

**MECHANICAL ENGINEERING**  
**MATERIAL TECHNOLOGY**  
**SEM-3 MAY,2019**

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**Q. 1] Write notes on any four : - (20)**

**a) Explain thermal fatigue of metal (5)**

**Answer :** Thermal fatigue of metal is

1. Fatigue failure can be produced by fluctuating thermal stresses under conditions where no stresses are produced by mechanical causes.
  2. Thermal stresses result when the change in dimensions of a member as the result of temperature changes.
  3. For the simple case of a bar with fixed end supports, the thermal stresses developed by a temperature change  $\Delta T$  is  
Is  $\sigma = \alpha E \Delta T$   
Where  $\alpha$  = liner thermal coefficient of expansion  
E = elastic modulus
  4. If a failure occurs by one application of thermal stress, the condition is called thermal shock
  5. However, if a failure occurs after repeated application of thermal stress, of a lower magnitude, it is called thermal fatigue.
  6. It exists at high temperature.
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**b) What are smart materials? Where are they used? (5)**

**Answer :** Smart materials are the materials that can significantly alter one or more inherent properties owing to the application of an external stimuli like stress, ph., magnetic field in a controlled fashion. They are classified as:

1. Piezoelectric-changes its voltage upon deformation.
2. Electrostrictive –changes shape upon application of voltage.
3. Magnetostrictive-changes shape upon application of magnetic field.
4. Thermoelectric-changes voltage upon change in temperature.
5. Shape Memory Alloys-changes shape upon change in temperature.
6. Thermochromic-changes colour upon change in temperature.

7. Photochromic-changes colour upon radiation.

**Applications:**

1. To make smart fibre
2. To make aircrafts
3. To make sports equipment
  
4. To make cleaning equipment
5. To reduce vibration in helicopter blades.
6. Used in robotics
7. Used in medical surgeries

**c) Write the difference between ductile and brittle fracture (5)**

**Answer :**

<b>Ductile fracture</b>	<b>Brittle fracture</b>
It involves large plastic failure	It is associated with minimum plastic deformation
It is always preceded by local failure called necking	It doesn't involve necking
Ductile fracture normally occurs in fcc materials	It is observed in bcc and hcp
It occurs through grains	It follows the grain boundaries
It presents a rough dirty surface	A complete brittle fracture shows sharp facets which reflects light
It occurs with slow tearing of metal with expenditure of considerable energy	It occurs suddenly without any warning

**d) Explain Hume-Rothery's rules of solid solubility (5)**

**Answer :** In formation of solid solutions, the solubility limit of solute in the solvent is governed by certain factors.

These factors are known as Hume-Rothery's rules of solid solubility, they are as below:

- 1) Atomic Size Factor - If the atomic size of solute and solvent differ by less than 15%, it is said to have a favourable size factor for solid solution formation. If the atomic size difference exceeds 15%, solid solubility is limited.
- 2) Chemical Affinity Factor - The greater the chemical affinity of two metals, the more restricted is their solid solubility and greater is the tendency of formation of a

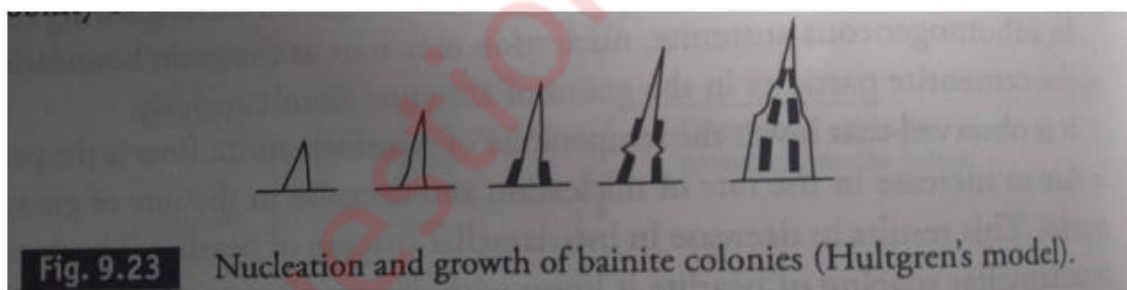
compound, generally wider the separation of elements in periodic table, greater is their chemical affinity.

- 3) **Relative Valency Factor** - A metal of higher valency, can dissolve only a small amount of a lower valency metal while the lower valency metal may have good solubility for the higher valency metal.
- 4) **Crystal Structure Factor** - Metals having same crystal structure will have greater solubility difference in crystal structure limit is the solid solubility.

e) Explain transformation of austenite to bainite (5)

