Material technology

Q.1.a) Define composite and discuss its classification. [5]

Ans

1. Composites are combinations of two or more different materials with significantly different physical or chemical properties which remain separate and distinct at the macroscopic or microscopic scale within the finished structure.
2. Each of the various components retains its identity in the composite and maintains its characteristics structure and properties.
3. Composite materials are generally possessing stiffness, strength, high temperature performance, corrosion resistance, hardness, and conductivity.
4. Analysis of these properties shows that they depend on properties of individual components, the shape, size and distribution of discontinuous components, the orientation of components and the degree of bonding between components.

Classification :

1. According to the particle reinforced
- Large particle
- Dispersion strengthened
2. According to fibre reinforced
- Continuous (aligned)
- Discontinuous (short)
3. According to structural
- Laminates
- Sandwich panels

Q 1] b] Discuss the differences and similarities between slip and twinning. [5]

Ans :

Sr.no	Slip	Twinning
1.	Stress required to produce slip is less.	Stress required to produce swimming is more.

2.	The direction of share can be either positive or negative.	Direction of shear is limited to that which produces its twin image.
3.	It consists of a shear displacement of an entire block.	It consists of each plane of atoms moves a definite distance.
4.	In this process the atomic movements are over large distances.	In this process the atomic movements are over a fraction of atomic spacing.
5.	It occurs on widely spaced planes.	It occurs on every atomic plane involved in the deformation within the twin region of the crystal.
6.	Sleep is more common in B.C.C and F.C.C. metals.	Twinning is more common in H.C.P. metals
7.	Slip lines are observed only after plastic deformation.	Twin lines are observed after mechanical working and annealing
8.	The slip portion has some orientation of atoms as that of original portion.	That twinned portion shows mirror image of the untwined portion.

Q.1] C] Why FCC metals are in general more ductile them BCC and HCP metals.   [5]

Ans :

1) FCC has a higher packing efficiency and the slip planes are more closely packed than BCC.
2) Infact BCC has more slip systems than FCC. But they are not as closely packed as FCC. For plastic deformation, we need at least 5 independent slip systems.
3) A face-centred cubic crystal structure will exhibit **more ductility** (deform **more** readily under load before breaking) than a body-centred cubic structure
4) Both FCC and BCC have those. But the previously mentioned factor makes FCC more ductile than BCC.

Q.1] D] What are MR fluids? Where are they used?   [5]

Ans :

1) A **magnetorheological fluid** (**MR fluid**) is a type of smart fluid in a carrier fluid, usually a type of oil. When subjected to magnetic field the fluid greatly increases its viscosity to the point of becoming a viscoelastic solid.
2) Importantly, the yield stress of the fluid when in its active state can be controlled very accurately by varying the magnetic field intensity.

3) The upshot is that the fluid's ability to transmit force can be controlled with an electromagnet which gives rise to its many possible control-based applications.

Q.1]E] What are limitations of plain Carbon steel? Explain the alloying effect on phase transformations [5]

Ans :

Limitations of plain carbon steels

1) Low hardenability
2) Low corrosion and oxidation resistance
3) Low strength at elevated temperature
4) During rapid quenching of fully martensitic structure distortion and cracking also occur.

Alloying effect on phase transformation

1) An alloy element is added to steel; it can influence several properties. The extent of effect on a given property depends on the type of element, its amount and the subsequent heat treatment given to steel.
2) In alloys based on Ti or Zr, very important effect of an alloying element pertains to the manner in which its addition, field effect the allotropic α phase to β phase transformation temperature.
3) Some element stabilizes the α phase and the other phase by raising this temperature.
4) Elements stabilize the be phase by lowering the temperature. Element which are dissolved in Ti or Zr causes the transformation temperature to increase or bring about little change in temperature is known as α- stabilizers.
5) These elements are generally non transition metals or interstitial elements (like C,N and O), element which alloys with Ti or Zr, brings down the transformation temperature at β **stabilizers**.
6) These elements are alloys transition metals and the noble metals with unfilled or just field electron bands among the interstitial elements.

Q.2]1] Define critical cooling rate. Describe various cooling curve on TTT diagram. How search curves are drawn? What factors affect critical cooling rate? [10]

Ans : Critical cooling rate : Is defined as the lowest cooling rate which produces 100% martensite with minimum internal stresses and distortion.

1) **T (time), T (temperature), T (transformation**) diagram is a plot of temperature versus the logarithm of a time for a steel alloy of definite composition. it is used to determine when transformation begin and end for a constant temperature heat treatment of a previously austenitized alloy.
2) When austenite is cooled slowly to a temperature below lower critical temperature, the metal structure which is obtained at room temperature is ferrite, Pearlite etc. The microstructure of a

metal is significantly altered as the cooling rate increases, we get martensite phase at room temperature.

