ME 8491-ENGINEERING METALLURGY

ME 8491 **ENGINEERING METALLURGY** **L T P C**

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OBJECTIVES:

To impart knowledge on the structure, properties, treatment, testing and applications of metals and non-metallic materials so as to identify and select suitable materials for various engineering applications.

UNIT I ALLOYS AND PHASE DIAGRAMS 9

Constitution of alloys – Solid solutions, substitutional and interstitial – phase diagrams, Isomorphous, eutectic, eutectoid, peritectic, and peritectoid reactions, Iron – carbon equilibrium diagram, Classification of steel and cast Iron microstructure, properties and application.

UNIT II HEAT TREATMENT 10

Definition – Full annealing, stress relief, recrystallisation and spheroidising – normalising, hardening and Tempering of steel. Isothermal transformation diagrams – cooling curves superimposed on I.T. diagram CCR – Hardenability, Jominy end quench test - Austempering, martempering – case hardening, carburizing, Nitriding, cyaniding, carbonitriding – Flame and Induction hardening – Vacuum and Plasma hardening.

UNIT III FERROUS AND NON-FERROUS METALS 9

Effect of alloying additions on steel- α and β stabilisers– stainless and tool steels – HSLA, Maraging steels – Cast Iron - Grey, white, malleable, spheroidal – alloy cast irons, Copper and copper alloys – Brass, Bronze and Cupronickel – Aluminium and Al-Cu – precipitation strengthening treatment – Bearing alloys, Mg-alloys, Ni-based super alloys and Titanium alloys.

UNIT IV NON-METALLIC MATERIALS 9

Polymers – types of polymer, commodity and engineering polymers – Properties and applications of various thermosetting and thermoplastic polymers (PP, PS, PVC, PMMA, PET,PC, PA, ABS, PI, PAI, PPO, PPS, PEEK, PTFE, Polymers – Urea and Phenol formaldehydes)- Engineering Ceramics – Properties and applications of Al2O3, SiC, Si3N4, PSZ and SIALON –Composites-Classifications-Metal Matrix and FRP - Applications of Composites.

UNIT V MECHANICAL PROPERTIES AND DEFORMATION MECHANISMS 8

Mechanisms of plastic deformation, slip and twinning – Types of fracture – Testing of materials under tension, compression and shear loads – Hardness tests (Brinell, Vickers and Rockwell), hardness tests, Impact test Izod and charpy, fatigue and creep failure mechanisms.

TOTAL : 45 PERIODS

UNIT – I

ALLOYS AND PHASE DIAGRAMS

1.1 CONSTITUTION OF ALLOYS :

Alloy is a mixture of two or more elements. Alloys have metallic properties. Alloy is defined as a combination of two or more elements, of which one of the element should be a metal in major proportion. It could be metals or non- metals. Pure metals are used where specific properties such as high electrical conductivity, high ductility and corrosion resistance are required. These properties are at a maximum value in pure metals, but the mechanical properties such as tensile strength, yield point and hardness are improved by alloying.

1.2 CLASSIFICATION OF ALLOYS :

Alloys can be either a single phase or a mixture of phases.
A phase is anything which is homogeneous and physically distinct.

In the solid state of alloy there are three phases :

i) Pure metal   ii) Solid Solutions   iii) Intermediate phase

i) Pure metal :

It is define melting or freezing point. If a cooling curve is plotted for a pure metal, it will show a horizontal line at the melting point or freezing point.

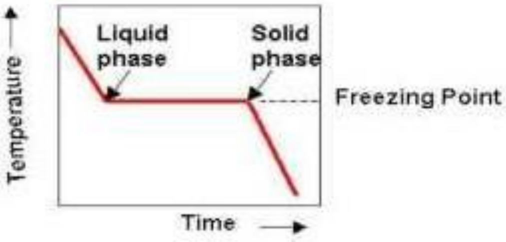


Fig 1.1 Solidification of Metal

ii) Solid Solution :

It is formed when two metals are completely soluble in liquid state and also completely soluble in solid state.

iii) Intermediate phase:

It is formed when one metal has chemical properties which are strongly metallic and the other metal has chemical properties which are weakly metallic. If an alloy has single phase, it could be either a solid solution or an intermediate phase. If the alloy is a mixture it could be composed of any combination of the above three phases.

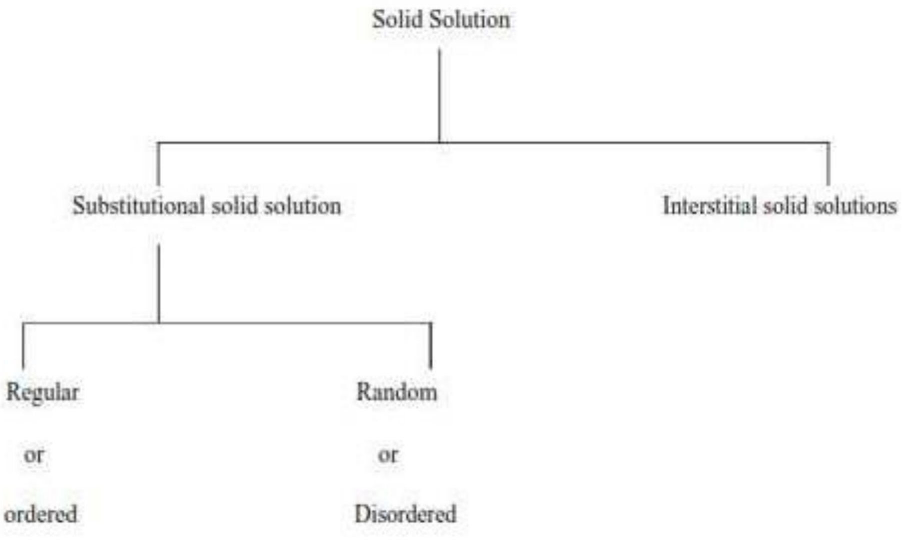
1.3 SOLID SOLUTIONS :

The solid solution exists as a single phase with two or more components.

Solid solution is an alloy in which the solute atoms are distributed in the solvent matrix and has the same structure of the solvent.

The element which is present in larger amount in the alloy is called solvent and the other element is called solute.

1.3.1 TYPES OF SOLID SOLUTIONS:



Substitutional solid solution:

The atoms of the solvent metal are replaced in the crystal lattice by atoms of the solute.

In the ordered solid solution, the substitution of either atoms in solvent is by a definite order, while this is not so in a disordered solid solution.

Substitution solid solution formation is favoured when the atomic sizes of the two metals are almost equal.

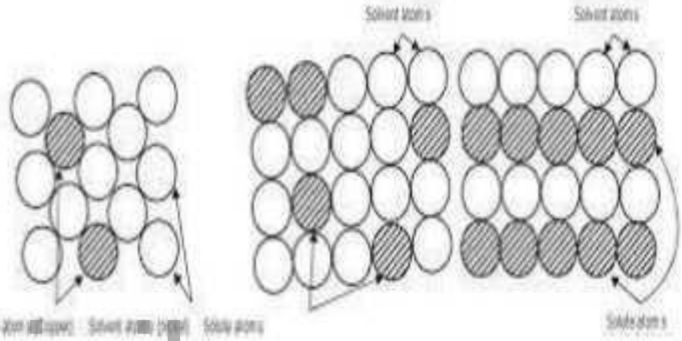


Fig 1.2 Substitutional solid solution

Interstitial solid Solution :

These are Formed only when the atoms of the solute element are very small compared with those of the solvent, thus enabling them to fit in to the interstices or spaces in the solvent.