**Answer : Transformation of austenite to bainite**

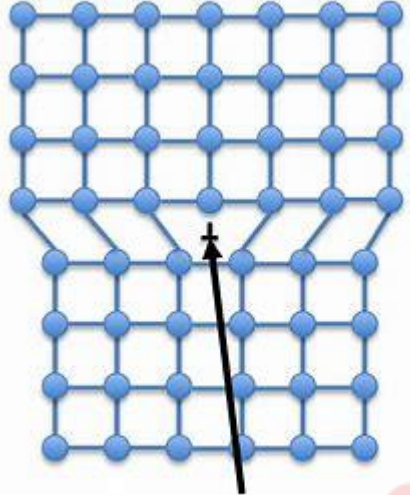
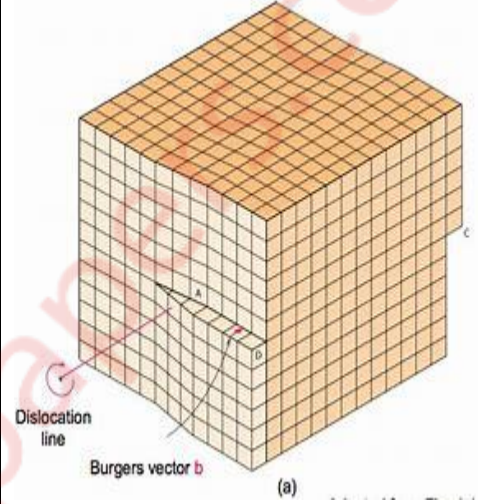
1. The transformation product of austenite at below 550-degree cel is called bainite.
2. It is an extremely fine mixture of ferrite and cementite.
3. Bainitic transformation starts by Nucleation of ferrite/
4. Since this takes place at low temperatures, the rate of nucleation is very high but the growth rate is very low due to relatively less mobility of carbon atoms at low temperatures.
5. This results in a structure with very fine distribution of ferrite and cementite phases and is usually unresolvable by the optical microscope.
6. The bainite formed at higher temperatures is called upper bainite and usually has a feathery appearance, whereas the bainite formed at lower temperatures is called lower bainite and has an acicular (needle like) appearance.



Q.2.] a) What is dislocation? What are the sources of dislocation? Compare edge and screw dislocation. (10)

**Answer : Dislocation** - A part of a line of atoms will be missing from its regular site and this missing row of atoms is called as dislocation.

- ❖ The distortion is centred along a line and hence this line defect is called as dislocation.
- ❖ Movement of dislocation is necessary for plastic deformation. The dislocation is a boundary between the slipped region and the unslipped region and lies in the slip plane.

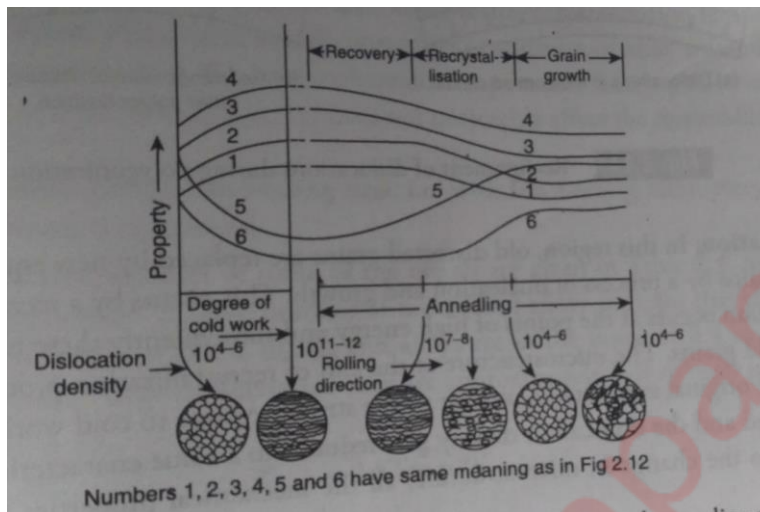
EDGE DISLOCATION	SCREW DISLOCATION
Defect due to the insertion of an extra half plane of atoms	Defect due to shearing of one plane of atom, parallel to another plane
Classified as positive dislocation and negative dislocation	Classified as clockwise and anticlockwise
The lattice above and below the dislocation line is in distorted state	The lattice is distorted along the dislocation line
Burgers vector is normal to the dislocation line	Burgers vector is parallel to the dislocation line
On applying stress dislocation moves parallel to the direction of stress	On applying stress dislocation moves perpendicular to the direction of stress
 <p>Edge dislocation line</p>	 <p>Dislocation line Burgers vector <math>b</math> (a)</p>

b) What is recrystallization annealing? Discuss the various stages of recrystallization annealing. (05)

Answer :

1. In recrystallization annealing, the old distorted grains are replaced by the new equiaxed stress free, strain free grains by a process of nucleation and growth.
2. This occurs by a recrystallization process.
3. Nucleation occurs at the points of high energy and subsequently these nuclei grow at the expense of old grains,
4. The micro structure at the end of recrystallization process is very much similar to the original structure. i.e. similar to the structure prior to the cold work,
5. The grains become equiaxed and the dislocation density gets reduced to a value characteristic of train free metal

6. Internal stresses are reduced almost to the original level with subsequent increase in corrosion resistance, electrical resistance also goes to its original level.
7. Recrystallization does not occur unless the degree of cold work is sufficient and temperature is sufficiently high.
8. The minimum degree of cold work necessary for recrystallization to occur is called the critical degree of cold work. this is of the order of 2- 3% for most of the metals and alloys.



c) difference between hot working and cold working .

(05)

.COLD WORKING	HOT WORKING
Working of metals and alloys below their recrystallization temperature.	Working of metals and alloys above their recrystallization temperature.
Strain hardening occurs during cold working. due to this, tensile strength and hardness rises while the impact strength and ductility decreases.	Strain hardening is removed by recrystallization which occurs at high temperature; hence no property change is observed during hot working .
Microstructure shows distorted grains.	Microstructure shows equiaxed and usually refined grains.
Defect density increases Hence the density of material slightly decreases .	Almost no change in defect densities Hence the density of material remains same.

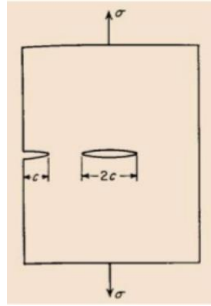
Energy required for plastic deformation is more.	Energy required for plastic deformation is less, because at high temperature, metal becomes soft and ductile.
Surface finish is good .	Surface finish is not so good due to oxidation at high temperatures .
Embrittlement does not occur due to less diffusion and no reaction of oxygen at low temp .	Heavy oxidation occurs during working and pickling is required to remove oxide .
Handling of materials Is easy .	Handling of materials is difficult .
It is easy to control the dimensions within the tolerance limits .	It is difficult to control the dimensions because of the contractions occurring during cooling.

