 in part-A

5. Discuss the characteristics of copper and its alloys, their properties and applications.

Refer question no. 17 and 19.

6. What are tool steel? Explain its types.

Refer question no. 8 and 18.

7. Explain age hardening of Al-Cu with the help of phase diagram.

Refer question no. 9

8. Classify stainless steel and tool steel and explain the following:

Maraging steel:

Maraging steels (a portmanteau of “martensitic” and “aging”) are steels (iron alloys) that are known for possessing superior strength and toughness without losing malleability, although they cannot hold a good cutting edge. Aging refers to the extended heat-treatment process. These steels are a special class of low-carbon ultra-high-strength steels that derive their strength not from carbon, but from precipitation of intermetallic compounds. The principal alloying element is 15 to 25 wt.% nickel.[1] Secondary alloying elements, which include cobalt, molybdenum, and titanium, are added to produce intermetallic precipitates,. [1] Original development (by Bieber of Inco in the late 1950s) was carried out on 20 and 25

wt.% Ni steels to which small additions of Al, Ti, and Nb were made; a rise in the price of cobalt in the late 1970s led to the development of cobalt-free maraging steels

Spheroidal graphite iron:

Ductile iron, also known as ductile cast iron, nodular cast iron, spheroidal graphite iron, spheroidal graphite cast iron and SG iron, is a type of cast iron. Ductile iron is not a single material but part of a group of materials which can be produced with a wide range of properties through control of their microstructure. The common defining characteristic of this group of materials is the shape of the graphite. In ductile irons, graphite is in the form of nodules rather than flakes as in grey iron. Whereas sharp graphite flakes create stress concentration points within the metal matrix, rounded nodules inhibit the creation of cracks, thus providing the enhanced ductility that gives the alloy its name. Nodule formation is achieved by adding nodulizing elements, most commonly magnesium (magnesium boils at 1100 °C and iron melts at 1500 °C) and, less often now, cerium (usually in the form of mischmetal). Tellurium has also been used. Yttrium, often a component of mischmetal, has also been studied as a possible nodulizer.

High speed steel in terms of composition, property and use.

High-speed steel (HSS or HS) is a subset of tool steels, commonly used in tool bits and cutting tools.

1. It is often used in power-saw blades and drill bits. It is superior to the older high-carbon steel tools used extensively through the 1940s in that it can withstand higher temperatures without losing its temper (hardness). This property allows HSS to cut faster than high carbon steel, hence the name high-speed steel. At room temperature, in their generally recommended heat treatment, HSS grades generally display high hardness (above Rockwell hardness 60) and abrasion resistance (generally linked to tungsten and vanadium content often used in HSS) compared with common carbon and tool steels. Alloys are tungsten, molybdenum and cobalt.

9. With part of phase diagram and relevant graphs explain precipitation hardening treatment of Al-Cu alloys.

Age hardenable alloys are one of the most important classes of alloys both from the practical and scientific points of view: from a practical viewpoint, they are important because they show that by a suitable heat treatment of solutionising and aging, it is possible to improve mechanical properties; from a scientific viewpoint, in age hardenable alloys, the correlation between microstructure and mechanical properties as well as the methodology of manipulation of the microstructures through appropriate phase transformation is very clearly seen.

In Fig. 1 we show the hardness in certain Al-Cu alloys as a function of aging time at, say, 130°C. These alloys were initially solution treated in the single phase  $\alpha$  region, quenched to room temperature and then aged at the given temperature. As is clear from these figures, the hardness increases with time at least in the initial stages of the aging treatment; however, in all alloys, the hardness starts dropping after some time; this drop in hardness with time is known as overaging. As shown in Fig. 2, broadly similar behaviour is also observed in Al-Cu alloys aged at 190°C. However, at this high temperature, the overaging sets in much earlier; further, the changes in hardness are more monotonous (with no plateau regions).



In Fig. 3 and Fig. 4, we show the aging curves; however, this time, we also superimpose the different phases that precipitate out of the matrix at these temperatures for the given times on the aging curves. There is a clear correlation between the phases that form and the change in hardness; typical increases in hardness are associated with the formation of GP (Guinier-Preston) zones and  $\theta\theta$  precipitates; in most cases, the formation of  $\theta$  leads to a decrease in hardness.

Immediately after quenching to room temperature the only contribution to strengthening (that is, resistance to the movement of dislocations) comes from the solid solution: copper atoms at the aluminium sites which resist the movement of dislocations. However, as the GP zones form, the elastic stresses associated with the coherent GP zones resist the movement of dislocations contributing to hardness. As the aging time increases, the coherent  $\theta\theta$  phases that form, due to the misfit strains that they produce, manage to resist the movement of dislocations and hence lead to further hardening. Finally the formation of semicoherent  $\theta$  can also increase the strength; however, in the case of both  $\theta\theta$  and  $\theta$  if the particles are coarser or the volume fractions of these phases are smaller (and hence are further apart) it leads to a decrease in hardness since the dislocations can bow between the precipitates and hence move in the matrix contributing to the plastic deformation. We also notice that at the higher temperature the peak hardness (the highest hardness that is achieved before overaging) is lower; this is because the lower driving force at the higher temperature for the formation of the  $\theta\theta$  phase leads to a coarsely dispersed phase with lower volume fractions. In the following sections, we discuss in detail the thermodynamics and kinetics of precipitation in age-hardenable Al-Cu alloys.

1. In Fig. 5, we show the Al-rich portion of the Al-Cu phase diagram (schematically). From the phase diagram, it is clear that the Al with a few percent copper is cooled from high temperature leads to the formation of a microstructure in which the phase precipitates out of the supersaturated matrix. However, if an alloy of composition Al - 4 wt.% Cu is solutionised at say, 540°C, and the resultant phase is rapidly quenched to room temperature, the solid solution is largely retained; if this alloy is kept at room temperature (or at any temperature below 180°C), a metastable phase known as Guinier-Preston zones (GP zones) is formed. Similarly, the aging treatment at other temperatures can produce other precipitates such as  $\theta\theta$  and  $\theta$ . The solvus for these metastable phases is shown in Fig. 6. Further, in Fig. 6, we also show the corresponding time-temperature-transformation curves for these metastable phase as well as the stable phase. In the following sections, we describe the crystallography and interface structure of all these phases as well as the reasons for their formation.

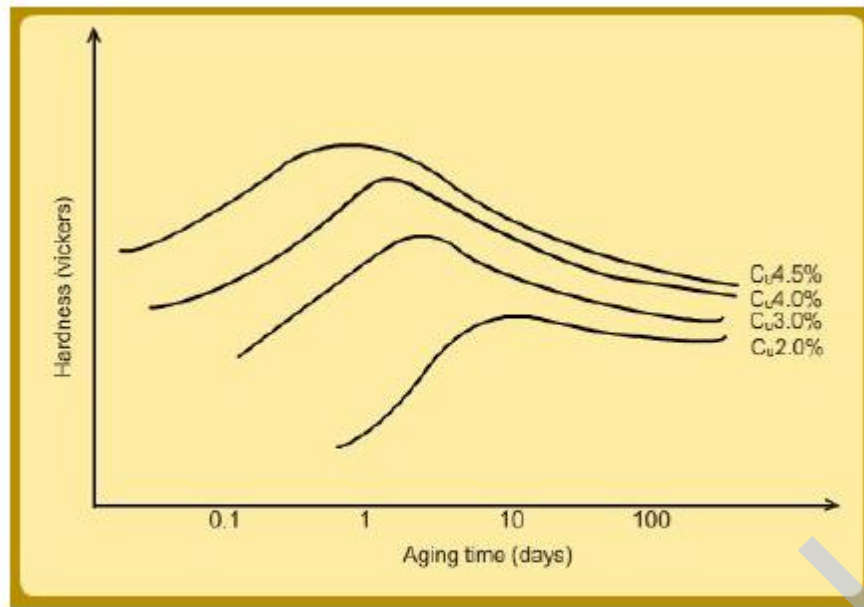


Figure 2: Aging curves at 190° C for Al-Cu system.

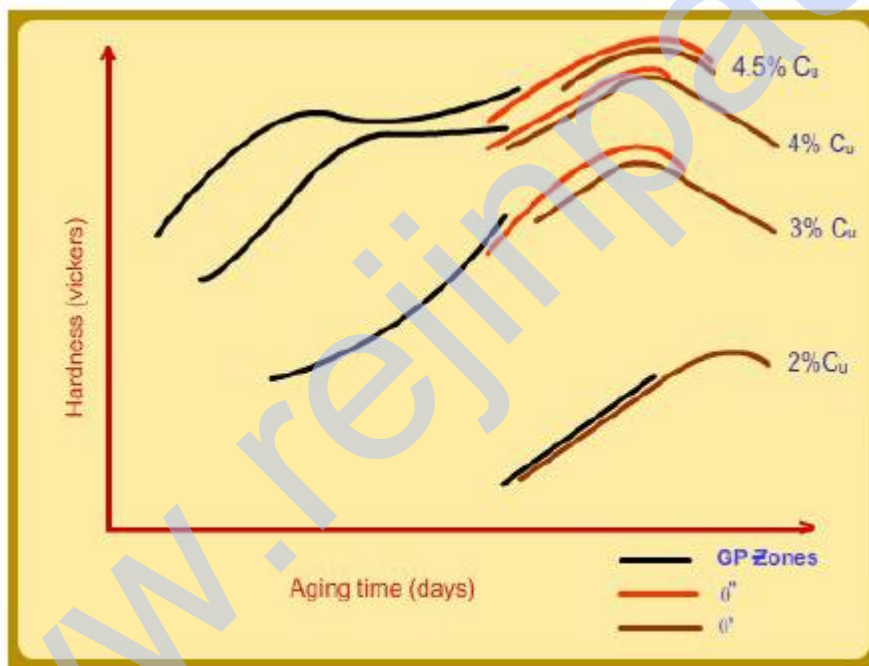


Figure 3: Aging curves with phases: 130°

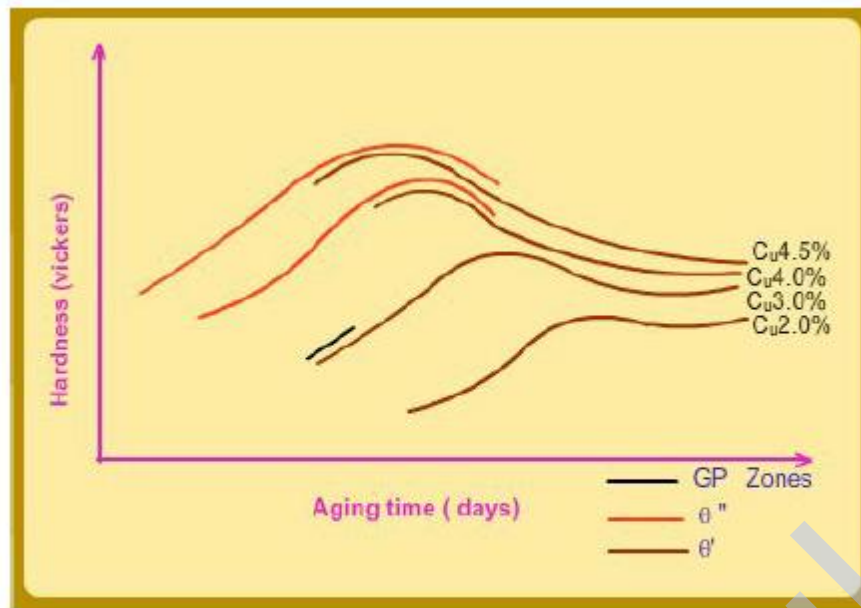


Figure 4: Aging curves with phases: 190°

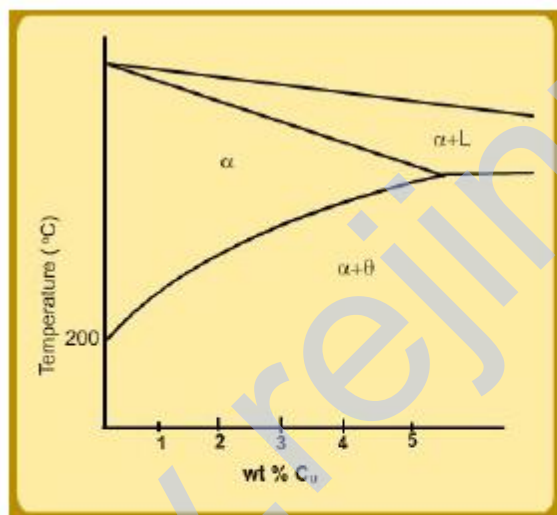


Figure 5: Al-rich portion of Al-Cu phase diagram.

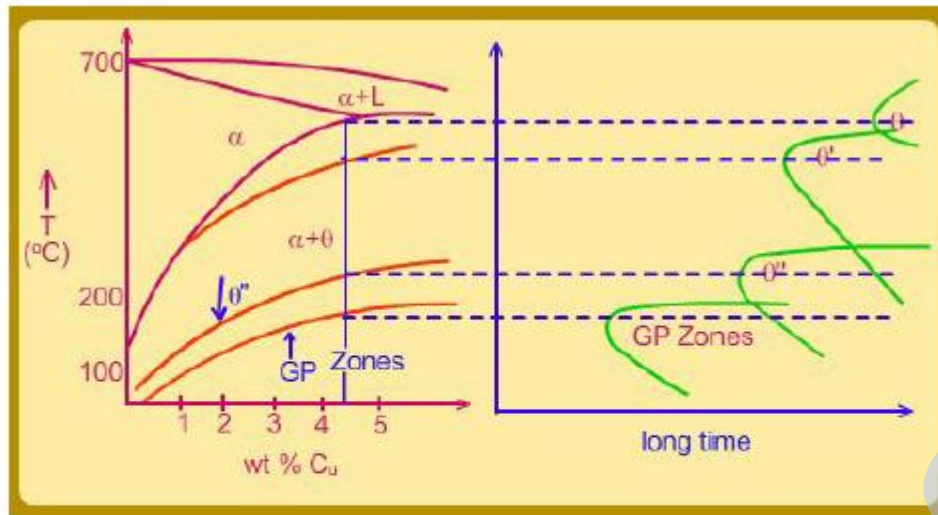


Figure 6: Metastable phases along with their TTT diagrams for Al-rich Al-Cu alloys.

#### 10. Brief on the influence of alloying elements in steel under classification of carbide former and non carbide former.

##### Carbon:

Carbon is alloyed with base metal Iron to make steel which affects the hardness and strength of material. Thus the addition of carbon enables a wide range of hardness and strength.

**Manganese:** Manganese is added to improve hot working properties and increase strength, toughness and hardenability. Manganese, like nickel, is an austenite forming element and can be used as a substitute for nickel.

**Chromium:** Chromium is added to the steel to increase corrosion resistance. The resistance increases as more chromium is added. 'Stainless Steel' has approximately 11% chromium and a very marked degree of general corrosion resistance when compared with steels with a lower percentage of chromium. When added to low alloy steels, chromium can increase the response to heat treatment, thus improving hardenability and strength.

##### Nickel:

Nickel is added in large amounts, over about 8%, to high chromium stainless steel to form the most important class of corrosion and heat resistant steels. These are the austenitic stainless steels, where the tendency of nickel to form austenite is responsible for a great toughness and high strength at both high and low temperatures. Nickel also improves resistance to oxidation and corrosion. It increases toughness at low temperatures when added in smaller amounts to alloy steels.

##### Molybdenum:

Molybdenum, when added to chromium-nickel steels, improves resistance to pitting corrosion especially by chlorides and sulphur chemicals. When added to low alloy steels, molybdenum improves high temperature strengths and hardness. When added to chromium steels it greatly diminishes the tendency of steels to decay in service or in heat treatment.

##### Titanium:

Used as stabilizing elements in stainless steels. Each has a high affinity for carbon and forms carbides, which are uniformly dispersed throughout the steel. Thus, localized precipitation of carbides at grain boundaries is prevented. Compared to chromium, carbon has higher affinity to titanium to form inter-granular carbides and hence accompanying loss of corrosion resistance at the grain boundaries.

**Phosphorus:**

Phosphorus is usually added with sulphur to improve machinability in low alloy steels, phosphorus, in small amounts, increases strength and corrosion resistance. Experimental work shows that phosphorus present in steel increases strength. Phosphorus additions are known to increase the tendency to cracking during welding. Sulphur:

When added in small amounts sulphur improves machinability but does not cause hot shortness. Hot shortness is reduced by the addition of manganese, which combines with the sulphur to form manganese sulphide. As manganese sulphide has a higher melting point than iron sulphide, which would form if manganese were not present, the weak spots at the grain boundaries are greatly reduced during hot working.

**Selenium:**

Selenium is added to improve machinability.

**Niobium (Columbium):**

Niobium is added to steel in order to stabilise carbon, and as such performs in the same way as described for titanium. Niobium also has the effect of strengthening steels and alloys for high temperature service.

**Nitrogen:**

Nitrogen has the effect of increasing the austenitic stability of stainless steels and is, as in the case of nickel, an austenite forming element. Yield strength is greatly improved when nitrogen is added to austenitic stainless steels.

**Silicon:**

Silicon is used as a deoxidizing (killing) agent in the melting of steel, as a result, most steels contain a small percentage of silicon. Silicon contributes to hardening of the ferritic phase in steels and for this reason silicon killed steels are somewhat harder and stiffer than aluminum killed steels.

**Cobalt:**

Cobalt becomes highly radioactive when exposed to the intense radiation of nuclear reactors, and as a result, any stainless steel that is in nuclear service will have a cobalt restriction, usually approximately 0.2% maximum. This problem is emphasized because there is residual cobalt content in the nickel used in producing these steels.

**Tantalum:**

Chemically similar to niobium and has similar effects. Copper:

Copper is normally present in stainless steels as a residual element. However it is added to a few alloys to produce precipitation-hardening properties.

**Vandium:**

Increases strength, hardness, wear resistance and resistance to shock impact. It retards grain growth, permitting higher quenching temperatures. It also enhances the red-hardness properties of high-speed metal cutting tools

**Tungsten:**

Increases strength, wear resistance, hardness and toughness. Tungsten steels have superior hot-working and greater cutting efficiency at elevated temperatures.

11. List the types and their typical application of stainless steel.

In the early nineteen hundreds, metallurgists noticed that chromium had a greater attraction to oxygen than iron did so they added the element chromium to steel. Studies prove that when at least 10% chromium was added, the chrome united with oxygen to form a very tight transparent layer over the steel surface that prevented rusting by precluding further oxidation. This transparent layer is self-healing when damaged by scratches, wear or denting. Stainless steels are materials of enduring beauty. These steels also withstand the corrosive attack of many acids. They possess strength and toughness at both extremes of the temperature scale, yet can be fabricated into intricate shapes for many uses. Because of this outstanding versatility, stainless deserves careful consideration for any product where one or more of the following requirements are involved: Corrosion Resistance Strength at Elevated Temperatures Strength and Ductility at Cryogenic Temperatures Oxidation Resistance at High Temperatures Appearance Abrasion Resistance Let's Go to Class There are more than 250 different stainless steels. These various grades of stainless are divided into five major families or classes. The general classes have been developed to consolidate the chemistries and mechanical properties required to meet specific customer application needs. Martensitic Stainless Steels These steels of the 400 series usually contain a minimum of 11.5% up to 18% chromium and have higher levels of carbon than ferritics. They are capable of being heat treated to a wide range of useful hardness and strength levels, and are used extensively in cutlery, sports knives and multipurpose tools. Ferritic Stainless Steels This group of steels in the 400 series contains 10.5% to 20% chromium for corrosion resistance and resistance to scaling at elevated temperatures. They are nonhardenable by heat treating and are always magnetic. Ferritic stainless is used in applications where resistance to corrosion is important, such as automotive emission control exhaust systems. Austenitic Stainless Steels Austenitic stainless steels are the most specified grades produced because of their excellent formability and corrosion resistance. All 200 and 300 series steels are austenitic and contain 15% to 30% chromium and 2% to 20% nickel for enhanced surface quality, formability and increased corrosion and wear resistance. They are non-magnetic in the annealed condition and depending on the composition, primarily the nickel content, they become slightly magnetic when cold worked. These steels are used for automotive trim, cookware, processing equipment and a variety of industrial applications

Precipitation-Hardening Stainless Steels There are two general areas of PH grade stainless steels; martensitic and semi-austenitic. The martensitic group includes 17-4 PH® and 15-5 PH® chromiumnickel, with columbium and copper additions. They develop their high strength and hardness through heat treatment, which precipitates the copper. The martensitic PH steels are used in aerospace, chemical and petrochemical, and food processing applications. The semi-austenitic grades are 17-7 PH® and PH 15-7 Mo®. They are austenitic in the annealed state, but martensitic in the hardened condition. 17-7 PH stainless has excellent high strength and fatigue properties, and is used in aerospace components. PH 15-7 Mo stainless is used in applications requiring high strength and hardness, such as retaining rings, springs and aircraft bulkheads. Duplex Stainless Steels These alloys have a mixture of austenite and ferrite in their structure. They exhibit characteristics of both phases with higher strength and ductility. Nitrogen is added to second generation duplex alloys and



provides strength and increased weldability. AK Steel's NITRONIC® 19D has good cyclic oxidation, high strength and excellent stress corrosion resistance, and the 2205 alloy provides very good pitting and uniform corrosion resistance, high strength and high resistance to stress corrosion cracking.

12. What are the types of titanium alloy their composition properties and application.

Titanium has been recognized as an element (Symbol Ti; atomic number 22; and atomic weight 47.9) for at least 200 years. However, commercial production of titanium did not begin until the 1950's. At that time, titanium was recognized for its strategic importance as a unique lightweight, high strength alloyed, structurally efficient metal for critical, high-performance aircraft, such as jet engine and airframe components. The worldwide production of this originally exotic, "Space Age" metal and its alloys has since grown to more than 50 million pounds annually. Increased metal sponge and mill product production capacity and efficiency, improved manufacturing technologies, a vastly expanded market base and demand have dramatically lowered the price of titanium products. Today, titanium alloys are common, readily available engineered metals that compete directly with stainless and specialty steels, copper alloys, nickel based alloys and composites. As the ninth most abundant element in the Earth's Crust and fourth most abundant structural metal, the current worldwide supply of feedstock ore for producing titanium metal is virtually unlimited. Significant unused worldwide sponge, melting and processing capacity for titanium can accommodate continued growth into new, high-volume applications. In addition to its attractive high strength to-density characteristics for aerospace use, titanium's exceptional corrosion resistance derived from its protective oxide film has motivated extensive application in seawater, marine, brine and aggressive industrial chemical service over the past fifty years. Today, titanium and its alloys are extensively used for aerospace, industrial and consumer applications. In addition to aircraft engines and airframes, titanium is also used in the following applications: missiles; spacecraft; chemical and petrochemical production; hydrocarbon production and processing; power generation; desalination; nuclear waste storage; pollution control; ore leaching and metal recovery; offshore, marine deepsea applications, and Navy ship components; armor plate applications; anodes, automotive components, food and pharmaceutical processing; recreation and sports equipment; medical implants and surgical devices; as well as many other areas. This booklet presents an overview of commercial titanium alloys offered by RMI Titanium Company. The purpose of this publication is to provide fundamental mechanical and physical property data, incentives for their selection, and basic guidelines for successful fabrication and use. Additional technical information can be found in the sources referenced in the back of this booklet. Further information, assistance, analysis and application support for titanium and its alloys, can be readily obtained by contacting RMI Titanium Company headquartered in Niles, Ohio, USA, or any of its facilities and offices worldwide listed in this booklet.

Titanium and its alloys exhibit a unique combination of mechanical and physical properties and corrosion resistance which have made them desirable for critical, demanding aerospace, industrial, chemical and energy industry service. Of the primary attributes of these alloys listed in Table 1, titanium's elevated strength-to-density represents the traditional primary incentive for selection and design into aerospace engines and airframe structures and components. Its exceptional corrosion/erosion resistance provides the prime motivation for chemical process, marine and industrial use. Figure 1 reveals the superior structural efficiency of high strength titanium alloys compared to structural steels and aluminum alloys, especially as service temperatures increase. Titanium alloys also offer attractive elevated

temperature properties for application in hot gas turbine and auto engine components, where more creep resistant alloys can be selected for temperatures as high as 600°C (1100°F) [see Figure 2]. The family of titanium alloys offers a wide spectrum of strength and combinations of strength and fracture toughness as shown in Figure 3. This permits optimized alloy selection which can be tailored for a critical component based on whether it is controlled by strength and S-N fatigue, or toughness and crack growth (i.e., critical flaw size) in service. Titanium alloys also exhibit excellent S-N fatigue strength and life in air, which remains relatively unaffected by seawater (Figure 4) and other environments. Most titanium alloys can be processed to provide high fracture toughness with minimal environmental degradation (i.e., good SCC resistance) if required.

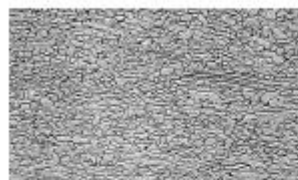
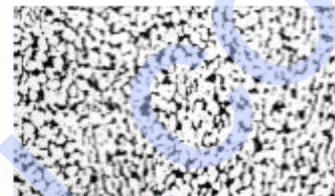
RMI titanium mill products, available in both commercially pure and alloy grades, can be grouped into three categories according to the predominant phase or phases in their microstructure ... alpha, alpha-beta, and beta. Although each of these three general alloy types requires specific and different mill processing methodologies, each offers a unique suite of properties which may be advantageous for a given application. In pure titanium, the alpha phase ... characterized by a hexagonal close packed crystalline structure ... is stable from room temperature to approximately 882°C (1620°F). The beta phase in pure titanium has a body-centered cubic structure and is stable from approximately 882°C (1620°F) to the melting point of about 1688°C (3040°F). Effects of Alloying Elements The selective addition of alloying elements to titanium enables a wide range of physical and mechanical properties to be obtained. Basic effects of a number of alloying elements are as follows: 1. Certain alloying additions, notably aluminum and interstitials (O, N,C), tend to stabilize the alpha phase, i.e., raise the temperature at which the alloy will be transformed completely to the beta phase. This temperature is known as the beta transus temperature. 2. Most alloying additions ... such as chromium, niobium, copper, iron, manganese, molybdenum, tantalum, vanadium ... stabilize the beta phase by lowering the temperature of transformation (from alpha to beta). 3. Some elements ... notably tin and zirconium ... behave as neutral solutes in titanium and have little effect on the transformation temperature, acting as strengtheners of the alpha phase. Titanium alloy microstructures are characterized by the various alloy additions and processing. A description of the various types of alloys and typical photomicrographs of various mill products manufactured are illustrated. Alpha Alloys The single-phase and near single-phase alpha alloys of titanium exhibit good weldability. The generally high aluminum content of this group of alloys assures excellent strength characteristics and oxidation resistance at elevated temperatures (in the range of 316-593°C (600 - 1100°F)). Alpha alloys cannot be heat-treated to develop higher strength since they are singlephase alloys. Alpha-Beta Alloys The addition of controlled amounts of beta-stabilizing alloying elements causes some beta phase to persist below the beta transus temperature, down to room temperature ... resulting in a twophase system. Even small amounts of beta stabilizers will stabilize the beta phase at room temperature. A group of alloys designed with high amounts of alpha stabilizers and with a small amount of beta stabilizers are alphabeta alloys, usually called high alpha or near alpha alloys. As larger amounts of beta stabilizers are added, a higher percentage of the beta phase is retained at room temperature. Such two-phase titanium alloys can be

significantly strengthened by heat treatment ... quenching from a temperature high in the alpha-beta range, followed by an aging cycle at a somewhat lower temperature. The transformation of the beta phase ... which would normally occur on slow cooling is suppressed by the quenching. The aging cycle causes the precipitation of fine alpha particles from the metastable beta, imparting a structure that is stronger than the annealed alpha-beta structure. Beta Alloys The high percentage of beta-stabilizing elements in this group of titanium alloys results in a microstructure that is metastable beta after solution annealing. Extensive strengthening can occur by the precipitation of alpha during aging.



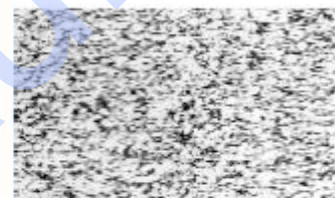
Ti-6Al-2Sn-2Zr-2Mo-2Cr-Si  
200X  
Alpha-beta alloy  
1.6mm (0.063 in.) sheet  
900°C (1650°F)/30 Min.;  
Air Cool +  
510°C (950°F)/10 Hr.;  
Air Cool  
(Solution treated and aged)

Ti-6Al-2Sn-4Zr-2Mo-Si  
200X  
Near alpha alloy  
230mm (9 in.) round  
billet  
(As forged condition)



Ti-4.5Al-3V-2Mo-2Fe  
(SF700)  
500X  
Alpha-beta alloy 45mm  
(1.7 in.) plate  
788°C (1450°F)/2 Hr.;  
Air Cool  
(Mill-annealed condition)

Ti-6Al-4V  
100X  
Alpha-beta alloy  
8mm (0.031 in.) sheet  
788°C (1450°F)/15 Min.;  
Air Cool  
(Mill-annealed condition)



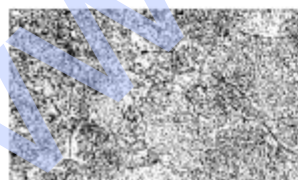
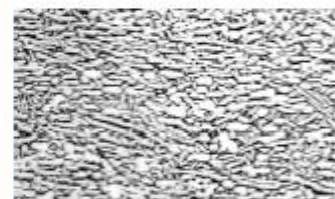
#### Beta Alloys

The high percentage of beta-stabilizing elements in this group of titanium alloys results in a microstructure that is metastable beta after solution annealing. Extensive strengthening can occur by the precipitation of alpha during aging.



Ti-1Al-8V-4Cr-4Zr-4Mo  
100X  
Beta alloy 16mm  
(0.625 in.) dia. bar  
816°C (1500°F)/30 Min.;  
Air Cool  
(Solution treated condition)

Ti-6Al-4V  
200X  
Alpha-beta alloy 38mm  
(1.5 in.) plate  
788°C (1450°F)/15 Min.;  
Air Cool  
(Mill-annealed condition)



Ti-1Al-8V-4Cr-4Zr-4Mo  
250X  
Beta alloy 16mm  
(0.625 in.) dia. bar  
816°C (1500°F)/15 Min.;  
Air Cool +  
560°C (1050°F)/10 Hr.;  
Air Cool  
(Solution treated and aged condition)

Ti-6Al-4V  
100X  
Alpha-beta alloy 38mm  
(1.5 in.) bar  
1016°C (1860°F)/20 Min.;  
Air Cool  
(Transformed-beta condition)



### 13. Brief on the precipitation hardening and ageing treatment of Al- Cu alloy.

Age hardenable alloys are one of the most important classes of alloys both from the practical and scientific points of view: from a practical viewpoint, they are important because they show that by a suitable heat treatment of solutionising and aging, it is possible to improve mechanical properties; from a scientific viewpoint, in age hardenable alloys, the correlation between microstructure and mechanical properties as well as the methodology of

manipulation of the microstructures through appropriate phase transformation is very clearly seen. In Fig. 1 we show the hardness in certain Al-Cu alloys as a function of aging time at, say, 130°C. These alloys were initially solution treated in the single phase  $\alpha$  region, quenched to room temperature and then aged at the given temperature. As is clear from these figures, the hardness increases with time at least in the initial stages of the aging treatment; however, in all alloys, the hardness starts dropping after some time; this drop in hardness with time is known as overaging. As shown in Fig. 2, broadly similar behaviour is also observed in Al-Cu alloys aged at 190°C. However, at this high temperature, the overaging sets in much earlier; further, the changes in hardness are more monotonous (with no plateau regions).