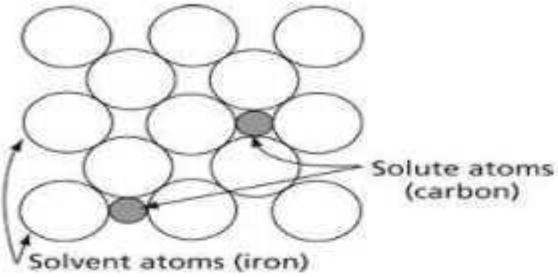


Fig 1.3 Interstitial solid solution

1.4 FACTORS GOVERNING SOLID SOLUBILITY (OR) HUME – ROTHER'S RULES :

In the formation of solid solution the solubility limit of a solute in the solvent is governed by certain factors.

1) Relative size :

If the atomic sizes of solute and solvent differ by less than 15% conditions are favorable for the formation of solid solutions. If the atomic size difference exceeds 15%,solid solution formation is extremely limited.

2) Chemical Affinity :

When two elements have a high chemical affinity for each other, the greater is the tendency to restrict the solid solution and to form intermediate phases. This occurs when one element is electronegative and the other is electropositive.

3) Relative valency:

A Metal of higher valency dissolves only a small amount of the lower valence metal, while the lower valence metal dissolves greater amount of the higher valence metal.

4) Crystal type :

If two metals are of the same crystal lattice and all other factors are favorable, it is possible for complete solid solubility to occur over the whole composition range.

1.5 INTERMEDIATE PHASES (OR)COMPOUNDS :

They are formed between two dissimilar elements having widely divergent electro chemical properties.

They are classified into three groups :

Intermetallic compounds

Electron compounds

Interstitial compounds

i) Intermetallic compound:

Intermettalic compounds obey the valence laws and are generally formed when one metal (such as Mg has chemical properties which are strongly metallic and other metal (such as sb, sn, Bi) which are only weakly metallic. They have strong bonding (ionic or covalent), they have higher melting point than the parent metals. They have poor ductility an low electrical conductivity.

Eg : Mg_3sb_2, Mg_2sn, Mg_3 Bi_2

ii) Electron compounds:

Electron compounds, the valence laws are not obeyed but there is a fixed ratio between the total number of valence electrons and total number of atoms. They have high ductility and low hardness.

Eg : cuzn, cu_3A1, cu_5s_n, Ag_3A_1

iii) Interstitial compounds :

They are formed between certain transition metals and small non – metallic atoms. When the solid solubility of an interstitially dissolved element is exceeded, a compound is precipitated from the solid solution.

In this compound, the small non – metal atoms still occupy the interstitial position, but the crystal structure of the compound is different from that of the original interstitial solid solution. Compound of this type have metallic properties and comprise hydrides, nitrides, borides and carbides of which TiH_2, TiN, TiB_2, Tac, w_2c, wc, Mo_2C, Fe_3c. These compounds are extremely hard.

1.6 PHASE DIAGRAMS (OR) EQUILIBRIUM DIAGRAMS (OR) CONSTITUTIONAL DIAGRAMS :

The properties of an alloy depends on Nature, amount, size, distribution and orientation of the phases. A Phase is the chemically are structurally homogenous portion of the micro structure.

It has the following Characteristics:

Same structure throughout.

Roughly the same composition and properties throughout.

Definite interface between the phase and surrounding.

Phase diagrams are graphical representation of phases in the system at various temperatures, pressures and compositions. The phase diagrams are constructed by using equilibrium conditions. Depending on the number of component (elements), the phase diagrams are called as unary (one component) binary (two component) and ternary (three component) phase diagrams.

1.7 GIBBS PHASE RULE :

J.W. Gibbs, American physicist derive an equation which established a definite relationship in a system between the number of phases, the number of degrees of freedom and the number of components.

$P+F= C+2$, Gibbs Phase rule

where,

P – Number of phases.

F- Degree of freedom

C- Number of components.

1.8 ISOMORPHOUS SYSTEM :

When two metals are completely soluble in the liquid and solid states, the resultant phase diagram is known as binary isomorphous phase diagram. In this system only a single type of crystal structure exists for all the compositions of components and therefore it is called isomorphous systems.

Eg : CU – Ni, Au- Ag. Au-Cu. Au –Ni.

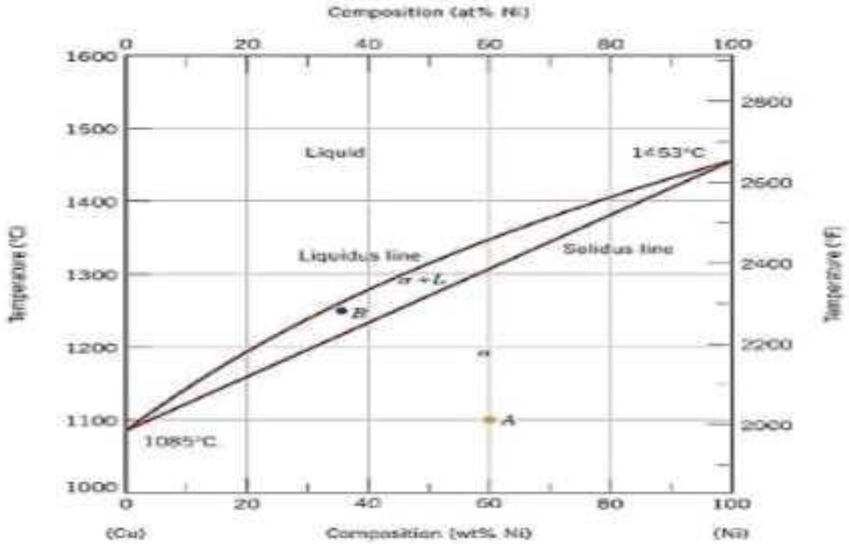


Fig 1.4 Binary isomophous systems for copper – Nickel system .

In a phase diagram, temperature is plotted a long y-axis and the composition of the alloy in weight percent is plotted along x- axis. The composition ranges from O weight% Ni(100%cu) on the left horizontal extremity to 100 weight % Ni(10%Cu) on the right side.

Three different phase regions appear on the diagram. They are α solid region, a liquid (L) region and a two phase region (α+L)

The liquid L is a homogenous liquid solution composed of both copper and nick. The α phase is a substitutional solid solution consisting of both cu and Ni atoms having F.C.C Crystal structure. At the temperatures below 1085°C, copper and nickel are mutually soluble in each other in solid state for all compositions. The complete, solubility is explained by the fact that both copper and nickel atoms have the same crystal Structure (F.C.C.),identical atomic radii, same electro- negativities and similar valencies. The copper-Nickel system is termed isomorphous because of this complete liquid and solid solubility of the two components.

In Fig, the line separating the L and α+ L phase region is termed as liquid us line. The liquid phase is present at all temperatures and compositions above this line. The solidus line is located between the α and α+L regions, below which only the solid α Phase exists. The solidus and liquidus lines intersect at the two composition extremities, these correspond to the melting temperatures of pure components.

For example, the melting point of copper is 1085°C and the melting point of nickel is 1453°C. While heating pure copper, copper remains solid until its melting temperature is reached.

1.9 INTERPRETATION OF BINARY ISOMORPHOUS PHASE DIAGRAM:

Phase that are present.

Composition of each phase

Lever arm rule.

i) Phases :

The phases present can be determined by locating temperature composition point on the diagram and noting the phase or phases with which the corresponding phase region.

ii) Composition :

To determine the composition of each phase in a two phase region, draw a horizontal line, OP at the given temperature.

iii) Lever arm rule :

It is used to determine the relative amounts of two phases in equilibrium at any particular temperature in a two phase region.