**Q.3.] a) What are the characteristics of brittle fracture? discuss Griffiths theory and derive its equation . (10)**

**Answer: The characteristics of brittle fracture are -**

- When gradual tensile load is applied on material in the tensile test, at the end of the elastic limit, without any prior indication material breaks. This type of fracture is called as brittle fracture.
- There is no change in the diameter of material after fracture and material breaks at the end of the elastic region.
- The characteristics of brittle fracture are:
  1. It occurs when a small crack in a material grows and the movement of crack involves very little plastic deformation of the metal adjacent to the crack. growth continues until fracture occurs.
  2. At the surface of a material, the atoms do not have as many neighbours as those in the interior of a solid and therefore they form fewer bonds, obviously, surface atoms are at a higher energy than a plane of interior atoms. brittle fracture contains in destroying the interatomic bonds by normal stresses/
  3. Brittle fracture in metals is characterized by a rapid rate of crack propagation with a minimum energy of absorption, with no gross deformation and very little micro-deformation.
  4. This does not produce plastic deformation and therefore requires less energy than a ductile fracture.
  5. It occurs along crystal plane with fewer atomic bonds.
  6. It occurs below the elastic limit of a material.
  7. The tendency for brittle fracture increases with decreasing temperature, increasing strain rate and stress concentration.

The Griffith theory states that a crack will propagate when the reduction in potential energy that occurs due to crack growth is greater than or equal to the increase in surface energy due to



the creation of new free surfaces.

Consider an element of thickness  $t$ , subjected to tensile stress  $s$ .

Let  $U_0$  be the strain energy of the material before applying stress.

Let  $U_a$  be the strain energy after application of stress.

Hence total elastic strain energy stored in the material per unit volume

$$= \Delta U$$

$$= U_a - U_0$$

$$= \frac{1}{2} \times \text{stress} \times \text{strain}$$

$$= \frac{1}{2} \times s \times s/E$$

Hence total elastic strain energy  $U_E = \text{volume} \times \text{strain energy per unit volume}$ .

$$= \pi/4 \times (2c)^2 \times t \times \frac{1}{2} \times s \times s/E$$

$$= \pi s^2 c^2 / E$$

Where

$U_E$  = total elastic energy.  $s$  = stress applied,  $E$  = young's modulus.  $t$  = thickness = 1

$C$  = length of the crack.

Along with strain energy, the crack is also subjected to the surface energy

. let  $U_s$  be the total surface energy

$$U_s = 2 \times 2c \times t \times \gamma$$

Where  $\gamma$  = surface energy per unit area of fracture surface

$2c \times t$  = area of surface

$$\text{Hence, } U_s = 4c \gamma.$$

By energy conservation, the total energy change during fracture is sum of elastic strain energy and surface energy

$$\text{Hence, } U_T = \pi s^2 c^2 / E + 4c \gamma.$$

Differentiating, with respect to  $c$ , we get

$$0 = \frac{2\pi s^2 c}{E} + 4\gamma.$$

Hence,  $s =$

$$\sigma = \left( \frac{2E\gamma_s}{\pi c} \right)^{1/2}$$

**B) Discuss ductile -brittle transition in steel.****(05)****Answer : Ductile – brittle transition in steel are**

- The temperature of a material can affect the behaviour when subjected to stress. Many materials which are ductile at high temperatures are brittle at low temperature.
- Steel may behave as a ductile material above 0°C, but below that temperature it becomes brittle.
- The notched bar impact test can be used to determine whether or not a material experiences a ductile to brittle transition as the temperature is decreased. In such a transition at higher temperature, the impact energy is relatively large since fracture is ductile. As the temperature is lowered, the impact energy drops over a narrow temperature range as the fracture becomes more brittle.
- In case of steel, it is brittle up to -100 degree C,
- Its transition takes place, from -100 degrees to 150 degrees. In this period, it exhibits properties of both brittle as well ductile.
- Above 150 degrees, steel becomes purely ductile.

