

MATERIAL TECHNOLOGY

(CBCGS DEC 2017)

Q1] a] Difference between steels and cast irons.

(05)

Solution:-

	Steel	Cast Iron
Definition	Steel is an alloy of iron containing low amount of carbon.	Cast iron is an alloy of iron containing high amount of carbon.
Carbon Content	Less than 2%.	More than 2%.
Main Alloying Element	Carbon and Silicon with percentage up to 0.60% by weight.	Carbon and Silicon with percentage up to 1-3% by weight.
Form Of Carbon	Iron Carbide.	Graphite or Iron carbide.
Rusting	Rust easily.	Does not rust easily.

Q1] b] Allotropic modifications of iron.

(05)

Solution:-

(1) Some metals change their crystal structure when there is a change in temperature, this tendency of metal is called as allotropic. Iron is allotropic in nature. Iron is in the liquid form above 1539°C temperature. If it cools below 1539°C liquid is converted into δ -iron (ferrite) which is in the body centered cubic (BCC) structure.

(2) During cooling process at 1400°C δ -iron is converted into γ -iron (Austenite), which is in the face centered cubic (FCC) structure. Below 910°C γ -iron is converted into α -iron (Ferrite), which is again in the body centered cubic (BCC) structure.

(3) α -iron is non-magnetic up to 768°C. If it cools below 768°C, it is in the BCC structure but magnetic in nature up to room temperature. Iron changes its crystal structure from BCC to FCC, this change of crystal structure called allotropy. These allotropic transformations are shown in Fig.