They are classified into four different types :

Eutectic phase diagram

Eutectoid phase diagram

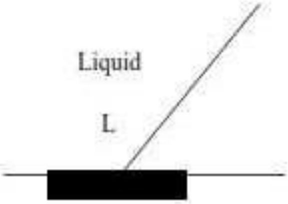
(iii)Peritectic phase diagram

Peritectoid phase diagram

i) Eutectic phase diagram :

In an eutectic reaction, when a liquid solution of fixed composition solidifies at a constant temperature, forms a mixture of two or more solid phases without an intermediate phase stage

$$\text{Liquid} \underset{\text{Cooling}}{\overset{\text{Heating}}{\rightleftarrows}} \text{solid 1} + \text{solid2}$$



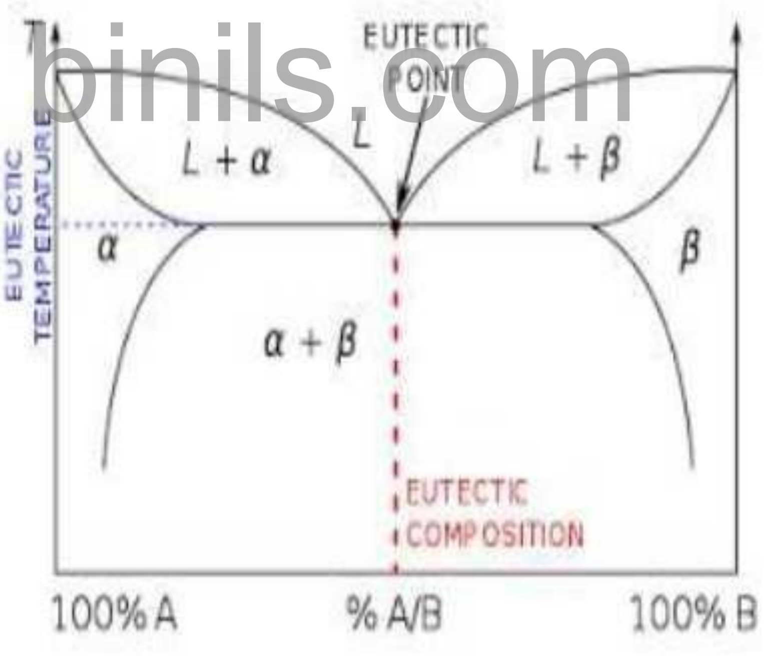
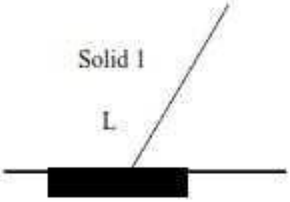


Fig 1.5 Eutectic phase diagram

ii) Eutectoid phase diagram :

Eutectoid reaction is an isothermal reversible reaction in which a solid phase is more converted in to two or intimately mixed solids on cooling, the number of solids the formed being the same as number of components in the system.

$$\text{Solid1} \underset{\text{Heating}}{\overset{\text{Cooling}}{\rightleftarrows}} \text{solid}_2 + \text{solid}_3$$



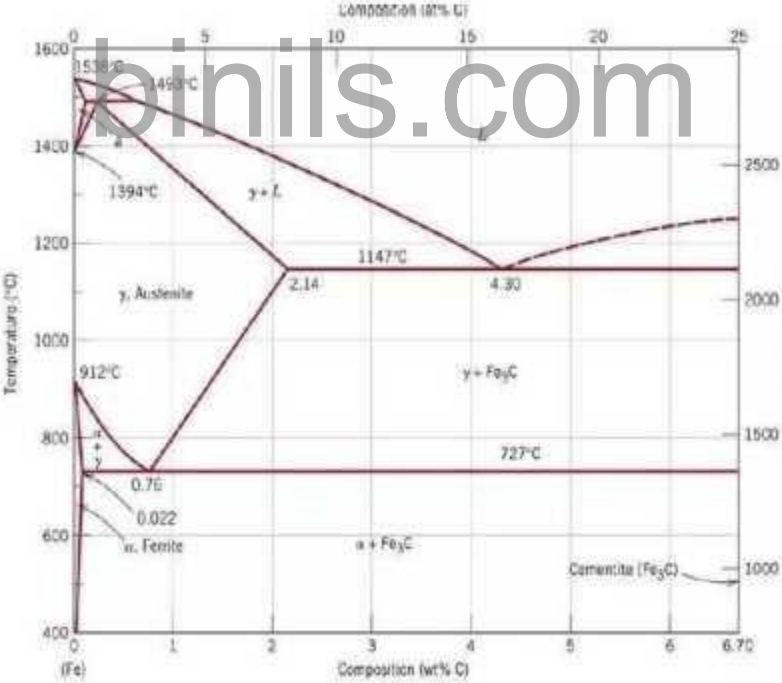
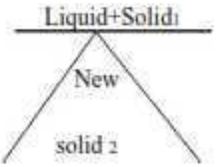


Fig 1.6 Eutectoid phase diagram

iii) Peritectic phase diagram :

Peritectic reaction up on heating one solid phase transforms in to a liquid phase and another solid phase. During solidification, liquid phase reacts with a solid phase to give a solid phase of different structure.

$$\text{Liquid+ solid}_1 \underset{\text{Heating}}{\overset{\text{Cooling}}{\rightleftarrows}} \text{New solid}_2$$



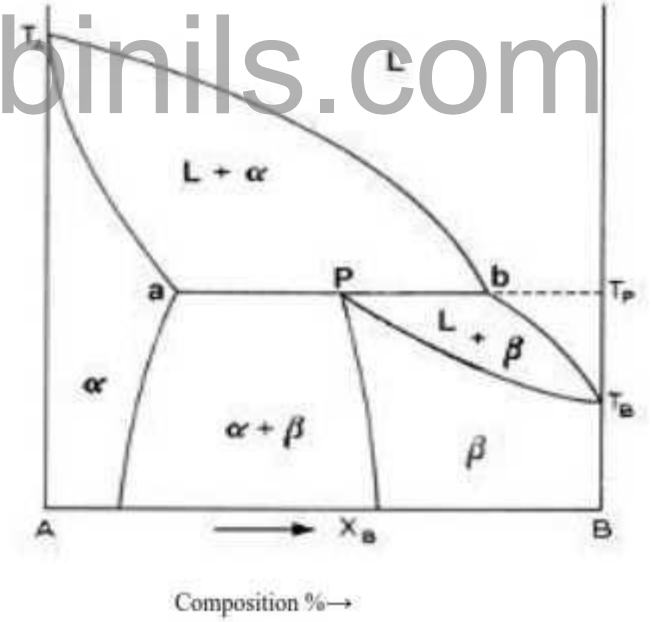
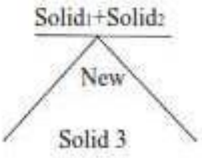


Figure 1.7 Peritectic phase diagram

iv) Peritectoid phase diagram :

The peritectoid reaction is the transformation of two solid into a third solid.It is an isothermal reversible reaction in which a solid phase reacts with a second solid phase to produce yet a third solid phase on cooling.

$$\text{solid}_1 + \text{solid}_2 \underset{\text{ating}}{\overset{\text{Cooling}}{\rightleftharpoons}} \text{New solid}_3$$



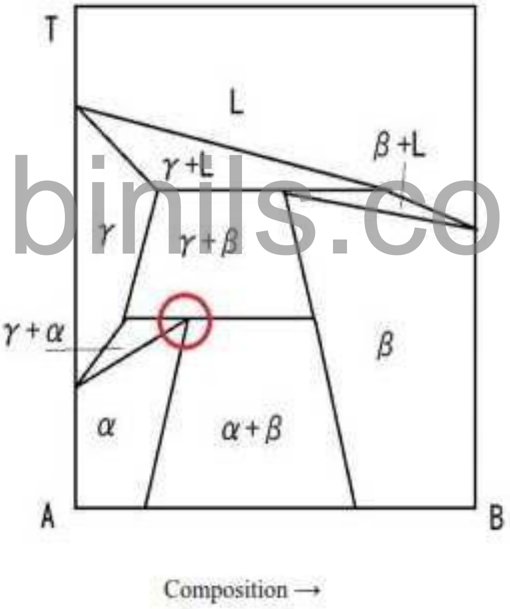


Figure 1.8 **Peritectoid phase diagram**

1.10 IRON – CARBON EQUILIBRIUM DIAGRAM (FE – FE3C):

Alloys of the iron – carbon system include steel and cast iron. Alloys with a carbon content up to 2% are known as steels whereas those having carbon above 2% are called cast- Irons.