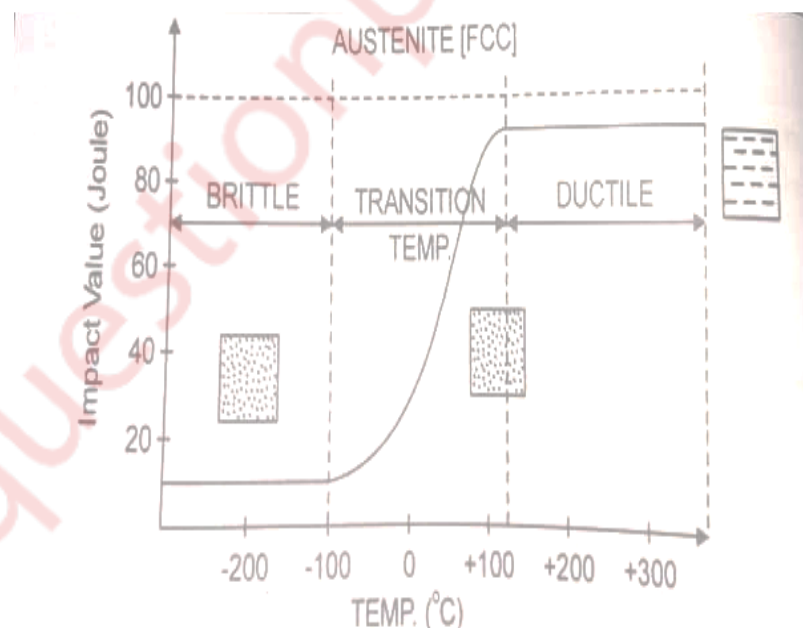


Fig. 2.7: Ductile - Brittle Transition in Steel



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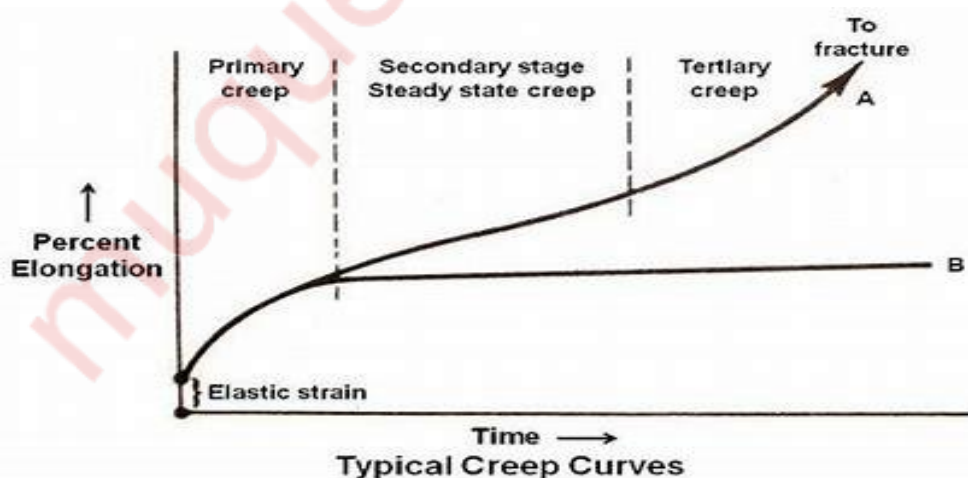
C) Define creep and explain stages of creep. (05)

Answer :

- Creep is slow plastic deformation of metal under constant stress at constant temperature for prolonged period.
- It can be understood by studying the classical creep curve
- It is a plot between the total creep or strain and the time for the entire duration of the test.
- For plotting creep curve of a metal, a constant load is applied to a tensile specimen maintained at a constant temperature and the extension of the specimen is determined as a function of time,

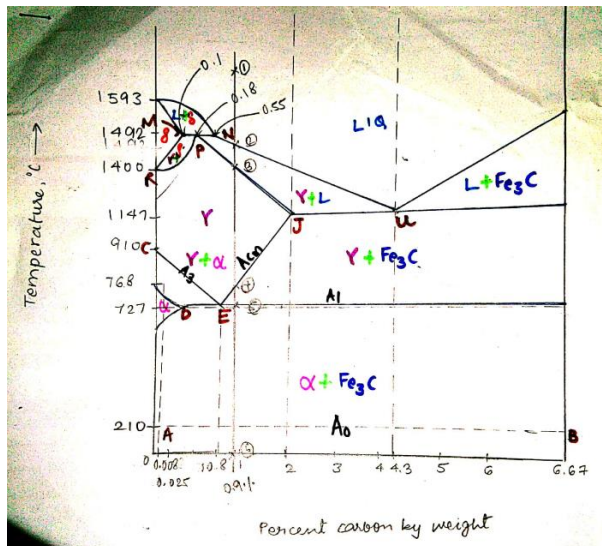
**The three stages of creep are as follows:-**

1. **Primary creep** – The primary or transient creep is a decreasing creep rate because of the work hardening process resulting from deformation.
2. **Secondary creep** – During the secondary or steady state creep (also called as minimum creep rate) the deformation continues at an approximately constant rate. during this process a balance exists between the rate of work hardening and rate of softening because of recovery or recrystallization. The steady state creeps may be essentially viscous or plastic in character, depending upon the stress level and temperature.
3. **Tertiary creep** – If the stress is sufficiently high and the temperature is also high, there is a tertiary stage in which the creep rate accelerates until a fracture occurs. In this stage, there is a void formation and extensive crack formation.



**Q. 4 a) Draw Fe-Fe<sub>3</sub>C diagram indicating all important temperatures, phases and compositions. Explain slow cooling of an alloy containing 0.9% carbon when cooled from 1600 C temperature to room temperature. (10)**

**Answer :**



**The various phases existing in the diagram are as follows-**

**1.  $\alpha$ -Ferrite:**

- an interstitial solid solution of carbon at low temperature.(BCC  $\alpha$ -ferrite)
- Almost a pure iron ,soft and ductile, strongly ferromagnetic upto 768°C.
- becomes paramagnetic at 768°C, due to heating

**2. Austenite ( $\gamma$ ):**

- Interstitial solid soln of carbon in fcc
- dissolves upto 20 % of carbon at 1147°C
- soft,ductile,malleable ,non magnetic .

**3.  $\delta$ -Ferrite: Unlike  $\alpha$ -ferrite ,it is interstitial solid of carbon at high temper, in bcc**

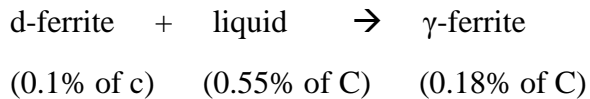
**4. Fe<sub>3</sub>C (cementite) :**

- Intermetallic compound of iron and carbon
- has complex orthorhombic crystal structure with 12 iron atoms and 4 carbon in unit cell.
- Occurs at 6.64 % by weight of carbon.
- Extremely hard and brittle.