3) TTT diagram indicates when a specific transformation starts and ends and it also shows what percentage of transformation of austenite at a particular temperature is achieved.
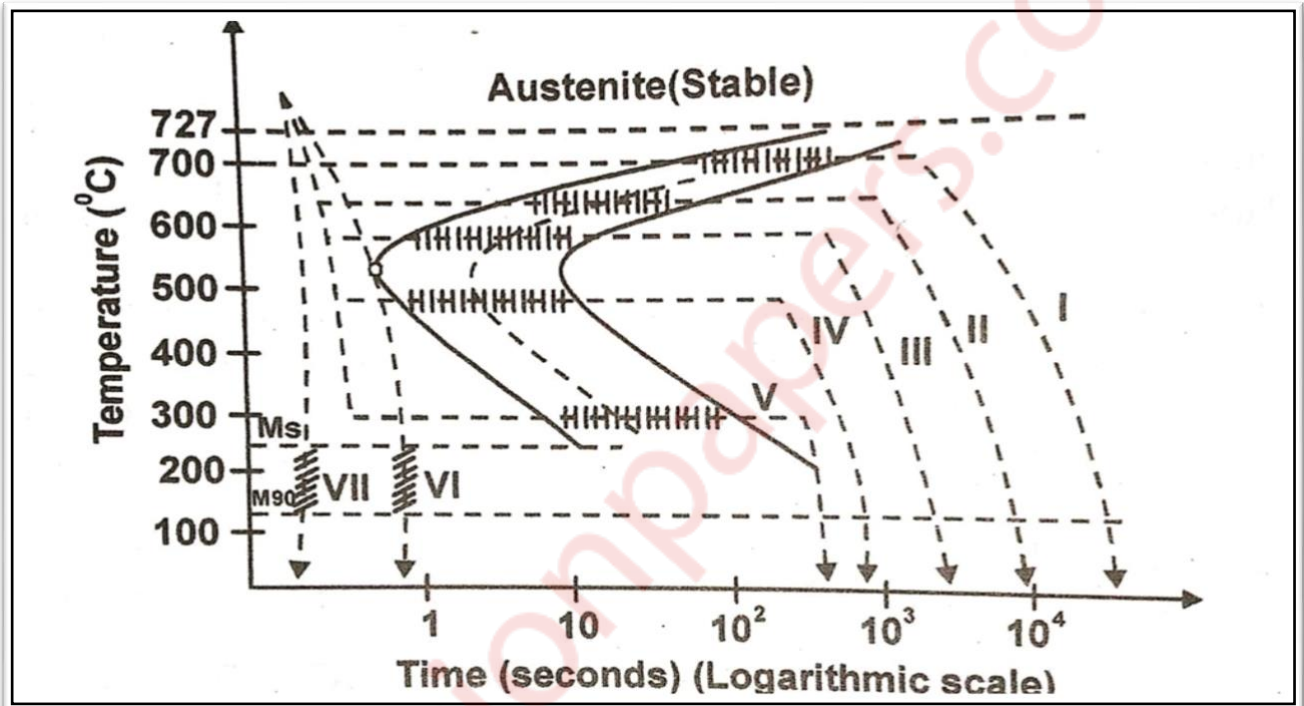
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Fig 1

How search curves are drawn

1) TTT curves are also known as s curve or C curve isothermal transformation diagram this diagram also involve non equilibrium rates of cooling. At very high rates of cooling or quenching, a metastable phase called martensite is formed in steels.

2) TTT diagram is the main source of information for the decomposition of austenite under non equilibrium conditions.

3) As shown in the figure the area on the left of the transformation curve represents the austenite region.

4) Left curve indicates the start of transformation and right curve represents the finish of a transformation. The area between the two curve indicates the transformation of austenite to different types of crystals. As shown in the figure the cooling rate a and b which indicate to rapid cooling process.

5) In this case curve will cause a higher distortion and higher internal stresses then the cooling rate B.
6) The end product of both the cooling rates will be martensite. Cooling rate b is also known as critical cooling rate, which is represented by cooling curve that is tangent to the nose of TTT diagram.

Factors affecting the cooling rate

1) Austenite is stable at temperature 723° Celsius, below this austenite is unstable.
2) Any cooling rate lower than CCR will forms of transformation products such as Pearlite or Bainite, but any cooling rate equal to what faster than CCR will form only martensite.

Q.2] 2] What is strain hardening? Explain the phenomenon on the basis of dislocation theory. Also discuss the role of Frank reed source in strain hardening.   [10]

Ans : Definition

1) Ductile material increase in strength and hardness when plastically deformed at temperature lower than the recrystallization temperature. This is called as work hardening or **strain hardening**.
2) In Elastic limit a small plastic deformation results in a relatively large increase in strain hardening.
3) The rate of strain hardening decreases rapidly beyond elastic limit and becomes a constant value until fracture occurs.
4) strain hardening process is of great significance in many metal formation and fabrication operations in industries. As a result, working electrical conductivity may be decreased and rate of chemical action increased.
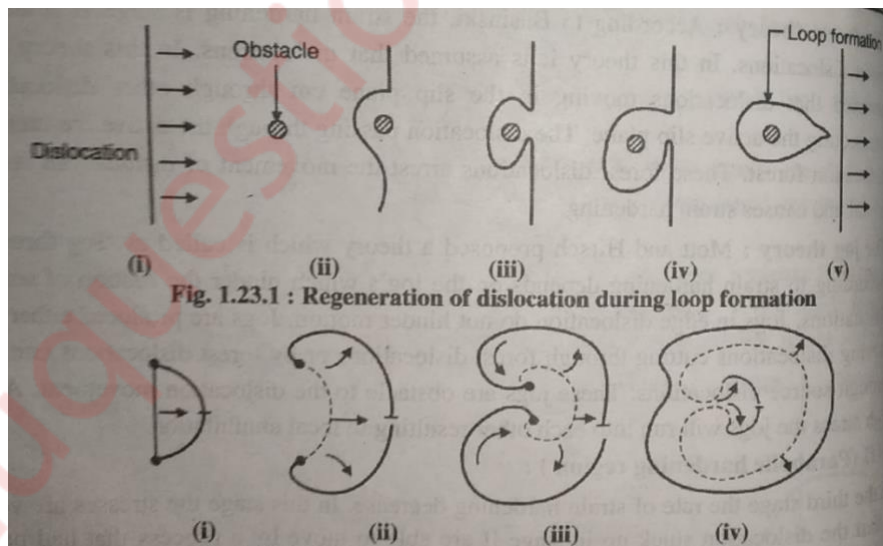

Fig. 1.23.1 : Regeneration of dislocation during loop formation

Fig 1 Disslocation regeneration by frank-Reed source

Dislocation theory of strain hardening

Work hardening can also be explained on the basis of dislocation theory, because slip occurs by the motion of dislocation.