Allotropy form of pure iron :

The pure iron exist in three allotropic form, i.e. ∝-iron , δ - iron , γ - iron.

Oc		OF	
1538	-	2800	∝-alpha iron
		δ- iron	δ-Delta iron
1394	-	2541	γ-Gamma iron
		γ- iron	
912	-	1674	
		∝- iron	
273	-	460	

From Fig. the temperature range in which allotropic form of pure iron exist under equilibrium condition.

∝ - iron	-273°c to 912°c
γ - iron	913°c to 1394°c
δ -iron	1395°c to 1538°c

Table 1.1 Temperature range

Iron is a relatively soft and ductile metal. Iron has a melting point of 1539°c. An equilibrium diagram is a graphic representation of the effects of temperature and composition up on the phases present in an alloy. An equilibrium diagram is constructed by plotting temperature along the y-axis and percentage composition of the alloy along the x- axis.

The microstructure and properties of steel and cast irons and provides a basis for the understanding of the principles of heat treatment.

Hypo eutectoid steels (0.008 to 0.8%C)

Hyper eutectoid steels (0.8 to 2.0%C)

Hypoeutectic cast irons (2 to 4.3%C)

Hyper eutectic cast irons (above 4.3% carbon)

The iron carbon equilibrium diagram has a peritectic, eutectic and eutectoid.

Peritectic reaction equation may be written as (2720°F)

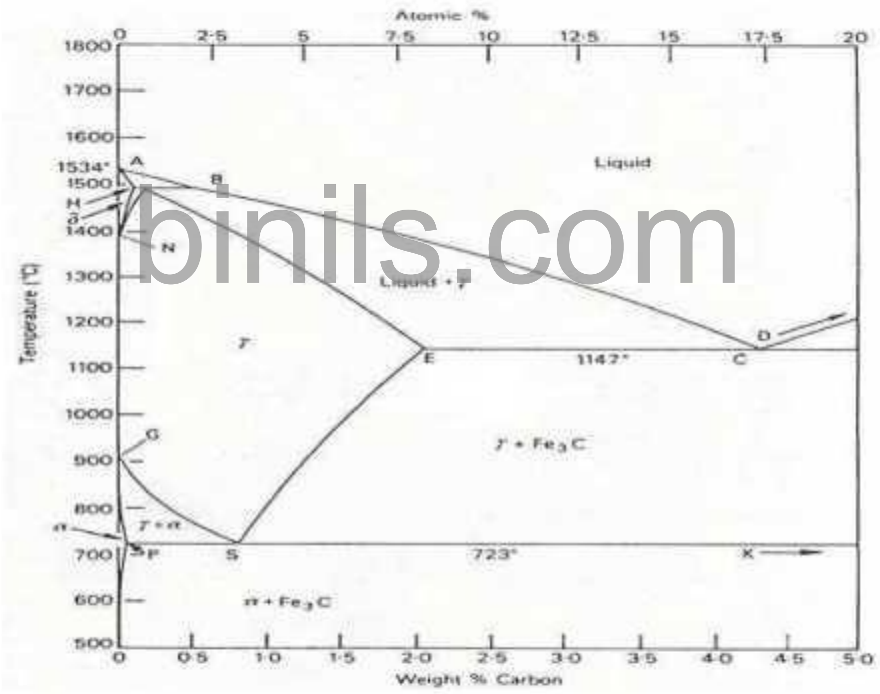


Fig 1.9 Iron carbon equilibrium diagram (Fe-Fe3C)

δ

Delta ( ) + Liquid $\underset{\text{Heating}}{\overset{\text{Cooling}}{\rightleftharpoons}}$ Austenite

Eutectic reaction takes places at (2066°F) and its equation may be written as

$$\text{Liquid} \xrightleftharpoons[\text{Heating}]{\text{Cooling}} \text{Austenite + cementite (Ledeburite)}$$

Eutectic point is at 4.3% carbon.

Eutectoid reaction takes place at (1333°F) and its equation may be written as

$$\text{Solid} \xrightleftharpoons[\text{Heating}]{\text{Cooling}} \text{Ferrite + cementite (Pearlite)}$$

1.11 TRANSFORMATION OF CAST IRON AND STEEL:

Eutectoid steel :

The steel that contains 0.8% of carbon are called eutectoid steel.

Hypo eutectoid steel :

The steel having less than 0.8% of carbon is known as hypo eutectoid steel.

Hyper eutectoid steel :

The steel having more 0.8% of carbon is known as hyper eutectoid steel.

Eutectic cast iron :

The cast iron which contain 4.3% of carbon is known as eutectic cast iron.

Hypo eutectic cast iron :

The cast iron which contain less the 4.3% of carbon is known as hypo eutectic cast iron .

Hyper eutectic cast iron :

The cast iron which contain above 4.3% of carbon is known hyper eutectic cast iron. This phase diagram presents the phases present at various temperature for very slowly pulled iron – carbon alloy with up to 6.67% carbon. The solid phase present in the phase diagram are ∝- iron , - iron, ς- iron. Two phase solids are ∝- iron, γ - iron , δ - iron . Two phases solids are ∝+Fe_3C, γ+ Fe_3C, γ+ δ.

1.12 CLASSIFICATION OF STEEL :

Classification of steel:

Steel can be classified as follows

- Plain carbon (or) non alloy steels
    - Low carbon steels
    - Medium carbon steels
    - High carbon steels
- Alloy steels
    - Low alloy steels
    - High alloy steels

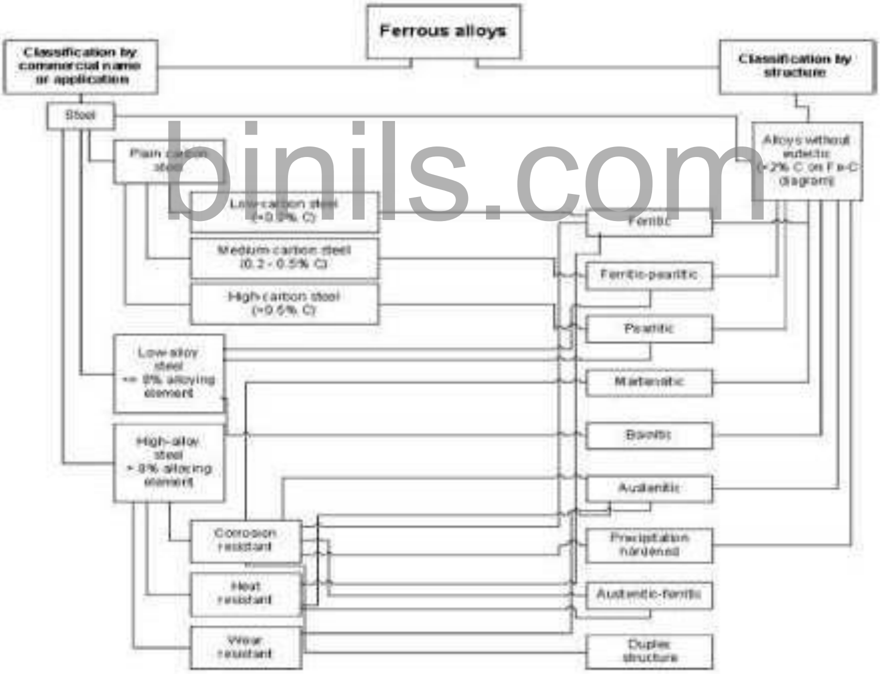


Fig 1.10 classification of steels

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 that 0.6%

Composition of plain carbon steels:

Carbon upto 1.5% Manganese upto 1.65% Copper upto 0.6% Silicon upto 0.6%

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.