### The following transformations take place-

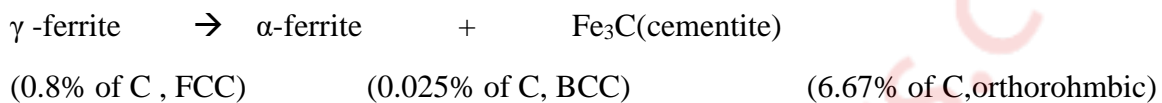
1. Peritectic transformation: At  $1492^{\circ}\text{C}$ ,  $\delta$ -ferrite and liq form austenite at point P.

$$\bullet \quad S1+L=S2$$



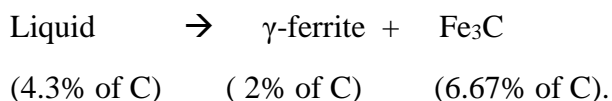
2. Eutectoid transformation: At  $727^{\circ}\text{C}$ , austenite converts into pearlite . ie-  $\alpha$ -ferrite and iron carbide .(at point E)

$$\bullet \quad S1=S2+S3$$



3. Eutectic transformation :At  $1147^{\circ}\text{C}$ , liquid at 4.3 % of carbon transforms into ledeburite i.e austenite and iron carbide .

$$\bullet \quad L= S2+S3.$$



At 0.9 percent carbon,

We get the following points :

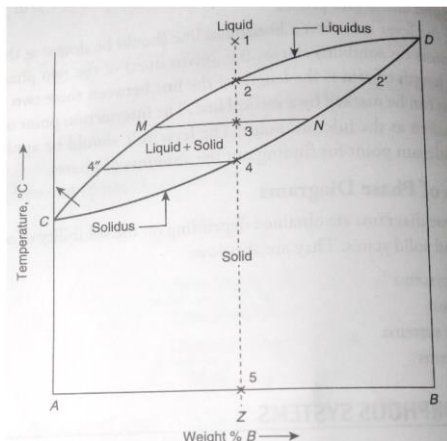
- At point 1: iron is present in pure liquid state .
- At point 2 : just above point 2, iron is in pure liquid state, and just below point 2, it starts separating out as austenite and liquid .  
Hence we get :  $L \rightarrow \gamma\text{-ferrite} + \text{Liquid}$  .
- At point 3: above point 3, most of the  $\gamma$ -ferrite separates out from the liquid. Hence below point 3, we only get  $\gamma$ -ferrite .  
 $\gamma\text{-ferrite} + \text{Liquid} \rightarrow \gamma\text{-ferrite}$  .
- At point 4: above point 4, pure  $\gamma$ -ferrite exists , but below point 4, it starts separating into cementite . we get  
 $\gamma\text{-ferrite} \rightarrow \gamma\text{-ferrite} + \text{Fe}_3\text{C}$ .
- At point 5: above point 5,  $\gamma$ -ferrite and  $\text{Fe}_3\text{C}$  coexist upto  $727^{\circ}\text{C}$ . However below 5, all the  $\gamma$ -ferrite converts into  $\alpha$ -ferrite and this forms pearlite .  
By lever rule ,  
$$\% \gamma\text{-ferrite} = \frac{6.67-0.9}{6.67-0.8} \times 100 = 98.29\%$$
  
$$\% \text{Fe}_3\text{C} = 100 - 98.29 = 1.71\%$$
- At point 6: all of the  $\gamma$ -ferrite converts into  $\alpha$ -ferrite and pearlite is formed.  
By lever rule,

$$\% \alpha\text{-ferrite} = \frac{6.67-0.9}{6.67-0.008} \times 100 = 14.87\%$$

$$\% \text{Fe}_3\text{C} = 100 - 14.87 = 85.31$$

**b) Draw and explain isomorphous phase diagram. (05)**

**Answer :** Isomorphous phase diagrams are of loop type and are obtained for two metals having complete solubility in the liquid state as well as solid state. E.g. Cu-Ni, Au-Ag, Au-Cu, Mo-W, Mo-V, Mo-Ti, W-V, Au-Ni and Bi-Sb.



In the given diagram, c and d are the melting temperatures of metals A and B respectively

Cooling of an alloy with Z% of B:

- From 1-2 the alloy is in the liquid state and no change occurs.
- At just below 2, solidification starts and solid phase starts separating out from the liquid.
- as temperature decreases, the amount of solid increases and this continues up to 4 where last liquid freezes to solid.
- between 2 and 4, the average composition of existing solid is indicated by the solidus line while that of liquid by the liquidus line.
- At the temperature consideration, amounts of solid and liquid can be obtained by applying lever rule.
- For example, at 3, average composition of the existing liquid is given by the point M and that of solid is by point N. the number of phases will be as below:

$$\begin{aligned} \text{Amount of liquid} &= \frac{\text{length on the opposite side of tie line}}{\text{The total length of tie -line}} \\ (\text{Of composition M\%B}) & \\ &= \frac{\text{length } 3N}{\text{Length MN}} \end{aligned}$$

