

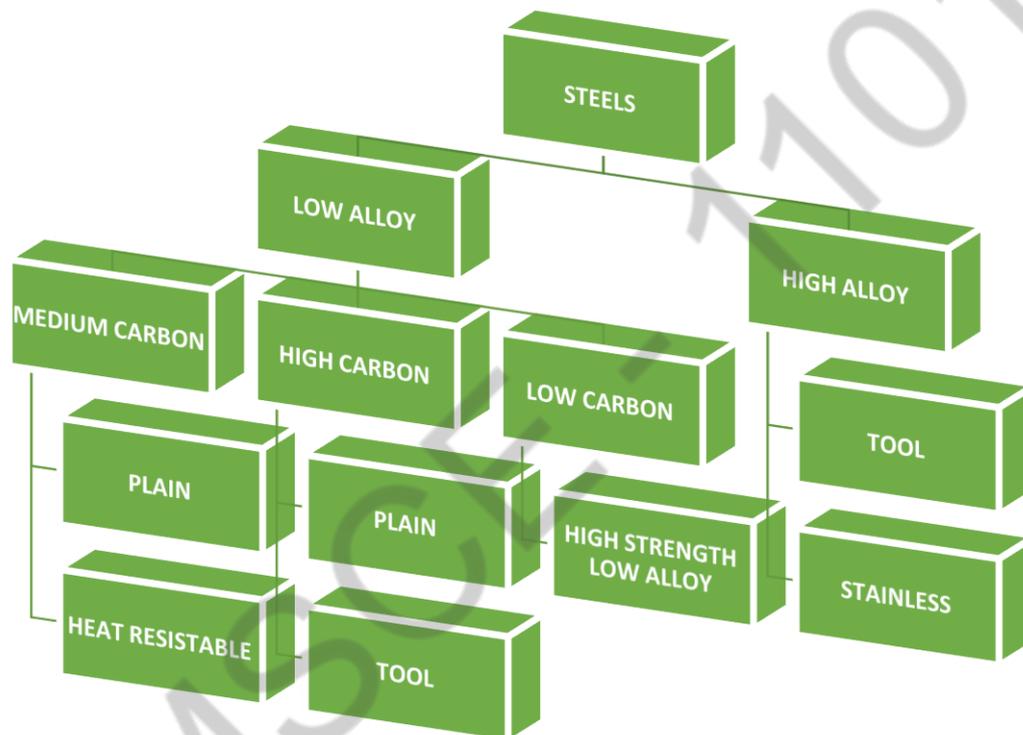
UNIT – I

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)

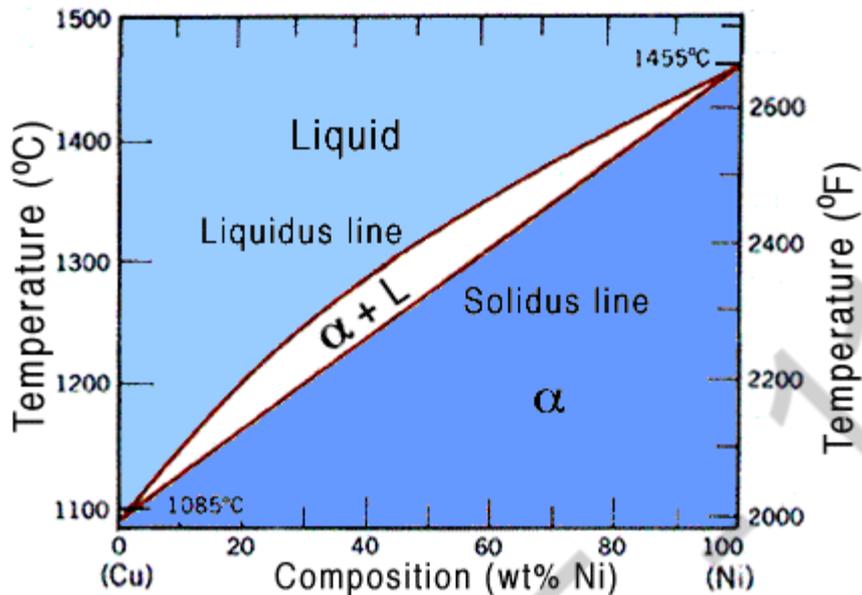
Give the relationship of composition of a solution as a function of temperatures and the quantities of phases in equilibrium. These diagrams do not indicate the dynamics when one phase transforms into another.

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 Fe_3C . 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)



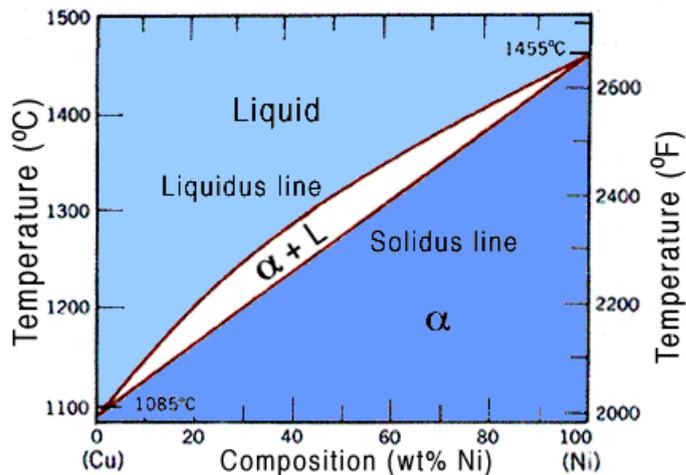
6. Write a typical peritectoid reaction.(Nov/Dec 2018)

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 $P + F = C + 2$

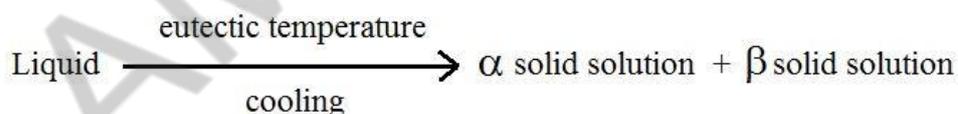
Where P = number of phases in the system

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 :