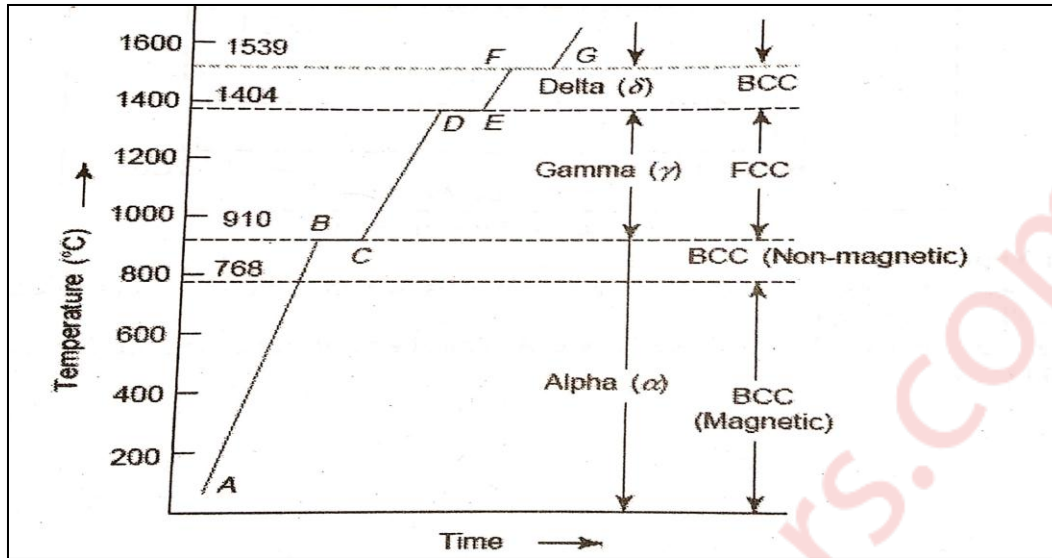


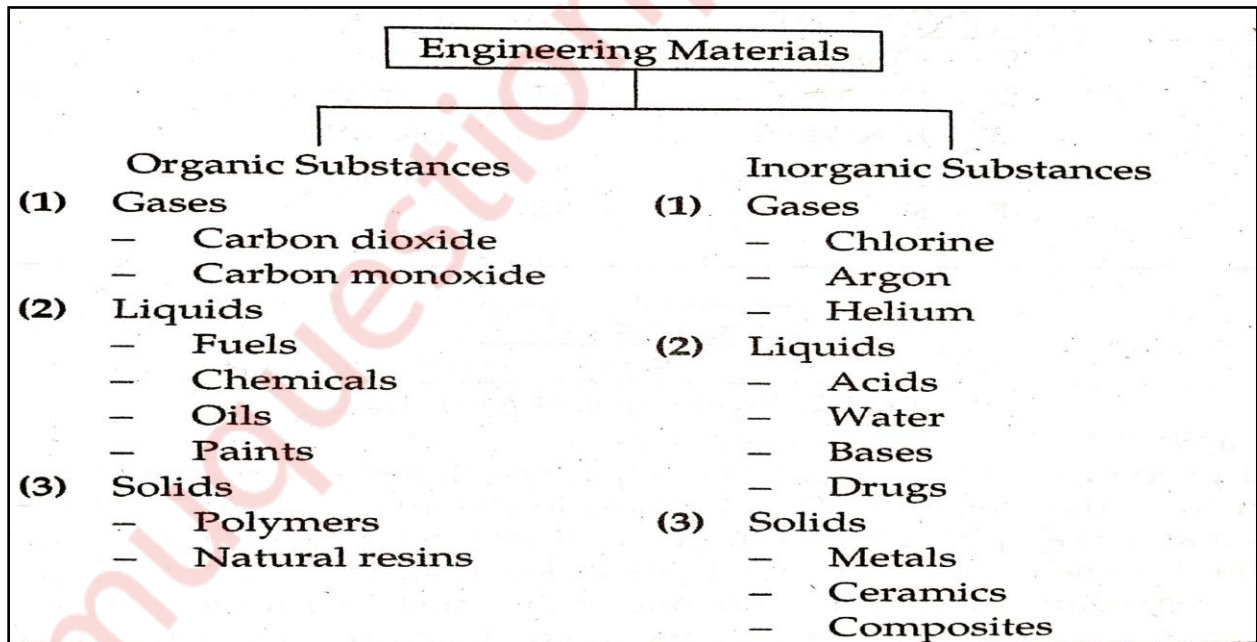
Fig:- Allotropic Forms of Iron

Q1] c] Classification of Materials.

(05)

Solution:-

Classification of Engineering Materials:-



Q1] d] Modes of deformation in materials.

(05)

Solution:-

Different modes of deformation in materials:

(i) Elastic:-

Deformation is completely temporary and after removing applied load it regains its original shape. If a metal is loaded within limits, a temporary deformation of the crystal takes place through displacement of atoms. In elastic deformation, if the load is applied on the material, atoms in the material are displaced from their original position. After gradual removal of the load, the atoms return to their original position and crystal recovers its original shape as shown in fig.

(ii) Plastic:-

Deformation is permanent even after removal of applied load is called as plastic deformation. If the load is applied gradually on metal, within elastic limit, stress is proportional to strain. When metal piece crosses elastic limit and enters into the plastic limit. The specimen gets plastically deformed in the plastic region. If the load is removed in the plastic region, the metal piece does not regain its original shape and a permanent (Plastic) strain always remains in the metal. Plastic deformation stages in the metal are shown in fig. below.

Q1] e] Stainless steel and its classification.

(05)

Solution:-

Stainless Steel:-

Stainless steel is defined as a steel alloy with a minimum of 10.5 or 11% chromium content by mass. Stainless steel does not stain, corrode or rust as easily as ordinary steel, but it is not stain-proof. It is also called corrosion-resistant steel.

Classification of Stainless Steel:-

(i) Austenitic stainless steel:-

These steels are not magnetic in annealed condition. They cannot be hardened by heat treatment. They can be hot worked or cold worked. They contain 0.02-0.15% carbon, a minimum of 16% chromium and sufficient nickel and manganese.

(ii) Ferritic stainless steels:-

These are chromium stainless steels with varying chromium content between 11% and 18%, but with low carbon (0.02 – 0.1%) content. They have a moderate to good corrosion resistance.

(iii) Martensitic stainless steels:-

They are plain chromium steels containing between 12 and 18% chromium, high carbon content (0.1-1.2%) compared to other grades of stainless steels.

(iv) Precipitation-hardening stainless steels:-

The precipitation-hardening stainless steels are iron-nickel-chromium alloys containing one or more precipitation hardening elements such as aluminium, titanium, and molybdenum.

(v) Duplex stainless steels:- these steels contain relatively high chromium (18 to 28%) and moderate amounts of nickel (4.5 to 8%).

Q2] A) Define critical cooling rate. Describe various cooling curves on TTT diagram for eutectoid steels and discuss the transformations. (10)

Solution:-

A) Critical Cooling rate:-

When the cooling curve is tangent to the nose of TTT curve, it is called as a critical cooling rate (CCR). CCR can be defined by two ways 'The slowest cooling rate at which unstable austenite can be transformed into martensite'.