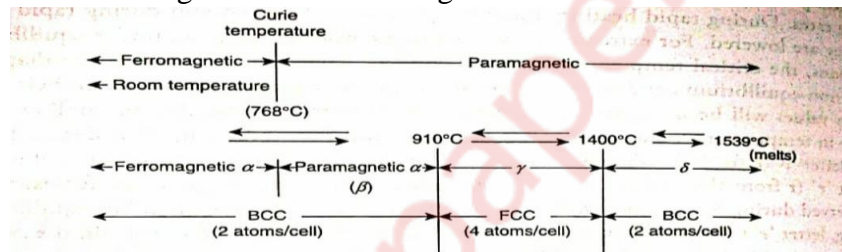
$$\begin{aligned} \text{Amount of solid} &= \frac{\text{length on the opposite side of tie line}}{\text{The total length of tie -line}} \\ (\text{Of composition N\%B}) & \end{aligned}$$

$$= \frac{\text{length M3}}{\text{Length MN}}$$

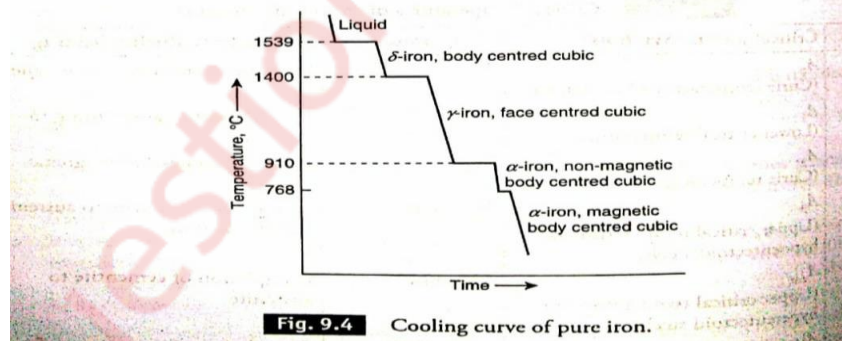
$$= 1\text{-amount of liquid}$$

**C) Write a short note on allotropic forms of iron. (05)**

1. At room temperature, Iron is present in bcc crystal structure, it is ferromagnetic up to its curie's temperature, (768 deg)  
It is called as alpha iron
2. At 768 degree it turns in a paramagnetic substance, retaining its bcc form.
3. At 910 degree, it changes from bcc to fcc.  
It is called as gamma iron.
4. Then again at 1400 it changes from fcc to bcc form.  
It is called as delta iron.
5. Upon further heating it melts at 1539 degree.



(ii) **Cooling curve of pure iron:** The cooling curve of pure iron is shown in Fig. 9.4



**Q.5] Write short notes on following : (20)**

**a) Nano materials:**

- Nano structured materials maybe defined as those materials whose structural element clusters, crystallites or molecules have dimensions in the 1-100nm range.

- Clusters of atoms consisting of typically hundreds of thousands on the nanometre scale are commonly called as the nano clusters.
  - They often have unique optical, electronic, or mechanical properties.
  - Current applications include healthcare, electronics, cosmetics, textiles, information technology and environmental protection.
  - Carbon based nano materials including fullerenes a nanotube plays an increasingly pervasive role in nanoscale science and technology
  - Fullerenes are a type of nano material, whose lattice is in the form of continuous blocks, they resemble football, each carbon atom is linked with two and three atoms.
  - Graphite is another type of nano material. It is formed by flat hexagonal layers of carbon atoms separated at 3.35 Å.
  - It has got high strength, good chemical stability at elevated temperatures, and in oxidizing atmosphere, high thermal conductivity, low coefficient of thermal expansion, good machinability.
  - Nanobuds are a newly discovered material, combining nanotubes and fullerenes. They have same mechanical properties and electrical conductivity of nanotubes, but higher reactivity of fullerene molecules.
  - Nanofibers consist of graphite sheet completely arranged in various orientations .these structures have a presence of plenty of sites which in turn readiness accessible to chemical or physical interaction especially adsorption.
  - Fullerenes and carbon nano tubes can be seen in pieces of graphite.
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#### b) **Nitriding:**

- Nitriding is done by heating the steel in contact with a source of atomic nitrogen at a temperature of about 550-degree C
- The atomic nitrogen diffuses into the steel and combines with iron and certain alloying elements present in the steel and forms respective nitrides.
- This layer does not get etched with most of the common etching reagents used in the microscopic examination of steels and hence appears white under the microscope.
- White layer is extremely hard and brittle and tends to crack or chip in service and hence it is not desirable.
- Plain carbon steels produce only white layer and therefore are not suitable for nitriding.
- In presence of alloying elements such as Al, Cr, Mo, V, W, Mn and Ti in solid solution, respective nitrides are formed, which are hard and tough and hence do not crack or chip.
- These nitrides increase the hardness and wear resistance of steels.
- Molecular nitrogen does not diffuse into the steel and hence is completely ineffective as a nitriding medium.

- The atomic nitrogen source can be a molten salt bath containing NaCN similar to that used liquid carburizing without the addition of alkaline earth salts or dissociated ammonia and accordingly the process is called liquid nitriding or gas nitriding.
  - During nitriding of alloy steels, first a white layer is formed on the surface from which nitrogen diffuses deeper into the steel and selectively precipitates the alloy nitrides.
- 

**c) What are composites, state their characteristics.**

**Answer :**

- ❖ Composites are combination of 2 or more different materials with significantly different physical or chemical properties which separate and distinct at macroscopic or microscopic scale.
- ❖ The continuous phase in a composite is called matrix, while the distributed phase is called as dispersed phase.
- ❖ Composites are classified as particle reinforced, fibre reinforced and structural composites, based on the type of dispersed phase present in the composite mixture.
- ❖ Based on the matrix, they are classified as ceramic matrix, polymer matrix and metallic matrix composites.

**The characteristics of composites are as follows-**

1. they are superior in strength.
  2. they have high resistance to heat.
  3. They are higher stiffness.
  4. they have higher fatigue strength
  5. Their principle of manufacture is borrowed from nature.
  6. The base or matrix of composites maybe metals or alloys.
- 

**d) State the Effect of retained austenite**

**Answer:** The retained austenite in steel has some advantages as below:

1. austenite reduces the tendency of cracking during hardening and hence about 10% retained austenite is desirable for this purpose.
2. if the amount of retained austenite is more such as 30-40%, the steel can be cold worked to some extent without cracking which would not have been possible in the absence of retained austenite.