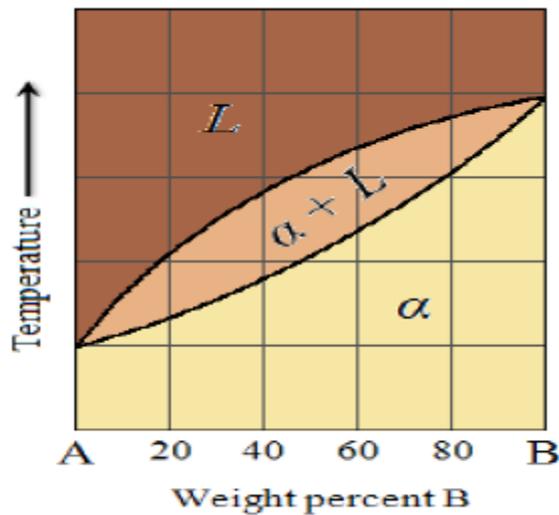
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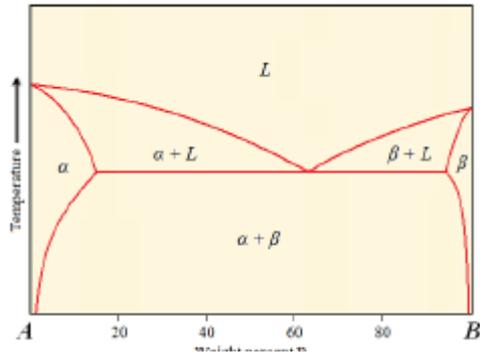
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17. Name and explain the standard rule for the formation of substitutional type of solid solution. (April/May 2015)

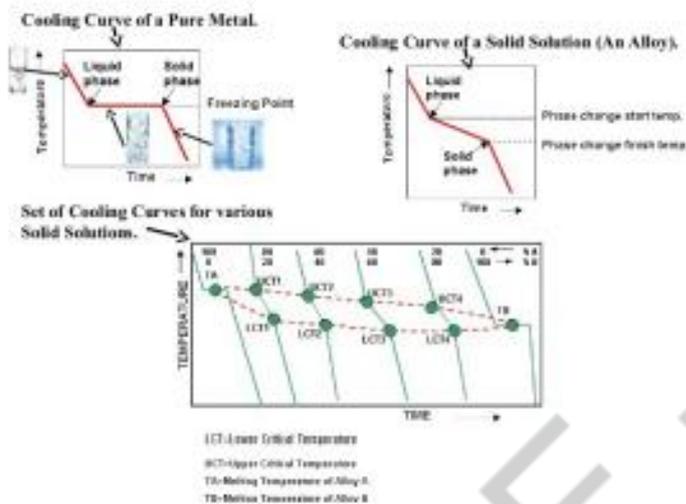
The Hume-Rothery rules, named after William Hume-Rothery, are a set of basic rules that describe the conditions under which an element could dissolve in a metal, forming a solid solution. There are two sets of rules, one refers to substitutional solid solutions, and the other refers to interstitial solid 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 : α - 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

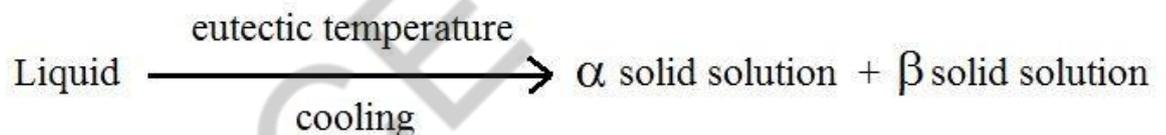
F = number of variables that can be changed independently without affecting the number of phases.

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 have more wear resistance.

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 to 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 gain 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 refine 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

Stain less steel to improving corrosion resistance.

3. Draw iron iron carbide phase diagram, name the various field, line 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 FeC, interstitial or substitutional? where does C atoms occupies in Ferrite? (NOV/DEC 2018)

FeC 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**

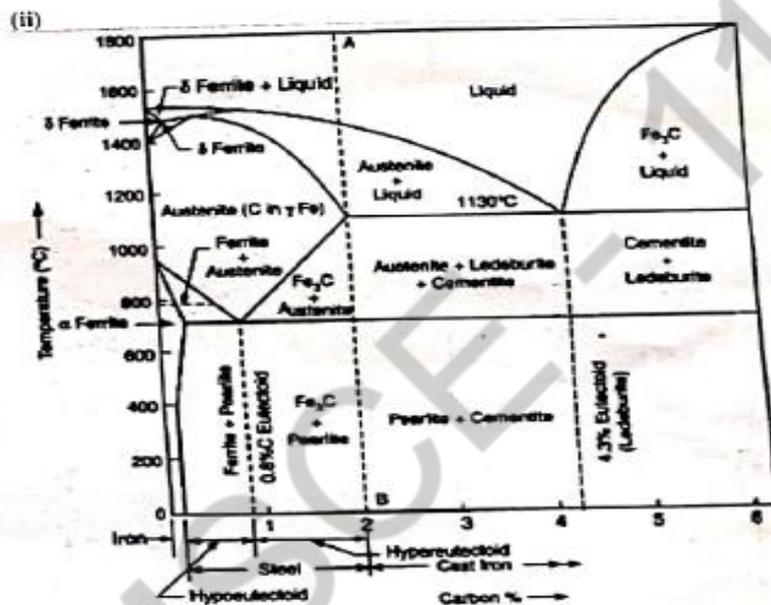
phase. The eutectic temperature and composition determine a point on the phase diagram known as 'eutectic point'.

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.