OR

'The fastest cooling rate or within minimum time at which unstable austenite can be transformed into pearlite.'

B) Various cooling curves and Transformations on TTT diagram:-

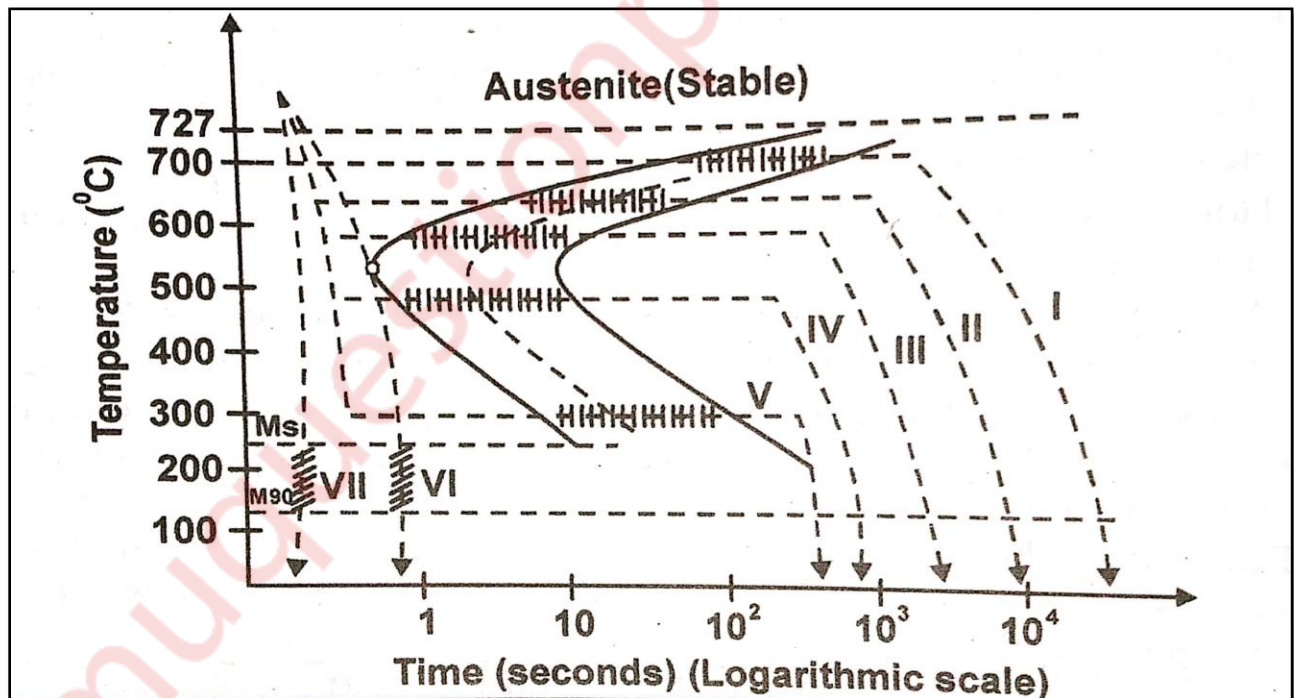


Fig :- Time-Temperature-Transformation (TTT) diagram

(1) Cooling Curve - I (Coarse Pearlite):-

The transformation product of this cooling curve will be a coarse pearlite. In TTT diagram, when cooling of unstable austenite will be carried out between 675°C to 727°C isothermally, it will transform into coarse perlite.

(2) Cooling Curve – II (Medium Pearlite):-

The transformation product of this cooling curve is medium pearlite. This transformation occurs when material cooled between 600 to 675°C at a constant temperature in TTT diagram.

(3) Cooling Curve – III (Fine pearlite):-

The transformation product of this cooling curve is fine pearlite. This transformation occurs when the material will be cooled between 500 to 600°C at a constant temperature in TTT diagram.

(4) Cooling Curve – IV (Upper Bainite):-

This cooling curve is obtained only by cooling material rapidly enough to miss the nose of the TTT curve and then held at a constant temperature for transformation. The transformation product of this curve is upper bainite.

(5) Cooling Curve – V (Lower Bainite):-

This cooling curve is obtained by cooling material rapidly enough to miss the nose of TTT curve just above 210°C temperature (M_s). Hold it at constant temperature for transformation.

(6) Cooling Curve – VI (Critical Cooling Rate):-

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

(7) Cooling Curve – VII (Martensite):-

This curve is obtained by very fast cooling rate (350°C/sec). The transformation product of this curve is martensite.