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% carbon.

Medium – carbon steels: those content 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 week.

They cannot by hardened appreciably by heat treatment.

Strengthening of low carbon steels are accomplished by cold work.

They have outstanding ductility and toughness.

The micro structure of low carbon steels consist of ferrite and peralite 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:

The plain medium-carbon steels have low hardenabilities.

In plain medium carbon steels the high strength and hardness properties are achieved.

They possess good formability and weldability

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 resistant.

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

Application of high carbon steels:

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

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.

Composition:

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 ad magnetic properties

Classification of Alloy steels:

Alloy steels can be divided into two main groups:

Low alloy steels: These contain upto 3 to 4% of alloying elements.

High alloy steels: These contain more than 5% of alloying elements.

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.

1.13 CAST IRON:

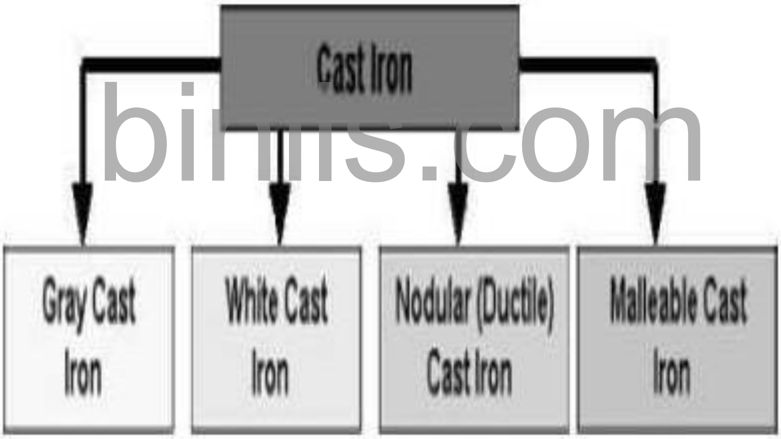


Fig 1.11 Types of cast iron

Malleable cast iron

Spheroidal cast iron Malleable cast iron

Malleable cast iron:

Malleable iron is a iron that has been heat treated so that is has significant ductility and malleability.

Composition:

The composition of a typical malleable cast iron is given below Carbon – 2.0% to 3.0% Manganese- 0.2% to 0.6% Silicon – 0.6% to 1.3% Phosphorus-0.15% silicon-0.10%

Micro structure of malleable cast iron

Malleable iron is produced by heat treating un alloyed (2.5%C, 0.5 si) white iron. During the heat treatment process, the cementite in the white cast iron structure breaks down into ferrite and graphite clumps (or) modules. This graphite nodule, also called tempered carbon, appears like poncorn. This graphite shape permits a good combination of strength and ductility in the pearlite matrix. The irons so produced are called pearlite.

Fig 1.12 Malleable cast iron

Characteristic of malleable cast iron:

The important properties of malleable cast iron are given below:

The malleable cast iron posses good ductility and malleability properties than grey cast iron.

It exhibits high yield strength and tensile strength.

It is not brittle as grey cast iron.

It has high young's modulus and low co-efficient of thermal expansion.

It has good wear resistance and vibration damping capacity.

Types malleable irons:

Two types of malleable irons, depending on the type of heat treatment cycle used to produce are,

1.Ferritic Malleable iron

2. Pearlitic malleable iron

1.Ferritic malleable iron:

The white iron castings are heating beyond the upper critical temperature and held for a prolonged period of time so that carbon in the cementite converts to graphite, subsequent low cooling through the eutectoid reaction results in a ferrite matrix. The cast iron so obtained is termed as ferritic malleable cast iron. The ferritic malleable cast iron has good toughness compared with the of other cast iron.

2. Pearlitic malleable iron:

When the white cast iron is cooled from temperature higher than a upper critical temperature more rapidly through the eutectoid transformation range, the carbon in the austenite will not have enough time to form additional graphite but is retained.

Application of malleable cast iron:

Brake-shoes , pedals, levers, wheel hubs, axle housing, connecting rods, transmission gears and door hinges.

(ii) Spheroidal graphite or nodular cast iron:

Spheroidal graphite cast iron is also known as nodular iron or as ductile iron.

Compostition:

The composition of a typical cast iron is given below Carbon -3.2 to 4% Silicon -1.8 to 3% Manganese-0.01% max.

The SG iron is the cast iron with nodular or spheroidal graphite. The nodules also called spheroids are about the same as those in malleable cast iron, expect that they are more perfect spheres.

Micro structure of SG cast iron:

The nodular cast iron is produced by adding magnesium and or cerium to molten cast iron(i.e. the gray iron before casting) The magnesium converts the graphite of cast iron from flake form into spheroidal or nodular form. The resulting alloy is called spheroidal or nodular cast iron.

The presence of spheroidal graphite improves the ductility strength, fracture toughness, and other mechanical properties. Ductility cast iron derives its name from the fact its ductility is increased by 20%. Addition of magnesium gives good results and hence it is widely used.

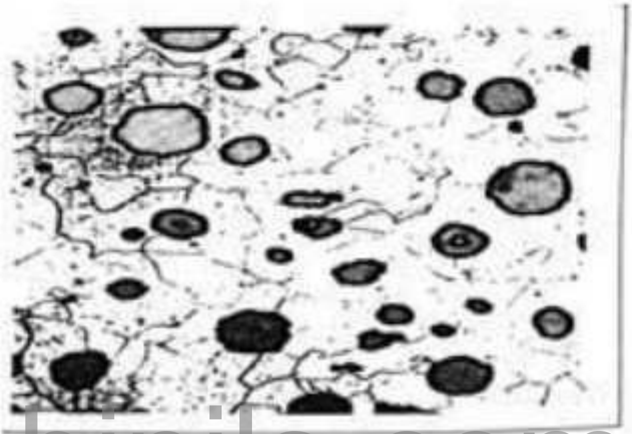


Fig 1.13 Microstructure of nodular cast iron

Magnesium is usually added in the form of a master alloy such as ferrous silicon magnesium or nickel magnesium alloyed: a grade 60-40-18 SG cast iron has a minimum tensile strength of 60×10^3 psi, minimum yield strength of 40×10^3 psi and 18% elongation.

Characteristics of SG cast iron:

It has good toughness than the grey cast iron.

It good fatigue strength.

It exhibits good impact strength.

It possesses good hardness and high modulus of elasticity.

It has corrosion resistance similar to that of gray iron.

It possesses excellent cast ability and wear resistance.

It has ability to resist oxidation at high temperatures.

It has good machinability.

Application of SG cast iron:-

The typical applications of SG cast iron include valves, pump, bodies, crankshaft, gears, pinions, rollers, rocker arms, flanges, pipe fittings, power transmission equipments, earth moving machineries and other machine components.

UNIT -1: ALLOYS AND PHASE DIAGRAMS

PART – A

1. What is meant by alloying elements? [M/J 12]

It is a mixture of two or more metals or a metals and a non – metals. The element which is present in the largest proportion is called the base metal, and other element present is called as alloying elements.