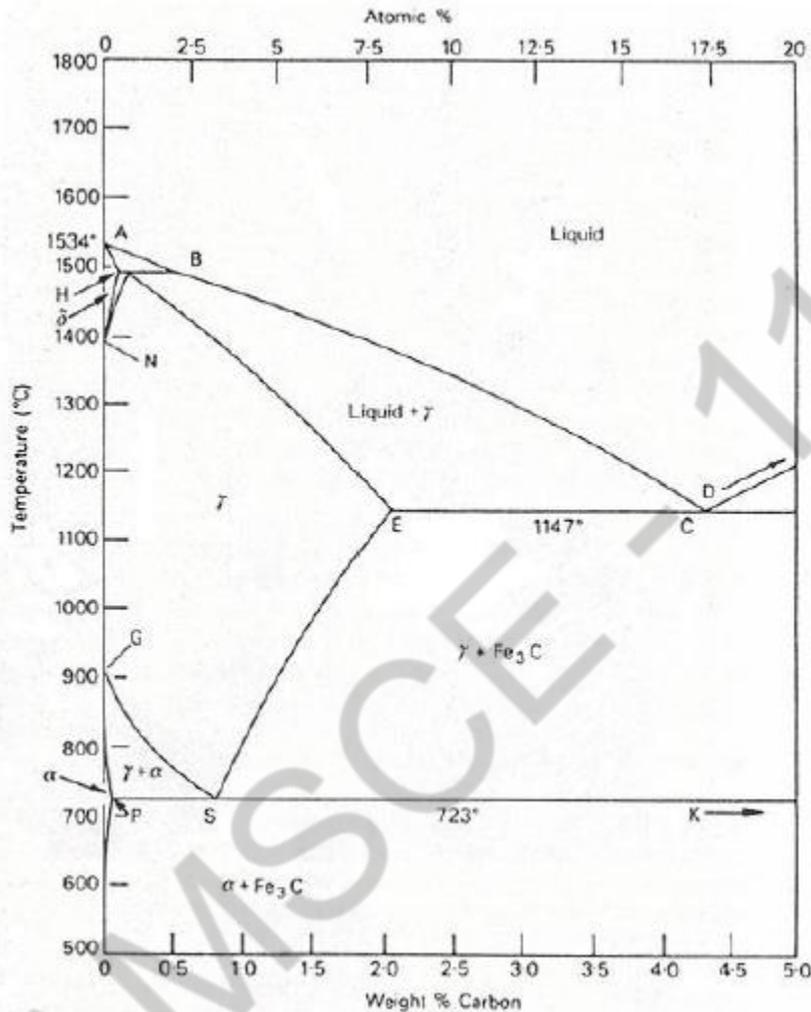
9. What are the micro-constituents of iron-carbon alloys? Explain the general characteristics of each.

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 γ -iron (austenite) compared with that of α -iron (ferrite) reflects the much greater solubility of carbon in γ -iron, with a maximum value of just over 2 wt % at 1147°C (E, Fig. 1). This high solubility of carbon in γ -iron is of extreme importance in heat treatment, when solution treatment in the γ -region followed by rapid quenching to room temperature allows a supersaturated solid solution of carbon in iron to be formed. The α -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%, α -iron is normally associated with iron carbide in one form or another. Similarly, the δ -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 A_1 , temperature, at which the eutectoid reaction occurs (P-S-K), which is 723°C in the binary diagram. Secondly, there is the A_3 , temperature when α -iron transforms to γ -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 A_4 at which γ -iron transforms to δ -iron, 1390°C in pure iron, but this is raised as carbon is added. The A_2 , 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 A_1 , A_3 and A_4 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. A_c for heating, A_r for cooling and A_e (equilibrium), but it should be emphasized that the A_c and A_r 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 γ - and α -iron leads normally to the rejection of carbon as iron carbide at the boundaries of the γ phase field. The transformation of γ to α – 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_{e1} , 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)**

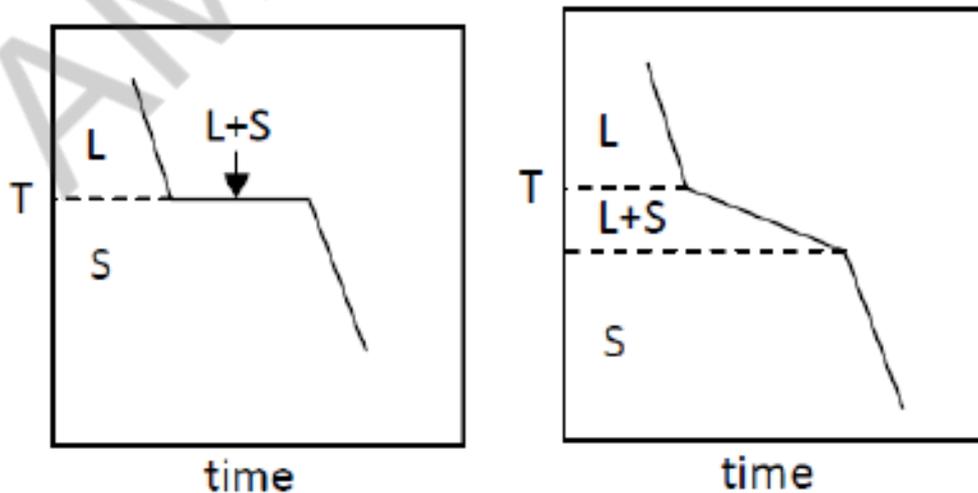
Let the two metals in a binary system be A & B. They are soluble in each other in all proportion in both solid and liquid states. Both A & B have definite melting points. Since the two are soluble in all proportion in solid state they must have similar crystal structures, nearly the same atomic diameters 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.

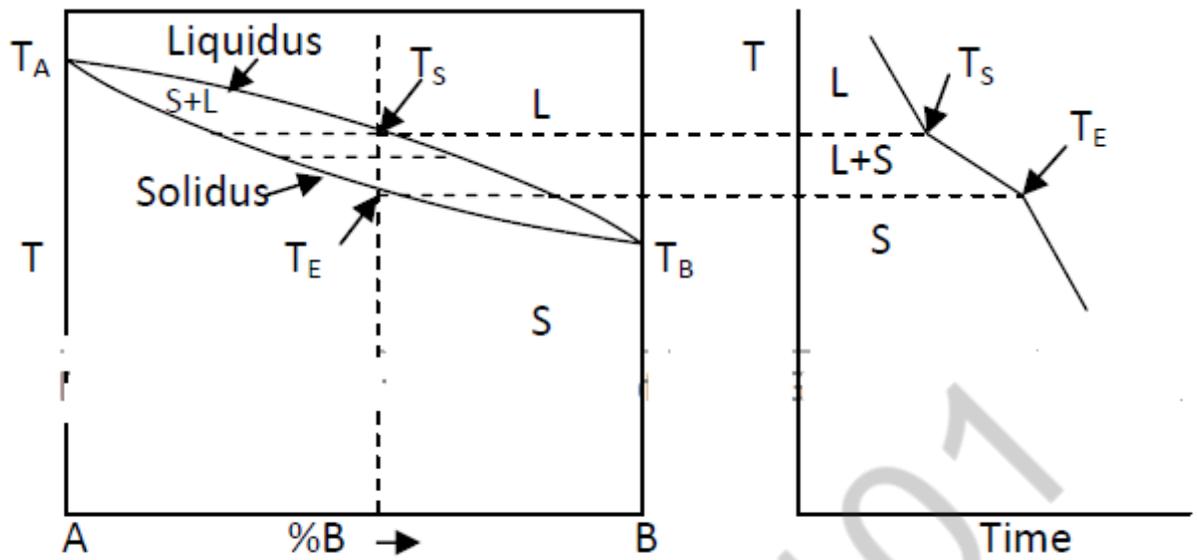
Fig 1: Shows a typical cooling curve of a pure metal. Note that liquid is stable above its melting point where as below its melting point it is solid. In this case $P=1$. Therefore $F = 1$. This is why both L & S exist over a range of temperature. Whereas both liquid (L) & solid (S) can coexist only 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 $P = 1$. 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.