- Dislocation is a linear defect observed in the crystal structure. Misalignment of atomic plane causes dislocation. The presence of an extra atomic plane or absence of an atomic plane results in the formation of dislocation.
- During plastic deformation, dislocation movement is observed. As a dislocation moves, the density increases. Is moving this location comes across any obstacle inclusion and impurities movement is restricted requiring more stress for their movement.
- Figure shows the dislocation forward by living a loop around the obstacle. If the dislocation is anchored at both the ends, it cannot easily bypass the obstacle.
- In this case, the dislocations under the applied stress. The dislocation gets served as shown in the figure in 3 steps i, ii and iii. Find the step iv, the curved dislocation forms a loop that travels outwards to the grain boundary.
- As the loop disappears the original dislocation is again created. The cycle repeats and dislocation density increases. This is known as Frank reed source.

Q.3]1] What is fatigue of metals? Explain the method of testing the metals for fatigue. Draw and discuss the S-N diagram. [10]

Ans : Fatigue

- With frequent stress fluctuations, the material may fail at stress level far below its static ultimate tensile strength is called as 'Fatigue Failure'.
- Fatigue failure in material occurs when it is subjected to repeated loading and vibrations. It is generally observed that these failures occur only after a considerable period of service.
- Fatigue failure occurs in aircraft, compressors, pumps, turbines, etc., subject to repeated loading and vibration.
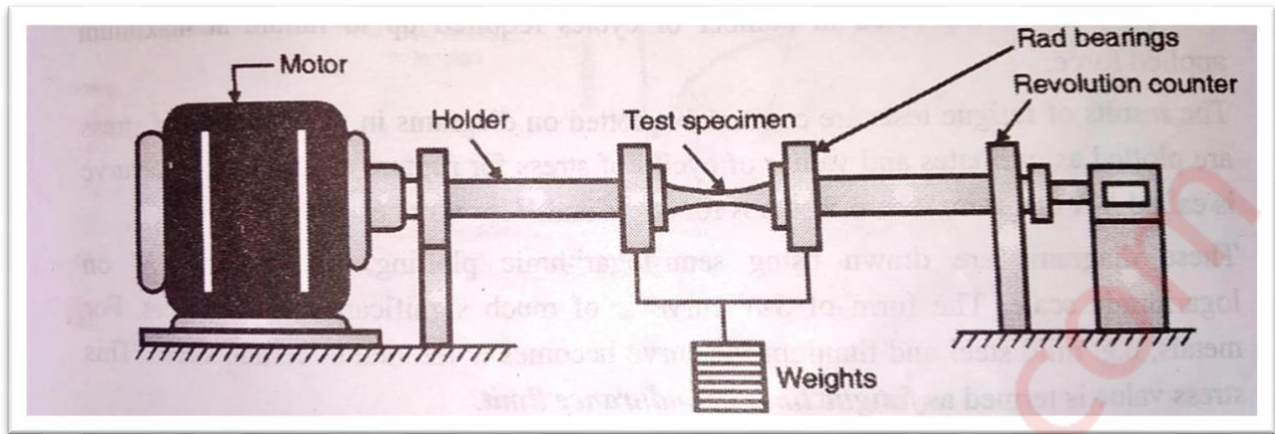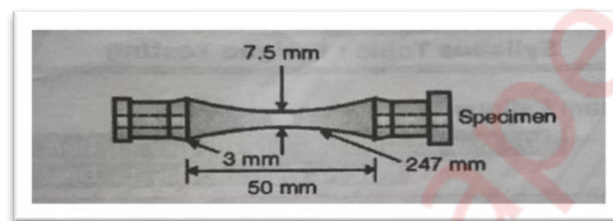
fig 1 rotating beam fatigue test machine

Fig 2 fatigue test specimen in bent state

Fatigue testing :

The fatigue testing can be conducted using rotating beam fatigue testing machine as shown in figure as following:

- The fatigue specimen is gripped on to a motor at one end to provide the rotational motion whereas the other end is attached to a bearing and also subjected to a load or stress.
- When the specimen is rotated about the longitudinal axis, the upper and the lower parts of the specimen gauge length are subjected to tensile and compressive stresses respectively. The test proceeds until specimen failure take place.
- The revolution counter is used to obtain the number of cycles to failures corresponding to the stress applied. When specimen breaks then the counter automatically disengages.
- Increasing weight applied to the fatigue specimen results in a reduction in a number of cycles to failure. We can use the experimental results to construct an S-N curve.
- The fatigue test is normally conducted using at least 8-12 specimens in order to provide sufficient information for the interpretation of fatigue behaviour of the tested material.
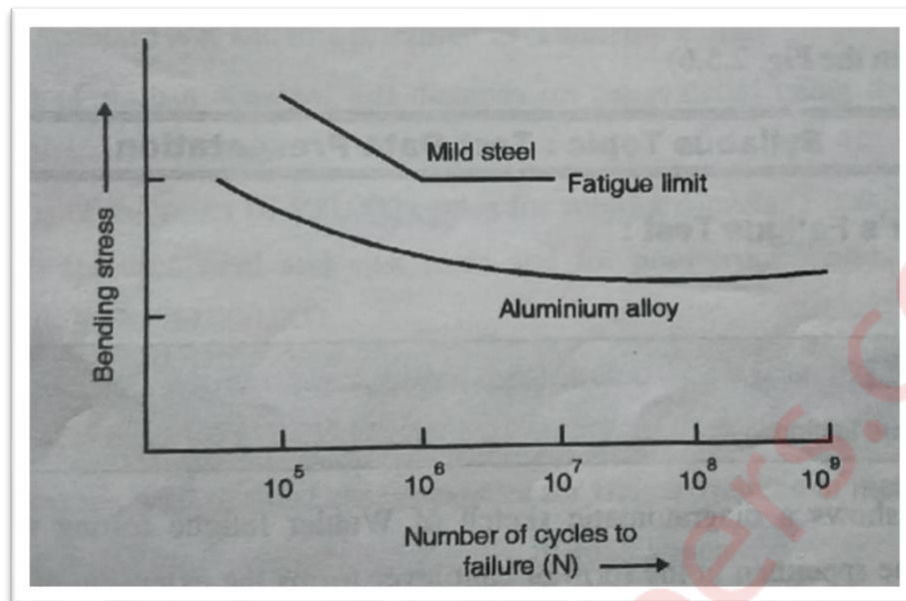
Fig 3 S-N diagram