2. State Hume rothery's rules? [A/M'15]

Size factor: The atoms must be of similar size, with less than 15% difference in atomic radius

Crystal structure: The material must have the same crystal structure. Otherwise, there is some point at which the transition occurs from one phase to a second phase with different structure.

Valence: The atoms must have the same valence. Other wise the valence electrons difference encourages the formation of compounds rather then solutions.

Electro negativity: The atoms must have approximately the same electro negativity.

3. What is phase diagram?

It is graphical representations of what phase are present in a materials system at various temperatures, pressures, and compositions. And the phase diagrams are also known as equilibrium diagram or constitutional diagrams.

4. State Gibbs phase rule?

It is a simple equation that relates the number of phases presents (P) in a system at equilibrium with the number of degrees of freedom (F), the number of components (C),And the number of non-compositional variables. Gibbs phase rule: F = C-P+2

5. Define critical cooling rate.

The slowest rate of cooling of austenite that will result in 100 percentage martensite transformation is known as critical cooling rate.

State the conditions under which two metallic elements will exhibit unlimited solid solutions [A/M'15]

i) Atomic size - for high solid solubility the atomic size of base metal and alloying must be similar

ii) Chemical affinity- element having lower chemical affinity have great solid solution.

iii) Relative valency - for higher solid solubility,the two elements have lower valency should be selected

iv)Crystal structure - metals with similarly crystal structure have higher solid solubility.

Differentiate Isomorphous and eutectic reaction.

Isomorphous is a system with complete liquid and solid soluability zero to hundred percentage When an isomorphous alloy is cooled very, very slowly it is undergoes a base change from liquid to solid form.

How steels are classified? [N/D'16]

PLAIN CARBON STEEL	ALLOY STEEL
Low carbon steel	Low alloy steel
High carbon steel	High alloy steel

Medium carbon steel

9. What does a Phase diagram inidcate?

The phase diagram indicates the temperature at which the solid alloy will start melting and finish melting.

10. What is the significance of lever rule?

Lever rule is a method used to find out the exact amount of phase existing in a binary system for a given alloy at any temperature under consideration.

11. Define the term solid solutions. [N/D'16]

A solid solution is formed when two metals are completely soluble in liquid state and also completely soluble in solid state.

12. What do you mean by invariant reaction. [N/D'15]

When a reaction occurs under equilibrium condition at a specific temperature and alloy composition that cannot be varied it is said to be invariant.

PART – B

With the help of neat sketch explain the two types of solid solution.(M/J2013) Types of solid solution:

There are two types of solid solutions formed

Substitutional solid solution

Interstitial solid solution

Substitutional solid solution :-

Substitutional solid solutions are formed when some of the solvent atoms (Base metal atoms) are replaced by the solute atoms (alloying elements atoms) in a crystal lattice.

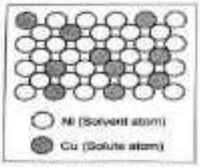


Fig. 1.3. Substitutional solid solution (with nickel atoms substituting for copper atoms on FCC atom sites)

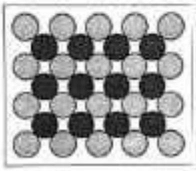


Fig. 1.5. Ordered substitutional solid solution

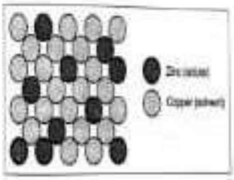


Fig. 1.4. Random substitutional solid solution (zinc in copper, i.e., brass). The crystal pattern is not altered.

Substitutional solid solution occurs when the solute and solvent solution (atoms) are equal or approximately equal in diameter.

Ex: Cu-Ni where Cu has radius of 1.28 A and Ni has radius of 1.24 A. Both copper and Nickel have FCC crystal structure. The crystal structure of the solvent is uncharged. But the lattice may be distorted by the presence of solute atoms, particularly if have is significant difference in atoms radii's of the solute and solvent atoms.

Random or Disordered substitution solid solution: In Random solid solution, the solute atoms do not occupy and specific position but are randomly distributed in the lattice structure of solvent. The concentrations of the solute atoms vary throughout the lattice structure of the solvent.

Ordered Substitutional solution:When the atoms of the solute material occupy similar lattice point with the crystal structure of the solvent material, the solid solution is called ordered solution. During slow coding, diffusion tends to produce uniform distribution of solute and solvent and solvent atoms. The solute atoms moves in definite orderly manner and occupy orderly position in the lattice. Cu-Zn , Au-Cu , Cu2 MnAl are some examples of ordered structures.

Interstitial solid solution

Interstitial solutions are formed when the solute atoms are very small in comparison with solvent atoms.

The solute atoms occupy the holes(or) interstices between the solvent atoms. Here the solution (or) solute atoms are much smaller than the parent atoms and have occupied randomly in the interstitial voids between parent atoms.

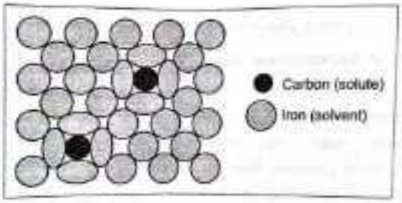


Fig. 1.6. Interstitial solid solution (carbon in FCC iron)

The most important interstitial solid solution present in ferrous metals is ferrite which consists of pure iron containing upto 0.008% carbon at room temperature. In several, hydrogen, carbon , nitrogen and boron having small atomic diameters form interstitial solid solutions with the base metal atoms.Atomic size is not only a parameter which determines whether or not an interstitial solid solution, will form but also small solute atoms like Fe, Ni, Mn, Mo , Cr, W etc dis solve more readily in transition metals.

Sketch neatly the ideal iron- carbide binary equilibrium diagram, indicating temperatures, composition and different phases present. Also explain the peritectic reaction of this system. [A/M'15]

Iron-Iron carbide equilibrium diagram is very much useful in understanding the microstructures and properties of cast irons and carbon steels

It is also used to understand the basic differences among iron alloys and the control of their properties

This phase diagram is constructed by plotting the carbon composition (weight per cent)along the X- axis and temperature along the Y- axis.

The iron-iron carbide ($Fe-Fe_3C$) phase diagram.

This phase diagram presents the phases present at various temperatures for very slowly cooled iron-carbon alloys with up to 6.67% carbon.

As discussed in the pure iron exists in three allotropic forms .i.e ,alpha iron,beta iron,comma iron it melts .At room temperature the stable form ,called ferrite exist with a BCC crystal structure. Upon heating, ferrite transforms to FCC austenite at 912 C. This austenite continues till 1394C;at this temperature the FCC austenite transforms back to a BCC phase known ass ferrite. Then finally the iron melts at 1538C.All these changes are seen the figure along the left vertical axis of the phase diagram.

Carbon is an interstitial impurity in iron and forms a solid solution with each of alpha and betta ferrites ,and also with austenite, an indicated by the alpha,betta,comma single phase fields as shown the figure.

The important information that can be obtained from the $Fe-Fe_3C$ can be studied under the following topics:

- Solid phases in the phase diagram.
- Invariant reactions in the phase diagram.
- Eutectoid,Hypoeutecoid,and hypereutectoidsteels.
- Eutectic,hypoeutectic,and hypereutectic cast irons.

Solid phases in the phase Diagram:

The $Fe-Fe_3C$ phase diagram contains the following four solid phases:

- Alpha Ferrite
- Austenite
- Cementite
- Betta Ferrite

1.Alpha –Ferrite:

This phase is an interstitial solid solution o carbon in the BCC iron crystal lattice.

The solid solubility of carbon in alpha ferrite is a maximum of 0.02% at 723C and decreases to 0.005% at 0C.