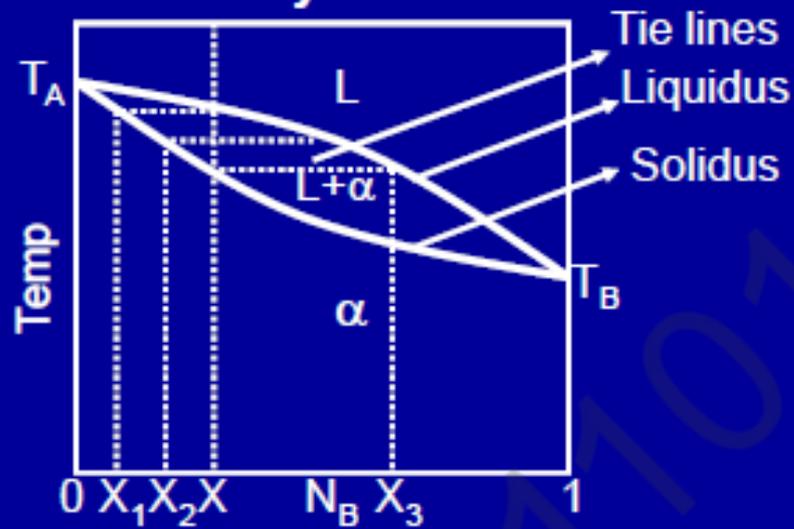
Slide 1: The sketch shows a typical phase diagram of a binary isomorphous system. The composition can be denoted either as weight fraction (or %) or atom fraction. Let NB denote the atom fraction of B in the alloy and X_i be the corresponding weight fraction. Alpha represents solid solution of B in A (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 .





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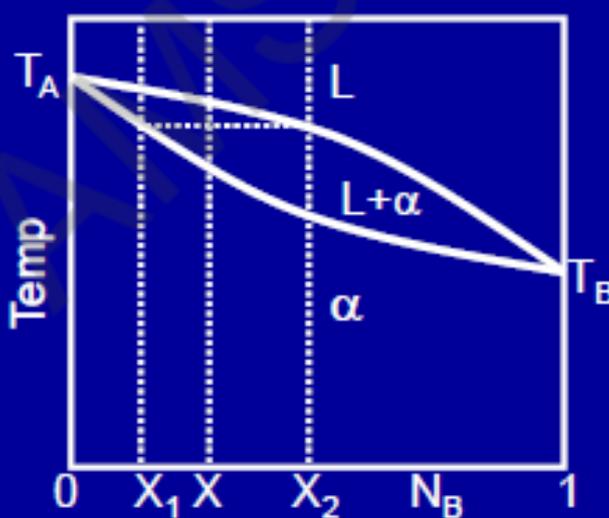
Phase diagram of a Binary Isomorphous system



Liquidus: onset of solidification / liquid composition

Solidus: completion of solidification / solid composition

Estimation of phase percent (wt fraction)



a: wt fraction α

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. shows disordered substitutional solid solution. Here the solute atoms have substituted disorderly for the solvent atoms on their lattice site. an ordered substitutional solid solution. Here the solute atoms have substituted in an orderly manner for the solvent atoms on their lattice site.