S-N curves and interpretation :

- The other specimens of the metal art tested relatively at lower stress than the previous one. With the decrease in stress value, the life of specimen increased.
- The number of repetition required to produce rupture, i.e., fracture increases as the stress decreases. Specimen with the stress below the endurance limit will not rupture. The life of the specimen is expressed in the number of cycles required up to failure at maximum applied force.
- The results of fatigue test are commonly plotted on diagram in which values of stress are plotted is coordinates and the values of cycles of stress for rupture as abscissa. The curve is called as S-N diagram where S -stands for stress and N for number of cycles.
- Which diagram are drawn using semi logarithmic plotting, plotting N on logarithmic scale. The form of S-N curve is of much significance to engineers. For metals e.g. mild steel and Titanium the curve becomes horizontal at certain stress. Distress value is termed as fatigue limit.
- Below the stress value the specimen does not fail or fracture example. the material will not fail even after infinite number of stress cycles.
- Obviously this shows that if the material is loaded to a stress below the fatigue limit it will not fail no matter how many time the stress is applied.
- For all ferrous metals tested and for most non-ferrous metals these S-N diagrams become almost horizontal for values of N ranging from 1- 10^6 to 5- 10^7 cycles thirst indicating a well-defined endurance limit.
- We must know that the number of cycle is arbitrarily taken

Q.3]2] Define creep. Draw the creep curve explain stages of creep. Discuss the development of creep resistance materials. **[10]**

Ans : Definition

1. It is essential as low rise of plastic deformation under the action of stresses below the yield strength of material.
2. Artificial curve of deformation versus loading time is shown
3. A Creep curve usually consists of three portions corresponding to particular stages of creep.
4. The first stage is the stage of what is called unstable, transient creep (also called initial or primary creep)
5. It features gradual decrease of the deformation rate to define and constant value.
6. The second stage is the stage of study state or secondary creep and is characterized by a constant deformation rate.
7. At the third stage (tertiary accelerated creep) the deformation rate increases up to the failure.
8. The third stage is as a rule short and should be avoided since quick failure of part is inevitable at this stage
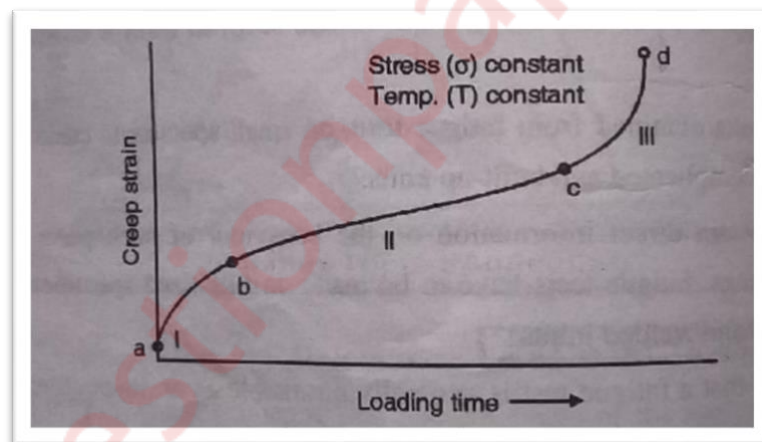

Fig 1 Creep curve at constant temperature and stress

Stages of creep

a) Primary creep
b) Secondary creep
c) Tertiary creep

Primary creep :

- This stage is mainly due to dislocation movement.
- The creep rate decreases with time and effect of work hardening is more than that of recovery process.

Secondary creep :

- The rates of work hardening and recovery during the stage are equal, so the material creeps at a steady rate.
- Depending upon the state level and temperature study creep maybe essentially viscous or plastic in character.
- Structural observation reveals that Pologonization is an important recovery process during secondary creep.

Tertiary creep :

- Creep rate increases with time until fracture occurs in which stage. Tertiary creep can occur due to necking of the specimen or a grain boundary sliding at high temperatures and this continues until specimen fracture.
- Development of each stage of creep depend on the temperature and stress. For the same stress an increase of temperature shortens the time of the second stage an accelerates failure.
- The phenomenon of creep is observable in metals, iconic and covalent crystals, the amorphous material such as glasses and polymers.
- In polymers, the phenomenon of creep is important at room temperature, in alloys at 100° C and in steel above 300° C
- Metals generally exhibit creep at high temperature where as plastics rubber and similar amorphous materials are very temperature sensitive to creep.
- A material is subjected to a constant tensile load at an elevated temperature will creep and undergo a time dependent deformation.

Creep resisting material

- At elevated temperatures materials used for machine parts and structural components must be creep resistant. Materials used for turbine blades must be creep resistance, i.e. they should not be formed by creep during service.
- Creep can be result in seizing the blades with turbine casing. The materials to be used at high temperature must have high melting point.
- The creep becomes significant at temperatures greater than 0.4 Tm. Refractory oxides, e.g. MgO and Al_2LO_3 have high melting point and as such are most suitable for use at high temperature. where only compressive stresses are encounter rate their brittleness limits their use two applications.
- The discovery of tougher ceramics e.g. Si_3N_4 (silicon nitride) indicate that selected parts of a heat engine piston rings and cylinder heads can be produced from ceramic materials. Under more versatile conditions metals and alloys can be used.
- Most creep resistant alloys consist of a base metal of a fairly high melting point. In aircraft industry aluminium alloys are mostly used. Aluminium alloy containing 4% copper, 2% nickel and 1.5% magnesium is quite useful group of creep – resisting light alloys called as Y– alloys.