In Fig. 3 and Fig. 4, we show the aging curves; however, this time, we also superimpose the different phases that precipitate out of the matrix at these temperatures for the given times on the aging curves. There is a clear correlation between the phases that form and the change in hardness; typical increases in hardness are associated with the formation of GP (Guinier-Preston) zones and  $\theta_0$  precipitates; in most cases, the formation of  $\theta$  leads to a decrease in hardness.

Immediately after quenching to room temperature the only contribution to strengthening (that is, resistance to the movement of dislocations) comes from the solid solution: copper atoms at the aluminium sites which resist the movement of dislocations. However, as the GP zones form, the elastic stresses associated with the coherent GP zones resist the movement of dislocations contributing to hardness. As the aging time increases, the coherent  $\theta_0$  phases that form, due to the misfit strains that they produce, manage to resist the movement of dislocations and hence lead to further hardening. Finally the formation of semicoherent  $\theta$  can also increase the strength; however, in the case of both  $\theta_0$  and  $\theta$  if the particles are coarser or the volume fractions of these phases are smaller (and hence are further apart) it leads to a decrease in hardness since the dislocations can bow between the precipitates and hence move in the matrix contributing to plastic deformation. We also notice that at the higher temperature the peak hardness (the highest hardness that is achieved before overaging) is lower; this is because the lower driving force at the higher temperature for the formation of the  $\theta_0$  phase leads to a coarsely dispersed phase with lower volume fractions. In the following sections, we discuss in detail the thermodynamics and kinetics of precipitation in age-hardenable Al-Cu alloys. In Fig. 5, we show the Al-rich portion of the Al-Cu phase diagram (schematically). From the phase diagram, it is clear that the Al with a few percent copper is cooled from high temperature leads to the formation of a microstructure in which the phase precipitates out of the supersaturated matrix.

However, if an alloy of composition Al - 4 wt.% Cu is solutionised at say, 540°C, and the resultant phase is rapidly quenched to room temperature, the solid solution is largely retained; if this alloy is kept at room temperature (or at any temperature below 180°C), a metastable phase known as Guinier-Preston zones (GP zones) is formed. Similarly, the aging treatment at other temperatures can produce other precipitates such as  $\theta_0$  and  $\theta$ . The solvus for these metastable phases is shown in Fig. 6. Further, in Fig. 6, we also show the corresponding time-temperature-transformation curves for these metastable phase as well as the stable phase. In the following sections, we describe the crystallography and interface structure of all these phases as well as the reasons for their formation.



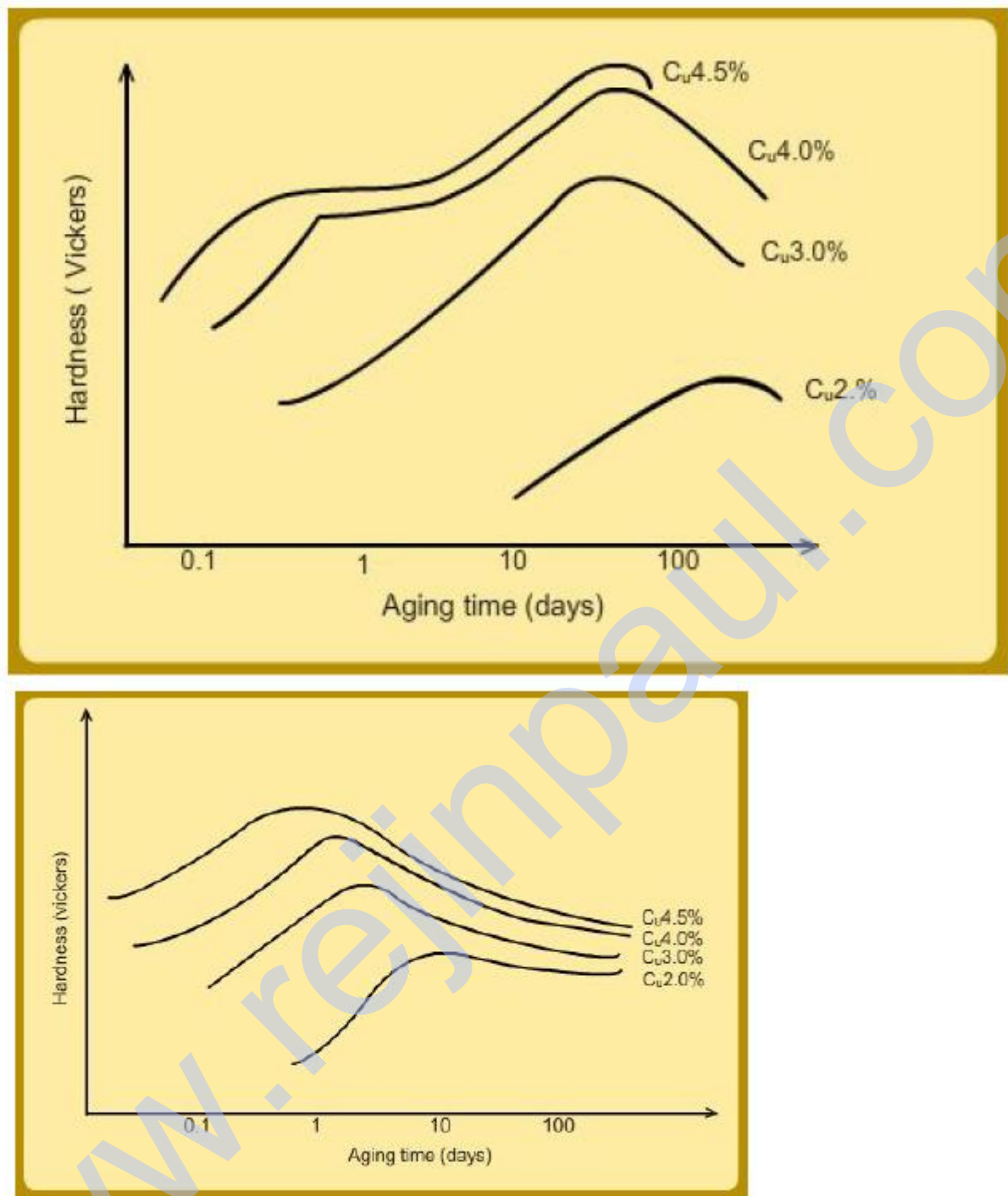


Figure 2: Aging curves at 190° C for Al-Cu system.



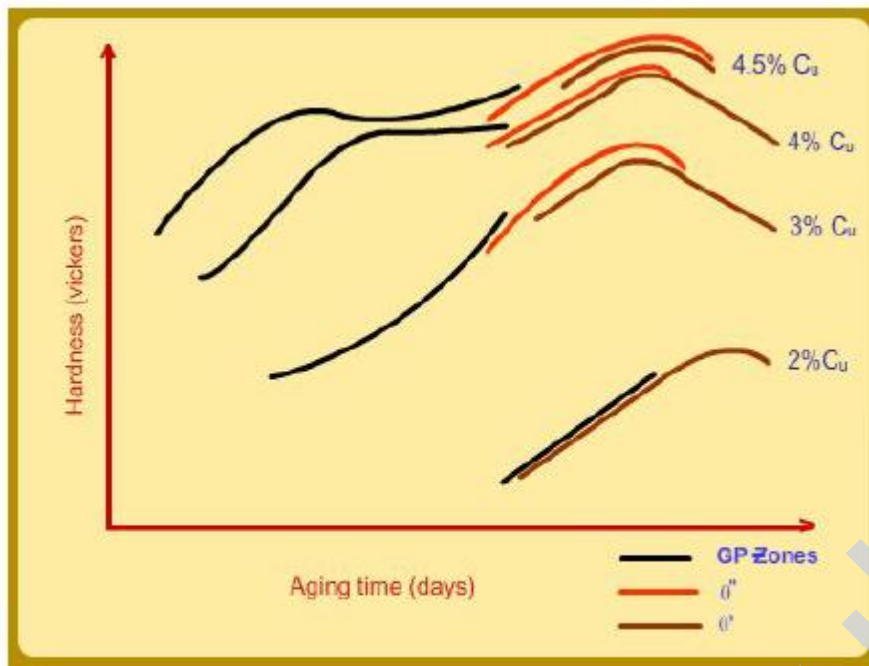


Figure 3: Aging curves with phases: 130°



Figure 4: Aging curves with phases: 190°

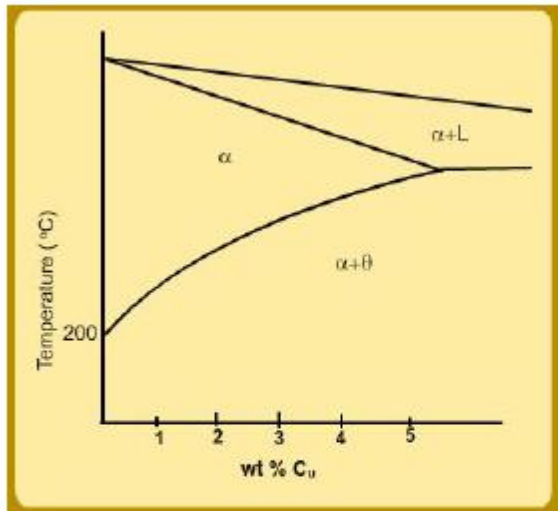


Figure 5: Al-rich portion of Al-Cu phase diagram.

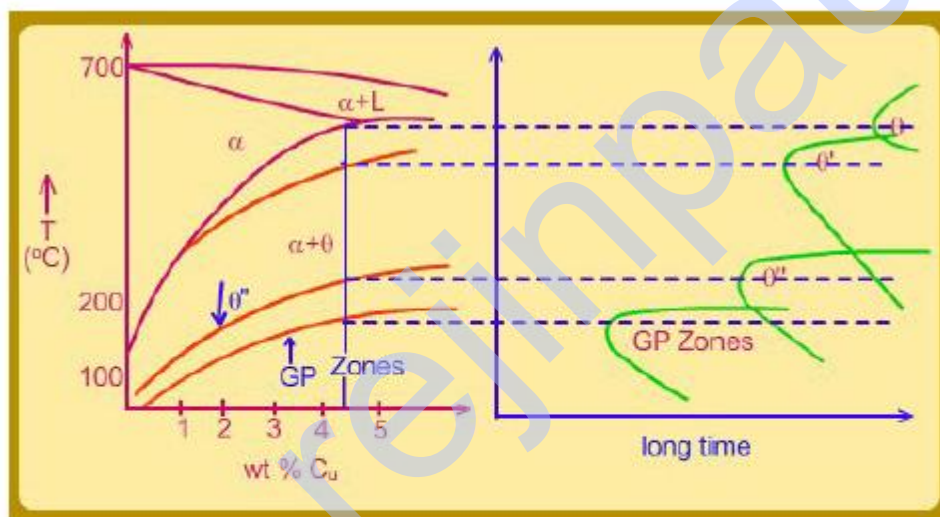


Figure 6: Metastable phases along with their TTT diagrams for Al-rich Al-Cu alloys.

14. With a neat sketch, explain precipitation hardening.

Solid solution hardening- strengthening by dissolving an alloying element.

Atoms of solute element distort the crystal lattice, resisting the dislocations motion. Interstitial elements are more effective in solid solution hardening, than substitution elements.

Dispersion strengthening – strengthening by adding second phase into metal matrix.

The second phase boundaries resist the dislocations motions, increasing the material strength. The strengthening effect may be significant if fine hard particles are added to a soft ductile matrix (composite materials).

Hardening by result of Spinodal decomposition. Spinodal structure is characterized by strains on the coherent boundaries between the Spinodal phases causing hardening of the alloy.

Precipitation hardening (age hardening) – strengthening by precipitation of fine particles of a second phase from a supersaturated solid solution.

The second phase boundaries resist the dislocations motions, increasing the material strength. The age hardening mechanism in Al-Cu alloys may be illustrated by the phase diagram of Al-Cu system. When an alloy Al-3% Cu is heated up to the temperature  $T_M$ , all  $CuAl_2$  particles are dissolved and the alloy exists in form of single phase solid solution ( $\alpha$ -phase). This operation is called solution treatment.

Slow cooling of the alloy will cause formation of relatively coarse particles of  $CuAl_2$  intermetallic phase, starting from the temperature  $T_N$ . However if the cooling rate is high (quenching), solid solution will retain even at room temperature  $T_F$ . Solid solution in this non-equilibrium state is called supersaturated solid solution.

Obtaining of supersaturated solid solution is possible when cooling is considerably faster, than diffusion processes. As the diffusion coefficient is strongly dependent on the temperature, the precipitation of  $CuAl_2$  from supersaturated solution is much faster at elevated temperatures (lower than  $T_N$ ). This process is called artificial aging. It takes usually a time from several hours to one aging. Natural aging takes several days or more.

Precipitation from supersaturated solid solution occurred in several steps:

Segregation of Cu atoms into plane clusters. These clusters are called Guinier-Preston zones (G-P1 zones).

Diffusion of Cu atoms to the G-P1 zones and formation larger clusters, called GP2 zones or  $\theta''$  phase. This phase is coherent with the matrix.

Formation of 'θ' phase which is partially coherent with the matrix. This phase provides maximum hardening.

15. State the composition, properties and uses of bearing alloys.

It is preferred over the term "white metal", because the latter term may refer to various bearing alloys, lead- or tin-based alloys, or zinc die-casting metal. Babbitt metal is most commonly used as a thin surface layer in a complex, multi-metal structure, but its original use was as a cast-in-place bulk bearing material. Babbitt metal is characterized by its resistance to galling. Babbitt metal is soft and easily damaged, which suggests that it might be unsuitable for a bearing surface. However, its structure is made up of small hard crystals dispersed in a softer metal, which makes it a metal matrix composite. As the bearing wears, the softer metal erodes somewhat, which creates paths for lubricant between the hard high spots that provide the actual bearing surface. When tin is used as the softer metal, friction causes the tin to melt and function as a lubricant, which protects the bearing from wear when other lubricants are absent.

Internal combustion engines use Babbitt metal which is primarily tin-based because it can withstand cyclic loading. Lead-based Babbitt tends to work-harden and develop cracks but it is suitable for constant-turning tools such as saw blades.

16. Write short notes about the following materials in terms of composition, properties and application.

i) Maraging steel

The common, non-stainless grades contain 17–19 wt.% nickel, 8–12 wt.% cobalt, 3–5 wt.% molybdenum, and 0.2–1.6 wt.% titanium. Addition of chromium produces stainless grades resistant to corrosion. This also indirectly increases hardenability as they require less nickel: high-chromium, high-nickel steels are generally austenitic and unable to transform to martensite when heat treated, while lower-nickel steels can transform to martensite. Alternative variants of Ni-reduced maraging steels are based on alloys of Fe and Mn plus minor additions of Al, Ni, and Ti where compositions between Fe-9wt.% Mn to Fe-15wt.% Mn have been used. The Mn has a similar effect as Ni, i.e. it stabilizes the austenite phase. Hence, depending on their Mn content, Fe-Mn maraging steels can be fully martensitic after quenching them from the high temperature austenite phase or they can contain retained austenite. The latter effect enables the design of maraging-TRIP steels where TRIP stands for Transformation-Induced-Plasticity.

ii) Alpha beta brasses

Alpha-beta brasses	55–65	35–45	Also called duplex brasses, these are suited for hot working. They contain both $\alpha$ and $\beta$ phases; the $\beta$ -phase is body-centered cubic and is harder and stronger than $\alpha$ . Alpha-beta brasses are usually worked hot. The higher proportion of zinc means these brasses are brighter than alpha brasses.
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iii) Austenitic stainless steel

These are alloys containing chromium and nickel, and sometimes molybdenum and nitrogen, structured around the Type 302 composition of iron, 18% chromium, and 8% nickel. 200 Series austenitic stainless steels replace the majority of their nickel content with manganese to reduce cost. Austenitic steels are not hardenable by heat treatment. The most familiar stainless steel is probably SAE 304 stainless steel, also called 18/8 or A2 stainless steel. Type 304 surgical stainless steel is an austenitic steel containing 18-20% chromium and 8-10% nickel.

Alloy 20 (Carpenter 20) is an austenitic stainless steel possessing excellent resistance to hot sulfuric acid and many other aggressive environments which would readily attack type 316 stainless. This alloy exhibits superior resistance to stress-corrosion cracking in boiling 20-40% sulfuric acid. Alloy 20 has excellent mechanical properties and the presence of Niobium in the alloy minimizes the precipitation of carbides during welding.

Austenitic stainless steel can be tested by nondestructive testing using the dye penetrant inspection method but not the magnetic particle inspection method. Eddy-current testing may also be used. It is the primary stainless steel used in aviation construction. Chemical and steel industry-applicable grades are SAE steel grades 308, 308L, 316, 316L, 316LN (nitrogen bearing), 312, 309L, and 310L. "L" denotes a carbon percentage less than 0.03%, mostly used for corrosion heat resistance and reducing sensitivity to chromium carbide formation. Another grade, 312, is used for dissimilar steel welding, also known as universal alloy steel as unknown composition steels can be welded. For high temperature applications at greater than 600°C, grades 309 and 310 are preferred. Grade 316 is alloyed with molybdenum (~2-3%) for high-temperature strength, pitting and crevice corrosion resistance.

iv) Ferrite stainless steels.

Ferritic steels are high chromium, magnetic stainless steels that have a low carbon content. Known for their good ductility, resistance to corrosion and stress corrosion cracking, ferritic steels are commonly used in automotive applications, kitchenware, and industrial equipment

17. What is cupronickel? Explain its application.

Cupronickel (also known as copper-nickel) is an alloy of copper that contains nickel and strengthening elements, such as iron and manganese. Despite its high copper content, cupronickel is silver in colour.

Due to the specific properties of nickel and copper alloys, they are applied in various domains of industry e.g. mint industry, armaments industry, desalination industry, marine engineering, extensively used in the chemical, petrochemical and electrical industries.[1]

Cupronickel is highly resistant to corrosion in seawater because its electrode potential is adjusted to be neutral with regard to seawater. For this reason, it is used for piping, heat exchangers and condensers in seawater systems, marine hardware, and sometimes for the propellers, crankshafts and hulls of premium tugboats, fishing boats and other working boats.

Another common use of cupronickel is in silver-coloured modern-circulated coins. A typical mix is 75% copper, 25% nickel, and a trace amount of manganese. In the past, true silver coins were debased with cupronickel. Marine engineering

Cupronickel alloys are used for marine applications due to their resistance to seawater corrosion, good fabricability, and their effectiveness in lowering macrofouling levels. Alloys ranging in composition from 90% Cu-10% Ni to 70% Cu-30% Ni are commonly specified in heat exchanger or condenser tubes in a wide variety of marine applications.



Important marine applications for cupronickel include:

Shipbuilding and repair: Cupronickel alloys are used in seawater cooling, bilge and ballast, sanitary, fire fighting, inert gas, hydraulic and pneumatic chiller systems.

Desalination plants: Cupronickel alloys are used in brine heaters, heat rejection and recovery, and in evaporator tubing.

Offshore oil and gas platforms and processing and FPSO vessels: Cupronickel alloys are used in systems and splash zone sheathings.

Power generation: Cupronickel alloys are used in steam turbine condensers, oil coolers, auxiliary cooling systems and high pressure pre-heaters at nuclear and fossil fuel power plants

Seawater system design: Cupronickel alloys are used in tubular heat exchangers and condensers, piping and high pressure systems.

Seawater system components: Cupronickel alloys are used in condenser and heat exchanger tubes, tubesheets, piping, fittings, pumps, and water boxes.

Hulls of boats and ships

Five Swiss francs

The successful use of cupronickel in coinage is due to its corrosion resistance, electrical conductivity, durability, malleability, low allergy risk, ease of stamping (metalworking), antimicrobial properties and recyclability.

In Europe, Switzerland pioneered the nickel *billon* coinage in 1850, with the addition of silver. In 1968, Switzerland adopted the far cheaper 75:25 copper to nickel ratio then being used by the Belgians, the United States, and Germany. From 1947 to 2012, all “silver” coinage in the UK was made from cupronickel, but from 2012 onwards the two smallest cupronickel denominations were replaced with lower-cost nickel-plated steel coins.

In part due to silver hoarding in the Civil War, the United States Mint first used cupronickel for circulating coinage in three-cent pieces starting in 1865, and then for five-cent pieces starting in 1866. Prior to these dates, both denominations had been made only in silver in the United States. Cupronickel is the cladding on either side of United States half-dollars (50¢) since 1971, and all quarters (25¢) and dimes (10¢) made after 1964. Currently, some circulating coins, such as the United States Jefferson nickel (5¢), [13] the Swiss franc, and the South Korean 500 and 100 won are made of solid cupronickel (75/25 ratio). [14]

Other usage

Single-core thermocouple cables use a single conductor pair of thermocouple conductors such as iron-constantan, copper constantan or nickel-chromium/nickel-aluminium. These have the heating element of constantan or nickel-chromium alloy within a sheath of copper, cupronickel or stainless steel.

Cupronickel is used in cryogenic applications. Its combination of good ductility retention and thermal conductivity at very low temperatures is advantageous for low-temperature processing and storage equipment as well as for heat exchangers at cryogenic plants.

Beginning around the turn of the 20th century, bullet jackets were commonly made from this material. It was soon replaced with gilding metal to reduce metal fouling in the bore.

Currently, cupronickel remains the basic material for silver-plated cutlery. It is commonly used for mechanical and electrical equipment, medical equipment, zippers, jewelry items, and as material for strings for string instruments. Fender Musical Instruments used “CuNiFe”

magnets in their “Wide Range Humbucker” pickup for various Telecaster and Starcaster guitars during the 1970s.

For high-quality cylinder locks and locking systems, cylinder cores are made from wear-resistant cupronickel.

#### Properties

Important properties of cupronickel alloys include corrosion resistance, inherent resistance to macrofouling, good tensile strength, excellent ductility when annealed, thermal conductivity and expansion characteristics amenable for heat exchangers and condensers, good thermal conductivity and ductility at cryogenic temperatures and beneficial antimicrobial touch surface properties.

#### ii) Effect of Si on steel discuss

Silicon - Usually only small amounts (0.20%) are present in rolled steel when it is used as a deoxidizer. However, in steel castings, 0.35 to 1.00% is commonly present. Silicon dissolves in iron and tends to strengthen it. Weld metal usually contains approximately 0.50% silicon as a deoxidizer. Some filler metals may contain up to 1% to provide enhanced cleaning and deoxidation for welding on contaminated surfaces. When these filler metals are used for welding on clean surfaces, the resulting weld metal strength will be markedly increased. The resulting decrease in ductility could present cracking problems.

#### 18. Write short notes on the following.

##### i) Tool steels

Tool steel refers to a variety of carbon and alloy steels that are particularly well-suited to be made into tools. Their suitability comes from their distinctive hardness, resistance to abrasion and deformation and their ability to hold a cutting edge at elevated temperatures. As a result, tool steels are suited for their use in the shaping of other materials.

With a carbon content between 0.5% and 1.5%, tool steels are manufactured under carefully controlled conditions to produce the required quality. The presence of carbides in their matrix plays the dominant role in the qualities of tool steel. The four major alloying elements in tool steel that form carbides are: tungsten, chromium, vanadium and molybdenum. The rate of dissolution of the different carbides into the austenite form of the iron determines the high temperature performance of steel (slower is better, making for a heat resistant steel). Proper heat treatment of these steels is important for adequate performance.[1] The manganese content is often kept low to minimize the possibility of cracking during water quenching.

There are six groups of tool steels: water-hardened, cold-worked, shock-resistant, high-speed, hot-work, and special purpose. The choice of group to select depends on cost, working temperature, required surface hardness, strength, shock resistance, and toughness requirements.[2] The more severe the service condition (higher temperature, abrasiveness, corrosiveness, loading), the higher the alloy content and consequent amount of carbides required for the tool steel.

Tool steels are used for cutting, pressing, extruding, and coining of metals and other materials. Their use, such as the production of injection molds, is essential, due to their resistance to abrasion, which is an important criterion for a mold that will be used to produce hundreds of thousands of moldings of a product or part.

The AISI-SAE grades of tool steel is the most common scale used to identify various grades of tool steel. Individual alloys within a grade are given a number; for example: A2, O1, etc.

ii) White malleable iron

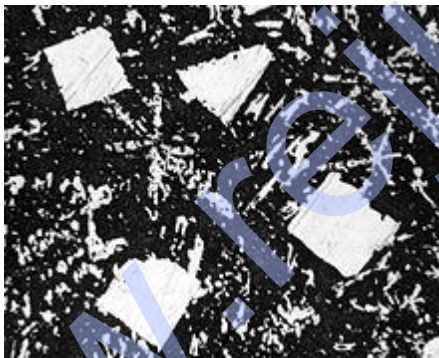
Malleable iron is cast as white iron, the structure being a metastable carbide in a pearlitic matrix. Through an annealing heat treatment, the brittle structure as first cast is transformed into the malleable form. Carbon agglomerates into small roughly spherical aggregates of graphite leaving a matrix of ferrite or pearlite according to the exact heat treatment used. Three basic types of malleable iron are recognized within the casting industry: *blackheart* malleable iron, *whiteheart* malleable iron and *pearlitic* malleable iron.

iii) Bearing alloys

It is preferred over the term “white metal”, because the latter term may refer to various bearing alloys, lead- or tin-based alloys, or zinc die-casting metal. Microstructure of babbitt

Babbitt metal is most commonly used as a thin surface layer in a complex, multi-metal structure, but its original use was as a cast-in-place bulk bearing material. Babbitt metal is characterized by its resistance to galling. Babbitt metal is soft and easily damaged, which suggests that it might be unsuitable for a bearing surface. However, its structure is made up of small hard crystals dispersed in a softer metal, which makes it a metal matrix composite. As the bearing wears, the softer metal erodes somewhat, which creates paths for lubricant between the hard high spots that provide the actual bearing surface. When tin is used as the softer metal, friction causes the tin to melt and function as a lubricant, which protects the bearing from wear when other lubricants are absent.

Internal combustion engines use Babbitt metal which is primarily tin-based because it can withstand cyclic loading. Lead-based Babbitt tends to work-harden and develop cracks but it is suitable for constant-turning tools such as sawblades.



19. Discuss the composition, properties and typical applications of any four copper alloys.  
(Apr/May 2017)

**Brass-** Brass is formed out of copper mixed with 45% zinc, a little percentage of lead to provide machinability and tin for strength. Where the zinc component is extra, the strength of the alloy increases. There are mainly three types of copper-zinc alloy- copper zinc alloy, Copper-zinc-tin alloy and copper-zinc-lead alloy.

Typical uses of brass are electrical components, fittings, locks, door handles, architecture etc.

**Bronze-** Bronzes are one brazing alloy of copper made out of amalgamating tin and one of the phosphorous elements- aluminum, nickel, magnesium etc. It is used for its properties of corrosion resistance, strength etc and generally used for architecture, manufacturing springs, fittings, connectors, terminals etc.

Nickel silvers- This kind of metal has a very misleading appearance, much like silver which leads to its confusing name. They are a mixture of copper with nickel, zinc and sometimes lead.

They are used to fashion coins, jewelry, name plates, keys etc.

Copper nickel- Copper mixed with nickel forms this variant and is generally what is used for pipes, boat sheathing etc.

20. Brief on the influence of alloying elements in steel under classification of alpha and gamma stabilizers: (Nov/Dec 2017)

Carbon: Carbon is alloyed with base metal Iron to make steel which affects the hardness and strength of material. Thus the addition of carbon enables a wide range of hardness and strength.

Manganese: Manganese is added to improve hot working properties and increase strength, toughness and hardenability. Manganese, like nickel, is an austenite forming element and can be used as a substitute for nickel.

Chromium: Chromium is added to the steel to increase corrosion resistance. The resistance increases as more chromium is added. 'Stainless Steel' has approximately 11% chromium and a very marked degree of general corrosion resistance when compared with steels with a lower percentage of chromium. When added to low alloy steels, chromium can increase the response to heat treatment, thus improving hardenability and strength.

Nickel: Nickel is added in large amounts, over about 8%, to high chromium stainless steel to form the most important class of corrosion and heat resistant steels. These are the austenitic stainless steels, where the tendency of nickel to form austenite is responsible for a great toughness and high strength at both high and low temperatures. Nickel also improves resistance to oxidation and corrosion. It increases toughness at low temperatures when added in smaller amounts to alloy steels.

Molybdenum: Molybdenum, when added to chromium-nickel steels, improves resistance to pitting corrosion especially by chlorides and sulphur chemicals. When added to low alloy steels, molybdenum improves high temperature strengths and hardness. When added to chromium steels it greatly diminishes the tendency of steels to decay in service or in heat treatment.

Titanium: Used as stabilizing elements in stainless steels. Each has a high affinity for carbon and forms carbides, which are uniformly dispersed throughout the steel. Thus, localized precipitation of carbides at grain boundaries is prevented. Compared to chromium, carbon has higher affinity to titanium to form inter-granular carbides and hence accompanying loss of corrosion resistance at the grain boundaries.

Phosphorus: Phosphorus is usually added with sulphur to improve machinability in low alloy steels, phosphorus, in small amounts, increases strength and corrosion resistance. Experimental work shows that phosphorus present in steel increases strength. Phosphorus additions are known to increase the tendency to cracking during welding.

Sulphur: When added in small amounts sulphur improves machinability but does not cause hot shortness. Hot shortness is reduced by the addition of manganese, which combines with the sulphur to form manganese sulphide. As manganese sulphide has a higher melting point than iron sulphide, which would form if manganese were not present, the weak spots at the grain boundaries are greatly reduced during hot working.

Selenium: Selenium is added to improve machinability.

**Niobium (Columbium):** Niobium is added to steel in order to stabilise carbon, and as such performs in the same way as described for titanium. Niobium also has the effect of strengthening steels and alloys for high temperature service.

**Nitrogen:** Nitrogen has the effect of increasing the austenitic stability of stainless steels and is, as in the case of nickel, an austenite forming element. Yield strength is greatly improved when nitrogen is added to austenitic stainless steels.

**Silicon:** Silicon is used as a deoxidizing (killing) agent in the melting of steel, as a result, most steels contain a small percentage of silicon. Silicon contributes to hardening of the ferritic phase in steels and for this reason silicon killed steels are somewhat harder and stiffer than aluminum killed steels.