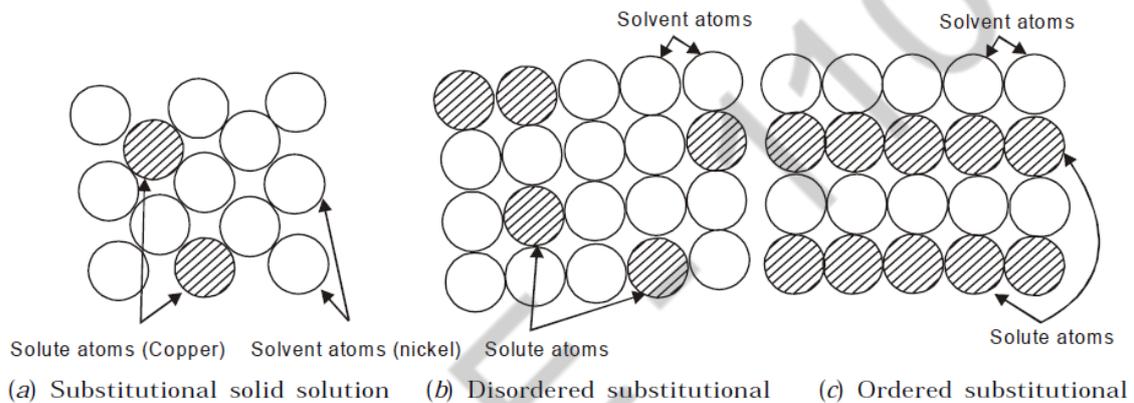
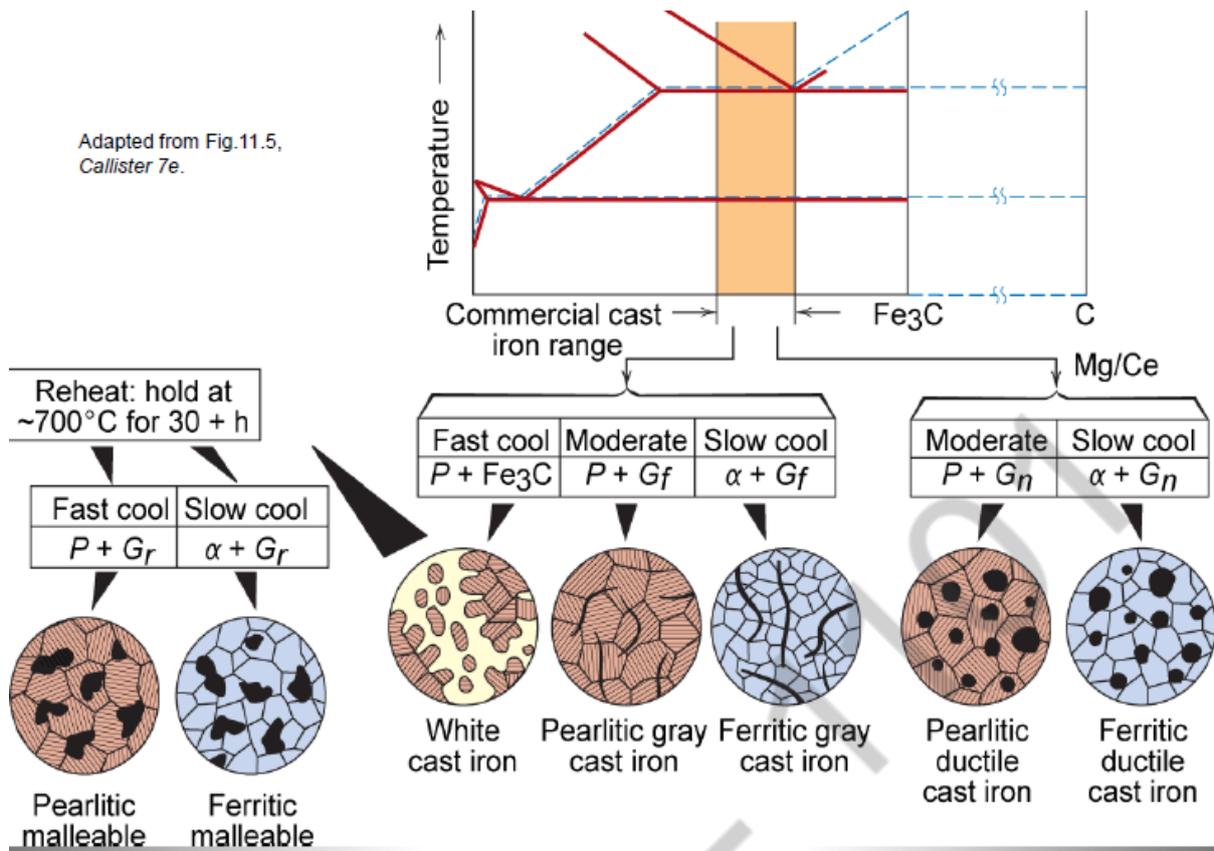


Fig. 5.1 Solid solutions

- 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 Fe₃C to graphite clusters.

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



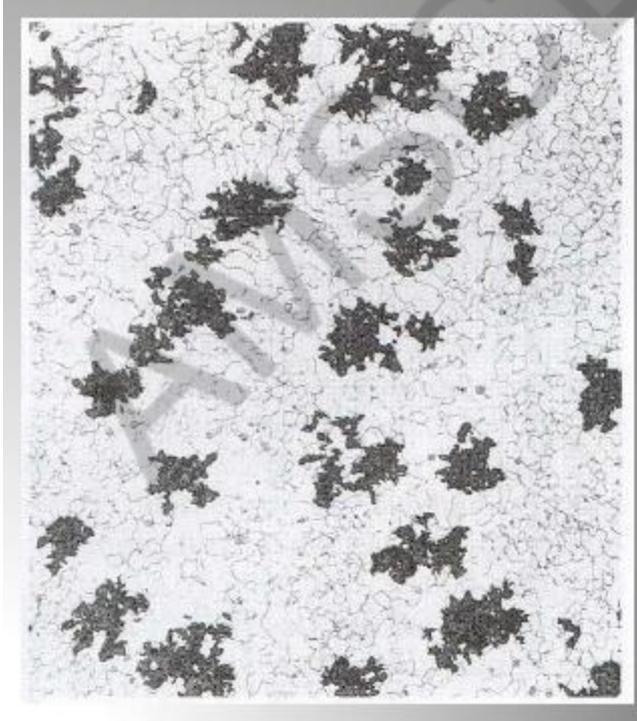
Malleable cast iron:

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

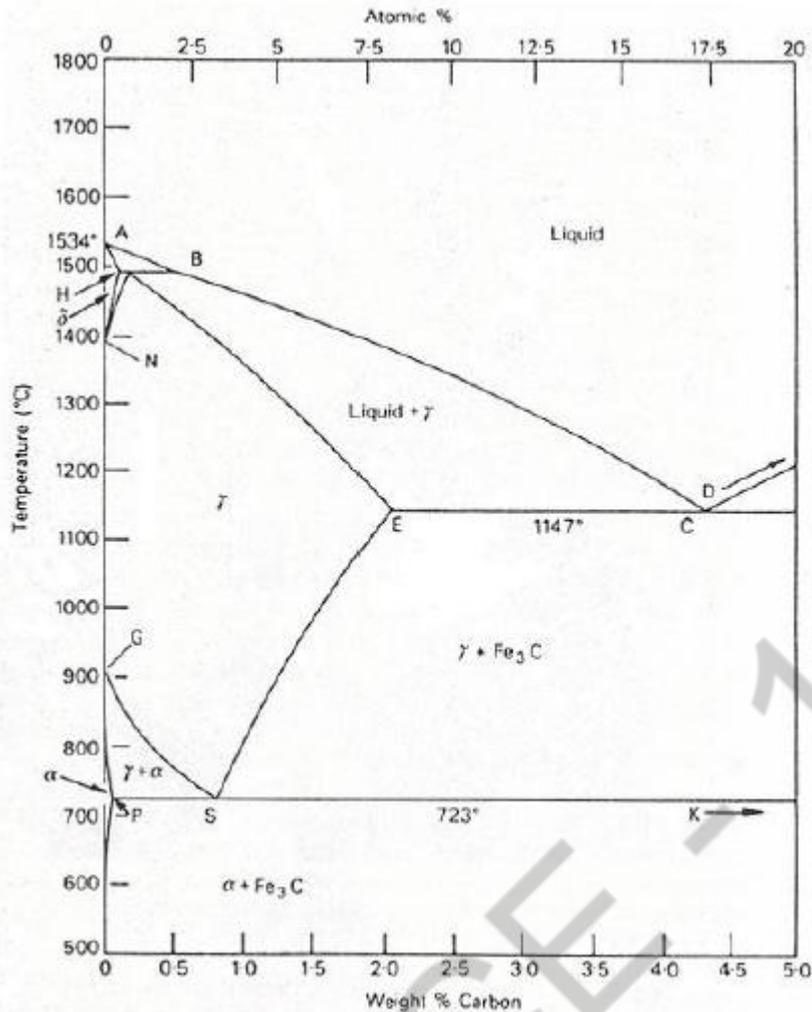
C is in the form of irregular spheroid.