- To develop creep resistance alloys there should be:
  1) Increased resistance of grains and grain boundaries to floor and
  2) Minimum softening of recovery effects.
- For better Mechanical properties in low temperature application, where is not important, a fine grained material is desirable. However, for high temperature applications find green materials are to be avoided as green boundary sliding can be adding to creep deformation.
- We must know that grain boundary sliding is not a problem in a single crystal as there are no grain boundaries in a single crystal. a less expensive way of minimising grain boundary sliding is to orient the grains in such a way that the boundary sliding does not result in cavities at grain junctions. The cavities, if present, can coalesce together and cause creep fracture.
- It has been observed that creep will not occur to any measurable extent below a certain temperature and the temperature is different for different materials as mentioned below

Q.4]1] Draw Fe-Fe₃C Diagram and label the temperature composition and phases. **[10]**

Ans :
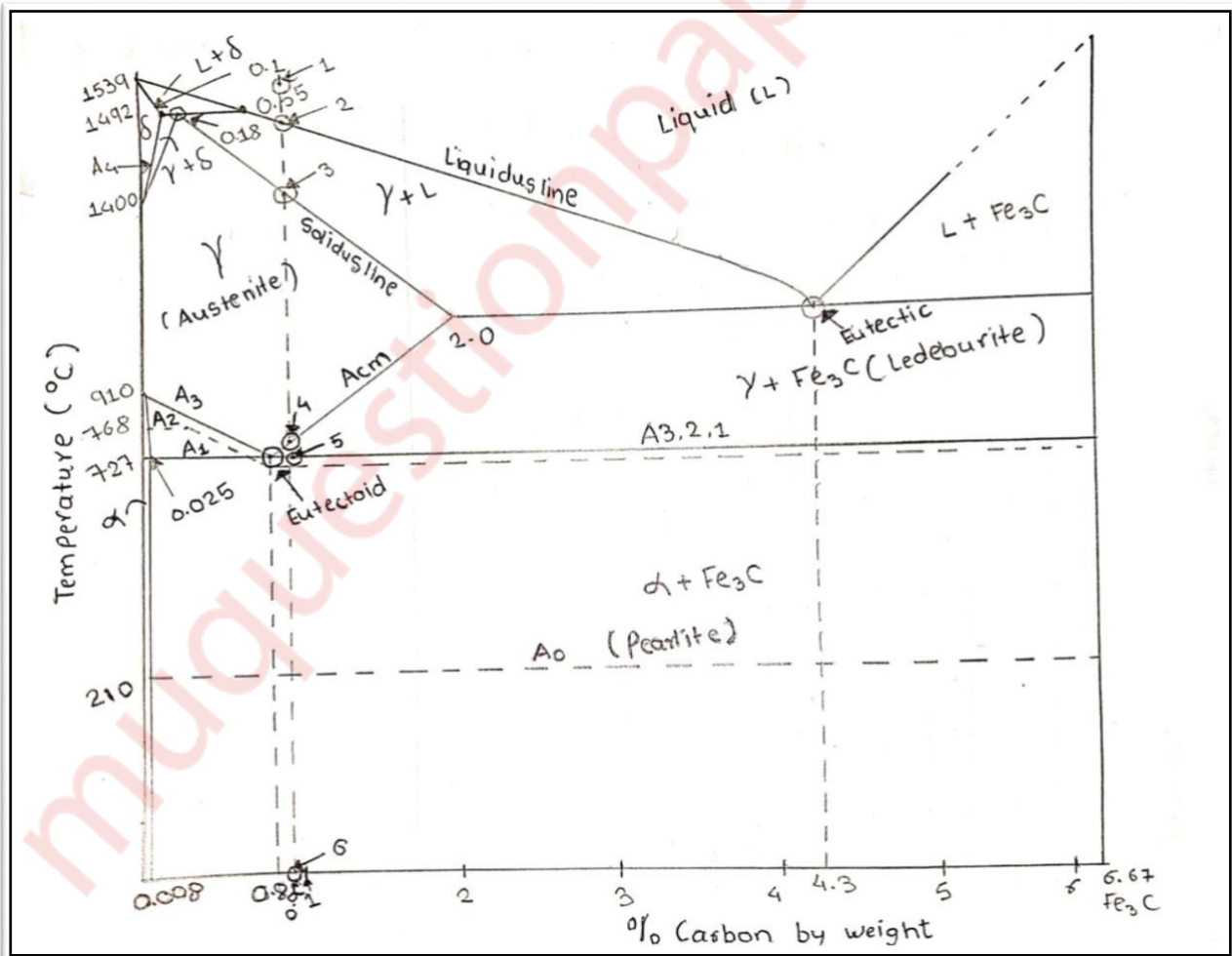
Q.4]2] Describe the cooling of the 0.4% C steel from liquid state to room temperature. Calculate the phases in the steel obtained at room temperature. [10]

Ans :

Steel containing 0.4 % carbon is a hypo eutectoid steel:

- Which steel is completely austenite above A_3 i.e. upper critical temperature line.
- As it is cooled below A_3 line the iron begins to change from FCC to BCC.
- As a result, small crystals and body centred cube (BCC) iron begin to separate out from austenite (FCC)

Microstructure of 0.4 % carbon:

- The microstructure of 0.4 % carbon are as follows
- The microstructure of medium carbon steel shows that 50% pearlite and 50% ferrite is obtained. The dark portion phase is pearlite and bright portion phase is ferrite.
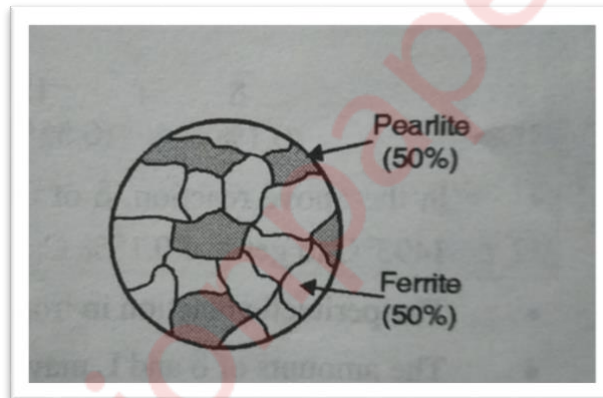