However, retained austenite is not desirable in the finished components due to following:

1. Austenite is a soft phase and hence the presence of retained austenite reduces the hardness of hardened steels

2. Small amount of retained austenite does not decrease the hardness much but it may increase the brittleness of steel. This is due to the fact that it is likely to get transformed to martensite by plastic deformation. this deformation (strain) induced transformation of austenite to martensite increases the internal stresses deteriorating the properties of steel.
3. The retained austenite may get slowly transformed to bainite at room temperature. this is accompanied by volume expansion resulting in linear expansion of about 0.0001cm/cm, for every 0.3% retained austenite by volume and is sufficient to create trouble in some applications like precision gauges and test blocks
4. Retained austenite is not at all desirable in some applications like tool steels for which the best possible combination of strength, hardness, toughness and dimensional stability is essential.

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**d) What are Stainless steels? give a brief of classification of stainless steels**

**Answer:**

- These steels have high corrosion resistance and hence they do not corrode in most of the usual environmental conditions. Due to this they are called as stainless steels.
- The high corrosion resistance is due to the presence of chromium in these steels, when they are exposed to oxidizing environment, chromium gets rapidly oxidized and forms a thin film of hydrous chromium oxide. this film of chromium is passive, self -healing in character and impervious to further attack.
- Corrosion and scale resistant steels are classified into four types of groups as below:
  - 1) **Group A-**
    - this group includes plain Fe-Cr alloys and the amount of Cr in the solid solution form is less than 13%.
    - they are hard, wear resistant and magnetic in character
    - are used for springs, ball bearings, valves, razors, and razor blades, surgical instruments, cutting tools, cutlery items, etc
  - 2) **Group B-**
    - these steels are also plain Fe-Cr alloys but the amount of Cr in the solid solution form exceeds 13%
    - they are soft, ductile, malleable and magnetic in character.
    - they contain chromium from 13% to 27% and carbon less than 0.2%
    - they are widely used in chemical and food industries, pressure vessels, furnace parts, heaters, heat exchangers, juice carrying pipes in sugar industries, architectural and automotive trim, restaurant equipment, pots and pans
  - 3) **Group C –**
    - these includes alloys which contain at least 24% of the total Cr, Ni and Mn, the amount of Cr in these alloys is at least 18% with carbon content between 0.03 and 0.25 %.



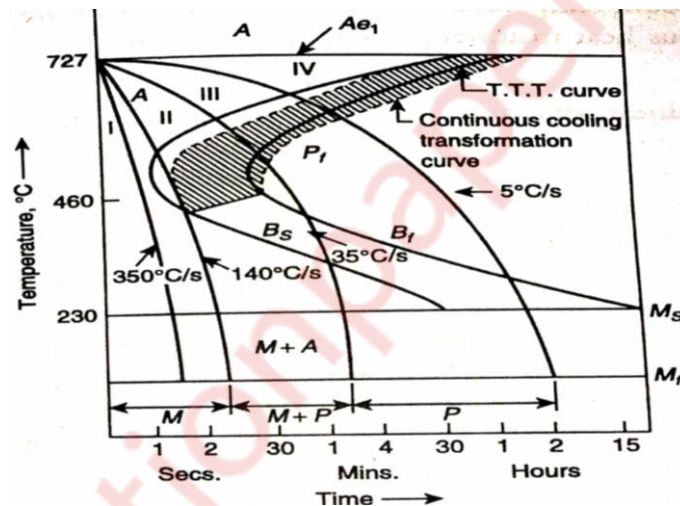
- they are soft, ductile, malleable and nonmagnetic in character.
- they are used for engine manifolds, food and chemical plants, tubular exchangers, utensils, wrist watches, sanitary fittings, etc.

#### 4) Precipitation hardenable stainless steels-

- they contain elements such as Mo, Cb, Ti, Al, Cu, N in addition to the basic elements Cr and Ni.
- higher strength is developed due to precipitation of certain compounds and they maintain high strength up to a temperature of 550 degrees,
- they are used in aircraft and missile industries for skins, ribs, bulk heads and for other structural components.

**Q.6] A) Draw TTT curve for a eutectoid steel and explain the effects of various cooling curves on transformation products (10)**

Answer



#### 1. Cooling Curve -1 (Coarse Pearlite)

- This curve is obtained by a very slow cooling rate in the conventional annealing process.
- The transformation product of this cooling curve will be coarse pearlite.
- In the diagram when cooling of unstable austenite will be carried out between 675 degree to 727 degree.
- Isothermally, it will transform into coarse pearlite.
- The same transformation can be carried out by continuous cooling curve, when unstable austenite will be cooled by! degree per second cooling rate.
- The transformation will start when the transformation product crosses starting TTT and finishes it crosses finishing TTT and CCT curve.
- After transformation, the rate of cooling will have no effect on the microstructure properties.

## **2. Cooling Curve 2 – (Medium Pearlite)**

- The cooling curve is obtained by isothermal or cycle annealing process.
- The transformation product of this cooling curve is medium pearlite.
- The transformation occurs when material cooled between 600 to 675 degree. at a constant temperature in TTT diagram and 3 degrees /sec CCT diagram,
- Microstructure shows uniform cementite in the matrix of Alpha -ferrite

## **3. Cooling Curve 3 – (Fine Pearlite)**

- This cooling curve is obtained by the normalising process
- The transformation product is fine pearlite.
- The transformation occurs when the material will be cooled between 500-600 degrees at a constant temperature in TTT diagram and 5 degrees/sec in CCT diagram.
- The microstructure of fine particles shows fine particles of cementite in the matrix of alpha ferrite.