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 γ -iron (austenite) compared with that of α -iron (ferrite) reflects the much greater solubility of carbon in γ -iron, with a maximum value of just over 2 wt % at 1147°C (E, Fig. 1). This high solubility of carbon in γ -iron is of extreme importance in heat treatment, when solution treatment in the γ -region followed by rapid quenching to room temperature allows a supersaturated solid solution of carbon in iron to be formed. The α -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%, α -iron is normally associated with iron carbide in one form or another. Similarly, the δ -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 α -iron transforms to γ -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 γ -iron transforms to δ -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. A_c for heating, A_r for cooling and A_e (equilibrium), but it should be emphasized that the A_c and A_r 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 γ - and α -iron leads normally to the rejection of carbon as iron carbide at the boundaries of the γ phase field. The transformation of γ to α – 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_{e1} , 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.

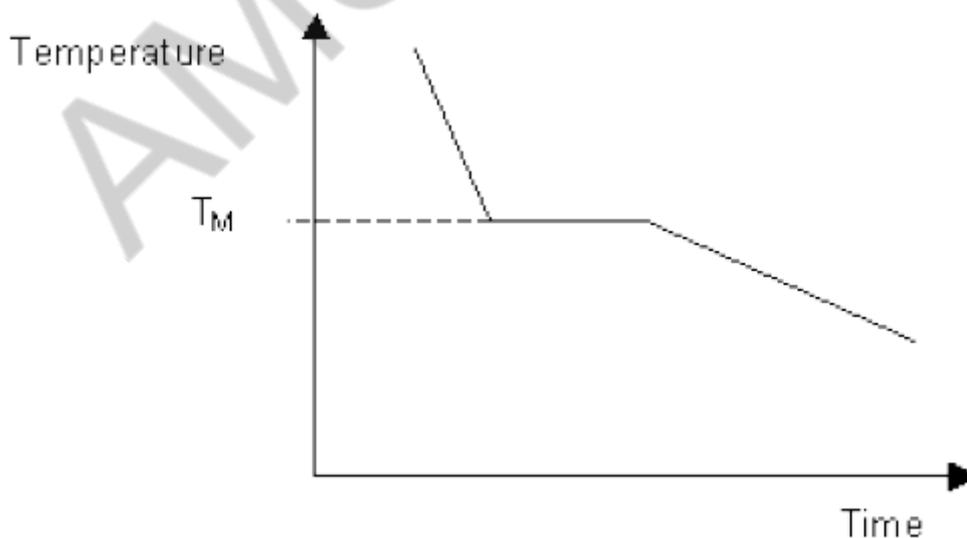
The austenite-pearlite reaction:

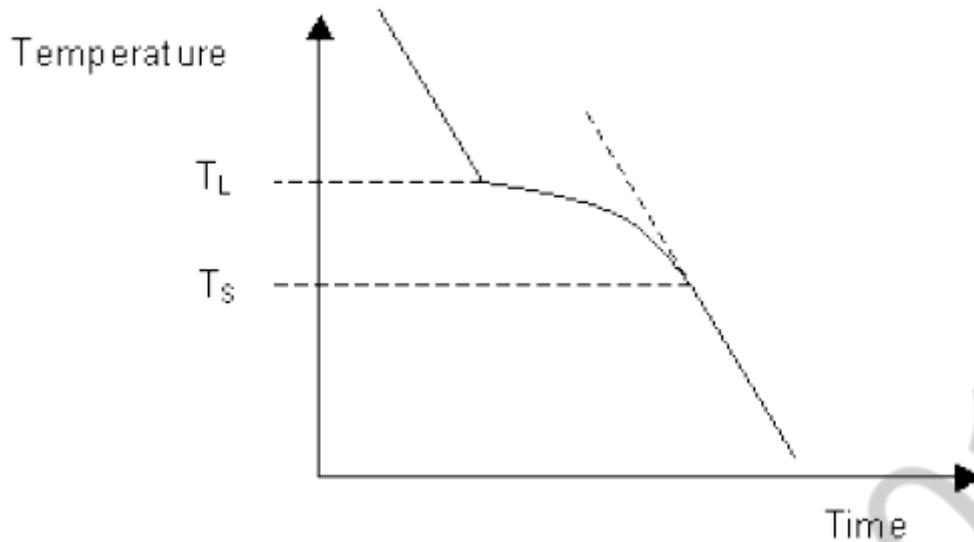
Pearlite is probably the most familiar micro structural feature in the whole science of metallography. It was discovered by Sorby over 100 years ago, who correctly assumed it to be a lamellar mixture of iron and iron carbide. Pearlite is a very common constituent of a wide variety of steels, where it 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)