Fig 1 Etchant: Nital magnification : 200X

Phases are involved in the transformation

1. **Li :** liquid solution of carbon in iron
2. **δ ferrite :** solid solution of carbon in iron. It is soft and ductile phase. Cold work without cracking. Maximum concentration of carbon in δ ferrite is 0.09% at 1493°C temperature of the peritectic transformation. Crystal structure of δ ferrite is BCC
3. **Austenite :** Inertial solid solution of carbon in γ iron. Austenite has FCC, permitting high solubility of carbon up to 2% it at 1147°C. Austenite does not exist below 727° C. It is a soft, ductile malleable and non-magnetic phase.
4. **α ferrite** : solid solution of carbon in α iron. α ferrite has BCC crystal structure and low solubility of carbon up to 0.025% 727° C. α ferrite and exist at room temperature it is a soft and ductile phase.
5. **Cementite :** cementite and intermetallic compound of iron and carbon having carbon content 6.67% cementite that has a complex orthorhombic crystal structure having 12 iron atoms and 4 carbon atoms unit cell. Cementite is hard and brittle phase.

6. **Ledeburite :** Ledeburite which consists of eutectic mixture of pearlite and cementite. It is observed in cast iron containing 4.3 % carbon.
7. **Transformed ledeburite :** Structure consists of pearlite and cementite . This mixture is called transform ledeburite.

Q.5]1] Define hot and cold working. Compare the two process giving a few example for each. [10]

Ans: Hot working : working of metals and alloys about the recrystallization temperature is known as **hot working.** It does not show any changes in properties and microstructure

Cold working : the process in which metals are the alloys are heated below the recrystallization temperature are known as cold working

Sr.No.	Cold working	Hot working
1.	Cold working is a process in which metals are work below the recrystallization temperature	Hot working is a process in which metals are brought about the recrystallization temperature
2.	In cold working annealing heat treatment is required	Any type of heat treatment is not required.
3.	Cold working does not involve hot working processes	It involves complete cold working process example. Hot working = cold working + annealing.
4.	It is easy to control the dimensions within the tolerance limit	It is difficult to control the dimensions within tolerance limit.
5.	More stress required for plastic deformation	Less stress is required for plastic deformation.
6.	Higher amount of energy is used for plastic deformation and some amount of energy is stored as internal energy	Complete energy is used for plastic deformation.
7.	Ordinary steel which are used for shaping the metals, hence cost of cold working plant is less	Special materials are required for shaping the metals, hence cost of hot working plant is more.
8.	In cold working handling of the materials is easy	In hot working handling of material is difficult.
9.	Continuous working on metal cannot be done to possibility of cracking	Material can be continuously working without any cracking.
10.	No oxidation of metal occurs during cold working	Heavy oxidation of metal occurs due to working at high temperature.

Q.5]2] What is hardenability? What are the factors affecting hardenability? Explain Jominy quench test? [10]

Ans : Definition

1. **Hardenability** may be defined as the ability of steel to develop its maximum hardness (depth of hardness) when subjected to normal hardening and quenching cycle.
2. Generally high alloy steels pose higher hardenability which shows lower critical cooling rate, so that even slow cooling will leads to a martensitic structure as compared with plain Carbon steels.
3. For plain carbon steels, hardenability is very low as compared with alloy steels.

Factors affecting hardenability

- **Alloying elements :** the alloying elements in steel have a big influence on hardenability, alloying element in steel increases hardenability.
- **Austenitic grain size :** hardenability is also affected by austenitic grain size. A fine grain size reduces hardenability, because of larger number density of heterogeneous nucleation sites.
- **Severity of quench :** certainly fast cooling with water or brain water will give lower hardenability as compared with oil quenching increases hardenability as the cooling rate is slightly slower.
- **Carbon content in steel :** generally increase in percentage of carbon, increases hardenability, but up to some extent. Otherwise at very high carbon, hardenability decreases.

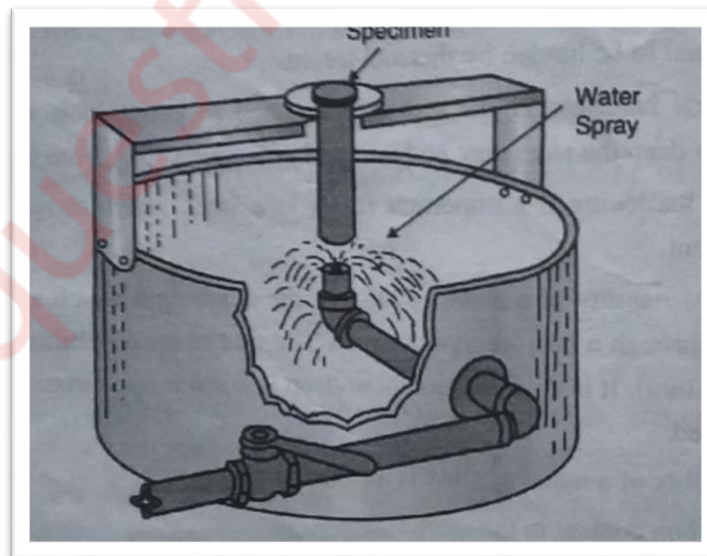**Hardenability measured by jominy end quench test**