**Cobalt:** Cobalt becomes highly radioactive when exposed to the intense radiation of nuclear reactors, and as a result, any stainless steel that is in nuclear service will have a cobalt restriction, usually approximately 0.2% maximum. This problem is emphasized because there is residual cobalt content in the nickel used in producing these steels.

**Tantalum:** Chemically similar to niobium and has similar effects.

**Copper:** Copper is normally present in stainless steels as a residual element. However it is added to a few alloys to produce precipitation-hardening properties.

**Vandium:** Increases strength, hardness, wear resistance and resistance to shock impact. It retards grain growth, permitting higher quenching temperatures. It also enhances the red-hardness properties of high-speed metal cutting tools

**Tungsten:** Increases strength, wear resistance, hardness and toughness. Tungsten steels have superior hot-working and greater cutting efficiency at elevated temperatures.

21. What are the classification of aluminium alloys and state the applications of any THREE alloy.

Aluminium alloys can be classified into the following types

- (i) Aluminium -Copper alloy
- (ii) Aluminium - Silicon alloy
- (iii) Aluminium - Magnesium alloy
- (iv) Aluminium - Manganese alloy
- (v) Aluminium- Magnesium- Silicon alloy

(i) Aluminium- Copper alloy:

Copper has been the most common alloying element almost since the beginning of the aluminum industry, and a variety of alloys in which copper is the major addition were developed. In the cast alloys the basic structure consists of cored dendrites of aluminum solid solution, with a variety of constituents at the grain boundaries or interdendritic spaces, forming a brittle, more or less continuous network of eutectics. Wrought products consist of a matrix of aluminum solid solution with the other soluble and insoluble constituents dispersed within it. Copper has been the most common alloying element almost since the beginning of the aluminum industry, and a variety of alloys in which copper is the major addition were developed. Most of these alloys fall within one of the following groups:

- a. Cast alloys with 5% Cu, often with small amounts of silicon and magnesium.
- b. Cast alloys with 7-8% Cu, which often contain large amounts of iron and silicon and appreciable amounts of manganese, chromium, zinc, tin, etc.



c. Cast alloys with 10-14% Cu. These alloys may contain small amounts of magnesium (0.10-0.30% Mg), iron up to 1.5%, up to 5% Si and smaller amounts of nickel, manganese, chromium.

d. Wrought alloys with 5-6% Cu and often small amounts of manganese, silicon, cadmium, bismuth, tin, lithium, vanadium

and zirconium. Alloys of this type containing lead, bismuth, and cadmium have superior machinability.

e. Dural, whose basic composition is 4-4.5% Cu, 0.5-1.5% Mg, 0.5- 1.0% Mn, sometimes with silicon additions.

f. Copper alloys containing nickel, which can be subdivided in two groups: the Y alloy type, whose basic composition is 4% Cu, 2% Ni, 1.5% Mg; and the Hyduminiums, which usually have lower copper contents and in which iron replaces 30me of the nickel.

#### (ii) Aluminium- Silicon alloy

Castings are the main use of aluminum-silicon alloys, although some sheet or wire is made for welding and brazing, and some of the piston alloys are extruded for forging stock. Often the brazing sheet has only a cladding of aluminum-silicon alloy and the core consists of some other high melting alloy. The copper-free alloys are used for low- to medium-strength castings with good corrosion resistance; the copper-bearing for medium- to high-strength castings, where corrosion resistance is not critical. Because of their excellent castability, it is possible to produce reliable castings, even in complex shapes, in which the minimum mechanical properties obtained in poorly fed sections are higher than in castings made from higher-strength but lower-castability alloys.

Silicon is the main alloying element; it imparts high fluidity and low shrinkage, which result in good castability and weldability. The low thermal expansion coefficient is exploited for pistons, the high hardness of the silicon particles for wear resistance. The maximum amount of silicon in cast alloys is of the order of 22-24% Si, but alloys made by powder metallurgy may go as high as 40-50% Si.

#### (iii) Aluminium-Magnesium alloy

The magnesium in the commercial alloys ranges all the way from 0.5 to 12- 13% Mg, the low-magnesium alloys having the best formability, the high-magnesium reasonably good castability and high strength. It is normal practice to prepare these alloys from the higher grades of aluminum (99.7 or better) to obtain maximum corrosion resistance and reflectivity; thus the iron and silicon contents are usually lower than in other aluminum alloys. Iron and zirconium are sometimes added to increase the recrystallisation temperature; silicon to improve the fluidity; manganese or chromium to correct for the corroding effect of iron. Copper is added to reduce pitting corrosion by enhancing general corrosion; zinc has little or no effect on corrosion but enhances castability and strength.

In the early days antimony was added, and to its oxide was attributed the corrosion resistance to seawater but later experiments disproved antimony's effectiveness. Titanium and titanium plus boron are often added as grain refiners; beryllium and sometimes lithium to reduce oxidation of magnesium at high temperature, and especially in the molten state. Lead has been added to improve machinability, supposedly without loss of strength or corrosion resistance.

In the aluminum-magnesium commercial alloys solidification starts with the aluminum as primary crystals and usually growing as dendrites, with the other constituents segregating at the grain boundaries or between the dendrite arms. In alloys with more than 10% Mg and



more than 0.5% Si,  $Mg_2Si$  crystals may be primary, in the form of cubes or hexagons. If iron, iron plus manganese or iron plus chromium is above 1-2% (depending on magnesium content), primary crystals of  $FeAl_3$ ,  $(FeMn)Al_6$ ,  $(FeMn)_3Si_2Al_{15}$ ,  $(FeCr)Al_7$ , or  $(FeCr)_4Si_4Al_{13}$  may form. These primary crystals do not have a substantial effect on strength but affect appreciably the formability, fatigue resistance and surface finish. The claim that magnesium additions reduce the size of  $FeAl_3$ , and  $Co_2Al_9$  primary crystals is doubtful.

The solid solubility of magnesium in commercial alloys ranges from 2% Mg at room temperature up to 14-15% at 720K. Therefore most magnesium is in solution and only non equilibrium conditions or annealing produces  $Mg_5Al_8$  as divorced eutectic at the boundaries in cast alloys, as globules in annealed or age hardened material.

Silicon usually forms  $Mg_2Si$ , mostly insoluble, especially in the alloys with more than 3-4% magnesium. Iron may form  $Fe_2SiAl_8$  in low-magnesium, high-silicon alloys;  $FeAl_3$  in the absence of chromium or manganese;  $(FeMn)Al_6$  or  $(FeMn)_3Si_2Al_{15}$  when manganese is present;  $(FeCr)Al_7$  or  $(FeCr)_4Si_4Al_{13}$  when chromium is present. Copper has been detected as  $CuMgAl_2$  and  $Cu_2FeAl_7$ . Zinc is seldom out of solution and then forms  $Mg_3Zn_3Al_2$ ; titanium, boron and beryllium are mostly in solution.

In most of the commercial alloys other elements are present only in small amounts, and their effect on physical properties is submerged by that of magnesium, so that the properties of the commercial alloys are within error of testing of those of the binary alloys. Magnesium is the main factor that controls mechanical properties, but all other alloying elements contribute to it.

## 22. Brief on the mechanism of ageing treatment of Al-Cu alloy.

Age hardenable alloys are one of the most important classes of alloys both from the practical and scientific points of view: from a practical view point, they are important because they show that by a suitable heat treatment of solutionizing and aging, it is possible to improve mechanical properties; from a scientific viewpoint, in age hardenable alloys, the correlation between microstructure and mechanical properties as well as the methodology of manipulation of the microstructures through appropriate phase transformation is very clearly seen.

In Figure we show the Al-rich portion of the Al-Cu phase diagram (schematically). From the phase diagram, it is clear that the Al with a few percent copper is cooled from high temperature leads to the formation of a microstructure in which the phase precipitates out of the supersaturated matrix. However, if an alloy of composition Al - 4 wt.% Cu is solutionized at say, 540°C, and the resultant phase is rapidly quenched to room temperature, the solid solution is largely retained; if this alloy is kept at room temperature (or at any temperature below 180°C), a meta stable phase known as Guinier-Preston zones (GP zones) is formed.

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**UNIT-III****PART A**

1. What are outstanding properties of PSZ?

- High toughness.
- Increased wear resistance.

2. List the typical applications of PTFE.

The major application of PTFE, consuming about 50% of production, is for the insulation of wiring in aerospace and computer applications (e.g. hookup wire, coaxial cables). This application exploits the fact that PTFE has excellent dielectric properties, especially at high radio frequencies, making it suitable for use as an excellent insulator in connector assemblies and cables, and in printed circuit boards used at microwave frequencies. Combined with its high melting temperature, this makes it the material of choice as a high-performance substitute for the weaker and lower-melting-point polyethylene commonly used in low-cost applications. In industrial applications, owing to its low friction, PTFE is used for plain bearings, gears, slide plates, seals, gaskets, bushings, and more applications with sliding action of parts, where it outperforms acetal and nylon. Its extremely high bulk resistivity makes it an ideal material for fabricating long-life electrets, the electrostatic analogues of permanent magnets.

3. Distinguish between thermoplastics and thermosetting plastics.

<b>Thermoplastics</b>	<b>Thermosetting Plastics</b>
They change their shape upon heating and cooling.	Once formed they do not undergo shape conversion upon heating and cooling
Expensive	Cheap
Recyclable	Not recyclable
The best example is polythene which changes its shape upon heating and cooling.	The best example is the Bakelite which once formed does not change its shape upon further heating.

4. What is meant by PSZ?

It is a ceramic in which the cubic crystal structure of zirconium dioxide is made stable at room temperature by an addition of yttrium oxide. These oxides are commonly called "zirconia" ( $\text{ZrO}_2$ ) and "yttria" ( $\text{Y}_2\text{O}_3$ ), hence the name.

5. What is the primary physical difference between thermo and thermosetting plastics.

The primary physical difference is that thermoplastics can be remelted back into a liquid, whereas thermoset plastics always remain in a permanent solid state.

6. What are the primary constituent of MMC.

MMC is composit material with at least two constituent parts, one being a metal necessarilty the other material may be a different metal or another material. Such as a ceramic or organic compound.

7. Differentiate between composite and alloy.

Alloy is a mixture of two or more metallic components with other elements	Composite is a mixture of non – metallic components
Always have at least one metal element	Do not have any metal atoms
Can be either homogeneous of heterogeneous	Are always heterogeneous
Have a luster due to presence of a metal	Do not have a luster
Most can conducted electricity due to the presence of a metal	Polymeric composites can conduct electricity whereas others cannot

8. Write a short note on pet. (Apr/May 2017)

PET (also abbreviated PETE) is short for polyethylene terephthalate, the chemical name for polyester. PET is a clear, strong, and lightweight plastic that is widely used for packaging foods and beverages, especially convenience-sized soft drinks, juices and water. Polyethylene terephthalate polyester (PETP) 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.

9. What are outstanding properties of PTFE? (Nov/Dec 2017)

The outstanding properties of PTFE are its high flexural strength, even in low temperatures, high electrical resistance and dielectric strength, resistance to water and low coefficient of friction. PTFE's density is also very high, at 2200 kg/m<sup>3</sup>.

10. List the typical applications of SiC. (Nov/Dec 2017)

Silicon carbide is used as an abrasive in many industrial applications. In the electronics industry, the main use is in lapping films which are used for polishing the ends of fiber-optic strands prior to splicing.

**11. Differentiate thermosetting and thermoplastic polymers.**  
**Refer question 7.**

**12. What is meant by metal matrix composite? Give one example each to matrix material and reinforcements used.**

A metal matrix composite (MMC) is composite material with at least two constituent parts, one being a metal necessarily, the other material may be a different metal or another material, such as a ceramic or organic compound. Carbon fibers are commonly used in aluminium matrix to synthesize composites showing low density and high strength. However, carbon reacts with aluminium to generate a brittle and water-soluble compound  $Al_4C_3$  on the surface of the fibre. To prevent this reaction, the carbon fibres are coated with nickel or titanium boride.

**13. What are the outstanding properties of PMMA**

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.

**14. List the typical applications of  $Al_2O_3$ .**

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.

**15. What is meant by the term 'unsaturated molecules'. State its significance in plastics.**

An unsaturated compound is a chemical compound that contains carbon-carbon double bonds or triple bonds, such as those found in alkenes or alkynes, respectively. Saturated and unsaturated compounds need not consist only of a carbon atom chain. They can form straight chain, branched chain, or ring arrangements. They can have functional groups, as well. It is in this sense that fatty acids are classified as saturated or unsaturated. The amount of unsaturation of a fatty acid can be determined by finding its iodine number. Unsaturated compounds are those in which addition reaction can be obtained. In a chain of carbons, such as a fatty acid, a double or triple bond will cause a kink in the chain. These kinks have macrostructural implications. Unsaturated fats tend to be liquid at room temperature, rather than solid, as the kinks in the chain prevent the molecules from packing closely together to form a



solid. These fats are called oils and are present in fish and plants. In other unsaturated hydrocarbons, the double bond between two carbons prevents rotation of the atoms about the bond, locking them into specific structural formations. When attached atoms occupy similar positions on each carbon, they are referred to as CIS, and when they are on opposite sides, they are called "trans". Most natural hydrocarbons exist in the cis state, but artificially manufactured hydrocarbons are trans. The body lacks the enzymes to properly break down the trans configuration. This is why trans fats are viewed as dangerous and unhealthy, as they tend to build up. Unsaturated compounds of the two formations are classified as geometric isomers of one another.

**16. What are sialons. What are their application.**

It is a ceramic by the combination of Aluminium, silica, oxygen and nitrogen. It is used in crucibles and in melting of ferrous alloys.

**17. What is polymer**

A substance which has a molecular structure built up chiefly or completely from a large number of similar units bonded together, e.g. many synthetic organic materials used as plastics and resins.

**18. What is fibre reinforced plastics**

Fibre-reinforced plastic (FRP) is a composite material made of a polymer matrix reinforced with fibres. The fibres are usually glass, carbon, aramid, or basalt. Rarely, other fibres such as paper or wood or asbestos have been used. The polymer is usually an epoxy, vinylester or polyester thermosetting plastic; and phenol formaldehyde resins are still in use.

FRPs are commonly used in the aerospace-, automotive-, marine- and construction industries; and in ballistic armor.

**19. Define the term polymer.**

Poly-many

Mer-single unit

Polymer – many units joined together

**20. What are the naturally occurring polymers?**

Wood, rubber, leather, etc.

**PART B**

1. Classify composite materials and list properties and application of FRP and metal matrix.

Refer question no. 19 and 17.

2. Classify engineering ceramics and list properties and applications of SiC and Si<sub>3</sub>N<sub>4</sub>.

Refer question no. 9, 12 and 11

3. Brief on properties and applications of any two polymers from the list: PTFE, PC, PET, ABS and PS.

Refer question no. 8

4. Explain the properties and applications of the following polymer materials.  
Polystyrene, polyethylene, polypropylene.

Refer question no. 8

5. Explain in detail about Ceramics, Formaldehyde and Poly methyl methacrylate (PMMA)

**14.(a) (i) Ceramics** are defined as inorganic non-metallic materials processed or consolidated at high temperatures. Advanced ceramics are materials characterized by a fine structure composed of numerous crystal particles and where the main constituents are Silicon, Aluminum or Zirconia. They are distinguished from more traditional ceramics by the specialized properties and sophisticated processing requirements. The manufacture of advanced ceramics involve chemical or physical treatment of sands, milling of the raw materials, forming either through pressing, extrusion or injection molding, sintering and bonding of the final product.

Ceramics can be classified in several groups according to their chemical composition, oxides of alumina based ceramics are the most widely used with applications in the electronics and industrial machine sectors. Other oxides include beryllia and zirconia. In addition, Silicon Carbide and Nitrides are used in many thermal and wear resistance applications. Other commonly used ceramics include oxide alloys, ceramic composites with metals and ticiania ceramics.

**(ii) Formaldehyde** is a colorless, strong-smelling gas used in making building materials and many household products. It is used in pressed-wood products, such as particleboard, plywood, and fiberboard; glues and adhesives; permanent-press fabrics; paper product coatings; and certain insulation materials **3 Marks**

**(iii) Poly(methyl methacrylate) (PMMA)**, also known as acrylic, acrylic glass, or plexiglass as well as by the trade names Crylux, Plexiglas, Acrylite, Lucite, and Perspex among several others (see below), is a transparent thermoplastic often used in sheet form as a lightweight or shatter-resistant alternative to glass. **3 Marks**

Or

Explain the growth of the plastic industry which has

6. Explain the engineering polymers in details

lightweight of plastic

OR

**14.(b) (i)** Engineering polymers are an outgrowth of the plastic industry which has quickly developed thanks to the strength and installed infrastructure of the world petrochemical sector. The term engineering polymers is somewhat vague but has been taken to include a large number of polymers with engineering applications; in simpler terms, it includes polymers that combine the structural properties of metals with the ease of processing and chemical characteristics of plastics. These properties, in combination with the economics of thermoplastic processing has enabled engineering polymers to become substitutes for metals and alloys in a variety of applications and to be used as unique materials in electronics, thermal, medical and chemical exposure applications. **4 Marks**

Engineering polymers include at least six classes of plastics :

- i) acetals (polyoxymethylenes); ii) ABS (acrylonitrile-butadiene-styrene); iii) polycarbonates;
- iv) polyphenylene ethers and oxides; v) polyamides (nylons); and vi) thermoplastic polyesters.

Other plastics, such as polypropylene, have also found engineering applications. Also included are polymers with stringent mechanical and thermal properties, collectively known as high performance engineering polymers. The latter group involves materials such as: Polyphenylene Sulphides, Polyetherketones, Polysulphones, Liquid Crystal Polymers and Polyimides. These are the materials that, together with thermosetting resins are also used as matrixes for the manufacture of composites. **4 Marks**

7. State the properties and uses of reinforced composites.

matrixes for the manufacture of composite

**14.b (ii)** Many composite materials are composed of just two phases; one is termed the matrix, which is continuous and surrounds the other phase, often called the dispersed phase. The properties of composites are a function of the properties of the constituent phases, their relative amounts, and the geometry of the dispersed phase. Dispersed phase geometry in this context means the shape of the particles and the particle size. **3 Marks**

Distribution, and orientation Materials that have specific and unusual properties are needed for a host of high technology applications such as those found in the aerospace, underwater, bioengineering, and transportation industries. For example, aircraft engineers are increasingly searching for structural materials that have low densities; are strong, stiff, and abrasion and impact resistant; and do not easily corrode. This is a rather formidable combination of characteristics. Among monolithic materials, strong materials are relatively dense; increasing the strength or stiffness generally results in a decrease in toughness. **2 Marks**

8. What is meant by 'Polymers'? discuss the properties, applications and chemical structure of any four types of polymers. (Apr/May 2017)

**i) PET**

The majority of the world's PET production is for synthetic fibers (in excess of 60%), with bottle production accounting for about 30% of global demand.<sup>[51]</sup> In the context of textile applications, PET is referred to by its common name, *polyester*, whereas the acronym *PET* is generally used in relation to packaging. Polyester makes up about 18% of world polymer production and is the fourth-most-produced polymer; polyethylene (PE), polypropylene (PP) and polyvinyl chloride (PVC) are first, second and third, respectively.



PET consists of polymerized units of the monomer ethylene terephthalate, with repeating ( $C_{10}H_8O_4$ ) units. PET is commonly recycled, and has the number “1” as its recycling symbol.

Depending on its processing and thermal history, polyethylene terephthalate may exist both as an amorphous (transparent) and as a semi-crystalline polymer. The semicrystalline material might appear transparent (particle size  $< 500$  nm) or opaque and white (particle size up to a few micrometers) depending on its crystal structure and particle size.

The monomer bis(2-hydroxyethyl) terephthalate can be synthesized by the esterification reaction between terephthalic acid and ethylene glycol with water as a byproduct, or by transesterification reaction between ethylene glycol and dimethyl terephthalate with methanol as a byproduct. Polymerization is through a polycondensation reaction of the monomers (done immediately after esterification/transesterification) with water as the byproduct.

PET in its natural state is a colorless, semi-crystalline resin. Based on how it is processed, PET can be semi-rigid to rigid, and it is very lightweight. It makes a good gas and fair moisture barrier, as well as a good barrier to alcohol (requires additional “barrier” treatment) and solvents. It is strong and impact-resistant. PET becomes white when exposed to chloroform and also certain other chemicals such as toluene.

About 60% crystallization is the upper limit for commercial products, with the exception of polyester fibers. Clear products can be produced by rapidly cooling molten polymer below  $T_g$  glass transition temperature to form an amorphous solid. Like glass, amorphous PET forms when its molecules are not given enough time to arrange themselves in an orderly, crystalline fashion as the melt is cooled. At room temperature the molecules are frozen in place, but, if enough heat energy is put back into them by heating above  $T_g$ , they begin to move again, allowing crystals to nucleate and grow. This procedure is known as solid-state crystallization.

When allowed to cool slowly, the molten polymer forms a more crystalline material. This material has spherulites containing many small crystallites when crystallized from an amorphous solid, rather than forming one large single crystal. Light tends to scatter as it crosses the boundaries between crystallites and the amorphous regions between them. This scattering means that crystalline PET is opaque and white in most cases. Fiber drawing is among the few industrial processes that produce a nearly single-crystal product.

Because PET is an excellent water and moisture barrier material, plastic bottles made from PET are widely used for soft drinks (see carbonation). For certain specialty bottles, such as those designated for beer containment, PET sandwiches an additional polyvinyl alcohol (PVOH) layer to further reduce its oxygen permeability.

Biaxially oriented PET film (often known by one of its trade names, «Mylar») can be aluminized by evaporating a thin film of metal onto it to reduce its permeability, and to make it reflective and opaque (MPET). These properties are useful in many applications, including flexible food packaging and thermal insulation. See: “space blankets”. Because of its high mechanical strength, PET film is often used in tape applications, such as the carrier for magnetic tape or backing for pressure-sensitive adhesive tapes.

Non-oriented PET sheet can be thermoformed to make packaging trays and blister packs. If crystallizable PET is used, the trays can be used for frozen dinners, since they withstand both freezing and oven baking temperatures. As opposed to amorphous PET, which is transparent, crystallizable PET or CPET tends to be black in colour.

When filled with glass particles or fibres, it becomes significantly stiffer and more durable.

PET is also used as a substrate in thin film solar cells. Terylene (a trademark formed by inversion of (polyeth)ylene ter(ephthalate)) is also spliced into bell rope tops to help prevent wear on the ropes as they pass through the ceiling.

## ii) PC

**Polycarbonates (PC)** are a group of thermoplastic polymers containing carbonate groups in their chemical structures. Polycarbonates used in engineering are strong, tough materials, and some grades are optically transparent. They are easily worked, molded, and thermoformed. Because of these properties, polycarbonates find many applications. Polycarbonates do not have a unique resin identification code (RIC) and are identified as «Other», 7 on the RIC list. Products made from polycarbonate can contain the precursor monomer bisphenol A (BPA). Polycarbonate is also known by a variety of trademarked names, including Lexan, Makrolon, Hammerglass and others.

Polycarbonate is a durable material. Although it has high impact-resistance, it has low scratch-resistance. Therefore, a hard coating is applied to polycarbonate eyewear lenses and polycarbonate exterior automotive components. The characteristics of polycarbonate compare to those of polymethyl methacrylate (PMMA, acrylic), but polycarbonate is stronger and will hold up longer to extreme temperature. Polycarbonate is highly transparent to visible light, with better light transmission than many kinds of glass.

Polycarbonate has a glass transition temperature of about 147 °C (297 °F), so it softens gradually above this point and flows above about 155 °C (311 °F). Tools must be held at high temperatures, generally above 80 °C (176 °F) to make strain-free and stress-free products. Low molecular mass grades are easier to mold than higher grades, but their strength is lower as a result. The toughest grades have the highest molecular mass, but are much more difficult to process.

Unlike most thermoplastics, polycarbonate can undergo large plastic deformations without cracking or breaking. As a result, it can be processed and formed at room temperature using sheet metal techniques, such as bending on a brake. Even for sharp angle bends with a tight radius, heating may not be necessary. This makes it valuable in prototyping applications where transparent or electrically non-conductive parts are needed, which cannot be made from sheet metal. PMMA/Acrylic, which is similar in appearance to polycarbonate, is brittle and cannot be bent at room temperature.

Main transformation techniques for polycarbonate resins:

Extrusion into tubes, rods and other profiles including multiwall

Extrusion with cylinders (calenders) into sheets (0.5–20 mm (0.020– 0.787 in)) and films (below 1 mm (0.039 in)), which can be used directly or manufactured into other shapes using thermoforming or secondary fabrication techniques, such as bending, drilling, or routing. Due to its chemical properties it is not conducive to laser-cutting.

Injection molding into ready articles

Polycarbonate may become brittle when exposed to ionizing radiation above 25 kGy (J/kg).

## iii) ABS

**Acrylonitrile butadiene styrene (ABS)** (chemical formula  $(C_8H_8)_x \cdot (C_4H_6)_y \cdot (C_3H_3N)_z$ ) is a common thermoplastic polymer. Its glass transition temperature is approximately 105 °C (221 °F). ABS is amorphous and therefore has no true melting point.

ABS is a terpolymer made by polymerizing styrene and acrylonitrile in the presence of polybutadiene. The proportions can vary from 15 to 35% acrylonitrile, 5 to 30% butadiene and 40 to 60% styrene. The result is a long chain of polybutadiene criss-crossed with shorter chains of poly(styrene-co-acrylonitrile). The nitrile groups from neighboring chains, being polar, attract each other and bind the chains together, making ABS stronger than pure polystyrene. The styrene gives the plastic a shiny, impervious surface. The polybutadiene, a rubbery substance, provides toughness even at low temperatures. For the majority of



applications, ABS can be used between  $-20$  and  $80\text{ }^{\circ}\text{C}$  ( $-4$  and  $176\text{ }^{\circ}\text{F}$ ) as its mechanical properties vary with temperature. The properties are created by rubber toughening, where fine particles of elastomer are distributed throughout the rigid matrix.

The most important mechanical properties of ABS are impact resistance and toughness. A variety of modifications can be made to improve impact resistance, toughness, and heat resistance. The impact resistance can be amplified by increasing the proportions of polybutadiene in relation to styrene and also acrylonitrile, although this causes changes in other properties. Impact resistance does not fall off rapidly at lower temperatures. Stability under load is excellent with limited loads. Thus, by changing the proportions of its components, ABS can be prepared in different grades. Two major categories could be ABS for extrusion and ABS for injection moulding, then high and medium impact resistance. Generally ABS would have useful characteristics within a temperature range from  $-20$  to  $80\text{ }^{\circ}\text{C}$  ( $-4$  to  $176\text{ }^{\circ}\text{F}$ ).



**Lego bricks are made from ABS.**

The final properties will be influenced to some extent by the conditions under which the material is processed to the final product. For example, molding at a high temperature improves the gloss and heat resistance of the product whereas the highest impact resistance and strength are obtained by molding at low temperature. Fibers (usually glass fibers) and additives can be mixed in the resin pellets to make the final product strong and raise the operating range to as high as  $80\text{ }^{\circ}\text{C}$  ( $176\text{ }^{\circ}\text{F}$ ). Pigments can also be added, as the raw material original color is translucent ivory to white. The aging characteristics of the polymers are largely influenced by the polybutadiene content, and it is normal to include antioxidants in the composition. Other factors include exposure to ultraviolet radiation, for which additives are also available to protect against.

ABS polymers are resistant to aqueous acids, alkalis, concentrated hydrochloric and phosphoric acids, alcohols and animal, vegetable and mineral oils, but they are swollen by glacial acetic acid, carbon tetrachloride and aromatic hydrocarbons and are attacked by concentrated sulfuric and nitric acids. They are soluble in esters, ketones, ethylene dichloride and acetone.

Even though ABS plastics are used largely for mechanical purposes, they also have electrical properties that are fairly constant over a wide range of frequencies. These properties are little affected by temperature and atmospheric humidity in the acceptable operating range of temperatures. ABS is flammable when it is exposed to high temperatures, such as a wood fire. It will melt then boil, at which point the vapors burst into intense, hot flames. Since pure ABS contains no halogens, its combustion does not typically produce any persistent organic pollutants, and the most toxic products of its combustion or pyrolysis are carbon monoxide and hydrogen cyanide. ABS is also damaged by sunlight. This caused one of the most widespread and expensive automobile recalls in US history due to the degradation of the seatbelt release buttons.

ABS can be recycled, although it is not accepted by all recycling facilities.

A Super Nintendo Entertainment System with its outer casing made of ABS. Over time, the casing changed colour from light grey to yellow as a result of oxidation.

When exposed to sunlight for a prolonged period of time, ABS will sometimes experience yellowing as a result of oxidation. This yellow colour can be cleaned through the use of hydrogen peroxide and UV light.

#### iv) Phenol formaldehydes

**Phenol formaldehyde resins (PF)** or **phenolic resins** are synthetic polymers obtained by the reaction of phenol or substituted phenol with formaldehyde. Used as the basis for Bakelite, PFs were the first commercial synthetic resins (plastics). They have been widely used for the production of molded products including billiard balls, laboratory countertops, and as coatings and adhesives. They were at one time the primary material used for the production of circuit boards but have been largely replaced with epoxy resins and fiberglass cloth, as with fire-resistant FR-4 circuit board materials.

There are two main production methods. One reacts phenol and formaldehyde directly to produce a thermosetting network polymer, while



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There are two main production methods. One reacts phenol and formaldehyde directly to produce a thermosetting network polymer, while the other restricts the formaldehyde to produce a prepolymer known as **novolac** which can be moulded and then cured with the addition of more formaldehyde and heat. There are many variations in both production and input materials that are used to produce a wide variety of resins for special purposes.

Phenolic resins are found in myriad industrial products. Phenolic laminates are made by impregnating one or more layers of a base material such as paper, fiberglass or cotton with phenolic resin and laminating the resin-saturated base material under heat and pressure. The resin fully polymerizes (cures) during this process. The base material choice depends on the intended application of the finished product. Paper phenolics are used in manufacturing electrical components such as punch-through boards, in household laminates, and in paper composite panels. Glass phenolics are particularly well suited for use in the high speed bearing market. Phenolic micro-balloons are used for density control. Snooker balls as well as balls from many table-based ball games are also made from phenol formaldehyde resin. The binding agent in normal (organic) brake pads, brake shoes and clutch disks are phenolic

resin. Synthetic resin bonded paper, made from phenolic resin and paper, is used to make countertops.

Phenolic resins are also used for making exterior plywood commonly known as WBP (Weather & boil proof) Plywood because phenolic resins have no melting point but only a decomposing point in the temperature zone of 220 degree Celsius and above.

Phenolic resin is used as a binder in loudspeaker driver suspension components which are made of cloth.

Sometimes people select phenolic resin parts because their coefficient of thermal expansion closely matches that of the aluminum used for other parts of a system, as in early computer systems\ and Duramold.