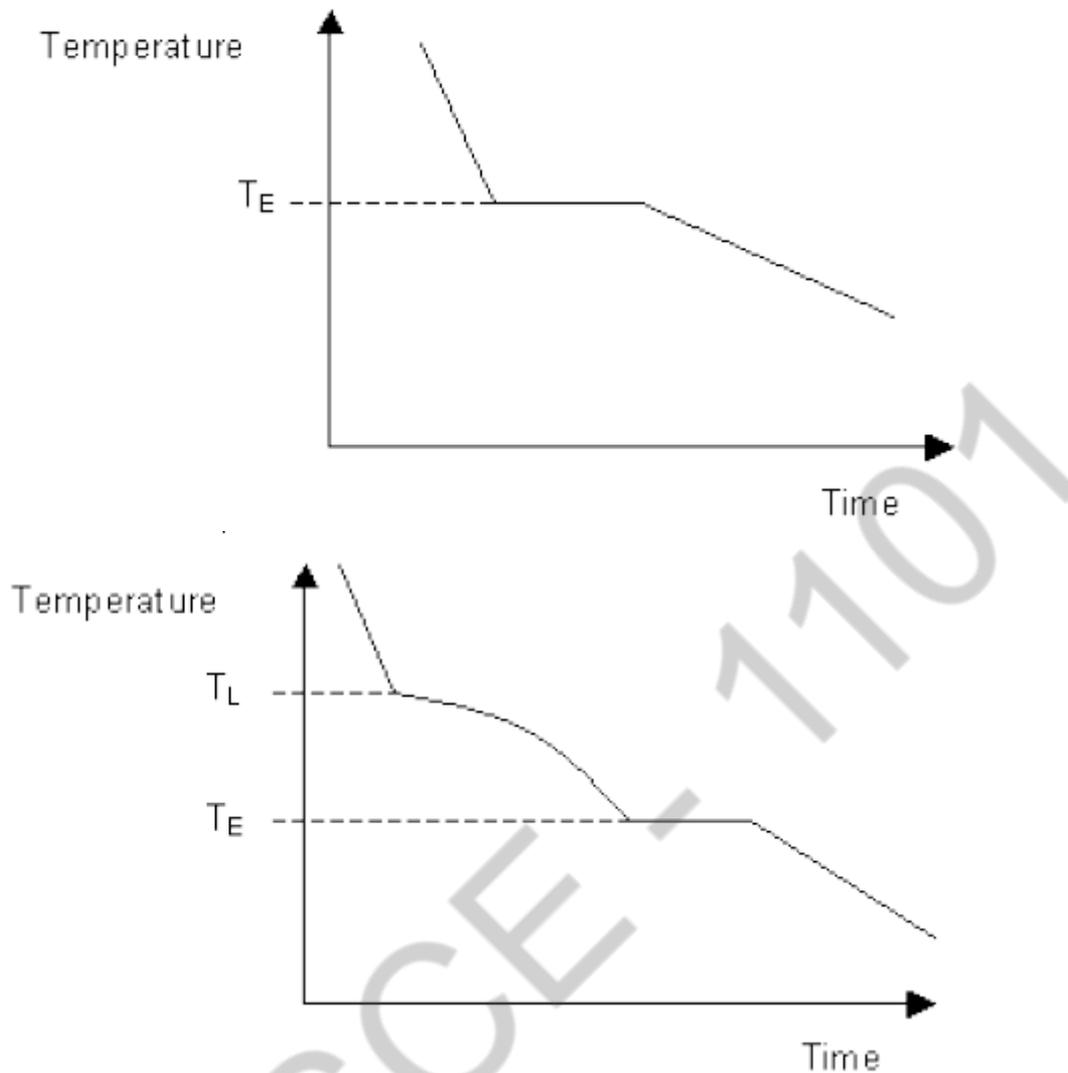
The melting temperature of any pure material (a one-component system) at constant pressure is a single unique temperature. The liquid and solid phases exist together in equilibrium only at this temperature. When cooled, the temperature of the molten material will steadily decrease until the melting point 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.

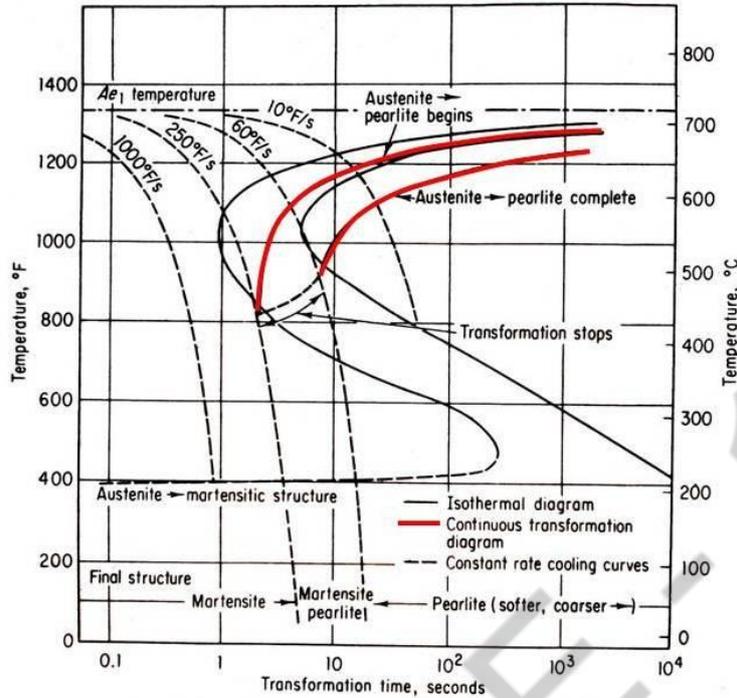
Hardenability refers to its ability to be hardened to a particular depth under a particular set of conditions.

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

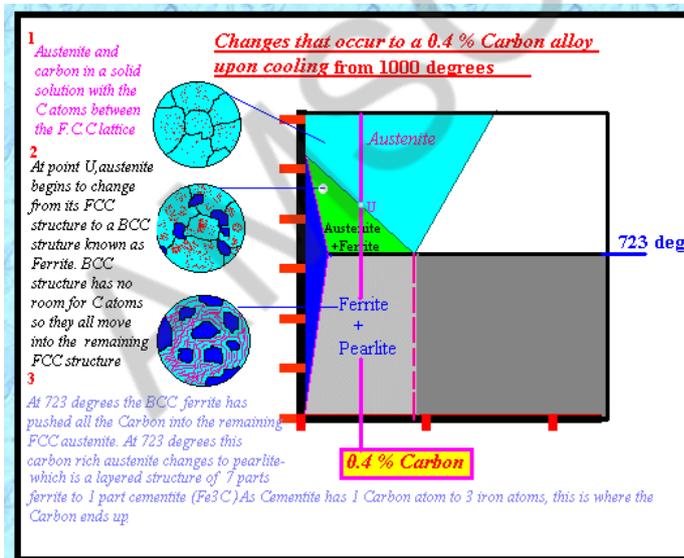
(b) Explain the mechanism of plastic deformation by slip and twinning with neat sketches.

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.