Fig 1 jominy end quench test setup

- This test has been standardized by the ASTM (American society of testing of materials) SAE (society of automotive engineering) and AISI.
- The test is conducted with standard sample as shown in the figure, prepared from the steel of which hardenability is to be found out.
- The test set up as shown in the figure, along with the dimensions of standard samples.
- Which standard sample is then heated to proper austenitizing temperature (according to the composition of steel under test) and after a proper socking time, the specimen is removed from the furnace and placed on the support.
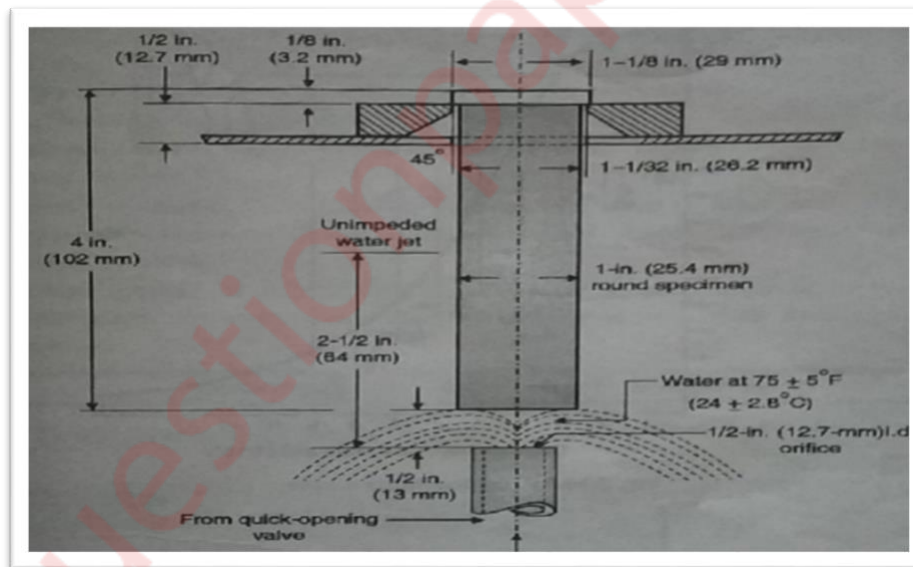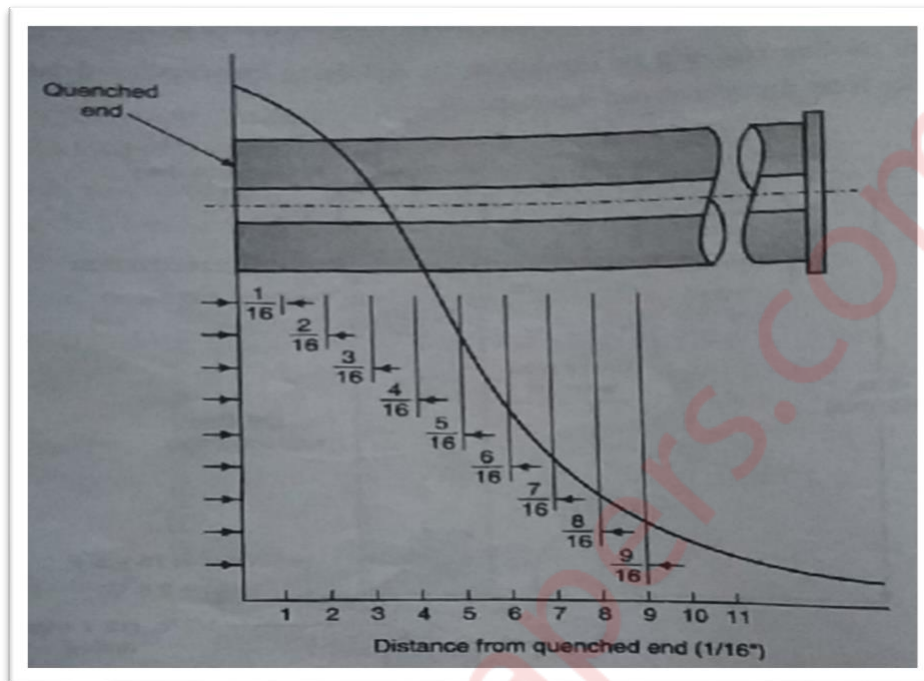

Fig 2 End quench hardenability

Fig 3 Hardenability curve

- Then a water jet is started the flow of water is so adjusted that the cooling effect will be obtained only on the bottom most surface of the specimen and gradually it cools up to collar end. The water it should show umbrella shape.
- After the bar has been cool to temperature, for measuring of hardness, 1 band is grind from collar end up to the quench end and polished, proper hardness measurement.
- The hardness is measured on the Rockwell hardness tester with RC scale. At a distance of 1/16 interval in which hardness point as shown in the figure.
- As the cooling rate will be the highest at the end being Quenched, and will decrease as distance from the Quench end increases.
- The hardenability is found out by measuring the hardness along the bar at show in the figure.
- Higher hardness is obtained at the Quench end where the highest cooling rate was obtained and gradually the hardness decreases towards the collar end. Hardenability is curve obtained as shown in the figure.
- As shown in the above, the measure of hardenability is a point where we get 50 RC as a hardness and the depth of the hardening can be found out by drawing the perpendicular to the x axis as shown.

Q.6]1] Discuss the importance of heat treatment. [5]

Ans :

1. Definition of heat treatment is a combination of heating and cooling operations timed and applied to a metal or alloy in the solid state in a way that will produce required properties.
2. Heat treatment can be further defined as a series of time temperature treatments. Heat treatment are used for variety of purpose is the most important being to control the the mechanical, specially hardness, ductility, strength, toughness and internal stresses.
3. In manufacturing processes of many machine parts and tools heat treatment plays an important role. It is possible to impart hi mechanical properties two metals by heat treatment
4. For any heat treatment cycle the metal is first heated to some temperature above the critical temperature to form austenite. The rate of heating to desired temperature is not very important. But highly stress metals produce by cold working, should be heated slowly, then a stress-free metal to avoid distortion.