## **4. Cooling Curve 4- (Upper Bainite)**

- This cooling curve is obtained by cooling material rapidly enough to miss the nose of the TTT curve and then at a constant temperature for transformation.
- The constant temperature is maintained just below the nose of TTT curve,
- The transformation product of this curve is upper bainite.
- Bainite is a fine pearlite and contains very fine distribution of ferrite and cementite phase
- Upper bainite has a feathery appearance under the optical microscope.

## **5. Cooling Curve 5 – (Lower Bainite)**

- This cooling curve is obtained by cooling material rapidly enough to miss the nose of TTT curve just above 210-degree temperature ( $M_s$ ).
- Hold it at a constant temperature for transformation.
- The transformation product is lower bainite.
- It is observed under an optical microscope as an acicular appearance.
- The hardness of lower bainite is between 50-60 Rc.
- It is not observed in TTT diagram

## **6. Cooling Curve 6-Critical Cooling Rate:**

- This curve is tangent to the nose of TTT and CCT curve.
- It is the slowest cooling rate at which austenite can be transformed into martensite.
- It is 140 deg/sec for eutectoid steel.

## **7. Cooling Curve 7- (Martensite)**

- This curve is obtained by very fast cooling rate of 350 deg/sec.
- The transformation product of this curve is martensite.
- It gives maximum hardness in the plain carbon steel which is 64 Rc

- This curve is obtained by rapid quenching enough to avoid transformation in the nose region.

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**b) Write classification of tool steels**

**(05)**

**Answer :** Tool steels are specially used for working, shaping and cutting of metals. Large number of steels are available for this purpose. They are classified and designated according to American iron and steel institute (AISI) as below-

1. Cold work tool steels
2. Hot work tool steels
3. High speed tool steels
4. Special purpose tool steels

**1. Cold Work Tool Steel :** resistance at low temperatures. Some of the steels from this group contain very little or no alloying elements and hence are less expensive. depending on their hardness they are classified as

- A) Water hardening steels:** they are plain carbon steels with high carbon content (0.6 to 1.4%)  
They are used for maintenance of sharp cutting edges and high wear resistance. since they have poor hardenability; they are hardened by water quenching hence the name water hardening steels.
- B) Oil hardening steels:** these contain small number of alloying elements such as W, Mn, Cr, Mo and V. due to this their hardenability is better than the water hardening tool steels and hence they can be hardened by oil quenching. they are used for blanking and forming dies, shear blades, master tools, etc.
- C) Air hardening steels:** these steels have high hardenability due to the addition of various alloying elements such as Mn, Cr, Mo, W in sufficient amount the total content of alloying elements exceed 5%.
- D) High carbon high chromium steels :**they contain carbon above 1.5 % and some of the grades contain carbon even more than 2% with chromium about 12% and other elements in small amount , they are used for drawing dies, blanking dies, forming dies ,coining dies, thread rolling dies, trimming dies, bushings ,shear blades, punches ,etc

**2. Hot Work Tool Steels :** These steels are mainly used for hot working of metals such as for stamping, drawing, forming, piercing, extruding, upsetting and swaging. they have good strength and toughness, hardness and wear resistance at elevated temperatures. they are of low to high alloy content with relatively less carbon (0.35 -0.65%) and are classified into three types depending upon the principal alloying element. these are chromium type, tungsten type, molybdenum type hot work tool steels.

**3. High Speed Tool Steels:** These steels maintain high hardness up to a temperature of 550 degree and hence can be used for cutting of metals at high speeds. they also have high wear resistance and cutting ability.

They are divided into two types, depending upon the principal alloying element

1. **Tungsten high speed steels or t -series** – they contain high amount of tungsten with very other elements like Cr, V, Co.
2. **Molybdenum steels or m- series** – a part of tungsten from the group of w-high speed steels is substituted by molybdenum. Hence this steel contains W, Cr, V, Co, Mo. this substitution results in lowering the cost of steel.

**4.Special Purpose Tool Steels :** Remaining tool steels are grouped together under the heading special purpose tool steels.

- 1.**shock resisting tool steels (s-series)**-contain less carbon (~0.5%) for better shock resistance,
- 2.**low alloy tool steels(L-series)**-principal alloy is chromium, used where high wear resistance and toughness are required.
- 3.**carbon-tungsten tool steels (F -series)**-contains high carbon (>1.0%) and tungsten as the alloying element.
4. **mould steels (P-series)**-used for plastic moulding, have high surface hardness.

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c) Explain Induction hardening process.

(05)

Answer :

- Here heating is done within thin layer of surface metal by using high frequency induced currents.
- The component is heated by means of an inductor coil, which consists of one or several turns of water -cooled copper tube.
- High frequency alternating currents flowing through the inductor generate alternating magnetic field. this electromagnetic field induces eddy currents of the same frequency in the surface layers which rapidly heat the surface of the component
- Within a short period of 2-5 minutes the temperature of the surface layer comes to above the upper critical temperature of that steel.
- the high frequency induced currents chiefly flow through the surface layer –skin effect.
- the layer through which these currents flow is inversely proportional to the square root of frequency of induced currents and hence the depth of hardened layer can be controlled by controlling the frequency of supply voltage.
- the usual range of frequency is from 1000 Hz to 100000 Hz and the hardened depths obtained are from 0.5 to 6mm

- after the necessary temperature is obtained. the component is quenched by water spray usually without removing the inductor coil.
  - due to very fast heating and no holding time. The austenitic grain size is very fine which results in fine grained martensite.
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