The Dutch forger Han van Meegeren mixed phenol formaldehyde with his oil paints before baking the finished canvas in order to fake the drying out of the paint over the centuries.

9. Give any two important properties of ceramics. Write short **notes on any four ceramic materials. (Apr/May 2017)**

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, Al<sub>2</sub>O<sub>3</sub>**

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.

#### **Typical Uses**

Gas laser tubes

Wear pads

Seal rings

High temperature electrical insulators  
High voltage insulators  
  
Furnace liner tubes  
Thread and wire guides  
Electronic substrates  
Ballistic armor  
Abrasion resistant tube and elbow liners  
Thermometry sensors  
Laboratory instrument tubes and sample holders  
Instrumentation parts for thermal property test machines  
Grinding media

### **General Information**

Aluminum oxide, commonly referred to as alumina, possesses strong ionic interatomic bonding giving rise to its 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<sup>2</sup>.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.

### **Silicon Carbide**

#### **Background**

Sintered alpha silicon carbide is produced by initially mixing fine (sub-micron) and pure silicon carbide powder with non-oxide sintering aids. The powdered material is formed or compacted by using most of the conventional ceramic forming processes such as die pressing, isostatic pressing and injection moulding. Following the forming stage the material is sintered in an inert atmosphere at temperatures above 2000°C. The sintered silicon carbide can then be machined to precise tolerances using a range of precision diamond grinding or lapping techniques. As with most advanced ceramics the cost of the component is reduced if the amount of diamond grinding is reduced i.e. either the material manufacturer can achieve the required tolerances “as sintered” or the designer removes unnecessary tolerances.

#### **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.

### **Fused Silica, SiO<sub>2</sub>**

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<sub>3</sub>N<sub>4</sub>**

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

#### **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
- Good oxidation resistance

#### **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

Precision shafts and axles in high wear environments

**10. Classify composite materials based on the type of reinforcement and state an example of each. (Nov/Dec 2017)**

Composite materials can be classified into the following types

- . Metal Matrix Composite
- . Fibre reinforced Composite
- . Laminate Composite

**a) Metal Matrix Composite:**

A metal matrix composite (MMC) is composite material with at least two constituent parts, one being a metal necessarily, the other material may be a different metal or another material, such as a ceramic or organic compound. When at least three materials are present, it is called a hybrid composite. An MMC is complementary to a cermets. Metal Matrix Composites are made by dispersing a reinforcing material into a metal matrix.

The reinforcement surface can be coated to prevent a chemical reaction with the matrix. For example, carbon fibers are commonly used in aluminium matrix to synthesize composites showing low density and high strength. However, carbon reacts with aluminium to generate a brittle and water-soluble compound  $Al_4C_3$  on the surface of the fibre. To prevent this reaction, the carbon fibres are coated with nickel or titanium boride.

The matrix is the monolithic material into which the reinforcement is embedded, and is completely continuous. This means that there is a path through the matrix to any point in the material, unlike two materials sandwiched together. In structural applications, the matrix is usually a lighter metal such as aluminum, magnesium, or titanium, and provides a compliant support for the reinforcement. In high-temperature applications, cobalt and cobalt-nickel alloy matrices are common.

The reinforcement material is embedded into a matrix. The reinforcement does not always serve a purely structural task (reinforcing the compound), but is also used to change physical properties such as wear resistance, friction coefficient, or thermal conductivity. The reinforcement can be either continuous, or discontinuous. Discontinuous MMCs can be isotropic, and can be worked with standard metalworking techniques, such as extrusion, forging, or rolling. In addition, they may be machined using conventional techniques, but commonly would need the use of polycrystalline diamond tooling (PCD).

Continuous reinforcement uses monofilament wires or fibers such as carbon fiber or silicon carbide. Because the fibers are embedded into the matrix in a certain direction, the result is an anisotropic structure in which the alignment of the material affects its strength. One of the first MMCs used boron filament as reinforcement. Discontinuous reinforcement uses «whiskers», short fibers, or particles. The most common reinforcing materials in this category are alumina and silicon carbide.

**b) Fibre reinforced composite**

A fiber-reinforced composite (FRC) is a composite building material that consists of three components: (i) the fibers as the discontinuous or dispersed phase, (ii) the matrix as the continuous phase, and (iii) the fine interphase region, also known as the interface. This is a type of advanced composite group, which makes use of rice husk, rice hull, and plastic as ingredients.

This technology involves a method of refining, blending, and compounding natural fibers from cellulosic waste streams to form a high-strength fiber composite material in a polymer matrix. The designated waste or base raw materials used in this instance are those of waste thermoplastics and various categories of cellulosic waste including rice husk and saw dust.

FRC is high-performance fiber composite achieved and made possible by cross-linking cellulosic fiber molecules with resins in the FRC material matrix through a proprietary molecular re-engineering process, yielding a product of exceptional structural properties. Through this feat of molecular re-engineering selected physical and structural properties of wood are successfully cloned and vested in the FRC product, in addition to other critical attributes to yield performance properties superior to contemporary wood.

This material, unlike other composites, can be recycled up to 20 times, allowing scrap FRC to be reused again and again. The failure mechanisms in FRC materials include delamination, intralaminar matrix cracking, longitudinal matrix splitting, fiber/matrix debonding, fiber pull-out, and fiber fracture.

### c) Laminate Composites

A laminate composite is an assembly of layers of fibrous composite materials which can be joined to provide required engineering properties, including in-plane stiffness, bending stiffness, strength, and coefficient of thermal expansion. The individual layers consist of high-modulus, high-strength fibers in a polymeric, metallic, or ceramic matrix material. Typical fibers used include cellulose, graphite, glass, boron, and silicon carbide, and some matrix materials are epoxies, polyimides, aluminium, titanium, and alumina.

Layers of different materials may be used, resulting in a hybrid laminate. The individual layers generally are orthotropic (that is, with principal properties in orthogonal directions) or transversely isotropic (with isotropic properties in the transverse plane) with the laminate then exhibiting anisotropic (with variable direction of principal properties), orthotropic, or quasi-isotropic properties.

Quasi-isotropic laminates exhibit isotropic (that is, independent of direction) in plane response but are not restricted to isotropic out-of-plane (bending) response. Depending upon the stacking sequence of the individual layers, the laminate may exhibit coupling between in plane and out-of-plane response. An example of bending-stretching coupling is the presence of curvature developing as a result of in-plane loading.

11. State the properties and applications of two ceramics from the list: PSZ, Si<sub>3</sub>N<sub>4</sub>, Al<sub>2</sub>O<sub>3</sub> and SAILON (Nov/Dec 2017)

#### PSZ:

Zirconia (ZrO<sub>2</sub>) may look like a an excellent engineering ceramic on paper due to its desirable physical properties such as extremely high melting temperature, high strength and fracture toughness. However the phase changes that it undergoes during sintering are deleterious to these properties and hence pure zirconia is not a useful engineering material.

#### Zirconia Phase Transformations

At room temperature, zirconia exists on the monoclinic phase. When heated to about 1170°C, it undergoes a phase transformation from monoclinic to tetragonal and a volume shrinkage of more than 3-5%. Further heating produces another change to cubic at 2370°C. The cubic phase is maintained until the melting point or zirconia is reached 2680°C.

On cooling from sintering temperatures and/or high temperature exposure, zirconia undergoes the tetragonal to monoclinic transformation at 950°C and an expansion similar in magnitude of the shrinkage during heat up. The large volumetric change associated with this

phase transformation is a large enough to affect the structural integrity of the material. Repeated heating and cooling cycles would result in further erosion of mechanical integrity and properties.

### **Producing Stabilized and Partially Stabilized Zirconia**

The additions of cubic oxides such as MgO, CaO, Y<sub>2</sub>O<sub>3</sub>, CeO<sub>2</sub> and other rare earth oxides stabilize the high temperature cubic phase all the way back to room temperature. They also tend to decrease the transformation temperature. In partially stabilized zirconias, similar additions are made, except, not enough to stabilize all of the material, hence the name “partially stabilized zirconia” or “PSZ”.

These materials typically consist of two or more of the phases cubic, tetragonal and monoclinic. If produced properly, the resultant microstructure consists of lens or elliptical-shaped precipitates of tetragonal zirconia within the cubic grains. Normally the tetragonal phase would transform into the monoclinic phase at low enough temperatures, but the high strength of the cubic phase prevents the required expansion from happening, freezing in the tetragonal precipitates.

Monoclinic zirconia may also be present in the cubic grains and at the grain boundaries. The toughening mechanism comes into play when a crack is encountered. The cubic grains are constraining the tetragonal precipitates that want to expand and release associated energy. When these grains are faced with a propagating crack tip, the tetragonal phase is released and allowed to change back to the more stable monoclinic phase. This results in the associated volumetric expansion, effectively closing the advancing crack. This is called transformation toughening and is a stress induced martensitic transformation to the monoclinic phase.

### **Transformation Toughening in Partially Stabilized Zirconias**

Typical Properties of Partially Stabilized Zirconias

Typical properties of PSZ materials include:

- Excellent fracture toughness
- Excellent wear resistance
- Excellent impact resistance
- Good resistance to thermal shock
- Good chemical resistance
- Good corrosion resistance

Applications of Partially Stabilized Zirconias

Typical application of PSZ materials include:

- Dies and tooling
- Knives, scissors and blades
- Wear resistant components including bearings and linings
- Pump parts
- Grinding media

### **Al<sub>2</sub>O<sub>3</sub> :**

Aluminium oxide is a chemical compound of aluminium and oxygen with the chemical formula Al<sub>2</sub>O<sub>3</sub>. It is the most commonly occurring of several aluminium oxides, and specifically identified as aluminium(III) oxide. It is commonly called alumina, and may also be called aloxide, aloxite, or alundum depending on particular forms or applications.

It occurs naturally in its crystalline polymorphic phase  $\alpha$ -Al<sub>2</sub>O<sub>3</sub> as the mineral corundum, varieties of which form the precious gemstones ruby and sapphire. Al<sub>2</sub>O<sub>3</sub> is significant in its use to produce aluminium metal, as an abrasive owing to its hardness, and as a refractory material owing to its high melting point.

12. List the properties and applications of any three types of **ceramics**.

**(i) Silicon Carbide:**

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.

**Fused Silica, SiO<sub>2</sub>**

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

**(ii) Silicon Nitride (Si<sub>3</sub>N<sub>4</sub>) :**

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 an 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

**(iii) Titanium di-oxide (TiO<sub>2</sub>):**

Titanium dioxide occurs in nature as the well-known minerals rutile, anatase and brookite, and additionally as two high pressure forms, a monoclinic baddeleyite-like form and an orthorhombic  $\alpha$ -PbO<sub>2</sub>-like form. One of these is known as akaogiite and should be considered as an extremely rare mineral. It is mainly sourced from ilmenite ore.

This is the most widespread form of titanium dioxide-bearing ore around the world. Rutile is the next most abundant and contains around 98% titanium dioxide in the ore. The metastable anatase and brookite phases convert irreversibly to the equilibrium rutile phase upon heating above temperatures in the range 600–800 °C.

Titanium dioxide has eight modifications – in addition to rutile, anatase, and brookite, three metastable phases can be produced synthetically (monoclinic, tetragonal and orthorhombic), and five high-pressure forms ( $\alpha$ -PbO<sub>2</sub>-like, baddeleyite-like, cotunnite-like, orthorhombic OI, and cubic phases) also exist.

The most important application areas are paints and varnishes as well as paper and plastics, which account for about 80% of the world's titaniumdioxide consumption. Other pigment applications such as printing inks, fibers, rubber, cosmetic products and food account for another 8%. The rest is used in other applications, for instance the production of technical pure titanium, glass and glass ceramics, electrical ceramics, catalysts, electric conductors

**13. Brief on properties and applications of any two polymers from the list. PP, PC, PEEK, ABS and PS (Nov/Dec 2017)**

**(i) PC:**

Polycarbonates (PC) are a group of thermoplastic polymers containing carbonate groups in their chemical structures. Polycarbonates used in engineering are strong, tough materials, and some grades are optically transparent. They are easily worked, molded, and thermoformed. Because of these properties, polycarbonates find many applications. Polycarbonates do not have a unique resin identification code (RIC) and are identified as «Other», 7 on the RIC list. Products made from polycarbonate can contain the precursor monomer bisphenol A (BPA). Polycarbonate is also known by a variety of trademarked names, including Lexan, Makrolon, Hammerglass and others.

Polycarbonate is a durable material. Although it has high impact-resistance, it has low scratch resistance. Therefore, a hard coating is applied to polycarbonate eyewear lenses and polycarbonate exterior automotive components. The characteristics of polycarbonate compare to those of polymethyl methacrylate (PMMA, acrylic), but polycarbonate is stronger and will hold up longer to extreme temperature. Polycarbonate is highly transparent to visible light, with better light transmission than many kinds of glass.

Polycarbonate has a glass transition temperature of about 147 °C (297 °F), so it softens gradually above this point and flows above about 155 °C (311 °F). Tools must be held at high temperatures, generally above 80 °C (176 °F) to make strain-free and stress-free products. Low molecular mass grades are easier to mold than higher grades, but their strength is lower as a result. The toughest grades have the highest molecular mass, but are much more difficult to process.

Unlike most thermoplastics, polycarbonate can undergo large plastic deformations without cracking or breaking. As a result, it can be processed and formed at room temperature using sheet metal techniques, such as bending on a brake. Even for sharp angle bends with a tight radius, heating may not be necessary.

This makes it valuable in prototyping applications where transparent or electrically non-conductive parts are needed, which cannot be made from sheet metal. PMMA/Acrylic, which is similar in appearance to polycarbonate, is brittle and cannot be bent at room temperature.

Main transformation techniques for polycarbonate resins:

Extrusion into tubes, rods and other profiles including multiwall

Extrusion with cylinders (calenders) into sheets (0.5–20 mm (0.020– 0.787 in)) and films (below 1 mm (0.039 in)), which can be used directly or manufactured into other shapes using thermoforming or secondary fabrication techniques, such as bending, drilling, or routing. Due to its chemical properties it is not conducive to laser-cutting.

Injection molding into ready articles

Polycarbonate may become brittle when exposed to ionizing radiation above 25J/kg.

## (ii) ABS :

Acrylonitrile butadiene styrene (ABS) (chemical formula  $(C_8H_8)_x \cdot (C_4H_6)_y \cdot (C_3H_3N)_z$ ) is a common thermoplastic polymer. Its glass transition temperature is approximately 105 °C (221 °F). ABS is amorphous and therefore has no true melting point.

ABS is a terpolymer made by polymerizing styrene and acrylonitrile in the presence of polybutadiene. The proportions can vary from 15 to 35% acrylonitrile, 5 to 30% butadiene and 40 to 60% styrene. The result is a long chain of polybutadiene criss-crossed with shorter chains of poly(styrene-co-acrylonitrile).

The nitrile groups from neighboring chains, being polar, attract each other and bind the chains together, making ABS stronger than pure polystyrene. The styrene gives the plastic a shiny, impervious surface. The polybutadiene, a rubbery substance, provides toughness even at low temperatures.

For the majority of applications, ABS can be used between –20 and 80 °C (–4 and 176 °F) as its mechanical properties vary with temperature. The properties are created by rubber toughening, where fine particles of elastomer are distributed throughout the rigid matrix.

The most important mechanical properties of ABS are impact resistance and toughness. A variety of modifications can be made to improve impact resistance, toughness, and heat resistance. The impact resistance can be amplified by increasing the proportions of polybutadiene in relation to styrene and also acrylonitrile, although this causes changes in other properties.

Impact resistance does not fall off rapidly at lower temperatures. Stability under load is excellent with limited loads. Thus, by changing the proportions of its components, ABS can be prepared in different grades. Two major categories could be ABS for extrusion and ABS for injection moulding, then high and medium impact resistance. Generally ABS would have useful characteristics within a temperature range from –20 to 80 °C (–4 to 176 °F).

The final properties will be influenced to some extent by the conditions under which the material is processed to the final product. For example, molding at a high temperature improves the gloss and heat resistance of the product whereas the highest impact resistance and strength are obtained by molding at low temperature. Fibers (usually glass fibers) and additives can be mixed in the resin pellets to make the final product strong and raise the operating range to as high as 80 °C (176 °F). Pigments can also be added, as the raw material original color is translucent ivory to white.

The aging characteristics of the polymers are largely influenced by the polybutadiene content, and it is normal to include antioxidants in the composition. Other factors include exposure to ultraviolet radiation, for which additives are also available to protect against. ABS polymers are resistant to aqueous acids, alkalis, concentrated hydrochloric and phosphoric acids, alcohols and animal, vegetable and mineral oils, but they are swollen by glacial acetic acid, carbon tetrachloride and aromatic hydrocarbons and are attacked by concentrated sulfuric and nitric acids.

They are soluble in esters, ketones, ethylene dichloride and acetone. Even though ABS plastics are used largely for mechanical purposes, they also have electrical properties that are fairly constant over a wide range of frequencies. These properties are little affected by temperature and atmospheric humidity in the acceptable operating range of temperatures. wood fire. It will melt then boil, at which point the vapors burst into intense, hot flames. Since pure ABS contains no halogens, its combustion does not typically produce any persistent organic pollutants, and the most toxic products of its combustion or pyrolysis are carbon monoxide and hydrogen cyanide. ABS is also damaged by sunlight. This caused one of the most widespread and expensive automobile recalls in US history due to the degradation of the seatbelt release buttons. ABS can be recycled, although it is not accepted by all recycling facilities.

A Super Nintendo Entertainment System with its outer casing made of ABS. Over time, the casing changed colour from light grey to yellow as a result of oxidation. When exposed to sunlight for a prolonged period of time, ABS will sometimes experience yellowing as a result of oxidation. This yellow colour can be cleaned through the use of hydrogen peroxide and UV light.

#### **14. Explain the properties and application of any eight varieties of polymers used as engineering materials.**

PEEK is an abbreviation for PolyEther Ether-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 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°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.

Polytetra fluoroethylene [Teflon,  $-(CF_2-CF_2)_n-$ ] is obtained by polymerizing (emulsion polymereization) tetra fluoroethylene (ie., When all the hydrogen atoms in polyethylene have been replaced by fluorine, polytetra fluoroethylene (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(-269°C). 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 resistivity exceeds 10<sup>20</sup> 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 1010-1011 poises has been measured at about 350°C. 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 with stand temperatures of 260°C and still have the same chemical properties. Teflon also retains its chemical properties in cryogenic temperatures of -240°C . It is a chemical inert material, making it relatively safe to use and handle. It has an initial melting point of 342 +- 10°C and a secondary melting point of 327 +- 10°C . Teflon has a low coefficient of friction, and is leophobic (resistant to oil) and hydrophobic, making it useful in cookware. This property of a non-wetting surface to both oils and water comes from Teflon being a polytetra fluoroethylene, which has an ultra low surface energy value of 18.6 Newtons per meter squared. Teflon has a high dielectric strength over many different frequencies, a low dissipation factor, and a high surface resistivity. The electro conductivity can be increased high enough to allow Teflon to be used as an anti-static coating. Teflon possesses outstanding optical clarity and transmission. Teflon® AF has outstanding light transmission from the deep UV range out through and including a significant portion of the IR range. Also, because it does not absorb light, Teflon® AF will not deteriorate with exposure to light. These optical properties, over such a wide range of wavelength and possible exposure conditions, are unmatched by any other polymer. PTFE is a tough, flexible, crystalline polymer that retains ductility down to -150°C. Its solvent and chemical resistance is the best of all the thermoplastics and it has the lowest coefficient of friction of any known solid (0.02). On the downside, it has to be moulded by a powder sintering technique, although it can be extruded very slowly, and it is very expensive with low strength and stiffness. Applications of PTFE are therefore limited to those that make use of its special properties, for example, bearings, chemical vessel linings, gaskets and non-stick coatings.

Teflon has the lowest known dielectric constant of any plastic material. It exhibits excellent mechanical and physical properties at end-use temperatures up to 300°C It has good dimensional stability, reduced mold shrinkage, a smooth surface, and rigidity at high-use temperatures. Teflon is used for gasket and packaging materials in chemical processing equipment, as electrical insulation, as bearings, seals, and piston rings in mechanical applications, especially those requiring anti-stick characteristics. In addition to chemical, heat, corrosion, and impact resistance. Teflon is weather resistant, flexible, non-flammable, etc. Ionized oxygen in oxygen plasma is often sufficiently energetic to react with the polymer chain. Electron bombardment at the mega rad level can sever the polymer chain. Techniques for molding polytetra fluoroethylene resemble those of powder metallurgy or ceramics rather than those of polymer fabrication. It may be extruded in a ram or screw extruder. The high degree of cohesion between cold pressed particles of PTFE is utilized in a calendering process for making tape and coating wire.

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.



The “MylarR-type” films are used for capacitors, 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°C and 74°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.

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 resistance 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 consist predominantly of ring structures and hence possess 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 pyromellitic anhydride and aromatic ether amine. Polyesterimides and polybismaleinimides are modified polyimides. **Polyvinyl chloride(PVC)( VINYL Plastic)** 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°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 accounts 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.

### **15. Name explain the properties and application of any four type of ceramics.**

#### **Alumina**

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.

#### **Silicon Carbide**

##### **Background**

Sintered alpha silicon carbide is produced by initially mixing fine (sub-micron) and pure silicon carbide powder with non-oxide sintering aids. The powdered material is formed or compacted by using most of the conventional ceramic forming processes such as die pressing, isostatic pressing and injection moulding. Following the forming stage the material is sintered in an inert atmosphere at temperatures above 2000°C. The sintered silicon carbide can then be machined to precise tolerances using a range of precision diamond grinding or lapping techniques. As with most advanced ceramics the cost of the component is reduced if the amount of diamond grinding is reduced i.e. either the material manufacturer can achieve the required tolerances “as sintered” or the designer removes unnecessary tolerances.

##### **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.

### **Fused Silica, SiO<sub>2</sub>**

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

### **Silicon nitride**

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

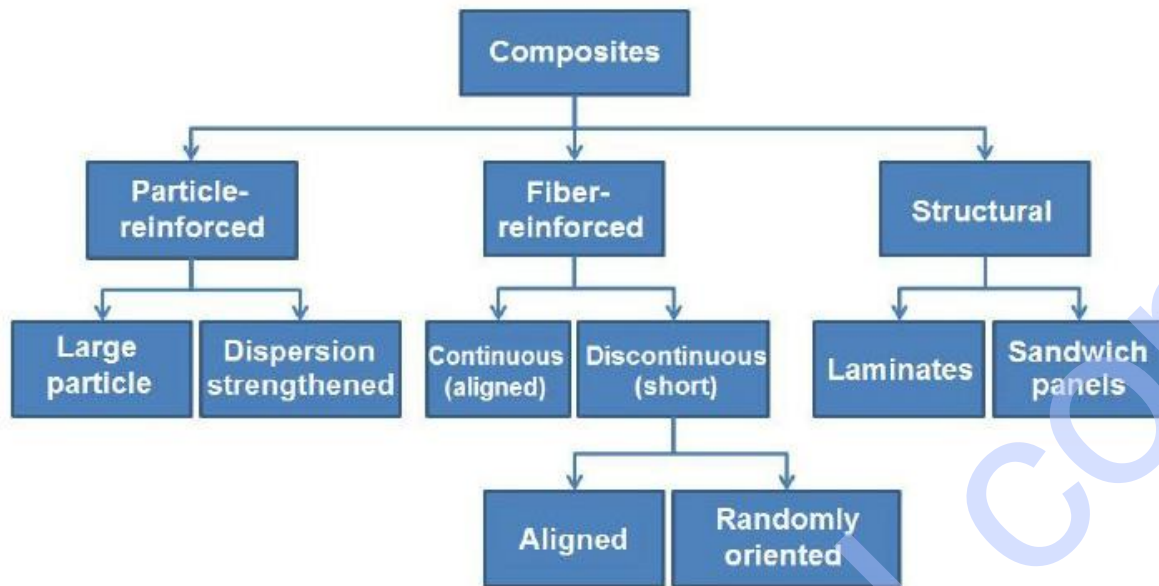
High hardness

Outstanding wear resistance, both impingement and frictional modes

Good thermal shock resistance

Good chemical resistance

**16. Classify composite materials and list two properties and application of them.**



### State the properties and application of PSZ or SiC.

Zirconia ( $\text{ZrO}_2$ ) may look like a an excellent engineering ceramic on paper due to its desirable physical properties such as extremely high melting temperature, high strength and fracture toughness. However the phase changes that it undergoes during sintering are deleterious to these properties and hence pure zirconia is not a useful engineering material.

### Zirconia Phase Transformations

At room temperature, zirconia exists on the monoclinic phase. When heated to about  $1170^\circ\text{C}$ , it undergoes a phase transformation from monoclinic to tetragonal and a volume shrinkage of more than 3-5%. Further heating produces another change to cubic at  $2370^\circ\text{C}$ . The cubic phase is maintained until the melting point or zirconia is reached  $2680^\circ\text{C}$ . On cooling from sintering temperatures and/or high temperature exposure, zirconia undergoes the tetragonal to monoclinic transformation at  $950^\circ\text{C}$  and an expansion similar in magnitude of the shrinkage during heat up. The large volumetric change associated with this phase transformation is a large enough to affect the structural integrity of the material. Repeated heating and cooling cycles would result in further erosion of mechanical integrity and properties. **Producing Stabilized and Partially Stabilized Zirconia**

The additions of cubic oxides such as  $\text{MgO}$ ,  $\text{CaO}$ ,  $\text{Y}_2\text{O}_3$ ,  $\text{CeO}_2$  and other rare earth oxides stabilize the high temperature cubic phase all the way back to room temperature. They also tend to decrease the transformation temperature. In partially stabilized zirconias, similar additions are made, except, not enough to stabilize all of the material, hence the name “partially stabilized zirconia” or “PSZ”. These materials typically consist of two or more of the phases cubic, tetragonal and monoclinic. If produced properly, the resultant microstructure consists of lens or elliptical-shaped precipitates of tetragonal zirconia within the cubic grains. Normally the tetragonal phase would transform into the monoclinic phase at low enough temperatures, but the high strength of the cubic phase prevents the required expansion from happening, freezing in the tetragonal precipitates. Monoclinic zirconia may also be present in the cubic grains and at the grain boundaries. The toughening mechanism comes into play when a crack is encountered. The cubic grains are constraining the tetragonal precipitates that want to expand and release associated energy. When these grains are faced with a propagating crack tip, the tetragonal phase is released and allowed to change back to the more stable monoclinic phase. This results in the associated volumetric expansion,

effectively closing the advancing crack. This is called transformation toughening and is a stress induced martensitic transformation to the monoclinic phase.

Transformation Toughening in Partially Stabilized Zirconias

Typical Properties of Partially Stabilized Zirconias

**Typical properties of PSZ materials include:**

- Excellent fracture toughness
- Excellent wear resistance
- Excellent impact resistance
- Good resistance to thermal shock
- Good chemical resistance
- Good corrosion resistance

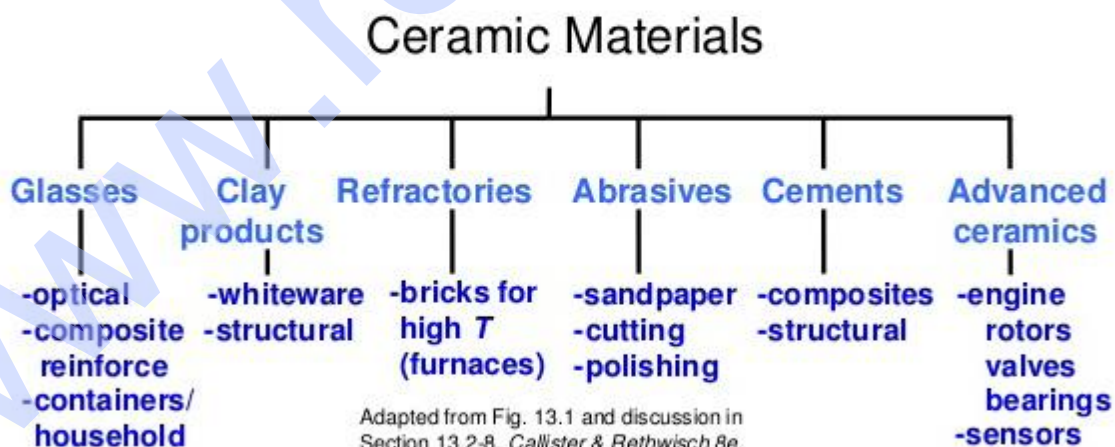
**Applications of Partially Stabilized Zirconias**

Typical application of PSZ materials include:

- Dies and tooling
- Knives, scissors and blades
- Wear resistant components including bearings and linings
- Pump parts
- Grinding media

17. **Classify engineering ceramics and list properties and applications of any two of them.**

## Classification of Ceramics



**Refractories:**

Used to make furnace lining, and in domestic buildings.



### Abrasives:

Used for fine machining and for delaminating for biological application.

## 18. Brief on properties and application of any two polymers from the list: PTFE, PC, PET, ABS and PS.

### i) PET

The majority of the world's PET production is for synthetic fibers (in excess of 60%), with bottle production accounting for about 30% of global demand.[5] In the context of textile applications, PET is referred to by its common name, *polyester*, whereas the acronym *PET* is generally used in relation to packaging. Polyester makes up about 18% of world polymer production and is the fourth-most-produced polymer; polyethylene (PE), polypropylene (PP) and polyvinyl chloride (PVC) are first, second and third, respectively.

PET consists of polymerized units of the monomer ethylene terephthalate, with repeating (C<sub>10</sub>H<sub>8</sub>O<sub>4</sub>) units. PET Depending on its processing and thermal history, polyethylene terephthalate may exist both as an amorphous (transparent) and as a semi-crystalline polymer. The semicrystalline material might appear transparent (particle size < 500 nm) or opaque and white (particle size up to a few micrometers) depending on its crystal structure and particle size.

The monomer bis(2-hydroxyethyl) terephthalate can be synthesized by the esterification reaction between terephthalic acid and ethylene glycol with water as a byproduct, or by transesterification reaction between ethylene glyco and dimethyl terephthalate with methanol as a byproduct. Polymerization is through a polycondensation reaction of the monomers (done immediately after esterification/transesterification) with water as the byproduct.

PET in its natural state is a colorless, semi-crystalline resin. Based on how it is processed, PET can be semi-rigid to rigid, and it is very lightweight. It makes a good gas and fair moisture barrier, as well as a good barrier to alcohol (requires additional "barrier" treatment) and solvents. It is strong and impact-resistant. PET becomes white when exposed to chloroform and also certain other chemicals such as toluene. About 60% crystallization is the upper limit for commercial products, with the exception of polyester fibers. Clear products can be produced by rapidly cooling molten polymer below T<sub>g</sub> glass transition temperature to form an amorphous solid. Like glass, amorphous PET forms when its molecules are not given enough time to arrange themselves in an orderly, crystalline fashion as the melt is cooled. At room temperature the molecules are frozen in place, but, if enough heat energy is put back into them by heating above T<sub>g</sub>, they begin to move again, allowing crystals to nucleate and grow. This procedure is known as solid-state crystallization.