2.Austenite:

The interstitial solid solution of carbon in betta iron is called austenite.

Austenite has an FCC crystal structure and a much higher solid solubility for carbon than alpha ferrite.

As indicated by fig, the solid solubility of carbon in austenite is a maximum of 2.08% at 1148C and decreases to 0.8% at 723C.

3.Cementite:

The intermetallic iron-carbon compound is called cementite.

Cementite has negligible solubility limits and a composition of 6.67%C and 93.3%Fe.

4.Comma ferrite:

The interstitial solid solution of carbon in comma iron is called comma ferrite.

Comma ferrite has a BCC crystal structure.

The maximum soild solubility of carbon in comma ferrite is 0.09% at 1465C.

Invariant Reactions in the Fe-Fe3C Phase Diagram: The Three important invariant reactions associated with the Fe-Fe3C diagram are peritectic,eutectic and eutectoid reactions.

1.Peritectic reaction:

As this peritectic reaction point, liquid of 0.53%C combines with comma ferrite of 0.09%C to form betta austenite of 0.17%C.

This peritectic reaction, which occurs at 1495C.

The peritectic reaction affects only solidification of steels with less than0.55%carbon.

2.Eutectic reaction: [M/J'16]

At the eutectic reaction point,liquid of 4.3% forms betta austentic of 2.08%C and the inter metallic compound Fe3C,which contains 6.67%C.

This Eutectic reaction, which occurs at 1148C.

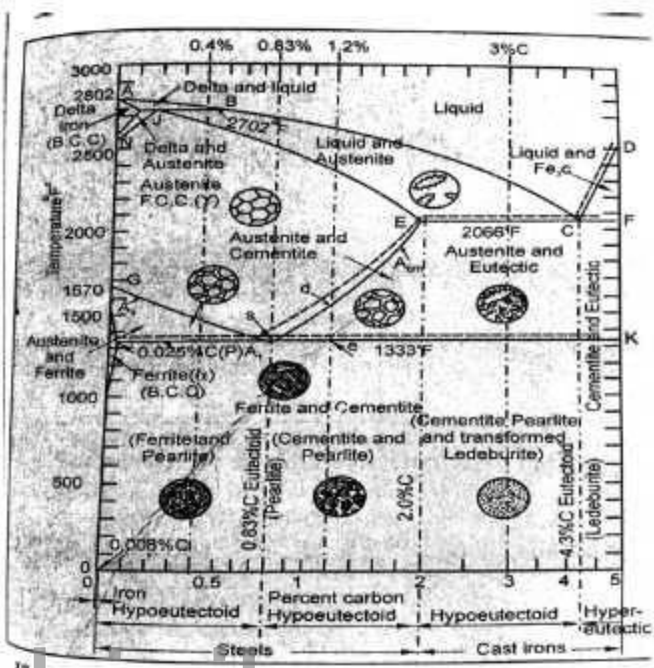
This reaction is of great importance in cast irons.

3.Eutectoid reaction:

- At the eutectoid reaction point, solid austenite of 0.8%C produces alpha ferrite with 0.02%C and fe3c that contains 6.67%C.

This eutectoid reaction, which occurs at 723C.

This reaction gains much importance for the heat treatment of steels.



Iron carbon equilibrium diagram indicates the phase changes that occur during heating and cooling and the nature and amount of the structural components that exist at temperature besides it establishes a correlation between the micro structure and properties of steel and cast irons and provides a basic for the understanding of the principles of heat treatment.

Discuss the classification, micro structure properties and application of steel [M/J'16]

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

Plain carbon (or) non alloy steels
- Low carbon steels
- Medium carbon steels
- High carbon steels

2, Alloy steels
- Low alloy steels
- 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 that 0.6%.

Composition of plan 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.

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 containg between 025 and 0.6 % carbon.

Medium – carbon steels: those content between 0.25 and 0.60% carbon. ○ High-carbon steels: those containing more than 0.6% carbon.

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

The cow-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 week.
- ○ They can not by hardened appreciably by heat treatment.
- ○ They possess good formability and weldability .

Strengthening of low carbon steels are accomplished by cold work.

- They have outstanding ductility and toughness.
- The micro structure of low carbon steels consist of ferrite and peralite 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.

The plain medium-carbon steels have low hardenabilities.

In plain medium carbon steels the high strength and hardness properties are achieved.

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

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

Dead mile 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.

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 ad magnetic properties

Low alloy steels: these contain upto 3 to 4% of alloying elements.

High alloy steels: These contain more than 5% of alloying elements.

Low Alloy Steels:

- Low alloy steels are steels which contain upto 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 gain refinement.

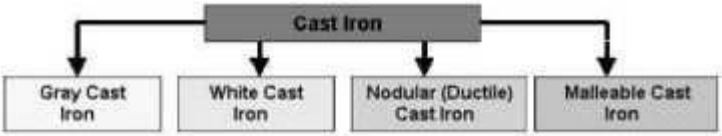
High Alloy steels:

- 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.

4.Discuss the composition, Properties and apply of the following cast iron. [M/J'16]



(i) Malleable cast iron **(ii) Spheroidal cast iron**

Malleable cast iron:

Malleable iron is a iron that has been heat treated so that is has significant ductility and malleability.

Composition:

The composition of a typical malleable cast iron is given below

Carbon – 2.0% to 3.0% Manganese-0.2% to 0.6% Silicon – 0.6% to 1.3% Phosphorus-0.15% Silicon -0.10%

Micro structure of malleable cast iron

Malleable iron is produced by heat treating un alloyed (2.5%C, 0.5 si) white iron. During the heat treatment process, the cementite in the white cast iron structure breaks down into ferrite and graphite clumps (or) modules. This graphite nodule, also called tempered carbon, appears like pop corn. This graphite shape permits a good combination of strength and ductility in the pearlite matrix. The irons so produced are called pearlite.

Microstructure of malleable cast iron

Designation of malleable cast iron

The designation system for malleable cast iron given by ASTM, is a five digit number.The first three digits represent the minimum yield strength in Psi of the iron, and the last two digits represent the percent of elongation.

A grade 32510 malleable cast iron has a minimum yield strength of 32.5 x10^3 ,Psi and 10% elongation, and a grade 35018 a minimum yield strength of 35x10^3 psi = 242 Mpa) and 18% elongation.

Characteristic of malleable cast iron:

The important properties of malleable cast iron are given below:

The malleable cast iron posses good ductility and malleability properties than grey cast iron.

It exhibits high yield strength and tensile strength.

It is not brittle as grey cast iron.

It has high young's modulus and low co-efficient of thermal expansion.

It has good wear resistance and vibration damping capacity.

It also has excellent Machinability

Types malleable irons:

Two types of malleable irons, depending on the type of heat treatment cycle used to produce, are

1. Ferritic Malleable iron 2. Pearlitic malleable iron

1. Ferritic malleable iron:

The white iron castings are heating beyond the upper critical temperature and held for a prolonged period of time so that carbon in the cementite converts to graphite, subsequent low cooling through the eutectoid reaction results in a ferrite matrix. The cast iron so obtained is termed as ferritic malleable cast iron. The ferritic malleable cast iron has good toughness compared with the of other cast iron.

2. Pearlitic malleable iron:

When the white cast iron is cooled from temperature higher than a upper critical temperature more rapidly through the eutectoid transformation range, the carbon in the austenite will not have enough time to form additional graphite but is retained.

Application of malleable iron:

Automobile industries because of their combination of castability , shouk resistance, and good Machinability. Typical components in clued brake-shoes , pedals, levers, wheel hubs, axle housing, connecting rods, transmission gears, and door hinges.