Q.6]2] A slowly cooled steel contains 40% ferrite and 60% pearlite at room temperature. Determine the total amount of ferrite and cementite present in the alloy. [5]

Ans :

Here, for 40% ferrite and 60% pearlite

Amount of ferrite $= \frac{6.7-0.76}{6.7-0.02} = \mathbf{0.889}$ **as 88.92%**

Amount of cementite $= \frac{0.76-0.02}{6.7-0.02} = \mathbf{0.111}$ **as 11.1%**

Q.6]3] Rule of mixtures for composites. [5]

Ans:

1. Two mathematical expressions have been formulated for the dependence of the elastic modulus on the volume fraction of the constituent phases for a two-phase composite.
2. These rule-of mixtures equations predict that the elastic modulus should fall between an upper bound and lower bound.
3. For upper bound the equation is,

$Ec (u) = EmVm + EpVp$

4. For lower bound the equation is,

$$Ec (l) = \frac{EmEp}{VmEp+VpEm}$$

Where, E and V denote the elastic modulus and volume fraction, respectively, whereas the subscripts c, m, and p represent composite, matrix, and particulate phases.

Q.6]4] What are smart materials? Discuss few of them giving application for the same.   [5]

Ans : Smart materials :

1. Smart materials are those that change one or more of their properties (shape, color, size, etc.)
   when subjected to an external stimulus.
2. These materials possess adaptive capabilities and perform better than ordinary, materials. They are considered smart because their in-built sensing and actuation capability

Some applications are as follows :

- Piezoelectric
  Generate an electric charge in response to applied mechanical stress and vice versa.
- Magnetostrictive
  Change in dimension of ferromagnetic material in magnetic field and vice versa
- Phase transition dependent
  "Remembers" its original shape and after being deformed returns to its original shape when heated.
- Electro/Magneto Rheological Materials
  Change is viscosity in response to electric/magnetic field.

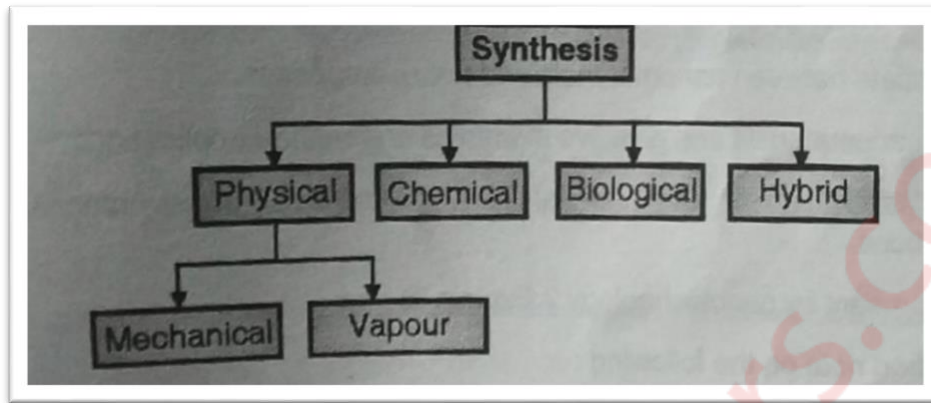**Q.6]5] Discuss with neat diagram any one method used for nanomaterial synthesis.   [5]**

Ans :

Fig1 Types of synthesis of nanomaterials

There are generally two approaches of synthesis of nanomaterials.

- Bottom up approach : These process includes the miniaturization of material components with further self assembly process leading to the formation of nano structures.
  Typical example are quantum dot formation during epitaxial growth and formation of nanoparticles from colloidal dispersion.
- Top down approach : These approaches use larger initial structures, which can be externally controlled in the process of nano structures.
  Typical example are etching through the mask, ball milling and application of sevre plastic deformation.

Top down method

- Begin with a pattern generated on a larger scale, then reduced to nanoscale.
- By nature, aren't cheap and quick to manufacture.
- Slow and not suitable for large scale production

Top down lithography

At the moment the most used top-down approach is photolithography. It has been used for a while to manufacture computer chips and produce structure smaller than 100 nm.

Typically and oxidized silicon (Si) wafer is coated with a 1um thick photoresist layer. After exposure to ultraviolet UV light, the photo resist undergoes a photochemical reaction which breaks down the polymer by rupturing the polymer chains.
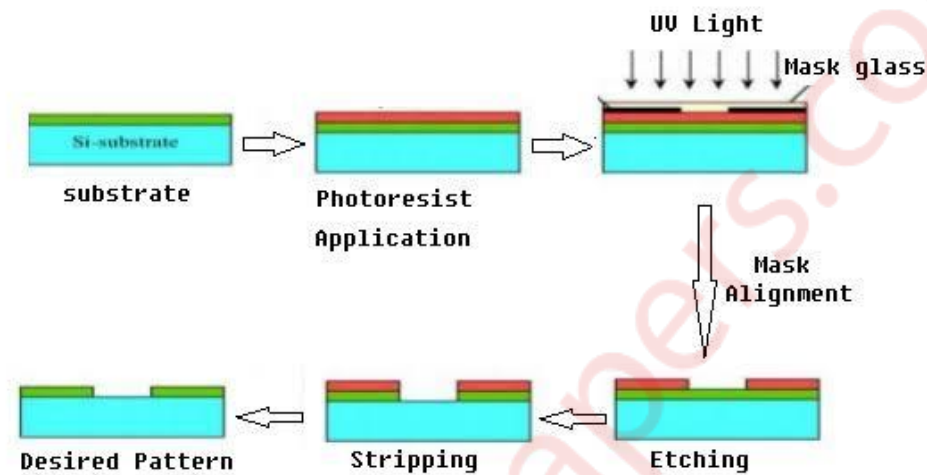
Subsequently when Wafer is rinsed developing solution, the exposed areas are removed.

Fig 2 Top Down Lithography