When allowed to cool slowly, the molten polymer forms a more crystalline material. This material has spherulites containing many small crystallites when crystallized from an amorphous solid, rather than forming one large single crystal. Light tends to scatter as it crosses the boundaries between crystallites and the amorphous regions between them. This scattering means that crystalline PET is opaque and white in most cases. Fiber drawing is among the few industrial processes that produce a nearly single-crystal product.

Because PET is an excellent water and moisture barrier material, plastic bottles made from PET are widely used for soft drinks(see carbonation). For certain specialty bottles, such as those designated for beer containment, PET sandwiches an additional polyvinyl alcohol (PVOH) layer to further reduce its oxygen permeability.

Biaxially oriented PET film (often known by one of its trade names, "Mylar") can be aluminized by evaporating a thin film of metal onto it to reduce its permeability, and to make

it reflective and opaque (MPET). These properties are useful in many applications, including flexible food packaging and thermal insulation. See: “space blankets”. Because of its high mechanical strength, PET film is often used in tape applications, such as the carrier for magnetic tape or backing for pressure-sensitive adhesive tapes.

Non-oriented PET sheet can be thermoformed to make packaging trays and blister packs[6]. If crystallizable PET is used, the trays can be used for frozen dinners, since they withstand both freezing and oven baking temperatures. As opposed to amorphous PET, which is transparent, crystallizable PET or CPET tends to be black in colour.

When filled with glass particles or fibres, it becomes significantly stiffer and more durable.

PET is also used as a substrate in thin film solar cells.

Terylene (a trademark formed by inversion of (polyeth)ylene ter(ephthalate)) is also spliced into bell rope tops to help prevent wear on the ropes as they pass through the ceiling.

## ii) PC

Polycarbonates (PC) are a group of thermoplastic polymers containing carbonate groups in their chemical structures. Polycarbonates used in engineering are strong, tough materials, and some grades are optically transparent. They are easily worked, molded, and thermoformed. Because of these properties, polycarbonates find many applications. Polycarbonates do not have a unique resin identification code (RIC) and are identified as “Other”, 7 on the RIC list. Products made from polycarbonate can contain the precursor monomer bisphenol A (BPA). Polycarbonate is also known by a variety of trademarked names, including Lexan, Makrolon, Hammerglass and others.

Polycarbonate is a durable material. Although it has high impact-resistance, it has low scratch-resistance. Therefore, a hard coating is applied to polycarbonate eyewear lenses and polycarbonate exterior automotive components. The characteristics of polycarbonate compare to those of polymethyl methacrylate (PMMA, acrylic), but polycarbonate is stronger and will hold up longer to extreme temperature. Polycarbonate is highly transparent to visible light, with better light transmission than many kinds of glass.

Polycarbonate has a glass transition temperature of about 147 °C (297 °F),[6] so it softens gradually above this point and flows above about 155 °C (311 °F).[7] Tools must be held at high temperatures, generally above 80 °C (176 °F) to make strain-free and stress-free products. Low molecular mass grades are easier to mold than higher grades, but their strength is lower as a result. The toughest grades have the highest molecular mass, but are much more difficult to process.

Unlike most thermoplastics, polycarbonate can undergo large plastic deformations without cracking or breaking. As a result, it can be processed and formed at room temperature using sheet metal techniques, such as bending on a brake. Even for sharp angle bends with a tight radius, heating may not be necessary. This makes it valuable in prototyping applications where transparent or electrically non-conductive parts are needed, which cannot be made from sheet metal. PMMA/Acrylic, which is similar in appearance to polycarbonate, is brittle and cannot be bent at room temperature.

### Main transformation techniques for polycarbonate resins:

Extrusion into tubes, rods and other profiles including multiwall

Extrusion with cylinders (calenders) into sheets (0.5–20 mm (0.020– 0.787 in)) and films (below 1 mm (0.039 in)), which can be used directly or manufactured into other shapes using thermoforming or secondary fabrication techniques, such as bending, drilling, or routing. Due to its chemical properties it is not conducive to laser-cutting.

## Injection molding into ready articles

Polycarbonate may become brittle when exposed to ionizing radiation above 25 kGy (J/kg).

### iii) ABS

Acrylonitrile butadiene styrene (ABS) (chemical formula  $(C_8H_8)_x \cdot (C_4H_6)_y \cdot (C_3H_3N)_z$ ) is a common thermoplastic polymer. Its glass transition temperature is approximately 105°C (221°F). ABS is amorphous and therefore has no true melting point.

ABS is a terpolymer made by polymerizing styrene and acrylonitrile in the presence of polybutadiene. The proportions can vary from 15 to 35% acrylonitrile, 5 to 30% butadiene and 40 to 60% styrene. The result is a long chain of polybutadiene criss-crossed with shorter chains of poly(styrene-co-acrylonitrile). The nitrile groups from neighboring chains, being polar, attract each other and bind the chains together, making ABS stronger than pure polystyrene. The styrene gives the plastic a shiny, impervious surface. The polybutadiene, a rubbery substance, provides toughness even at low temperatures. For the majority of applications, ABS can be used between -20 and 80 °C (-4 and 176 °F) as its mechanical properties vary with temperature. The properties are created by rubber toughening, where fine particles of elastomer are distributed throughout the rigid matrix.

The most important mechanical properties of ABS are impact resistance and toughness. A variety of modifications can be made to improve impact resistance, toughness, and heat resistance. The impact resistance can be amplified by increasing the proportions of polybutadiene in relation to styrene and also acrylonitrile, although this causes changes in other properties. Impact resistance does not fall off rapidly at lower temperatures. Stability under load is excellent with limited loads. Thus, by changing the proportions of its components, ABS can be prepared in different grades. Two major categories could be ABS for extrusion and ABS for injection moulding, then high and medium impact resistance. Generally ABS would have useful characteristics within a temperature range from -20 to 80 °C (-4 to 176 °F).

The final properties will be influenced to some extent by the conditions under which the material is processed to the final product. For example, molding at a high temperature improves the gloss and heat resistance of the product whereas the highest impact resistance and strength are obtained by molding at low temperature. Fibers (usually glass fibers) and additives can be mixed in the resin pellets to make the final product strong and raise the operating range to as high as 80 °C (176 °F). Pigments can also be added, as the raw material original color is translucent ivory to white. The aging characteristics of the polymers are largely influenced by the polybutadiene content, and it is normal to include antioxidants in the composition. Other factors include exposure to ultraviolet radiation, for which additives are also available to protect against. ABS polymers are resistant to aqueous acids, alkalis, concentrated hydrochloric and phosphoric acids, alcohols and animal, vegetable and mineral oils, but they are swollen by glacial acetic acid, carbon tetrachloride and aromatic hydrocarbons and are attacked by concentrated sulfuric and nitric acids. They are soluble in esters, ketones, ethylene dichloride and acetone. Even though ABS plastics are used largely for mechanical purposes, they also have electrical properties that are fairly constant over a wide range of frequencies. These properties are little affected by temperature and atmospheric humidity in the acceptable operating range of temperatures.

ABS is flammable when it is exposed to high temperatures, such as a wood fire. It will melt then boil, at which point the vapors burst into intense, hot flames. Since pure ABS contains no halogens, its combustion does not typically produce any persistent organic pollutants, and the most toxic products of its combustion or pyrolysis are carbon monoxide and hydrogen

cyanide. ABS is also damaged by sunlight. This caused one of the most widespread and expensive automobile recalls in US history due to the degradation of the seatbelt release buttons. ABS can be recycled, although it is not accepted by all recycling facilities. A Super Nintendo Entertainment System with its outer casing made of ABS. Over time, the casing changed colour from light grey to yellow as a result of oxidation. When exposed to sunlight for a prolonged period of time, ABS will sometimes experience yellowing as a result of oxidation. This yellow colour can be cleaned through the use of hydrogen peroxide and UV light.

**Free radical polymerization** (unsaturated compounds, e.g., alkenes and their derivatives) that can participate in a chain reaction. A chain reaction consists of three stages, Initiation, Propagation and Termination. In the Initiation step an initiator molecule is thermally decomposed or allowed to undergo a chemical reaction to generate an "active species". This "active species," which can be a free radical or a cation or an anion, then initiates the polymerization by adding to the monomer's carbon-carbon double bond. The reaction occurs in such a manner that a new free radical or cation or anion is generated. The initial monomer becomes the first repeat unit in the incipient polymer chain. In the Propagation step, the newly generated "active species" adds to another monomer in the same manner as in the initiation step. This procedure is repeated over and over again until the final step of the process, termination, occurs. In the Termination step, the growing chain terminates through reaction with another growing chain, by reaction with another species in the polymerization mixture, or by the spontaneous decomposition of the active site. Under certain conditions, anionic can be carried out without the termination step to generate so-called "living" polymers.

**General characteristics of addition polymerization** [1] Once initiation occurs, the polymer chain forms very quickly [2] The concentration of active species is very low. Hence, the polymerisation mixture consists of primarily of newly-formed polymer and unreacted monomer. Since the carbon-carbon double bonds in the monomers are, in effect, converted to two single carbon-carbon bonds in the polymer, so energy is released making the polymerization exothermic with cooling often required.

### Condensation Polymerisation:

This type of polymerisation generally involves a repetitive condensation reaction (two molecules join together, resulting loss of small molecules) between two bi-functional monomers. These polycondensation reactions may result in the loss of some simple molecules as water, alcohol, etc., and lead to the formation of high molecular mass condensation polymers. In these reactions, the product of each step is again a bi-functional species and the sequence of condensation goes on. Since, each step produces a distinct functionalised species and is independent of each other; this process is also called as step growth polymerisation. The type of end polymer product resulting from a condensation polymerization is dependent on the number of functional end groups of the monomer which can react. Monomers with only one reactive group terminate a growing chain, and thus give end products with a lower molecular weight. Linear polymers are created using monomers with two reactive end groups and monomers with more than two end groups give three dimensional polymers which are cross linked. Polyester is created through ester linkages between monomers, which involve the functional groups carboxyl and hydroxyl (an organic acid and an alcohol monomer). The formation of polyester like terylene or dacron by the interaction of ethylene glycol and terephthalic acid is an example of this type of polymerisation. Polyamide is created through amide linkages between monomers, which involve the functional groups carboxyl and amine (an organic acid and an amine monomer). Nylon-6 is an example which can be manufactured by the condensation polymerisation of hexamethylenediamine with adipic acid under high pressure and at high temperature. This type of polymerization normally employs two difunctional monomers that are capable of undergoing typical organic reactions. For example, a diacid can be allowed to react with a



diol in the presence of an acid catalyst to afford polyester, in this case, chain growth is initiated by the reaction of one of the diacid's carboxyl groups with one of the diol's hydroxyl groups. The free carboxyl or hydroxyl group of the resulting dimer can then react with an appropriate functional group in another monomer or dimer, this process is repeated throughout the polymerization mixture until all of the monomers are converted to low molecular weight species, such as dimers, trimers, tetramers, etc. These molecules, which are called oligomers, can then further react with each other through their free functional groups. Polymer chains that have moderate molecular weight can be built in this manner. The following are several general characteristics of this type of polymerization: (1) The polymer chain forms slowly, sometimes requiring several hours to several days (2) All of the monomers are quickly converted to oligomers, thus, the concentration of growing chains is high (3) Since most of the chemical reactions employed have relatively high energies of activation, the polymerization mixture is usually heated to high temperatures (4) Step-reaction polymerizations normally afford polymers with moderate molecular weights, i.e., Condensation Polymerisation. This type of polymerisation generally involves a repetitive condensation reaction (two molecules join together, resulting loss of small molecules) between two bi-functional monomers. These polycondensation reactions may result in the loss of some simple molecules as water, alcohol, etc., and lead to the formation of high molecular mass condensation polymers. In these reactions, the product of each step is again a bi-functional species and the sequence of condensation goes on. Since, each step produces a distinct functionalised species and is independent of each other; this process is also called as step growth polymerisation. The type of end polymer product resulting from a condensation polymerization is dependent on the number of functional end groups of the monomer which can react. Monomers with only one reactive group terminate a growing chain, and thus give end products with a lower molecular weight. Linear polymers are created using monomers with two reactive end groups and monomers with more than two end groups give three dimensional polymers which are cross linked. Polyester is created through ester linkages between monomers, which involve the functional groups carboxyl and hydroxyl (an organic acid and an alcohol monomer). The formation of polyester like terylene or dacron by the interaction of ethylene glycol and terephthalic acid is an example of this type of polymerisation. Polyamide is created through amide linkages between monomers, which involve the functional groups carboxyl and amine (an organic acid and an amine monomer). Nylon-6 is an example which can be manufactured by the condensation polymerisation of hexamethylenediamine with adipic acid under high pressure and at high temperature. This type of polymerization normally employs two difunctional monomers that are capable of undergoing typical organic reactions. For example, a diacid can be allowed to react with a diol in the presence of an acid catalyst to afford polyester, in this case, chain growth is initiated by the reaction of one of the diacid's carboxyl groups with one of the diol's hydroxyl groups. The free carboxyl or hydroxyl group of the resulting dimer can then react with an appropriate functional group in another monomer or dimer, this process is repeated throughout the polymerization mixture until all of the monomers are converted to low molecular weight species, such as dimers, trimers, tetramers, etc. These molecules, which are called oligomers, can then further react with each other through their free functional groups. Polymer chains that have moderate molecular weight can be built in this manner. The following are several general characteristics of this type of polymerization: (1) The polymer chain forms slowly, sometimes requiring several hours to several days (2) All of the monomers are quickly converted to oligomers, thus, the concentration of growing chains is high (3) Since most of the chemical reactions employed have relatively high energies of activation, the polymerization mixture is



usually heated to high temperatures (4) Step-reaction polymerizations normally afford polymers with moderate molecular weights

**19. Write short note about the different types of matrix materials and reinforcement materials used to make polymer matrix composites.**

Fibre-reinforced plastic (FRP) (also *fibre-reinforced polymer*) is a composite material made of a polymer matrix reinforced with fibres. The fibres are usually glass, carbon, aramid, or basalt. Rarely, other fibres such as paper or wood or asbestos have been used. The polymer is usually an epoxy, vinylester or polyester thermosetting plastic; and phenol formaldehyde resins are still in use.

FRPs are commonly used in the aerospace-, automotive-, marine- and construction industries; and in ballistic armor.

Fibre preforms are how the fibres are manufactured before being bonded to the matrix. Fibre preforms are often manufactured in sheets, continuous mats, or as continuous filaments for spray applications. The four major ways to manufacture the fibre preform is through the textile processing techniques of weaving, knitting, braiding and stitching.

**1. Weaving**

Weaving can be done in a conventional manner to produce two-dimensional fibres as well in a multilayer weaving that can create three-dimensional fibres. However, multilayer weaving is required to have multiple layers of warp yarns to create fibres in the z- direction creating a few disadvantages in manufacturing, namely the time to set up all the warp yarns on the loom. Therefore, most multilayer weaving is currently used to produce relatively narrow width products, or high value products where the cost of the preform production is acceptable. Another one of the main problems facing the use of multilayer woven fabrics is the difficulty in producing a fabric that contains fibres oriented with angles other than 0° and 90° to each other respectively.

**2. Braiding**

1. The second major way of manufacturing fibre preforms is Braiding. Braiding is suited to the manufacture of narrow width flat or tubular fabric and is not as capable as weaving in the production of large volumes of wide **What do you understand by polymerization. With the help of suitable examples, compare and contrast the process of addition polymerization and condensation polymerization.**

In polymer chemistry, polymerization is a process of reacting monomer molecules together in a chemical reaction to form polymer chains or three-dimensional networks. There are many forms of polymerization and different systems exist to categorize them.

**Addition Polymerisation:**

In this type of polymerisation, the molecules of the same monomer or different monomers add together on a large scale to form a polymer. The monomers normally employed in this type of polymerization contain a carbon-carbon double bond. Braiding is done over top of mandrels that vary in cross-sectional shape or dimension along their length. Braiding is limited to objects about a brick in size. Unlike standard weaving, braiding can produce fabric that contains fibres at 45 degree angles to one another. Braiding three-dimensional fibres can be done using four step, two-step or Multilayer Interlock Braiding. Four step or row and column braiding utilizes a flat bed containing rows and columns of yarn carriers that form the shape of the desired preform. Additional carriers are added to the outside of the array, the precise location and quantity of which depends upon the exact preform shape and structure required. There are four separate

sequences of row and column motion, which act to interlock the yarns and produce the braided preform. The yarns are mechanically forced into the structure between each step to consolidate the structure in a similar process to the use of a reed in weaving. Two-step braiding is unlike the four-step process because the two-step includes a large number of yarns fixed in the axial direction and a fewer number of braiding yarns. The process consists of two steps in which the braiding carriers move completely through the structure between the axial carriers. This relatively simple sequence of motions is capable of forming preforms of essentially any shape, including circular and hollow shapes. Unlike the four-step process, the two-step process does not require mechanical compaction the motions involved in the process allows the braid to be pulled tight by yarn tension alone. The last type of braiding is multilayer interlocking braiding that consists of a number of standard circular braiders being joined together to form a cylindrical braiding frame. This frame has a number of parallel braiding tracks around the circumference of the cylinder but the mechanism allows the transfer of yarn carriers between adjacent tracks forming a multilayer braided fabric with yarns interlocking to adjacent layers. The multilayer interlock braid differs from both the four step and two-step braids in that the interlocking yarns are primarily in the plane of the structure and thus do not significantly reduce the in-plane properties of the preform. The four-step and two-step processes produce a greater degree of interlinking as the braiding yarns travel through the thickness of the preform, but therefore contribute less to the in-plane performance of the preform. A disadvantage of the multilayer interlock equipment is that due to the conventional sinusoidal movement of the yarn carriers to form the preform, the equipment is not able to have the density of yarn carriers that is possible with the two step and four step machines. **3. Knitting**

Knitting fibre preforms can be done with the traditional methods of Warp and [Weft] Knitting, and the fabric produced is often regarded by many as two-dimensional fabric, but machines with two or more needle beds are capable of producing multilayer fabrics with yarns that traverse between the layers. Developments in electronic controls for needle selection and knit loop transfer, and in the sophisticated mechanisms that allow specific areas of the fabric to be held and their movement controlled. This has allowed the fabric to form itself into the required three-dimensional preform shape with a minimum of material wastage.

#### **4. Stitching**

Stitching is arguably the simplest of the four main textile manufacturing techniques and one that can be performed with the smallest investment in specialized machinery. Basically stitching consists of inserting a needle, carrying the stitch thread, through a stack of fabric layers to form a 3D structure. The advantages of stitching are that it is possible to stitch both dry and prepreg fabric, although the tackiness of the prepreg makes the process difficult and generally creates more damage within the prepreg material than in the dry fabric. Stitching also utilizes the standard two-dimensional fabrics that are commonly in use within the composite industry therefore there is a sense of familiarity concerning the material systems. The use of standard fabric also allows a greater degree of flexibility in the fabric lay-up of the component than is possible with the other textile processes, which have restrictions on the fibre orientations that can be produced.

#### **Forming processes**

A rigid structure is usually used to establish the shape of FRP components. Parts can be laid up on a flat surface referred to as a “caul plate” or on a cylindrical structure referred to as a “mandrel”. However most fibre-reinforced plastic parts are created with a mold or “tool.” Molds can be concave female molds, male molds, or the mold can completely enclose the part with a top and bottom mold.

The moulding processes of FRP plastics begins by placing the fibre preform on or in the mold. The fibre preform can be dry fibre, or fibre that already contains a measured amount of resin called “prepreg”. Dry fibres are “wetted” with resin either by hand or the resin is injected into a closed mold. The part is then cured, leaving the matrix and fibres in the shape created by the mold. Heat and/or pressure are sometimes used to cure the resin and improve the quality of the final part. The different methods of forming are listed below.

### **Bladder moulding**

Individual sheets of prepreg material are laid up and placed in a female-style mould along with a balloon-like bladder. The mould is closed and placed in a heated press. Finally, the bladder is pressurized forcing the layers of material against the mould walls.

### **Compression moulding**

When the raw material (plastic block, rubber block, plastic sheet, or granules) contains reinforcing fibres, a compression molded part qualifies as a fibre-reinforced plastic. More typically the plastic preform used in compression molding does not contain reinforcing fibres. In compression molding, a “preform” or “charge”, of SMC, BMC is placed into mould cavity. The mould is closed and the material is formed & cured inside by pressure and heat. Compression moulding offers excellent detailing for geometric shapes ranging from pattern and relief detailing to complex curves and creative forms, to precision engineering all within a maximum curing time of 20 minutes.[20]

### **Autoclave and vacuum bag**

Individual sheets of prepreg material are laid-up and placed in an open mold. The material is covered with release film, bleeder/breather material and a vacuum bag. A vacuum is pulled on part and the entire mould is placed into an autoclave (heated pressure vessel). The part is cured with a continuous vacuum to extract entrapped gasses from laminate. This is a very common process in the aerospace industry because it affords precise control over moulding due to a long, slow cure cycle that is anywhere from one to several hours.[21] This precise control creates the exact laminate geometric forms needed to ensure strength and safety in the aerospace industry, but it is also slow and labour-intensive, meaning costs often confine it to the aerospace industry.

### **Mandrel wrapping**

Sheets of prepreg material are wrapped around a steel or aluminium mandrel. The prepreg material is compacted by nylon or polypropylene cello tape. Parts are typically batch cured by vacuum bagging and hanging in an oven. After cure the cello and mandrel are removed leaving a hollow carbon tube. This process creates strong and robust hollow carbon tubes.

### **Wet layup**

Wet layup forming combines fibre reinforcement and the matrix as they are placed on the forming tool. Reinforcing Fibre layers are placed in an open mould and then saturated with a wet resin by pouring it over the fabric and working it into the fabric. The mould is then left so that the resin will cure, usually at room temperature, though heat is sometimes used to ensure a proper cure. Sometimes a vacuum bag is used to compress a wet layup. Glass fibres are most commonly used for this process, the results are widely known as fibreglass, and is used to make common products like skis, canoes, kayaks and surf boards.

### **Chopper gun**

Continuous strands of fibreglass are pushed through a hand-held gun that both chops the strands and combines them with a catalysed resin such as polyester. The impregnated chopped glass is shot onto the mould surface in whatever thickness and design the human operator thinks is appropriate. This process is good for large production runs at economical

cost, but produces geometric shapes with less strength than other moulding processes and has poor dimensional tolerance.

### **Filament winding**

Machines pull fibre bundles through a wet bath of resin and wound over a rotating steel mandrel in specific orientations. Parts are cured either room temperature or elevated temperatures. Mandrel is extracted, leaving a final geometric shape but can be left in some cases.

### **Pultrusion**

Fibre bundles and slit fabrics are pulled through a wet bath of resin and formed into the rough part shape. Saturated material is extruded from a heated closed die curing while being continuously pulled through die. Some of the end products of pultrusion are structural shapes, i.e. I beam, angle, channel and flat sheet. These materials can be used to create all sorts of fibreglass structures such as ladders, platforms, handrail systems tank, pipe and pump supports. **Resin transfer molding**

Also called resin infusion. Fabrics are placed into a mould into which wet resin is then injected. Resin is typically pressurized and forced into a cavity which is under vacuum in resin transfer molding. Resin is entirely pulled into cavity under vacuum in vacuum-assisted resin transfer molding. This moulding process allows precise tolerances and detailed shaping but can sometimes fail to fully saturate the fabric leading to weak spots in the final shape.

### **Advantages and limitations**

FRP allows the alignment of the glass fibres of thermoplastics to suit specific design programs. Specifying the orientation of reinforcing fibres can increase the strength and resistance to deformation of the polymer. Glass reinforced polymers are strongest and most resistive to deforming forces when the polymers fibres are parallel to the force being exerted, and are weakest when the fibres are perpendicular. Thus this ability is at once both an advantage or a limitation depending on the context of use. Weak spots of perpendicular fibres can be used for natural hinges and connections, but can also lead to material failure when production processes fail to properly orient the fibres parallel to expected forces. When forces are exerted perpendicular to the orientation of fibres the strength and elasticity of the polymer is less than the matrix alone. In cast resin components made of glass reinforced polymers such as UP and EP, the orientation of fibres can be oriented in two-dimensional and three-dimensional weaves. This means that when forces are possibly perpendicular to one orientation, they are parallel to another orientation; this eliminates the potential for weak spots in the polymer.

### **Failure modes**

Structural failure can occur in FRP materials when:

- Tensile forces stretch the matrix more than the fibres, causing the material to shear at the interface between matrix and fibres.

- Tensile forces near the end of the fibres exceed the tolerances of the matrix, separating the fibres from the matrix.

- Tensile forces can also exceed the tolerances of the fibres causing the fibres themselves to fracture leading to material failure.

### **Material requirements**

#### **Basalt fibre**

The matrix must also meet certain requirements in order to first be suitable for FRPs and ensure a successful reinforcement of itself. The matrix must be able to properly saturate,

and bond with the fibres within a suitable curing period. The matrix should preferably bond chemically with the fibre reinforcement for maximum adhesion. The matrix must also completely envelop the fibres to protect them from cuts and notches that would reduce their strength, and to transfer forces to the fibres. The fibres must also be kept separate from each other so that if failure occurs it is localized as much as possible, and if failure occurs the matrix must also debond from the fibre for similar reasons. Finally the matrix should be of a plastic that remains chemically and physically stable during and after the reinforcement and moulding processes. To be suitable as reinforcement material, fibre additives must increase the tensile strength and modulus of elasticity of the matrix and meet the following conditions; fibres must exceed critical fibre content; the strength and rigidity of fibres itself must exceed the strength and rigidity of the matrix alone; and there must be optimum bonding between fibres and matrix

### **Glass fibre material**

“Fibreglass reinforced plastics” or FRPs (commonly referred to simply as fibreglass) use textile grade glass fibres. These textile fibres are different from other forms of glass fibres used to deliberately trap air, for insulating applications (see glass wool). Textile glass fibres begin as varying combinations of  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{B}_2\text{O}_3$ ,  $\text{CaO}$ , or  $\text{MgO}$  in powder form. These mixtures are then heated through direct melting to temperatures around 1300 degrees Celsius, after which dies are used to extrude filaments of glass fibre in diameter ranging from 9 to 17  $\mu\text{m}$ . These filaments are then wound into larger threads and spun onto bobbins for transportation and further processing. Glass fibre is by far the most popular means to reinforce plastic and thus enjoys a wealth of production processes, some of which are applicable to aramid and carbon fibres as well owing to their shared fibrous qualities.

Roving is a process where filaments are spun into larger diameter threads. These threads are then commonly used for woven reinforcing glass fabrics and mats, and in spray applications. Fibre fabrics are web-form fabric reinforcing material that has both warp and weft directions. Fibre mats are web-form non-woven mats of glass fibres. Mats are manufactured in cut dimensions with chopped fibres, or in continuous mats using continuous fibres. Chopped fibre glass is used in processes where lengths of glass threads are cut between 3 and 26 mm, threads are then used in plastics most commonly intended for moulding processes. Glass fibre short strands are short 0.2–0.3 mm strands of glass fibres that are used to reinforce thermoplastics most commonly for injection moulding.

### **Carbon fibre**

Carbon fibres are created when polyacrylonitrile fibres (PAN), Pitch resins, or Rayon are carbonized (through oxidation and thermal pyrolysis) at high temperatures. Through further processes of graphitizing or stretching the fibres strength or elasticity can be enhanced respectively. Carbon fibres are manufactured in diameters analogous to glass fibres with diameters ranging from 4 to 17  $\mu\text{m}$ . These fibres wound into larger threads for transportation and further production processes.[2] Further production processes include weaving or braiding into carbon fabrics, cloths and mats analogous to those described for glass that can then be used in actual reinforcements.[1]

### **Aramid fibre material**

Aramid fibres are most commonly known as Kevlar, Nomex and Technora. Aramids are generally prepared by the reaction between an amine group and a carboxylic acid halide group (aramid);[ commonly this occurs when an aromatic polyamide is spun from a liquid concentration of sulphuric acid into a crystallized fibre Fibres are then spun into larger threads in order to weave into large ropes or woven fabrics (Aramid). Aramid fibres are manufactured with varying grades to based on varying qualities for strength and rigidity, so



that the material can be somewhat tailored to specific design needs concerns, such as cutting the tough material during manufacture.

## 20. Discuss the properties and application of $\text{Al}_2\text{O}_3$ and $\text{SiC}$ .

Aluminium oxide is a chemical compound of aluminium and oxygen with the chemical formula  $\text{Al}_2\text{O}_3$ . It is the most commonly occurring of several aluminium oxides, and specifically identified as aluminium(III) oxide. It is commonly called alumina, and may also be called aloxide, aloxite, or alundum depending on particular forms or applications. It occurs naturally in its crystalline polymorphic phase  $\alpha\text{-Al}_2\text{O}_3$  as the mineral corundum, varieties of which form the precious gemstones ruby and sapphire.  $\text{Al}_2\text{O}_3$  is significant in its use to produce aluminium metal, as an abrasive owing to its hardness, and as a refractory material owing to its high melting point.

Silicon carbide ( $\text{SiC}$ ), also known as carborundum, is a compound of silicon and carbon with chemical formula  $\text{SiC}$ . It occurs in nature as the extremely rare mineral moissanite. Silicon carbide powder has been mass-produced since 1893 for use as an abrasive. Grains of silicon carbide can be bonded together by sintering to form very hard ceramics that are widely used in applications requiring high endurance, such as car brakes, car clutches and ceramic plates in bulletproof vests. Electronic applications of silicon carbide such as light-emitting diodes (LEDs) and detectors in early radios were first demonstrated around 1907.  $\text{SiC}$  is used in semiconductor electronics devices that operate at high temperatures or high voltages, or both. Large single crystals of silicon carbide can be grown by the Lely method; they can be cut into gems known as synthetic moissanite. Silicon carbide with high surface area can be produced from  $\text{SiO}_2$  contained in plant material.

## 21. Write short notes on:

### i) Phenol formaldehydes

Phenol formaldehyde resins (PF) or phenolic resins are synthetic polymers obtained by the reaction of phenol or substituted phenol with formaldehyde. Used as the basis for Bakelite, PFs were the first commercial synthetic resins (plastics). They have been widely used for the production of molded products including billiard balls, laboratory countertops, and as coatings and adhesives. They were at one time the primary material used for the production of circuit boards but have been largely replaced with epoxy resins and fiberglass cloth, as with fire-resistant FR-4 circuit board materials.

There are two main production methods. One reacts phenol and formaldehyde directly to produce a thermosetting network polymer, while the other restricts the formaldehyde to produce a prepolymer known as novolac which can be moulded and then cured with the addition of more formaldehyde and heat. There are many variations in both production and input materials that are used to produce a wide variety of resins for special purposes.