Spheroidal graphite or nodular cast iron:

Spheroidal graphite cast iron is also known as nodular iron or as ductile iron.

Compostition:

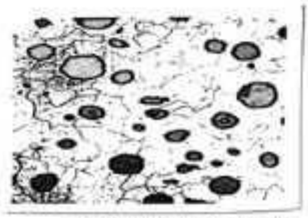
The composition of a typical cast iron is given below Carbon -3.2 to 4% Silicon -1.8 to 3% Manganese-0.01% max

The SG iron is the cast iron with nodular or spheroidal graphite. The nodules also called spheroids are about the same as those in malleable cast iron, expect that they are more perfect spheres.

Micro structure of SG cast iron

The nodular cast iron is produced by adding magnesium and or cerium to molten cast iron(ie the gray iron before casting) The magnesium converts the graphite of cast iron from flake form into spheroidal or nodular form. The resulting alloy is called spheroidal or nodular cast iron.

The presence of spheroidal graphite improves the ductility strength, fracture toughness, and other mechanical properties.Ductility cast iron derives its name from the fact its ductility is increased by 20%. Addition of magnesium gives good results and hence it is widely used.



Microstructure of a nodular iron

Magnesium is usually added in the form of a master alloy such as ferrous silicon magnesium or nickel magnesium alloyed: a grade 60-40-18 SG cast iron has a minimum tensile strength of $60x10^3$ psi, minimum yield strength of $40x10^3$ psi and 18% elongation.

Characteristics of SG cast iron

It has good toughness than the grey cast iron.

It good fatigue strength.

It exhibits good impact strength.

It possesses good hardness and hish modulus of elasticity.

It has corrosion resistance similar to that of gray iron.

It possesses excellent castability and wear resistance.

It has ability to resist oxidation at high temperatures.

It has good machinability.

Application of SG cast iron:-

The typical applications of SG cast iron include valves, pump, bodies, crankshaft, gears, pinions, rollers, rocker arms, flanges, pipe fittings, power transmission equipments, earth moving machineries and other machine components.

PART-C

Explain: [N/D'16]

Eutectic reaction (4)

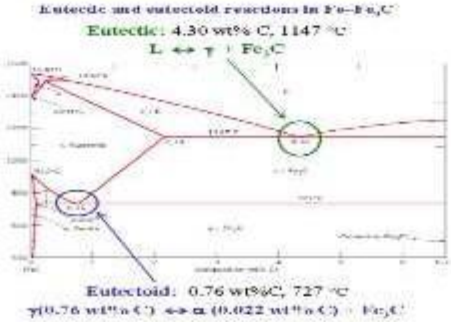
Eutectoid reaction (4)

Peritectic reaction (4)

Peritectoid reaction

(4) Eutectic reaction:

A eutectic reaction is a three-phase reaction, by which, on cooling, a liquid transforms into two solid phases at the same time. It is a phase reaction, but a special one. For example: liquid alloy becomes a solid mixture of alpha and beta at a specific temperature (rather than over a temperature range). The eutectic solid is commonly lamellar (stripy) in form.



Eutectoid reaction:

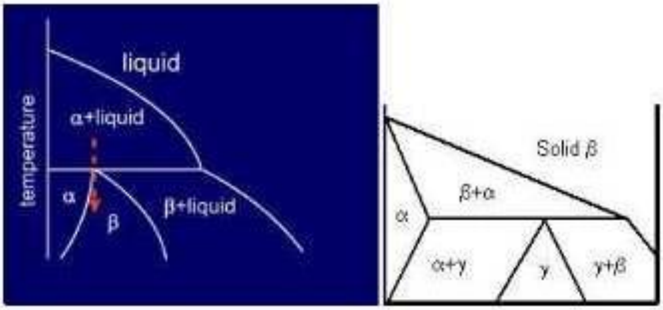
The eutectoid reaction describes the phase transformation of one solid into two different solids. In the Fe-C system, there is a eutectoid point at approximately 0.8wt% C, 723°C. The phase just above the eutectoid temperature for plain carbon steels is known as austenite or gamma. We now consider what happens as this phase is cooled through the eutectoid temperature (723°C).

Peritectic Reaction:

A peritectic reaction is a reaction where a solid phase and liquid phase will together form a second solid phase at a particular temperature and composition - e.g. Liquid + alpha --> beta

These reactions are rather sluggish as the product phase will form at the boundary between the two reacting phases thus separating them, and slowing down any further reaction. Peritectics are not as common as eutectics and eutectiods, but do occur in some alloy systems. There's one in the Fe-C system.

Diagram showing the Peritectic reaction, where a liquid and solid together form a new solid phase.



Peritectoid reaction:

A three-phase reaction in which, upon cooling, two solid phases transform to give a third solid phase.

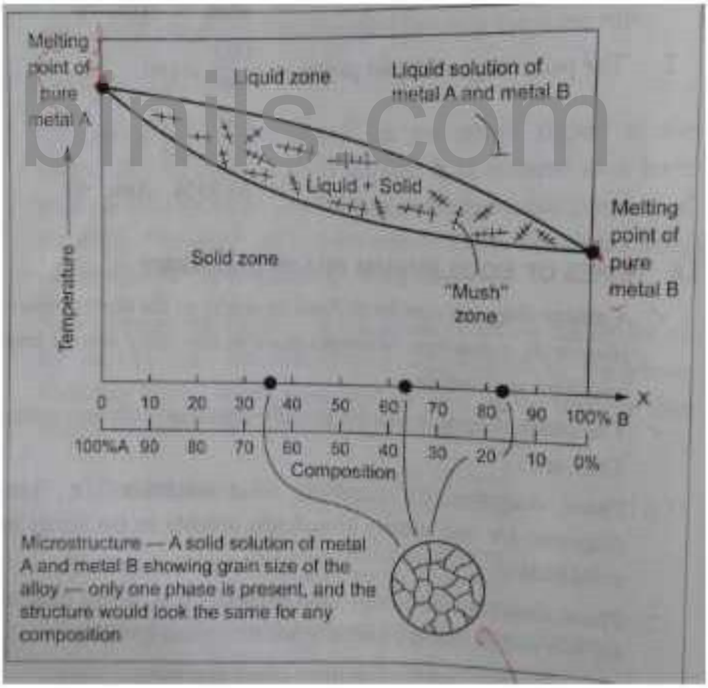
2.**Explain the procedural steps for constructing the binary phase diagram where the components show complete liquid and solid solubility. Draw the labelled diagram and name the system. Give one example for the alloy system showing above mentioned behaviour.**

Phase diagram for completely soluble Metals (Two metals completely soluble in the liquid and solid state)

A mixture of two metals is called **binary alloy**

In some binary alloy system, the two elements are completely soluble in each other in both the liquid and solid states. In these system only a single type of crystal structure exists for all composition of the components, and therefore they are called **isomorphous systems.**

The equilibrium phase diagram for the isomorphous system is given below



Microstructure — A solid solution of metal A and metal B showing grain size of the alloy — only one phase is present, and the structure would look the same for any composition

The common examples of isomorphous system are:

Copper -Nickel (Cu-Ni) system
Antimony- Bismuth (Sb-Bi) system
Gold -Silver (Au-Ag) system
Cromium -Molybdenum (Cr-Mo) system
Tungsten - Molybdenum (W-Mo) system
Copper -Gold (Cu - Au) system

The phase diagram is divided into three separate areas by two phase boundaries namely the liquid and solidus.

Above the liquid there is a uniform liquid solution, while below the solidus, there is a single solid solution. Between the liquids and solidus, both liquid and solid solution coexist.

Unlike pure metals, alloy freeze over a range of temperature and that the region between the liquids and solidus curves represents the temperature interval during which the alloy are in a pasty condition.