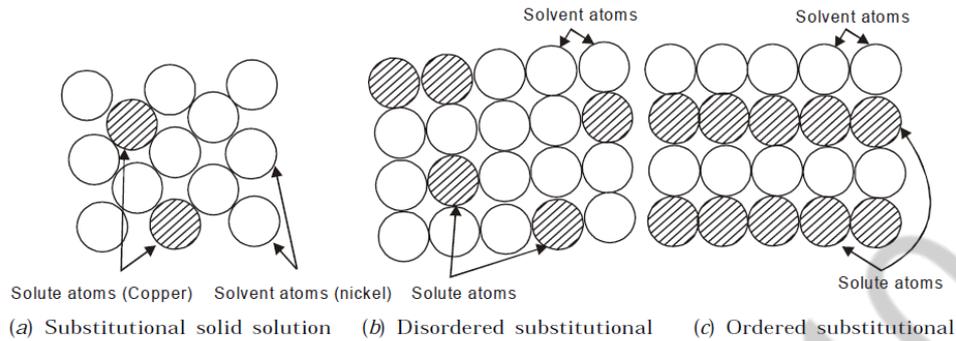
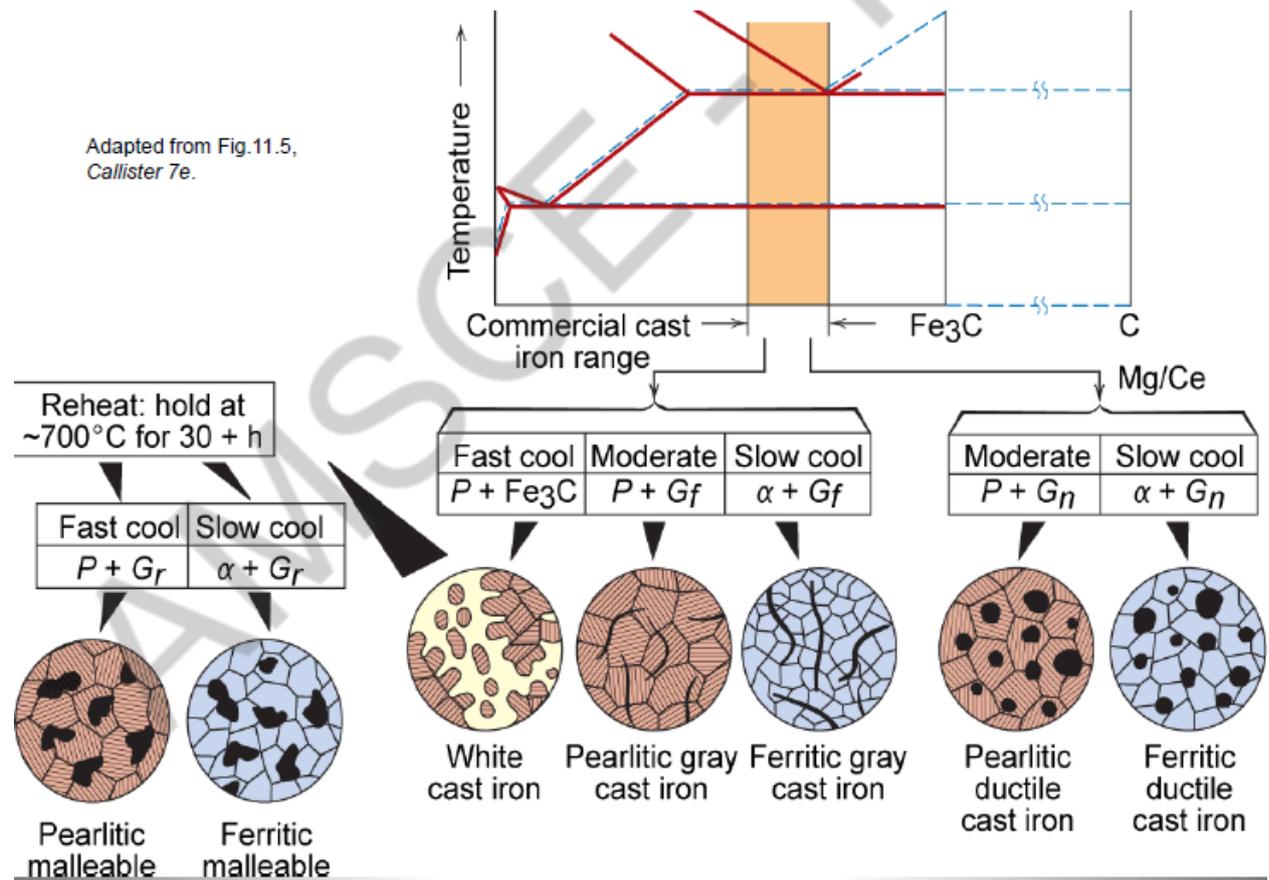


Fig. 5.1 Solid solutions

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



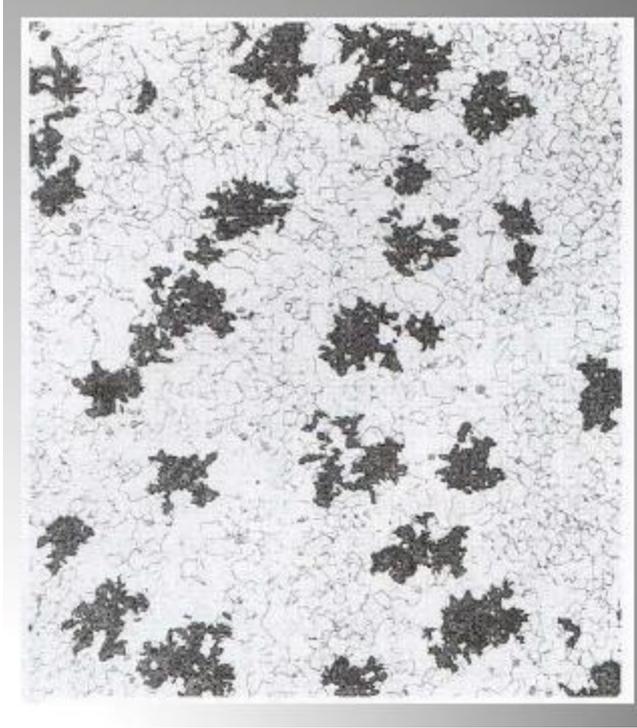
White cast iron:

- 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 Fe_3C 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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