Phenolic resins are found in myriad industrial products. Phenolic laminates are made by impregnating one or more layers of a base material such as paper, fiberglass or cotton with phenolic resin and laminating the resin-saturated base material under heat and pressure. The resin fully polymerizes (cures) during this process. The base material choice depends on the intended application of the finished product. Paper phenolics are used in manufacturing electrical components such as punch-through boards, in household laminates, and in paper composite panels. Glass phenolics are particularly well suited for use in the high speed bearing market. Phenolic micro-balloons are used for density control. Snooker balls as well as balls from many table-based ball games are also made from phenol formaldehyde resin. The binding agent in normal (organic) brake pads, brake shoes and clutch disks are phenolic resin. Synthetic resin bonded paper, made from phenolic resin and paper, is used to make countertops.

Phenolic resins are also used for making exterior plywood commonly known as WBP (Weather & boil proof) Plywood because phenolic resins have no melting point but only a decomposing point in the temperature zone of 220 degree Celsius and above.

Phenolic resin is used as a binder in loudspeaker driver suspension components which are made of cloth.

Sometimes people select phenolic resin parts because their coefficient of thermal expansion closely matches that of the aluminum used for other parts of a system, as in early computer systems[3] and Duramold.

The Dutch forger Han van Meegeren mixed phenol formaldehyde with his oil paints before baking the finished canvas in order to fake the drying out of the paint over the centuries.

### **Application of PMMA and PPO.**

#### **Poly(methyl acrylate)**

The polymer of methyl acrylate, PMA or poly(methyl acrylate), is similar to poly(methyl methacrylate), except for the lack of methyl groups on the backbone carbon chain.[23] PMA is a soft white rubbery material that is softer than PMMA because its long polymer chains are thinner and smoother and can more easily slide past each other. **Uses**

Being transparent and durable, PMMA is a versatile material and has been used in a wide range of fields and applications such as: rear-lights and instrument clusters for vehicles, appliances and lenses for glasses. PMMA in the form of sheets affords shatter resistant panels for building windows, skylights, bullet proof security barriers, signs & displays, sanitary ware (bathtubs), LCD screens, furniture and many other applications. It is also used for coating polymers based on MMA provides outstanding stability against environmental conditions with reduced emission of VOC. Methacrylate polymers are used extensively in medical and dental applications where purity and stability are critical to performance. Close-up of pressure sphere of Bathyscaphe Trieste, with single conical window of PMMA (Plexiglas) set into sphere hull. The very small black circle (smaller than the man's head) is the inner side of the plastic "window," and is only a few inches in diameter. The larger circular clear black area represents the larger outer-side of the thick one-piece plastic cone "window."

PMMA acrylic glass is commonly used for constructing residential and commercial aquariums. Designers started building big aquariums when poly(methyl methacrylate) could be used. It is less-used in other building types due to incidents such as the Summerland disaster.

Acrylic is used for viewing ports and even complete pressure hulls of submersibles, such as the Alicia submarine's viewing sphere and the window of the bathyscaphe Trieste.

PMMA is used in the lenses of exterior lights of automobiles.[24]

The spectator protection in ice hockey rinks is made from PMMA.

Historically, PMMA was an important improvement in the design of aircraft windows, making possible such iconic designs as the bombardier's transparent nose compartment in the Boeing B-17 Flying Fortress.

Police vehicles for riot control often have the regular glass replaced with acrylic to protect the occupants from thrown objects.

Acrylic is an important material in the making of certain lighthouse lenses.[25]

PMMA was used for the roofing of the iconic compound in the Olympic Park for the 1972 Summer Olympics in Munich. It enabled a light and translucent construction underlining the democratic approach to the games.[26]

PMMA (under the brand name “Lucite”) was used for the ceiling of the Houston Astrodome.

#### Daylight redirection

Laser cut acrylic panels have been used to redirect sunlight into a light pipe or tubular skylight and, from there, to spread it into a room.[27] Their developers Veronica Garcia Hansen, Ken Yeang, and Ian Edmonds were awarded the Far East Economic Review Innovation Award in bronze for this technology in 2003.

Attenuation being quite strong for distances over one meter (more than 90% intensity loss for a 3000 K ), acrylic broadband light guides are then dedicated mostly to decorative uses.

Pairs of acrylic sheets with a layer of microreplicated prisms between the sheets can have reflective and refractive properties that let them redirect part of incoming sunlight in dependence on its angle of incidence. Such panels act as miniature light shelves. Such panels have been commercialized for purposes of daylighting, to be used as a window or a canopy such that sunlight descending from the sky is directed to the ceiling or into the room rather than to the floor. This can lead to a higher illumination of the back part of a room, in particular when combined with a white ceiling, while having a slight impact on the view to the outside compared to normal glazing.

#### Medical technologies and implants

PMMA has a good degree of compatibility with human tissue, and it is used in the manufacture of rigid intraocular lenses which are implanted in the eye when the original lens has been removed in the treatment of cataracts. This compatibility was discovered by the English ophthalmologist Sir Harold Ridley in WWII RAF pilots, whose eyes had been riddled with PMMA splinters coming from the side windows of their Supermarine Spitfire fighters – the plastic scarcely caused any rejection, compared to glass splinters coming from aircraft such as the Hawker Hurricane.[33] Ridley had a lens manufactured by the Rayner company (Brighton & Hove, East Sussex) made from Perspex polymerised by ICI. On 29 November 1949 at St Thomas’ Hospital, London, Ridley implanted the first intraocular lens at St Thomas’s Hospital in London.[34]

In particular, acrylic-type contact lenses are useful for cataract surgery in patients that have recurrent ocular inflammation (uveitis), as acrylic material induce less inflammation.

Eyeglass lenses are commonly made from PMMA.

Historically, hard contact lenses were frequently made of this material. Soft contact lenses are often made of a related polymer, where acrylate monomers containing one or more hydroxyl groups make them hydrophilic.

In orthopedic surgery, PMMA bone cement is used to affix implants and to remodel lost bone. It is supplied as a powder with liquid methyl methacrylate (MMA).

Although PMMA is biologically compatible, MMA is considered to be an irritant and a possible carcinogen. PMMA has also been linked to cardiopulmonary events in the operating room due to hypotension.[35] Bone cement acts like a grout and not so much like a glue in arthroplasty. Although sticky, it does not bond to either the bone or the implant, it primarily fills the spaces between the prosthesis and the bone preventing motion. A disadvantage of this bone cement is that it heats up to 82.5 °C

(180.5 °F) while setting that may cause thermal necrosis of neighboring tissue. A careful balance of initiators and monomers is needed to reduce the rate of polymerization, and thus the heat generated. A major consideration when using PMMA cement is the effect of stress shielding. Since PMMA has a Young's modulus between 1.8 and 3.1 GPa, which is lower than that of natural bone (around 14 GPa for human cortical bone),[37] the stresses are loaded into the cement and so the bone no longer receives the mechanical signals to continue bone remodeling and so resorption will occur.

Dentures are often made of PMMA, and can be color-matched to the patient's teeth & gum tissue. PMMA is also used in the production of ocular prostheses, such as the osteo-odonto-keratoprosthesis.

In cosmetic surgery, tiny PMMA microspheres suspended in some biological fluid are injected under the skin to reduce wrinkles or scars permanently. PMMA is also used to create false "muscles" by body builders.

Plombage is an outdated treatment of tuberculosis where the pleural space around an infected lung was filled with PMMA balls, in order to compress and collapse the affected lung.

Emerging biotechnology and Biomedical research uses PMMA to create microfluidic lab-on-a-chip devices, which require 100

micrometre-wide geometries for routing liquids. These small geometries are amenable to using PMMA in a biochip fabrication process and offers moderate biocompatibility.

.□ Bioprocess chromatography columns use cast acrylic tubes as an alternative to glass and stainless steel. These are pressure rated and satisfy stringent requirements of materials for biocompatibility, toxicity and extractables.

### **Artistic and aesthetic uses**

Acrylic paint essentially consists of PMMA suspended in water; however since PMMA is hydrophobic, a substance with both hydrophobic and hydrophilic groups needs to be added to facilitate the suspension.

Modern furniture makers, especially in the 1960s and 1970s, seeking to give their products a space age aesthetic, incorporated Lucite and other PMMA products into their designs, especially office chairs. Many other products (for example, guitars) are sometimes made with acrylic glass to make the commonly opaque objects translucent.

Perspex has been used as a surface to paint on, for example by Salvador Dalí.

Diasec is a process which uses acrylic glass as a substitute for normal glass in picture frames. This is done for its relatively low cost, light weight, shatter-resistance, aesthetics and because it can be ordered in larger sizes than standard picture framing glass.

As early as 1939, Los Angeles-based Dutch sculptor Jan De Swart experimented with samples of Lucite sent to him by DuPont; De Swart created tools to work the Lucite for sculpture and mixed chemicals to bring about certain effects of color and refraction[40]

From approximately the 1960s onward, sculptors and glass artists such as Jan Kubiček and Leroy Lamis began using acrylics, especially taking advantage of the material's flexibility, light weight, cost and its capacity to refract and filter light.

In the 1950s and 1960s, Lucite was an extremely popular material for jewelry, with several companies specialized in creating high-quality pieces from this material. Lucite beads and ornaments are still sold by jewelry suppliers.

Acrylic Sheets are produced in dozens of standard colors,[41] most commonly sold using color numbers developed by Rohm & Haas in the 1950s.

### Other uses

Acrylic is used in tanning beds as the transparent surface that separates the occupant from the tanning bulbs while tanning. The type of acrylic used in tanning beds is most often formulated from a special type of polymethyl methacrylate, a compound that allows the passage of ultraviolet rays

Sheets of PMMA are commonly used in the sign industry to make flat cut out letters in thicknesses typically varying from 3 to 25 millimeters (0.1 to 1.0 in). These letters may be used alone to represent a company's name and/or logo, or they may be a component of illuminated channel letters. Acrylic is also used extensively throughout the sign industry as a component of wall signs where it may be a backplate, painted on the surface or the backside, a faceplate with additional raised lettering or even photographic images printed directly to it, or a spacer to separate sign components.

PMMA was used in Laserdisc optical media. (CDs and DVDs use both acrylic and polycarbonate for impact resistance.)

It is used as a light guide for the backlights in TFT-LCDs.

Plastic optical fiber used for short distance communication is made from PMMA, and perfluorinated PMMA, clad with fluorinated PMMA, in situations where its flexibility and cheaper installation costs outweigh its poor heat tolerance and higher attenuation over glass fiber.

PMMA, in a purified form, is used as the matrix in laser dye-doped organic solid-state gain media for tunable solid state dye lasers.[42]

In semiconductor research and industry, PMMA aids as a resist in the electron beam lithography process. A solution consisting of the polymer in a solvent is used to spin coat silicon and other semiconducting and semi-insulating wafers with a thin film. Patterns on this can be made by an electron beam (using an electron microscope), deep UV light (shorter wavelength than the standard

chain scission or (de-cross-linking) within the PMMA, allowing for the selective removal of exposed areas by a chemical developer, making it a positive photoresist. PMMA's advantage is that it allows for extremely high resolution patterns to be made. Smooth PMMA surface can be easily nanostructured by treatment in oxygen radio-frequency plasma and nanostructured PMMA surface can be easily smoothed by vacuum ultraviolet (VUV) irradiation.

- .PMMA is used as a shield to stop beta radiation emitted from radioisotopes

- .Small strips of PMMA are used as dosimeter devices during the Gamma Irradiation process. The optical properties of PMMA change as the gamma dose increases, and can be measured with a spectrophotometer.

- .A blacklight-reactive tattoo ink using PMMA microcapsules has been developed.

- .PMMA can be used as a dispersant for ceramic powders to stabilize colloidal suspensions in non-aqueous media. Due to its high viscosity upon dissolution, it can also be used as binder material for solution deposition processes, e.g. printing of solar cells.[45]



.PMMA has also been used extensively as a hybrid rocket fuel

.In the 1960s, luthier Dan Armstrong developed a line of electric guitars and basses whose bodies were made completely of acrylic. These instruments were marketed under the Ampeg brand. Ibanez and B.C. Rich have also made acrylic guitars.

.Ludwig-Musser makes a line of acrylic drums called Vistalites, well known as being used by Led Zeppelin drummer John Bonham.

.Artificial fingernails are sometimes made of acrylic.

.Some modern briar, and occasionally meerschaum, tobacco pipes sport stems made of Lucite.

.PMMA technology is utilized in roofing and waterproofing applications. By incorporating a polyester fleece sandwiched between two layers of catalyst-activated PMMA resin, a fully reinforced liquid membrane is created *in situ*.

PMMA is a widely used material to create deal toys and financial tombstones.

Poly (*p*-phenylene oxide) or poly(*p*-phenylene ether) (PPE) is a high-temperature thermoplastic. It is rarely used in its pure form due to difficulties in processing. It is mainly used as blend with polystyrene, high impact styrene-butadiene copolymer or polyamide. PPO is a registered trademark of SABIC Innovative Plastics IP B.V. under which various polyphenylene ether resins are sold.

PPE blends are used for structural parts, electronics, household and automotive items that depend on high heat resistance, dimensional stability and accuracy. They are also used in medicine for sterilizable instruments made of plastic. This plastic is processed by injection molding or extrusion; depending on the type, the processing temperature is 260-300 °C. The surface can be printed, hot-stamped, painted or metallized. Welds are possible by means of heating element, friction or ultrasonic welding. It can be glued with halogenated solvents or various adhesives.

This plastic is also used to produce air separation membranes for generating nitrogen. The PPO is spun into a hollow fiber membrane with a porous support layer and a very thin outer skin. The permeation of oxygen occurs from inside to out across the thin outer skin with an extremely high flux. Due to the manufacturing process, the fiber has excellent dimensional stability and strength. Unlike hollow fiber membranes made from polysulfone, the aging process of the fiber is relatively quick so that air separation performance remains stable throughout the life of the membrane. PPO makes the air separation performance suitable for low temperature (35-70F) (2-21C) applications where polysulfone membranes require heated air to increase permeation.

**22. Briefly explain the application and properties of various thermosetting and thermo plastics.**

Refer question number 8.

**23. Enumerate about various engineering ceramic materials.**

Refer question number 2.

**UNIT-V****PART A**

1. What are the characteristics features of ductile fracture surface?

- Cup and cone formation.
- Very high roughness on fractured surfaces.
- Micro cones when observed through microscope.

2. Under what condition, twinning is preferred mechanism of plastic deformation.

In BCC metals deform by slip, as do FCC metals with medium to high values of *stacking fault energy (SFE)* such as copper ( $\sim 80 \text{ mJ/m}^2$ ) and aluminum ( $\sim 170 \text{ mJ/m}^2$ ). In metals with low values of *SFE* such as silver or in alloys like 70:30 brass and austenitic stainless steels with *SFE*  $\sim 20 \text{ mJ/m}^2$ , the dislocations dissociate to form stacking faults, and twinning is the preferred mode of deformation. The tendency to deform by twinning is increased if the deformation temperature is lowered or the strain rate increased. Iron has a high stacking fault energy, as do all the BCC metals, but it too exhibits mechanical twinning at low temperatures and high strain rates.

3. Differentiate between brittle and ductile fracture.

Ductile fracture	Brittle fracture
• Material fractures after plastic deformation and slow propagation of crack	• Material fractures with very little or no plastic deformation.
• Surface obtained at the fracture is dull or fibrous in appearance	• Surface obtained at the fracture is shining and crystalline appearance
• It occurs when the material is in plastic condition.	• It occurs when the material is in elastic condition.
• It is characterized by the formation of cup and cone	• It is characterized by separation of normal to tensile stress.
• The tendency of ductile fracture is increased by dislocations and other defects in metals.	• The tendency brittle fracture is increased by decreasing temperature, and increasing strain rate.
• There is reduction in cross – sectional area of the specimen	• There is no change in the cross – sectional area.

4. What are the factors affecting fatigue.

Fatigue life is affected by cyclic stresses, residual stresses, material properties, internal defects, grain size, temperature, design geometry, surface quality, oxidation, corrosion, etc. The fatigue life of a component under the following different fatigue mechanisms can be ranked from low to high as: thermal shock, high temperature LCF, low temperature LCF, and HCF. In the assessment of the risk

5. How will the creep rupture surface look like.

Creep rupture surface has the features of a ductile fracture.

6. Rockwell hardness test involves pressing either a diamond shaped penetrator or a hard ball penetrator into the surface of the metal and measuring the penetration depth. A number of different sized indenters and loads are used. This method can give variable results depending on the preparation of the test material and equipment.
7. **Differentiate between ductile and brittle fracture?(Apr/May 2017)**

<b>Ductile failure</b>	<b>Brittle failure</b>
1) It involves large plastic deformation.	1) It is associated with minimum plastic deformation.
2) It is always preceded by the localized deformation called “necking”	2) It does not involve “necking”.
3) Ductile fracture normally occurs in F.C.C metals.	3) Brittle fracture is normally observed in B.C.C and H.C.P metal not in F.C.C metal.
4) Ductile fracture normally occurs through the grains.	4) Brittle fracture normally follows the grain boundaries.
5) A complete ductile fracture present a rough dirty surface. It has rough dirty contour	5) A complete brittle fracture shows sharp facets which reflect light.
6) It occurs by slow tearing of the metal with expenditure of considerable energy.	6) It occurs suddenly without any warning.

8. **What is the difference between HRB and HRC? (Apr/May 2017)**

<b>Rock well Scale</b>	<b>Hardness symbol</b>	<b>Indenter</b>	<b>Load (kg)</b>	<b>Typical Material Tested</b>
A	HRA	Cone	60	Carbides, ceramic
B	HRB	1.6 mm ball	100	Nonferrous metals
C	HRC	Cone	150	Ferrous metals, tool steels

9. **What are the characteristic features of brittle fracture?**

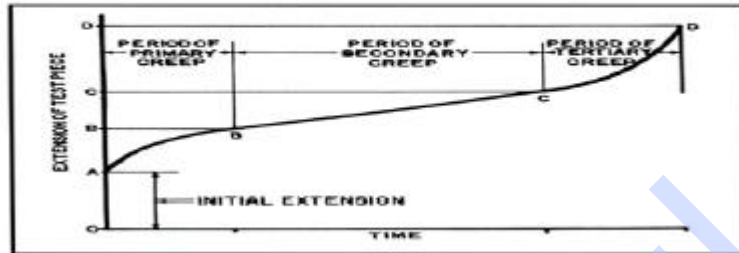
There is no gross, permanent deformation of the material. The surface of the brittle fracture tends to be perpendicular to the principal tensile stress although other components of stress can be factors.

10. **State hardness whether corresponds to ultimate tensile strength or yield strength. (Nov/Dec 2017)**

Hardness corresponds to ultimate tensile strength

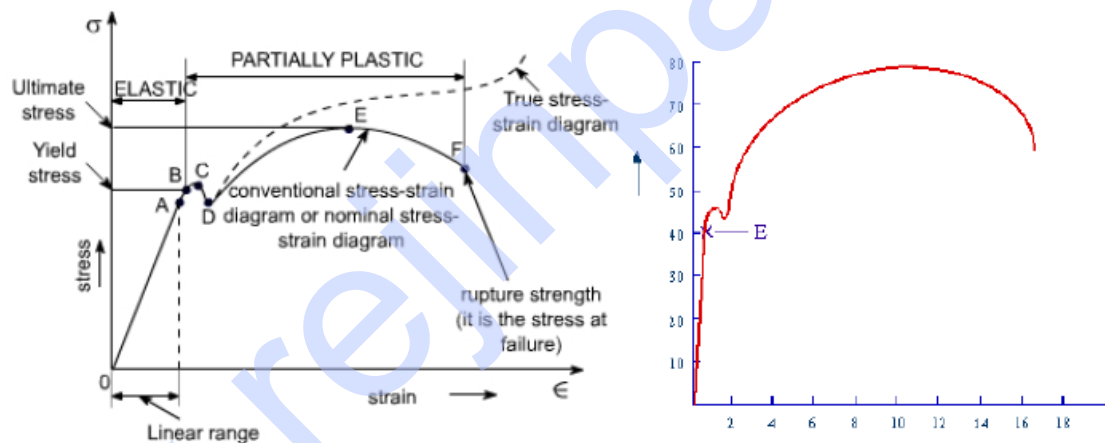
11.

**Draw typical creep curve for ductile metal and explain the regions. (April/May 2015)**



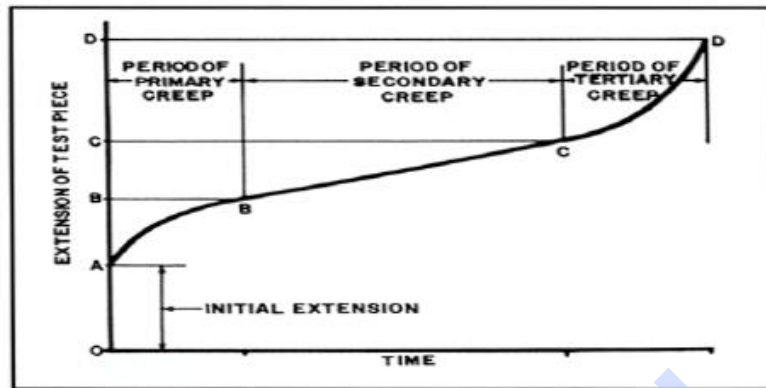
12.

**Draw a typical load versus percentage elongation curve for ductile material and explain the tensile properties (April/May 2015)**



13.

**What are the characteristic features of fracture surface of creep rupture component**  
(Nov/Dec 2015)



14.

**State the advantages of Rockwell hardness testing over other techniques.** (Nov/Dec 2015)

Among the commonly used hardness methods, Rockwell is the only one that allows direct reading of the hardness value without need of optical reading as per Vickers and Brinell methods. Therefore, it is the most rapid method and the only one that can be fully automated. The instruments working according to the Rockwell principle are the most popular, because they are less subject to operators influence. Even if, according to the standards, the test surface must be carefully smooth, among the different methods for hardness testing, the Rockwell test is the least influenced by surface roughness. The main limitations are due to the fact that between maximum and minimum load there is only a 10:1 ratio. In hardness testing, the most required loads by foundries and workshops are included in the range between 1 and 3000 kgf. For example, a Rockwell scale suitable for testing of cast iron or of steel sheets having a thickness lower than 0.15 mm does not exist. To overcome the limitation on light loads, instruments working according to the Rockwell principle are produced to work also with non-standardized light loads. Although the Rockwell method employs a wide range of hardness scales, for a range of materials of high importance, such as untreated steel, there is not a specific scale. In this case, it is advisable to employ an instrument working according to the Rockwell principle with Brinell loads and penetrators.

15.

**What is the effect of the grain size on the mechanical properties of the material?**

Size of the grain has the inversely proportional relation with ductility and fracture toughness.

**16. What is S-N diagram. what is the significance of it?**

S-N diagram shows the variation in strength of the material with respect to the various cycle of repeated loading and unloading cycles. Its significance is to find the fatigue strength of material and predict the robustness.

**17. What is twinning?**

Crystal twinning occurs when two separate crystals share some of the same crystal lattice points in a symmetrical manner. The result is an intergrowth of two separate



crystals in a variety of specific configurations. A twin boundary or composition surface separates the two crystals. Crystallographers classify twinned crystals by a number of twin laws. These twin laws are specific to the crystal system. The type of twinning can be a diagnostic tool in mineral identification.

**18. What is charpy?**

It is the impact test method to measure the impact strength and fracture toughness.

**19. What are the two components of the process of fracture?**

Crack initiation

Crack propagation

**20. What are the different types of fracture? Brittle**

- a. Ductile
- b. Fatigue
- c. Creep

**PART B**

1. Compare charpy and izod impact test.

Refer question no 7

2. Draw a typical creep curve and brief on the mechanism.

Refer question no 13.

3. Compare rockwell and Brinell hardness test.

Refer question no 10.

4. Draw a typical SN curve of fatigue testing and brief on the mechanism.

Refer question no 13.

5. Explain testing procedure for rockwell hardness test.

Refer question no 10.

6. Explain the testing procedure of Tensile test of material.

Refer question no 18.

7. **With geometry and arrangement of impact test specimens explain Charpy and Izod test with relative advantages and disadvantages. (May/June 2015)**

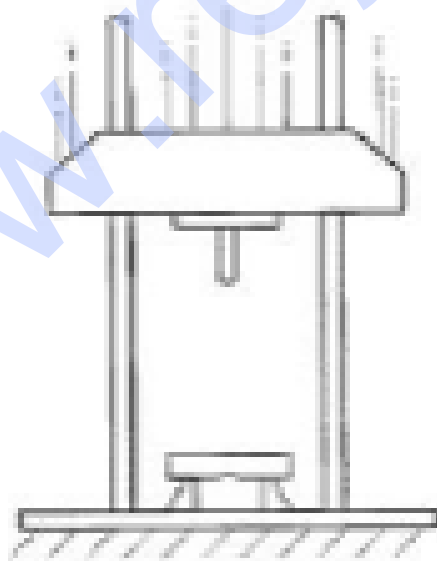
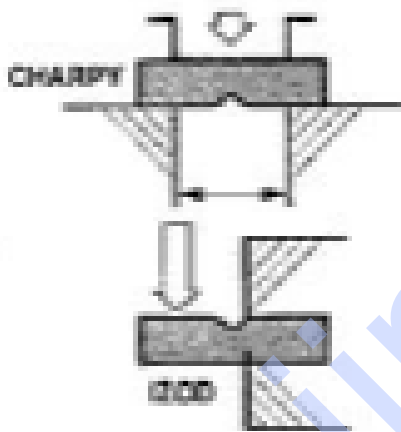
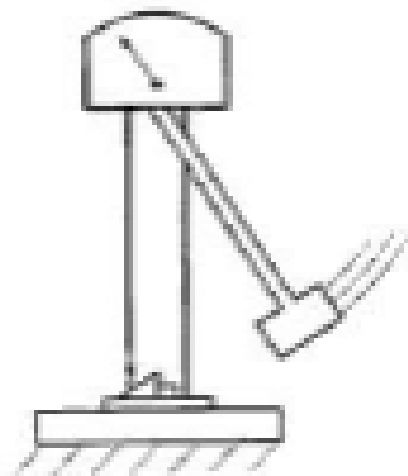
During the first part of the 20th century, a metallurgist named Izod invented an impact test for determining the suitability of various metals to be used as cutting tools. The test involved a pendulum with a known weight at the end of its arm swinging down and striking the

specimen as it stood clamped in a vertical position. Some years later another metallurgist named Charpy modified the test slightly by orienting the specimen in a horizontal fashion. These pendulum impact test methods proved to be very useful, providing reliable, qualitative impact data throughout WWII up until the early 70's. It then became apparent that higher velocities and impact energies could be achieved with vertical style drop towers and thus the trend began to shift. Pendulum machines remained popular with those testing to Izod and Charpy while more high speed, product oriented impact applications became the dominion of the drop tower.

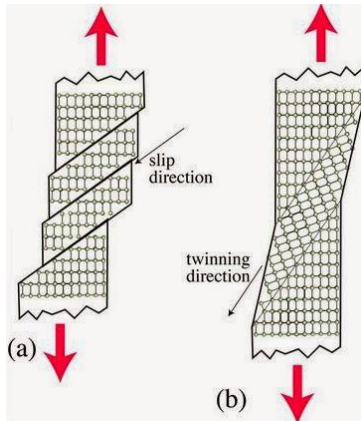
### **Specimens for Charpy and Izod Testing**

While still used, pendulum impact testing has inherent weaknesses. In notched Izod testing, samples are mounted in a vise fixture with the notch facing a pendulum. A weighted pendulum, fixed at a point directly above the sample vise, is swung up and held stationary. This height and thus the speed of the pendulum at impact is a constant for this test. When released, the pendulum swings through the path where the sample is fixed. As the sample breaks, energy is absorbed by the sample. The height the pendulum attains after impact is measured by an indicator on a fixed scale which reads in joules (ft-lb). The impact strength is the loss of momentum in the pendulum while breaking the sample off at the notch. The Izod pendulum test configuration served as the standard in impact testing in the plastics and metals industry for many years. The problems with the Izod pendulum test involve several parameters which can drastically alter the results if not strictly controlled. First the radius of the notch is critical. It is meant to simulate conditions which might exist in applications where the features such as internal corner on an enclosure will act as a stress concentrator upon impact. In a pendulum test, the radius cannot be varied. The notch radius has a significant effect on the ability of a sample to absorb impact. Most polymers, especially polycarbonate and nylon have critical notch radii below which their impact strength falls off dramatically. In a fixed radius test, the data can give a false impression about the relative impact resistance of different polymers. In addition, the creation of the notch in the sample has been a problem. Notch consistency has been difficult so comparison between testing labs is difficult. Notching blades can overheat polymers and degrade the material around the notch thus resulting in inaccurate test results. Industry round robin studies have shown that test results among participants were impossible to correlate because of the tremendous variations in notches.

1. A Charpy pendulum impact test is a variation of Izod. In a Charpy test, a sample is laid horizontally on two supports against an anvil. The sample is notched in the center and the notch side is positioned away from the pendulum. When the pendulum swings through the gap in the anvil, it impacts the center of the sample with a radius hammer. The energy to break is measured and reported in the same way as with an Izod test.



8. Discuss the role of slip and twinning in plastic deformation of materials.  
(Nov/Dec 2015)



When a metal is stressed below its elastic limit, the resulting deformation or strain produced in the metal is temporary. This strain or deformation vanishes after the removal of stress and the metal goes back to the original dimensions. When it is stressed above the elastic limit, permanent deformation takes place and the metal does not return to its original shape after the removal of stress. The ability of a metal to undergo plastic deformation is one of the important property which is utilized for shaping of metals by various fabrication process such as rolling, forging, drawing, extrusion etc.,

### Mechanism Of Plastic Deformation

#### Plastic deformation take place by slip, twinning, some times by both Slip:

Slip is a permanent displacement of one part of crystal relative to the other part. slip involves sliding of one plane of atoms over the other. The plane on which the slip occurs are called slip planes and the direction in which this occurs are called slip direction. Slip occurs when shear stress applied exceeds a critical value. During slip each atom usually moves same integral number of atomic distances along the slip plane producing a step, but the orientation of the crystal remains the same. Slip planes are usually the closest packed planes i.e., the planes of maximum atomic density. Such planes obviously will be widely spaced i.e., the inter planar distance between such planes is more. Slip results from the motion of dislocations from one place to the other place. There are two basic types of dislocations movements called as glide and climb. In glide, the dislocation moves in a surface defined by its line and Burger's vector (glide is conservative motion of dislocations). In climb, the dislocation moves out of the glide surface and therefore, climb becomes a non conservation motion of dislocation. Slip is the most common manifestation of glide.

#### Twinning:

Twinning is a process in which the atoms in a part of the crystal subjected to stress rearrange themselves so that the orientation of the part changes in such a way that the distorted part becomes a mirror image of the other part. The plane across which the two parts are mirror images is called twinning plane or composition plane. Like slip, twinning also occurs along the certain crystallographic planes and directions. These planes and directions are called as twin planes and twin directions. The important role of twinning in plastic deformation is that it causes changes in plane orientation so that further slip can occur.

9. Discuss the mechanisms of slip and twinning in detail. (Apr/May 2017)  
Refer, Question No.8.

10. Name and explain the different types of hardness tests with respect to procedure, relative advantages and disadvantages. (May/June 2015)

### Rockwell Hardness Test

The Rockwell hardness test method consists of indenting the test material with a diamond cone or hardened steel ball indenter. The indenter is forced into the test material under a preliminary minor load  $F_0$  (Fig. 1A) usually 10 kgf. When equilibrium has been reached, an indicating device, which follows the movements of the indenter and so responds to changes in depth of penetration of the indenter is set to a datum position. While the preliminary minor load is still applied an additional major load is applied with resulting increase in penetration (Fig. 1B). When equilibrium has again been reached, the additional major load is removed but the preliminary minor load is still maintained. Removal of the additional major load allows a partial recovery, so reducing the depth of penetration. The permanent increase in depth of penetration, resulting from the application and removal of the additional major load is used to calculate the Rockwell hardness number.

$$HR = E - e$$

$F_0$  = preliminary minor load in kgf

$F_1$  = additional major load in kgf

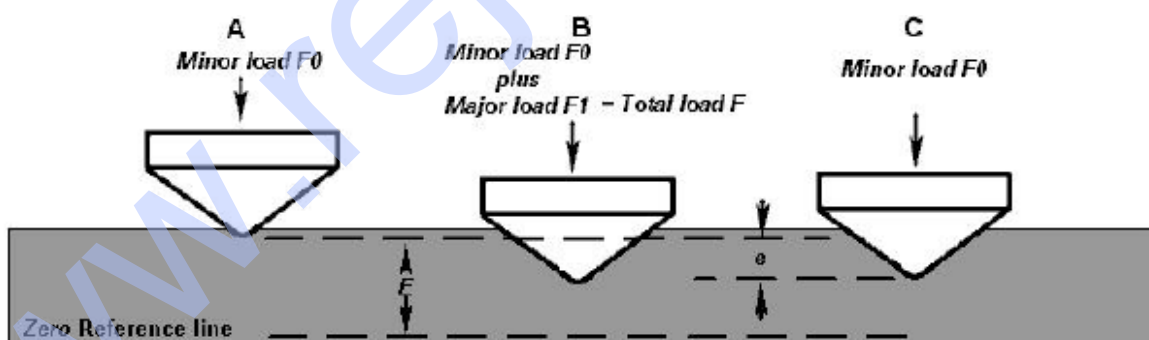
$F$  = total load in kgf

$e$  = permanent increase in depth of penetration due to major load  $F_1$  measured in units of 0.002 mm

$E$  = a constant depending on form of indenter: 100 units for diamond indenter, 130 units for steel ball indenter

HR = Rockwell hardness number

$D$  = diameter of steel ball



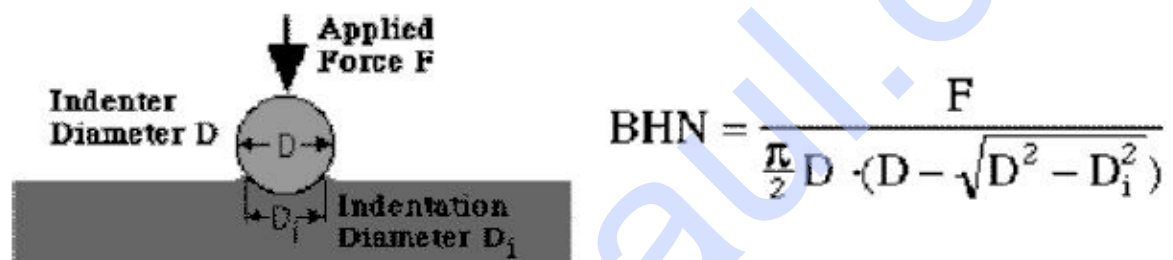
Rockwell Principle

### 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 hardness number is calculated by dividing the load applied by the surface area of the



indentation. 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.

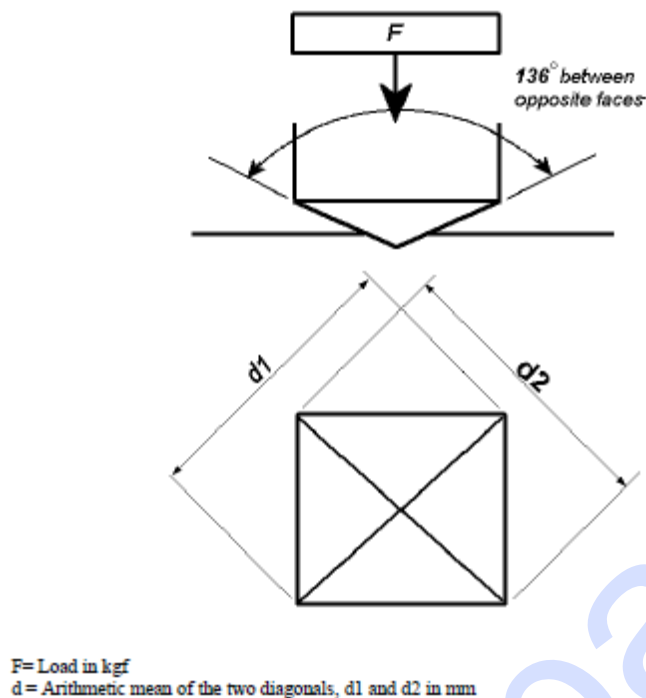


### Vickers Hardness Test

The Vickers hardness test method consists of indenting the test material with a diamond indenter, in the form of a right pyramid with a square base and an angle of 136 degrees between opposite faces subjected to a load of 1 to 100 kgf. The full load is normally applied for 10 to 15 seconds. The two diagonals of the indentation left in the surface of the material after removal of the load are measured using a microscope and their average calculated. The area of the sloping surface of the indentation is calculated. The Vickers hardness is the quotient obtained by dividing the kgf load by the square mm area of indentation. When the mean diagonal of the indentation has been determined the Vickers hardness may be calculated from the formula, but is more convenient to use conversion tables. The Vickers hardness should be reported like 800 HV/10, which means a Vickers hardness of 800, was obtained using a 10 kgf force. Several different loading settings give practically identical hardness numbers on uniform material, which is much better than the arbitrary changing of scale with the other hardness testing methods. The advantages of the Vickers hardness test are that extremely accurate readings can be taken, and just one type of indenter is used for all types of metals and surface treatments. Although thoroughly adaptable and very precise for testing the softest and hardest of materials, under varying loads, the Vickers machine is a floor standing unit that is more expensive than the Brinell or Rockwell machines.

There is now a trend towards reporting Vickers hardness in SI units (MPa or GPa) particularly in academic papers. Unfortunately, this can cause confusion. Vickers hardness (e.g. HV/30) value should normally be expressed as a number only (without the units kgf/mm<sup>2</sup>). Rigorous application of SI is a problem. Most Vickers hardness testing machines use forces of 1, 2, 5, 10, 30, 50 and 100 kgf and tables for calculating HV. SI would involve reporting force in newtons (compare 700 HV/30 to HV/294 N = 6.87 GPa) which is practically meaningless and messy to engineers and

technicians. To convert a Vickers hardness number the force applied needs converting from kgf to newtons and the area needs converting from mm<sup>2</sup> to m<sup>2</sup> to give results in pascals using the formula above.



HV = Vickers hardness

$$HV = \frac{2F \sin \frac{136^\circ}{2}}{d^2} \quad HV = 1.854 \frac{F}{d^2} \text{ (approximately)}$$

11. Sketch and describe the following hardness test.

1. Brinell
2. Vickers.

Refer question no. 10.

12. Compare slip and twinning (Nov/Dec 2017)

When a metal is stressed below its elastic limit, the resulting deformation or strain produced in the metal is temporary. This strain or deformation vanishes after the removal of stress and the metal goes back to the original dimensions. When it is stressed above the elastic limit, permanent deformation takes place and the metal does not return to its original shape after the removal of stress. The ability of a metal to undergo plastic deformation is one of the important property which is utilized for shaping of metals by various fabrication process such as rolling, forging, drawing, extrusion etc.,

### Mechanism of Plastic Deformation

#### Plastic deformation take place by slip and twinning:

Slip is a permanent displacement of one part of crystal relative to the other part. slip involves sliding of one plane of atoms over the other. The plane on which the slip occurs are called slip planes and the direction in which this occurs are called slip direction. Slip occurs when shear stress applied exceeds a critical value.

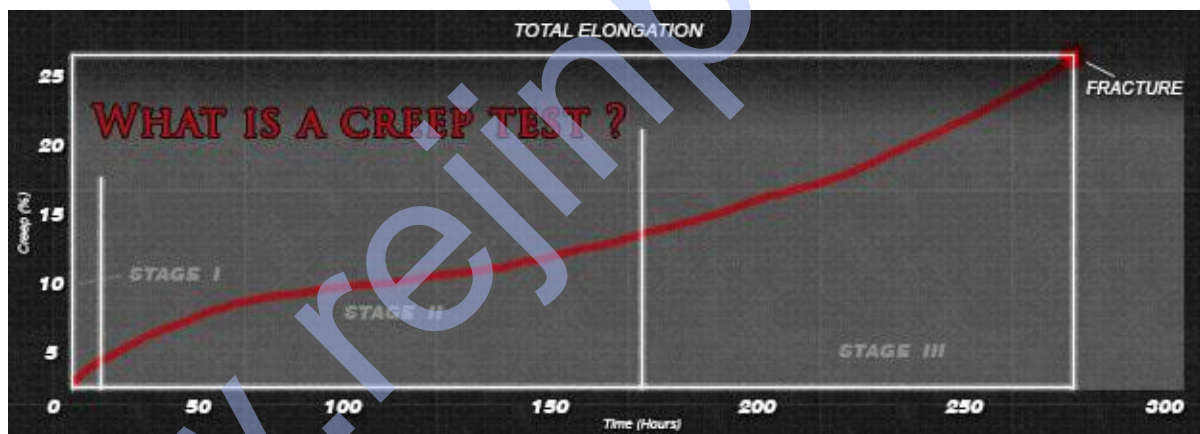
During slip each atom usually moves same integral number of atomic distances along the slip plane producing a step, but the orientation of the crystal remains the same. Slip planes are usually the closest packed planes i.e., the planes of maximum atomic density. Such planes obviously will be widely spaced i.e., the inter planar distance between such planes is more.

Slip results from the motion of dislocations from one place to the other place. There are two basic types of dislocations movements called as glide and climb. In glide, the dislocation moves in a surface defined by its line and Burger's vector (glide is conservative motion of dislocations). In climb, the dislocation moves out of the glide surface and therefore, climb becomes a non conservation motion of dislocation. Slip is the most common manifestation of glide.

### **Twinning:**

Twinning is a process in which the atoms in a part of the crystal subjected to stress rearrange themselves so that the orientation of the part changes in such a way that the distorted part becomes a mirror image of the other part. The plane across which the two parts are mirror images is called twinning plane or composition plane. Like slip, twinning also occurs along the certain crystallographic planes and directions. These planes and directions are called as twin planes and twin directions. The important role of twinning in plastic deformation is that it causes changes in plane orientation so that further slip can occur.

13. Draw a typical creep curve and brief on the mechanism. (Nov/Dec 2017)



### **Creep Curve**

Creep is high temperature progressive deformation at constant stress. "High temperature" is a relative term dependent upon the materials involved. Creep rates are used in evaluating materials for boilers, gas turbines, jet engines, ovens, or any application that involves high temperatures under load. Understanding high temperature behavior of metals is useful in designing failure resistant systems.

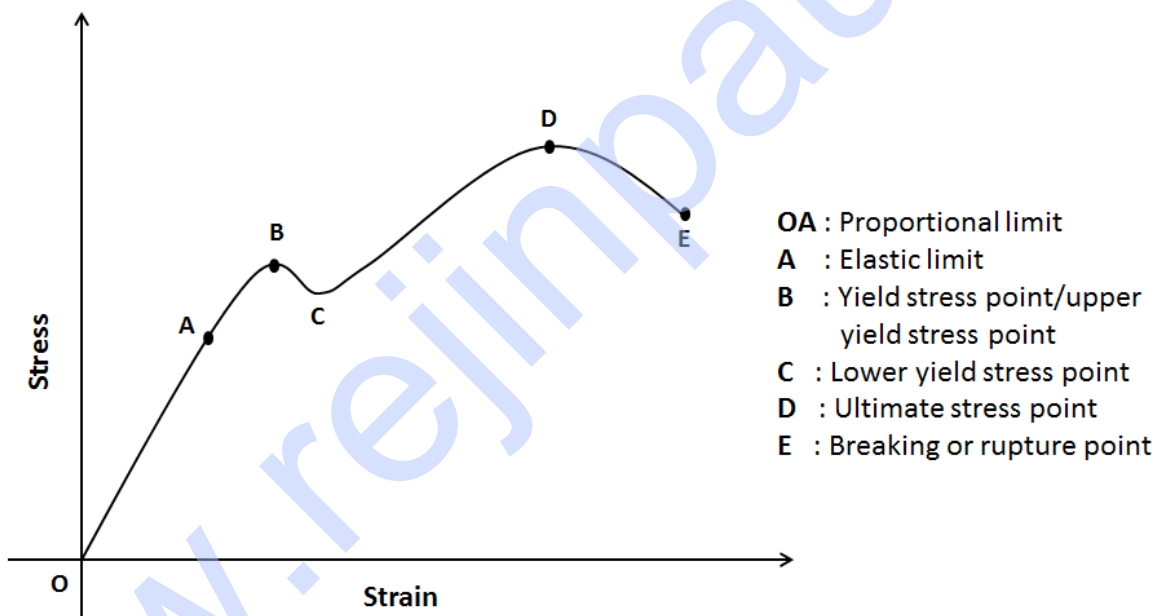
A creep test involves a tensile specimen under a constant load maintained at a constant temperature. Measurements of strain are then recorded over a period of time. Creep occurs in three stages: Primary, or Stage I; Secondary, or Stage II; and Tertiary, or Stage III. Stage I, or Primary creep occurs at the beginning of the tests, and creep is mostly transiently, not at a steady rate. Resistance to creep increases until Stage II is reached. In Stage II, or Secondary

creep, The rate of creep becomes roughly steady. This stage is often referred to as steady state creep. In Stage III, or tertiary creep, the creep rate begins to accelerate as the cross sectional area of the specimen decreases due to necking or internal voiding decreases the effective area of the specimen. If stage III is allowed to proceed, fracture will occur.

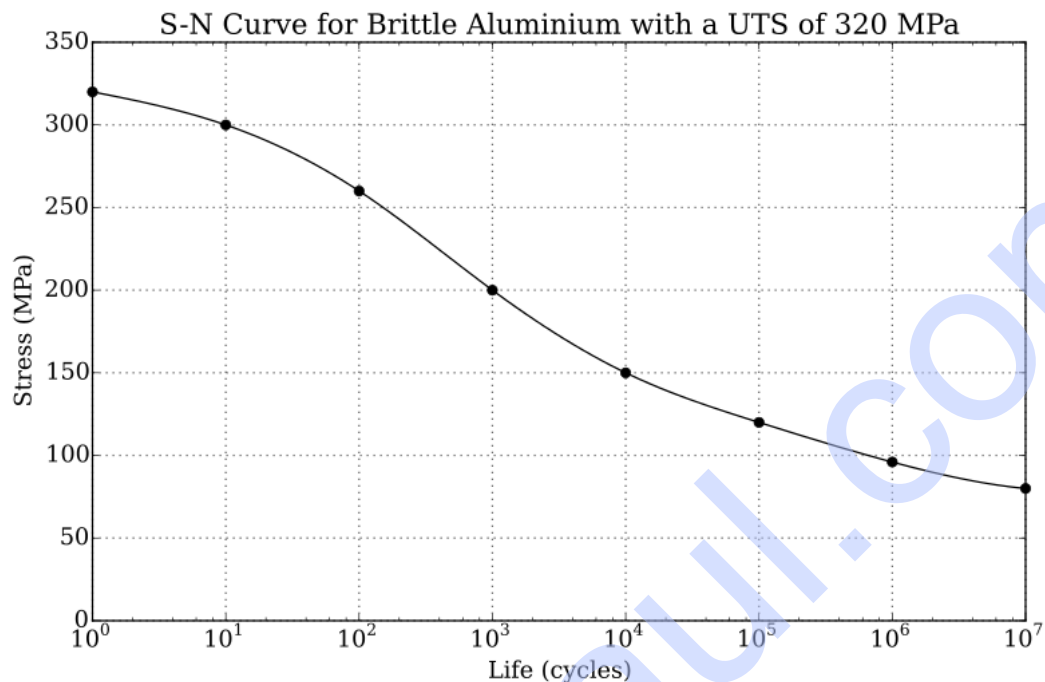
The creep test is usually employed to determine the minimum creep rate in Stage II. Engineers need to account for this expected deformation when designing systems.

Like the Creep Test, Stress Rupture Testing involves a tensile specimen under a constant load at a constant temperature. Stress rupture testing is like creep testing aside from the stresses is being higher than those utilized within a creep testing. Stress rupture tests are utilized to find out the time it takes for failure so stress rupture testing is always continued until failure of the material occurs. Data is plotted similar to the graph above. A straight line or best fit bend is normally obtained at every temperature of interest. The Stress Rupture test is used to determine the time to failure and elongation.

**14. Draw a typical tensile test curve for a metallic sample, mark the different points/regions that represent different mechanical properties.**



15. Draw a typical S-N Curve of fatigue testing and brief on the **mechanism**.



Fatigue is the weakening of a material caused by repeatedly applied loads. It is the progressive and localized structural damage that occurs when a material is subjected to cyclic loading. The nominal maximum stress values that cause such damage may be much less than the strength of the material typically quoted as the ultimate tensile stress limit, or the yield stress limit.

Fatigue occurs when a material is subjected to repeated loading and unloading. If the loads are above a certain threshold, microscopic cracks will begin to form at the stress concentrators such as the surface, persistent slip bands (PSBs), and grain interfaces. Eventually a crack will reach a critical size, the crack will propagate suddenly, and the structure will fracture. The shape of the structure will significantly affect the fatigue life; square holes or sharp corners will lead to elevated local stresses where fatigue cracks can initiate. Round holes and smooth transitions or fillets will therefore increase the fatigue strength of the structure.

### **Fatigue life**

ASTM defines fatigue life,  $N_f$ , as the number of stress cycles of a specified character that a specimen sustains before failure of a specified nature occurs. For some materials, notably steel and titanium, there is a theoretical value for stress amplitude below which the material will not fail for any number of cycles, called a fatigue limit, endurance limit, or fatigue strength. Engineers have used any of three methods to determine the fatigue life of a material: the stress-life method, the strain-life method, and the linear-elastic fracture mechanics method. One method to predict fatigue life of materials is the Uniform Material Law (UML). UML was developed for fatigue life prediction of aluminium and titanium alloys by the end of 20th century and extended to high-strength steels, and cast iron.



### Characteristics of fatigue

Fracture of an aluminium crank arm. Dark area of striations: slow crack growth. Bright granular area: sudden fracture. In metal alloys, and for the simplifying case when there are no macroscopic or microscopic discontinuities, the process starts with dislocation movements at the microscopic level, which eventually form persistent slip bands that become the nucleus of short cracks. Macroscopic and microscopic discontinuities (at the crystalline grain scale) as well as component design features which cause stress concentrations (holes, keyways, sharp changes of load direction etc.) are common locations at which the fatigue process begins. Fatigue is a process that has a degree of randomness (stochastic), often showing considerable scatter even in seemingly identical sample in well controlled environments. Fatigue is usually associated with tensile stresses but fatigue cracks have been reported due to compressive loads.

The greater the applied stress range, the shorter the life. Fatigue life scatter tends to increase for longer fatigue lives. Damage is cumulative. Materials do not recover when rested. Fatigue life is influenced by a variety of factors, such as temperature, surface finish, metallurgical microstructure, presence of oxidizing or inert chemicals, residual stresses, scuffing contact (fretting), etc. Some materials (e.g., some steel and titanium alloys) exhibit a theoretical fatigue limit below which continued loading does not lead to fatigue failure. High cycle fatigue strength (about  $10^4$  to  $10^8$  cycles) can be described by stress-based parameters. A load-controlled servo-hydraulic test rig is commonly used in these tests, with frequencies of around 20–50 Hz. Other sorts of machine like resonant magnetic machine can also be used, to achieve frequencies up to 250 Hz. Low cycle fatigue (loading that typically causes failure in less than  $10^4$  cycles) is associated with localized plastic behavior in metals; thus, a strain-based parameter should be used for fatigue life prediction in metals. Testing is conducted with constant strain amplitudes typically at 0.01–5 Hz.

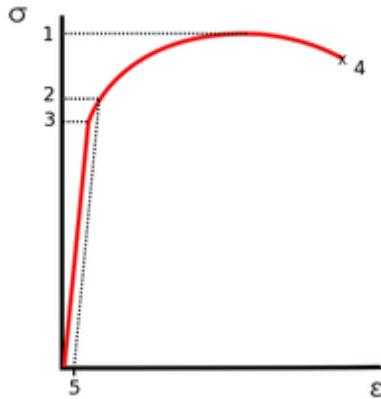
### 16. Explain the different types of fracture?

A fracture is the separation of an object or material into two or more pieces under the action of stress. The fracture of a solid usually occurs due to the development of certain displacement discontinuity surfaces within the solid. If a displacement develops perpendicular to the surface of displacement, it is called a normal tensile crack or simply a crack; if a displacement develops tangentially to the surface of displacement, it is called a shear crack, slip band, or dislocation. Fracture strength or breaking strength is the stress when a specimen fails or fractures.

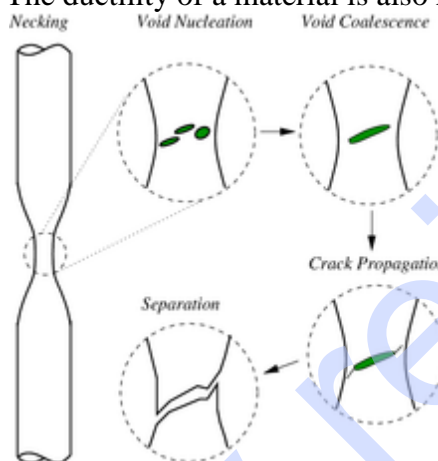
The word fracture is often applied to bones of living creatures (i.e. a bone fracture), or to crystalline materials, such as gemstones or metal. Sometimes, individual crystals fracture without the structure actually separating into two or more pieces. Depending on the substance, a fracture reduces strength (most substances) or inhibits transmission of waves, such as light (optical crystals). A detailed understanding of how fracture occurs in materials may be assisted by the study of fracture mechanics.

Fracture strength, also known as breaking strength, is the stress at which a specimen fails via fracture. This is usually determined for a given specimen by a tensile test, which charts the stress-strain curve (see image). The final recorded point is the fracture strength.

Ductile materials have a fracture strength lower than the ultimate tensile strength (UTS), whereas in brittle materials the fracture strength is equivalent to the UTS. If a ductile material reaches its ultimate tensile strength in a load-controlled situation, it will continue to deform, with no additional load application, until it ruptures. However, if the loading is displacement-controlled, the deformation of the material may relieve the load, preventing rupture.



In ductile fracture, extensive plastic deformation (necking) takes place before fracture. The terms rupture or ductile rupture describe the ultimate failure of ductile materials loaded in tension. Rather than cracking, the material “pulls apart,” generally leaving a rough surface. In this case there is slow propagation and absorption of large amount energy before fracture. The ductility of a material is also referred to as toughness.



Many ductile metals, especially materials with high purity, can sustain very large deformation of 50–100% or more strain before fracture under favorable loading condition and environmental condition. The strain at which the fracture happens is controlled by the purity of the materials. At room temperature, pure iron can undergo deformation up to 100% strain before breaking, while cast iron or high-carbon steels can barely sustain 3% of strain.

Because ductile rupture involves a high degree of plastic deformation, the fracture behavior of a propagating crack as modeled above changes fundamentally. Some of the energy from stress concentrations at the crack tips is dissipated by plastic deformation ahead of the crack as it propagates.

The basic steps in ductile fracture are: void formation, void coalescence (also known as crack formation), crack propagation, and failure, often resulting in a cup-and-cone shaped failure surface.

Brittle fracture is the fracture of a metal or other material without appreciable prior plastic deformation. It is a break in a brittle piece of metal which failed because stress exceeded cohesion.

Brittle fracture is a breakage or cracking of a material into discernible parts, from which no deformation can be identified (a clean break). It is characterized by rapid crack propagation with low energy release and without significant plastic deformation. The fracture may have a bright granular appearance. The fractures are generally of the flat type and chevron patterns may be present.

In brittle crystalline materials, fracture can occur by cleavage as the result of tensile stress acting normal to crystallographic planes with low bonding (cleavage planes). In amorphous solids, by contrast, the lack of a crystalline structure results in a conchoidal fracture, with cracks proceeding normal to the applied tension.

In brittle fracture, cracks run close to perpendicular to the applied stress. This perpendicular fracture leaves a relatively flat surface at the break. Besides having a nearly flat fracture surface, brittle materials usually contain a pattern on their fracture surfaces. Some brittle materials have lines and ridges beginning at the origin of the crack and spreading out across the crack surface. Since there is very little plastic deformation before failure occurs, in most cases this is the worst type of fracture because the visible damage cannot be repaired in a part or structure before it breaks. Brittle fractures display either transgranular or intergranular fracture. This depends upon whether the grain boundaries are stronger or weaker than the grains:

Transgranular fracture - The fracture travels through the grain of the material. Cracks choose the path of least resistance.

Intergranular fracture - The crack travels along the grain boundaries, and not through the actual grains. This usually occurs when the phase in the grain boundary is weak and brittle.

#### 17. Explain Compression and Shear testing:

When a specimen of material is loaded in such a way that it extends it is said to be in tension. On the other hand, if the material compresses and shortens it is said to be in compression.

On an atomic level, the molecules or atoms are forced apart when in tension whereas in compression they are forced together. Since atoms in solids always try to find an equilibrium position, and distance between other atoms, forces arise throughout the entire material which oppose both tension and compression. The phenomena prevailing on an atomic level are therefore similar.

The “strain” is the relative change in length under applied stress; positive strain characterizes an object under tension load which tends to lengthen it, and a compressive stress that shortens an object gives negative strain. Tension tends to pull small sideways deflections back into alignment, while compression tends to amplify such deflection into buckling.

Compressive strength is measured on materials, components and structures.

By definition, the ultimate compressive strength of a material is that value of uniaxial compressive stress reached when the material fails completely. The compressive strength is usually obtained experimentally by means of a compressive test. The apparatus used for this experiment is the same as that used in a tensile test. However, rather than applying a uniaxial tensile load, a uniaxial compressive load is applied. As can be imagined, the specimen (usually cylindrical) is shortened as well as spread laterally. A stress–strain curve is plotted by the instrument and would look similar to the following:



The compressive strength of the material would correspond to the stress at the red point shown on the curve. In a compression test, there is a linear region where the material follows Hooke's Law. This linear region terminates at what is known as the yield point. Above this point the material behaves plastically and will not return to its original length once the load is removed.

In engineering design practice, professionals mostly rely on the engineering stress. In reality, the true stress is different from the engineering stress. Hence calculating the compressive strength of a material from the given equations will not yield an accurate result. This is because the cross sectional area  $A_0$  changes and is some function of load  $A = \phi(F)$ .

The difference in values may therefore be summarized as follows:

On compression, the specimen will shorten. The material will tend to spread in the lateral direction and hence increase the cross sectional area.

In a compression test the specimen is clamped at the edges. For this reason, a frictional force arises which will oppose the lateral spread. This means that work has to be done to oppose this frictional force hence increasing the energy consumed during the process. This results in a slightly inaccurate value of stress obtained from the experiment.

As a final note, it should be mentioned that the frictional force mentioned in the second point is not constant for the entire cross section of the specimen. It varies from a minimum at the centre, away from the clamps, to a maximum at the edges where it is clamped. Due to this, a phenomenon known as barreling occurs where the specimen attains a barrel shape.

### Shear test:

A shear test is a common method to measure the mechanical properties of many deformable solids, especially soil (e.g., sand, clay) rock, and other granular materials or powders. There are several variations on the test.

In shear test, stress is applied to a sample of the material being tested in a way which results in stresses along one axis being different from the stresses in perpendicular directions. This is typically achieved by placing the sample between two parallel platens which apply stress in one (usually vertical) direction, and applying fluid pressure to the specimen to apply stress in the perpendicular directions.

The application of different compressive stresses in the test apparatus causes shear stress to develop in the sample; the loads can be increased and deflections monitored until failure of the sample. During the test, the surrounding fluid is pressurized, and the stress on the platens is increased until the material in the cylinder fails and forms sliding regions within itself, known as shear bands. The geometry of the shearing in a triaxial test typically causes the sample to become shorter while bulging out along the sides. The stress on the platen is then reduced and the water pressure pushes the sides back in, causing the sample to grow taller again. This cycle is usually repeated several times while collecting stress and strain data about the sample. During the test the pore pressures of fluids (e.g., water, oil) or gasses in the sample may be measured using Bishop's pore pressure apparatus.

From the triaxial test data, it is possible to extract fundamental material parameters about the sample, including its angle of shearing resistance, apparent cohesion, and dilatancy angle. These parameters are then used in computer models to predict how the material will behave in a larger-scale engineering application. An example would be to predict the stability of the soil on a slope, whether the slope will collapse or whether the soil will support the shear stresses of the slope and remain in place. Triaxial tests are used along with other tests to make such engineering predictions.

During the shearing, a granular material will typically have a net gain or loss of volume. If it had originally been in a dense state, then it typically gains volume, a characteristic known as Reynolds' dilatancy. If it had originally been in a very loose state, then contraction may occur before the shearing begins or in conjunction with the shearing.

Sometimes, testing of cohesive samples is done with no confining pressure, in an unconfined compression test. This requires much simpler and less expensive apparatus and sample preparation, though the applicability is limited to samples that the sides won't crumble when exposed, and the confining stress being lower than the in-situ stress gives results which may be overly conservative. The compression test performed for concrete strength testing is essentially the same test, on apparatus designed for the larger samples and higher loads typical of concrete testing.

#### **18. With neat sketch explain in detail about Tensile testing:**

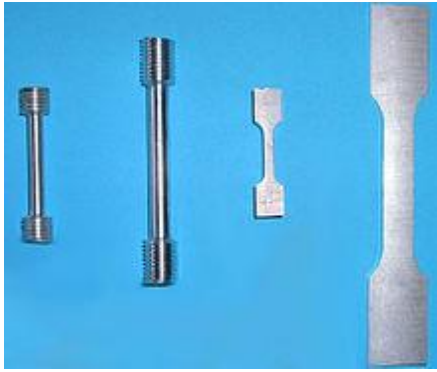
Tensile testing, is also known as tension testing, is a fundamental materials science test in which a sample is subjected to a controlled tension until failure. The results from the test are commonly used to select a material for an application, for quality control, and to predict how a material will 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. Uniaxial tensile testing is the most commonly used for obtaining the mechanical characteristics of isotropic materials. For anisotropic materials, such as composite materials and textiles, biaxial tensile testing is required.

##### **Tensile specimen:**

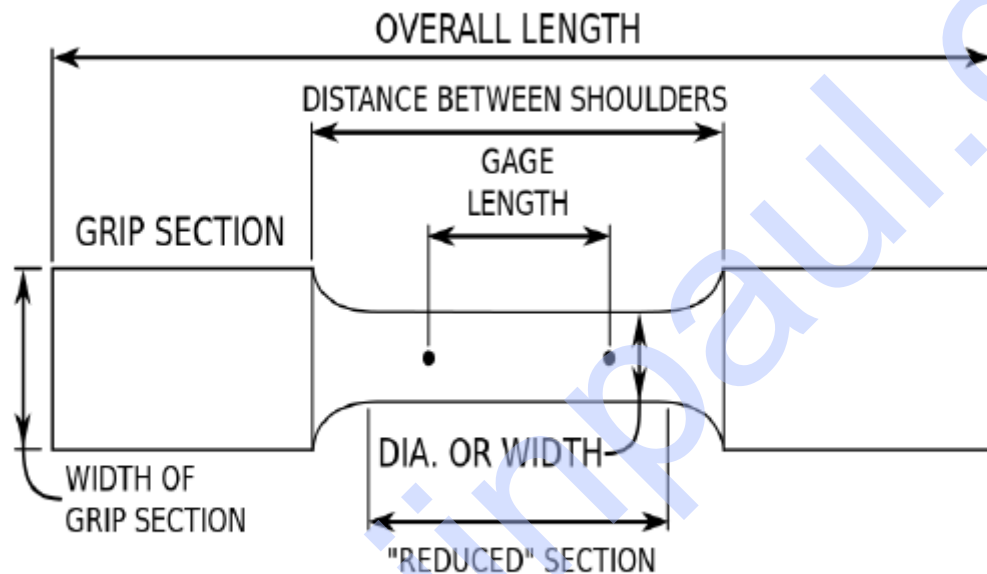
A tensile specimen is a standardized sample cross-section. It has two shoulders and a gage (section) in between. The shoulders are large so they can be readily gripped, whereas the gauge section has a smaller cross-section so that the deformation and failure can occur in this area. The shoulders of the 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 specimens may not be exact representation of the whole work piece because the grain structure may be different throughout. In smaller work pieces or when critical parts of the casting must be tested, a work piece may be sacrificed to make the test specimens. For work pieces that are machined from bar stock, the test specimen can be made from the same piece as the bar stock





The left two specimens have a round cross-section and threaded shoulders.  
The right two is flat specimens designed to be used with separate grips.



### Test specimen nomenclature

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.

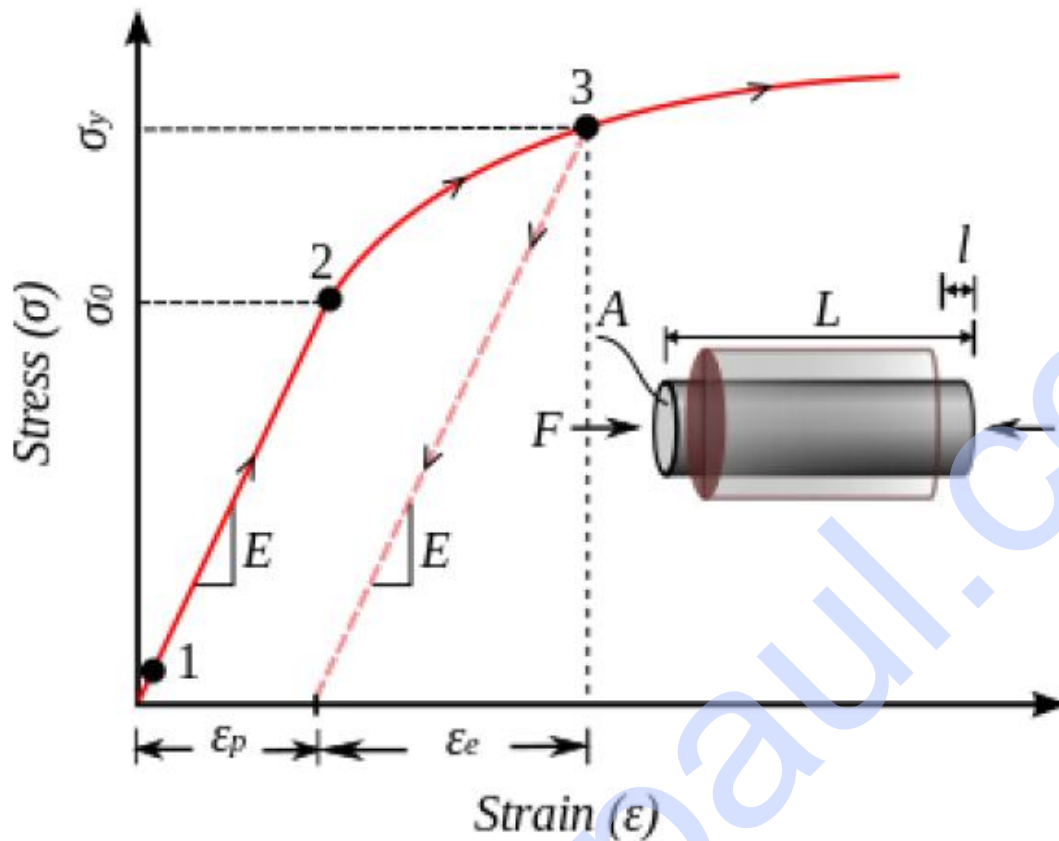
The machine must have the proper capabilities for the test specimen being tested. There are four main parameters: force capacity, speed, precision and accuracy. Force capacity refers to the fact that the machine must be able to generate enough force to fracture the specimen. The machine must be able 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 gauge 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. If the initial portion of the stress-strain curve is curved and not linear, it indicates the specimen is misaligned in the testing machine.

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.

Work hardening, also known as strain hardening or cold working, is the strengthening of a metal by plastic deformation. This strengthening occurs because of dislocation movements and dislocation generation within the crystal structure of the material. Many non-brittle metals with a reasonably high melting point as well as several polymers can be strengthened in this fashion. Alloys not amenable to heat treatment, including low-carbon steel, are often work-hardened. Some materials cannot be work-hardened at low temperatures, such as indium, however others can only be strengthened via work hardening, such pure copper and aluminum.

Work hardening may be desirable or undesirable depending on the context. An example of undesirable work hardening is during machining when early passes of a cutter inadvertently work-harden the work piece surface, causing damage to the cutter during the later passes. Certain alloys are more prone to this than others; super alloys such as Inconel require machining strategies that take it into account. An example of desirable work hardening is that which occurs in metalworking processes that intentionally induce plastic deformation to exact a shape change. These processes are known as cold working or cold forming processes. They are characterized by shaping the work piece at a temperature below its recrystallization temperature, usually at ambient temperature. Cold forming techniques are usually classified into four major groups: squeezing, bending, drawing, and shearing. Applications include the heading of bolts and cap screws and the finishing of cold rolled steel. In cold forming, metal is formed at high speed and high pressure using tool steel or carbide dies. The cold working of the metal increasing the hardness, yield strength, and tensile strength.



A phenomenological uniaxial stress-strain curve showing typical work hardening plastic behavior of materials in uniaxial compression. Before work hardening, the lattice of the material exhibits a regular, nearly defect-free pattern (almost no dislocations). The defect-free lattice can be created or restored at any time by annealing. As the material is work hardened it becomes increasingly saturated with new dislocations, and more dislocations are prevented from nucleating (a resistance to dislocation-formation develops). This resistance to dislocation-formation manifests itself as a resistance to plastic deformation; hence, the observed strengthening.

In metallic crystals, irreversible deformation is usually carried out on a microscopic scale by defects called dislocations, which are created by fluctuations in local stress fields within the material culminating in a lattice rearrangement as the dislocations propagate through the lattice. At normal temperatures the dislocations are not annihilated by annealing. Instead, the dislocations accumulate, interact with one another, and serve as pinning points or obstacles that significantly impede their motion. This leads to an increase in the yield strength of the material and a subsequent decrease in ductility.

Such deformation increases the concentration of dislocations which may subsequently form low-angle grain boundaries surrounding sub-grains. Cold working generally results in higher yield strength as a result of the increased number of dislocations and the Hall-Petch effect of the sub-grains, and a decrease in ductility. The effects of cold working may be reversed by annealing the material at high temperatures where recovery and recrystallization reduce the dislocation density.

A material's work hardenability can be predicted by analyzing a stress-strain curve, or studied in context by performing hardness tests before and after a process.

**Elastic and Plastic deformation:**

Work hardening is a consequence of plastic deformation, a permanent change in shape. This is distinct from elastic deformation, which is reversible. Most materials do not exhibit only one or the other, but rather a combination of the two. The following discussion mostly applies to metals, especially steels, which are well studied. Work hardening occurs most notably for ductile materials such as metals. Ductility is the ability of a material to undergo plastic deformations before fracture (for example, bending a steel rod until it finally breaks). The tensile test is widely used to study deformation mechanisms. This is because under compression, most materials will experience trivial (lattice mismatch) and non-trivial (buckling) events before plastic deformation or fracture occur. Hence the intermediate processes that occur to the material under uniaxial compression before the incidence of plastic deformation make the compressive test fraught with difficulties.

A material generally deforms elastically under the influence of small forces; the material returns quickly to its original shape when the deforming force is removed. This phenomenon is called elastic deformation. This behavior in materials is described by Hooke's Law. Materials behave elastically until the deforming force increases beyond the elastic limit, which is also known as the yield stress. At that point, the material is permanently deformed and fails to return to its original shape when the force is removed. This phenomenon is called plastic deformation. For example, if one stretches a coil spring up to a certain point, it will return to its original shape, but once it is stretched beyond the elastic limit, it will remain deformed and won't return to its original state.

Elastic deformation stretches the bonds between atoms away from their equilibrium radius of separation, without applying enough energy to break the inter-atomic bonds. Plastic deformation, on the other hand, breaks inter-atomic bonds, and therefore involves the rearrangement of atoms in a solid material.

#### **Increase of dislocations and work hardening:**

Increase in the number of dislocations is a quantification of work hardening. Plastic deformation occurs as a consequence of work being done on a material; energy is added to the material. In addition, the energy is almost always applied fast enough and in large enough magnitude to not only move existing dislocations, but also to produce a great number of new dislocations by jarring or working the material sufficiently enough. New dislocations are generated in proximity to a Frank-Read source.

Yield strength is increased in a cold-worked material. Using lattice strain fields, it can be shown that an environment filled with dislocations will hinder the movement of any one dislocation. Because dislocation motion is hindered, plastic deformation cannot occur at normal stresses. Upon application of stresses just beyond the yield strength of the non-cold-worked material, a cold-worked material will continue to deform using the only mechanism available: elastic deformation, the regular scheme of stretching or compressing of electrical bonds (without dislocation motion) continues to occur, and the modulus of elasticity is unchanged. Eventually the stress is great enough to overcome the strain-field interactions and plastic deformation resumes.

However, ductility of a work-hardened material is decreased. Ductility is the extent to which a material can undergo plastic deformation, that is, it is how far a material can be plastically deformed before fracture. A cold-worked material is, in effect, a normal (brittle) material that has already been extended through part of its allowed plastic deformation. If dislocation motion and plastic deformation have been hindered enough by dislocation accumulation, and stretching of electronic bonds and elastic deformation has reached their limit, a third mode of deformation occurs: fracture.

**19. Explain in detail about the hot working process and also compare hot working and cold working process?**

Hot working refers to processes where metals are plastically deformed above their recrystallization temperature. Being above the recrystallization temperature allows the material to recrystallize during deformation. This is important because recrystallization keeps the materials from strain hardening, which ultimately keeps the yield strength and hardness low and ductility high. This contrasts with cold working.

The lower limit of the hot working temperature is determined by its recrystallization temperature. As a guideline, the lower limit of the hot working temperature of a material is 60% its melting temperature (on an absolute temperature scale). The upper limit for hot working is determined by various factors, such as: excessive oxidation, grain growth, or an undesirable phase transformation. In practice materials are usually heated to the upper limit first to keep forming forces as low as possible and to maximize the amount of time available to hot work the work piece.

The most important aspect of any hot working process is controlling the temperature of the work piece. 90% of the energy imparted into the work piece is converted into heat. Therefore, if the deformation process is quick enough the temperature of the work piece should rise, however, this does not usually happen in practice. Most of the heat is lost through the surface of the workpiece into the cooler tooling. This causes temperature gradients in the work piece, usually due to non-uniform cross-sections where the thinner sections are cooler than the thicker sections. Ultimately, this can lead to cracking in the cooler, less ductile surfaces. One way to minimize the problem is to heat the tooling. The hotter the tooling the less heat lost to it, but as the tooling temperature rises, the tool life decreases. Therefore the tooling temperature must be compromised; commonly, hot working tooling is heated to 500–850 °F (325–450 °C).

The advantages are:

- Decrease in yield strength, therefore it is easier to work and uses less energy or force

- Increase in ductility

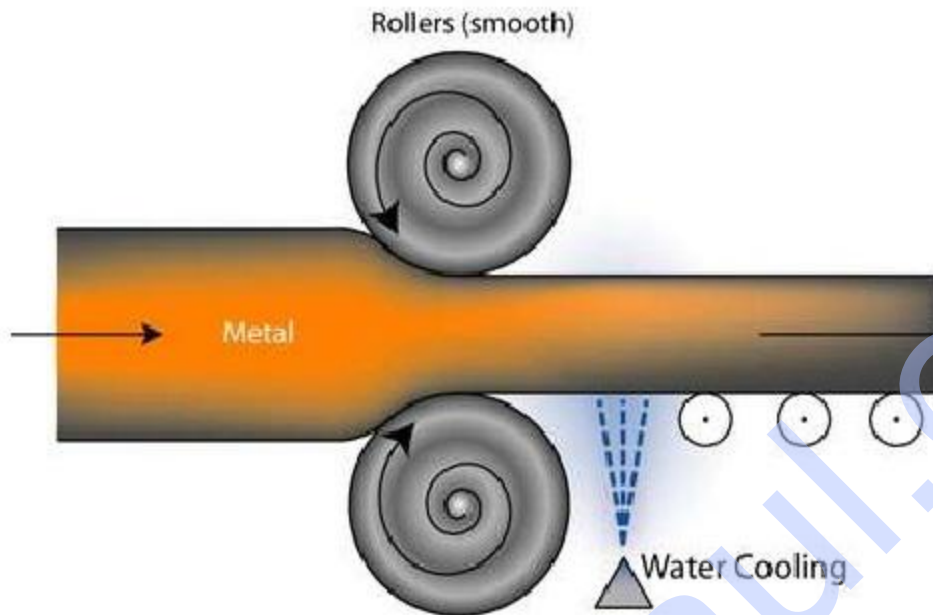
- Elevated temperatures increase diffusion which can remove or reduce chemical inhomogeneities

- Pores may reduce in size or close completely during deformation

- In steel, the weak, ductile, face-centered-cubic austenite microstructure is deformed instead of the strong body-centered-cubic ferrite microstructure found at lower temperatures

Usually the initial work piece that is hot worked was originally cast. The microstructure of cast items does not optimize the engineering properties, from a microstructure standpoint. Hot working improves the engineering properties of the work piece because it replaces the microstructure with one that has fine spherical shaped grains. These grains increase the strength, ductility, and toughness of the material.





The engineering properties can also be improved by reorienting the inclusions (impurities). In the cast state the inclusions are randomly oriented, which, when intersecting the surface, can be a propagation point for cracks. When the material is hot worked the inclusions tend to flow with the contour of the surface, creating stringers. As a whole the strings create a flow structure, where the properties are anisotropic (different based on direction). With the stringers oriented parallel to the surface it strengthens the work piece, especially with respect to fracturing. The stringers act as “crack-arrestors” because the crack will want to propagate through the stringer and not along it.

The disadvantages are:

- Undesirable reactions between the metal and the surrounding atmosphere (scaling or rapid oxidation of the work piece)

- Less precise tolerances due to thermal contraction and warping from uneven cooling

- Grain structure may vary throughout the metal for various reasons

- Requires a heating unit of some kind such as a gas or diesel furnace or an induction heater, which can be very expensive.

### Comparison between Hot working and Cold working

S.No	Hot Working	Cold Working
1	Hot working is carried out above the recrystallization temperature and below the melting point. Hence the deformation of metal and recovery take place simultaneously.	Cold working is carried out below the recrystallization temperature. As such, there is no appreciable recovery.
2	No internal or residual stresses are set-up in the metal in hot working process.	In cold working process internal or residual stresses are set-up in the metal.
3	If cracks and blow holes are present in the metal, they can be finished through hot working.	In cold working the existing cracks propagate and new cracks may develop.
4	Close tolerance cannot be maintained.	Better tolerance can be easily maintained.

5	Surface finish of hot working process is comparatively not good.	Surface finish of cold working process is better.
6	It results in improvements of properties like impact strength and elongation.	It also results in improvements of properties like impact strength and elongation.
7	If hot working process is performed properly, it does not affect ultimate tensile strength, hardness, corrosion resistance yield strength and fatigue strength of the metal.	It improves ultimate tensile strength, hardness, yield strength but reduces the corrosion resistance of strength of the metal.
8	Due to recrystallisation very negligible hardening of metal takes place.	Since cold working is done below recrystallisation temperature the metal gets work hardened.
9	Hot working refines metal grains resulting in improved mechanical properties.	Most of the cold working processes lead to distortion of grains.
10	Due to higher deformation temperatures, the stress required for deformation is much less.	The stress required to cause deformation is much higher.

## 20. Explain about the various factors affecting fatigue life?

Fatigue is failure under a repeated or varying load, never reaching a high enough level to cause failure in a single application. The fatigue process embraces two basic domains of cyclic stressing or straining, differing distinctly in character. In each domain, failure occurs by different physical mechanisms:

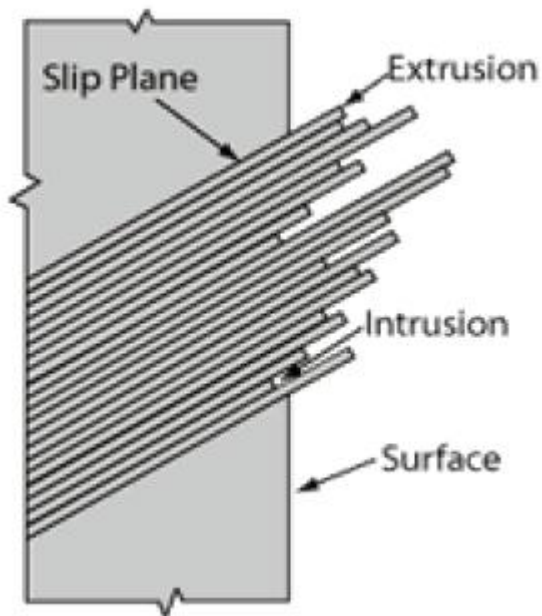
1. Low-cycle fatigue—where significant plastic straining occurs. Low-cycle fatigue involves large cycles with significant amounts of plastic deformation and relatively short life. The analytical procedure used to address strain-controlled fatigue is commonly referred to as the Strain-Life, Crack-Initiation, or Critical Location approach.
2. High-cycle fatigue—where stresses and strains are largely confined to the elastic region. High-cycle fatigue is associated with low loads and long life. The Stress-Life (S-N) or Total Life method is widely used for high-cycle fatigue applications—here the applied stress is within the elastic range of the material and the number of cycles to failure is large. While low-cycle fatigue is typically associated with fatigue life between 10 to 100,000 cycles, high-cycle fatigue is associated with life greater than 100,000 cycles.

### **Fatigue Properties:**

Fatigue cracking is one of the primary damage mechanisms of structural components. Fatigue cracking results from cyclic stresses that are below the static yield strength of a material. The name “fatigue” is based on the concept that a material becomes “tired” and fails at a stress level below the nominal strength of the material. The facts that the original bulk design strengths are not exceeded and the only warning sign of an impending fracture is an often hard to see crack, makes fatigue damage especially dangerous.

The fatigue life of a component can be expressed as the number of loading cycles required to initiate a fatigue crack and to propagate the crack to critical size. Therefore, it can be said that fatigue failure occurs in three stages – crack initiation; slow, stable crack growth; and rapid fracture.

As discussed previously, dislocations play a major role in the fatigue crack initiation phase. In the first stage, dislocations accumulate near surface stress concentrations and form structures called persistent slip bands (PSB) after a large number of loading cycles. PSBs are areas that rise above (extrusion) or fall below (intrusion) the surface of the component due to movement of material along slip planes. This leaves tiny steps in the surface that serve as stress risers where tiny cracks can initiate. These tiny cracks (called micro cracks) nucleate along planes of high shear stress which is often 45° to the loading direction.

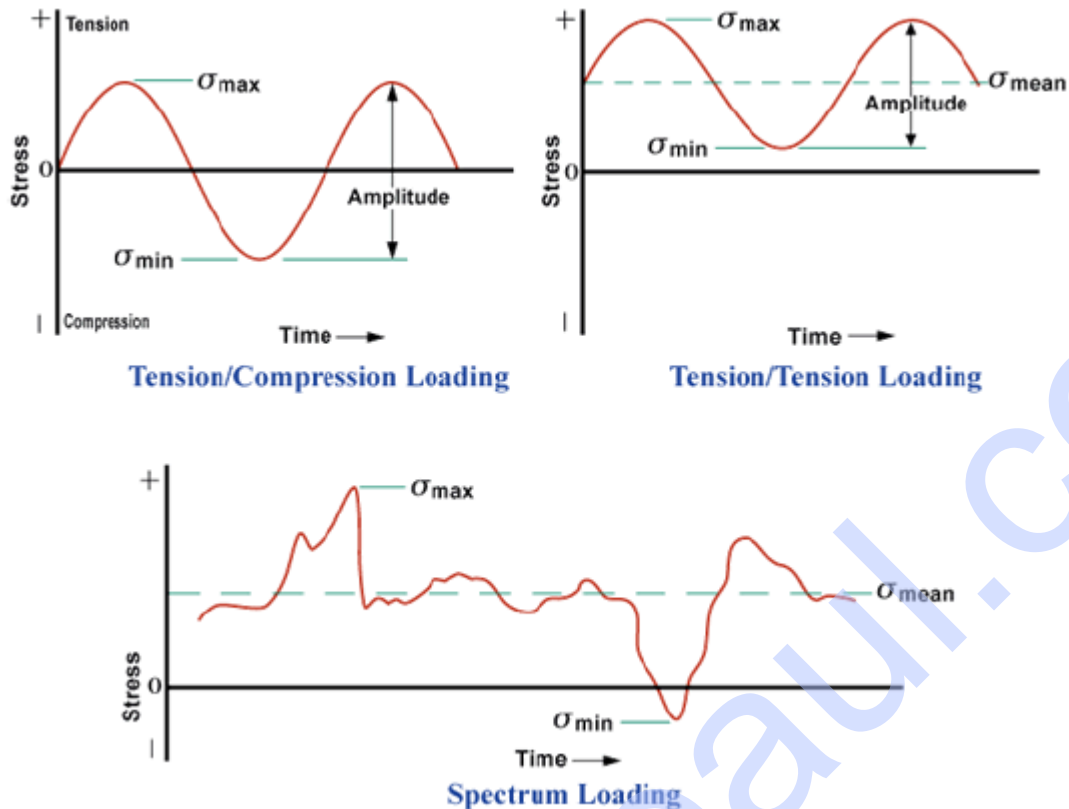


In the second stage of fatigue, some of the tiny micro cracks join together and begin to propagate through the material in a direction that is perpendicular to the maximum tensile stress. Eventually, the growth of one or a few crack of the larger cracks will loading, the growth of the dominate crack or cracks will continue until the remaining un-cracked section of the component can no longer support the load. At this point, the fracture toughness is exceeded and the remaining cross-section of the material experiences rapid fracture. This rapid overload fracture is the third stage of fatigue failure. Dominate over the rest of the cracks.

#### **Factors affecting fatigue life:**

In order for fatigue cracks to initiate, three basic factors are necessary. First, the loading pattern must contain minimum and maximum peak values with large enough variation or fluctuation. The peak values may be in tension or compression and may change over time but the reverse loading cycle must be sufficiently great for fatigue crack initiation. Secondly, the peak stress levels must be of sufficiently high value. If the peak stresses are too low, no crack initiation will occur. Thirdly, the material must experience a sufficiently large number of cycles of the applied stress. The number of cycles required to initiate and grow a crack is largely dependant on the first to factors.

In addition to these three basic factors, there are a host of other variables, such as stress concentration, corrosion, temperature, overload, metallurgical structure, and residual stresses which can affect the propensity for fatigue. Since fatigue cracks generally initiate at a surface, the surface condition of the component being loaded will have an effect on its fatigue life. Surface roughness is important because it is directly related to the level and number of stress concentrations on the surface. The higher the stress concentration the more likely a crack is to nucleate. Smooth surfaces increase the time to nucleation. Notches, scratches, and other stress risers decrease fatigue life. Surface residual stress will also have a significant effect on fatigue life. Compressive residual stresses from machining, cold working, heat treating will oppose a tensile load and thus lower the amplitude of cyclic loading.



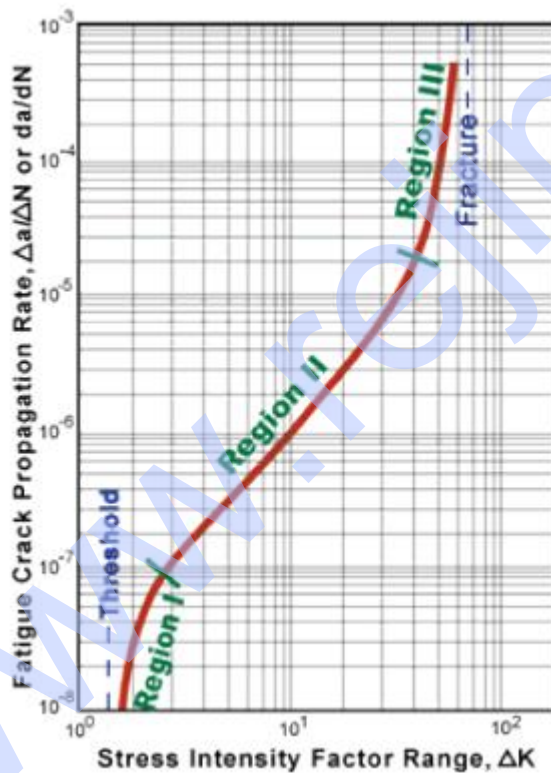
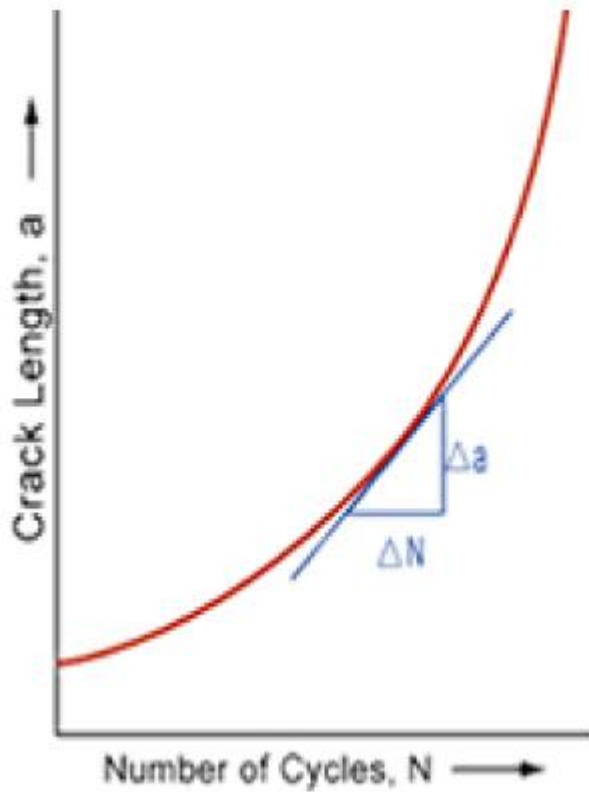
The above figure shows several types of loading that could initiate a fatigue crack. The upper left figure shows sinusoidal loading going from a tensile stress to a compressive stress. For this type of stress cycle the maximum and minimum stresses are equal. Tensile stress is considered positive, and compressive stress is negative. The figure in the upper right shows sinusoidal loading with the minimum and maximum stresses both in the tensile realm. Cyclic compression loading can also cause fatigue. The lower figure shows variable-amplitude loading, which might be experienced by a bridge or airplane wing or any other component that experiences changing loading patterns. In variable-amplitude loading, only those cycles exceeding some peak threshold will contribute to fatigue cracking.

#### **Fatigue Crack Growth Rate Properties:**

For some components the crack propagation life is neglected in design because stress levels are high, and/or the critical flaw size small. For other components the crack growth life might be a substantial portion of the total life of the assembly. Moreover, preexisting flaws or sharp design features may significantly reduce or nearly eliminate the crack initiation portion of the fatigue life of a component. The useful life of these components may be governed by the rate of sub critical crack propagation.

Aircraft fuselage structure is a good example of structure that is based largely on a slow crack growth rate design. Many years ago, the USAF reviewed a great number of malfunction reports from a variety of aircraft. The reports showed that the preponderance of structural failures occurred from 1) built-in preload stresses, 2) material flaws and 3) flaw caused by in-service usage. These facts led to a design approach that required the damage tolerance analysis to assume a material flaw exists in the worst orientation and at the most undesirable location. The analysis helps to ensure that structures are designed that will support slow stable crack growth until the crack reaches a length where it can reliably be detected using NDT methods.





The data can be reduced to a single curve by presenting the data in terms of crack growth rate per cycle of loading ( $Da/ DN$  or  $da/dN$ ) versus the fluctuation of the stress-intensity factor at the tip of the crack ( $DKI$ ).  $DKI$  is representative of the mechanical driving force, and it incorporates the effect of changing crack length and the magnitude of the cyclic loading. (See the page on fracture toughness for more information on the stress-intensity factor.) The

most common form of presenting fatigue crack growth data is a log-log plot of  $da/dN$  versus  $DKI$ .

The fatigue crack propagation behavior of many materials can be divided into three regions as shown in the image. Region I is the fatigue threshold region where the  $DKI$  is too low to propagate a crack. Region II encompasses data where the rate of crack growth changes roughly linearly with a change in stress intensity fluctuation. In region III, small increases in the stress intensity amplitude, produce relatively large increases in crack growth rate since the material is nearing the point of unstable fracture.