Q2] B) Explain property and micro-structure changes occurring during cold working and recrystallization annealing of metals. (10)

Solution:-

(i) Cold working:-

During cold working, strain hardening is observed and also the grains become distorted. Cold working increases hardness, yield strength, internal stresses and electrical resistance as well as ductility and corrosion resistance. After cold working, metal becomes hard and brittle, hence it is

not possible work them without cracking beyond a certain limit of cold is to be continued, the metal must be made soft and ductile by suitable heat treatment.

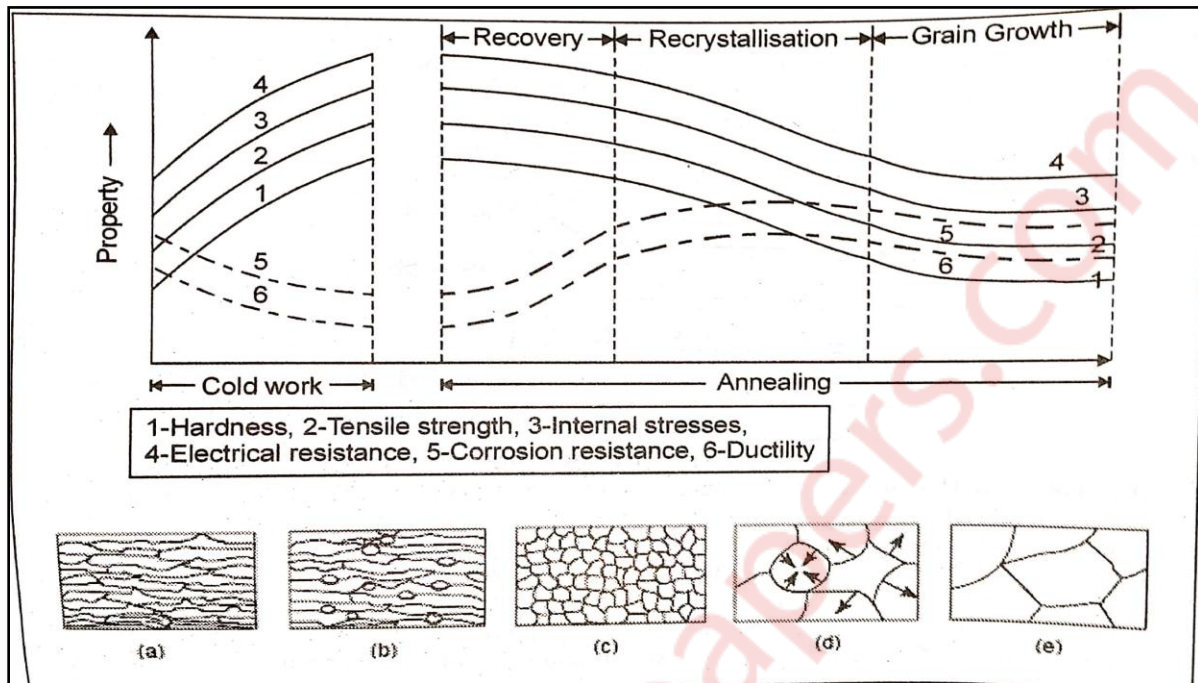


Fig: Property changes occurring during cold working and Recrystallization Annealing

(ii) Recrystallization Annealing:-

(a) Recovery:-

This term implies all changes in the fine structure and properties of a metal which involve no changes in the microstructure of the deformed metal. Physical properties such as electrical and thermal conductivities and the like are recovered to their pre cold-worked states.

(b) Recrystallization:-

In recrystallization annealing old grains are replaced by new equiaxed stress free, strain free grains by the process of nucleation and growth. Microstructure at the end of recrystallization process is much similar to that of original structure i.e. similar to the structure prior to cold working. Due to change in the microstructure, all the mechanical properties are changed and become almost similar to that of original material.

(c) Grain Growth:-

In this process, low angle boundary appears between a recrystallization center and deformed matrix. After a certain time, centers of new grains increase in size due to the passage of atoms from the deformed surroundings to a perfect lattice; the high angle boundaries of new grains then move into the depth of strained-hardened metal.

Q3] A] Draw Fe-Fe₃C equilibrium diagram and label all the important temperatures, composition and phases clearly. Also write the invariant reactions. (10)

Solution:-

A) Fe-Fe₃C equilibrium diagram:-

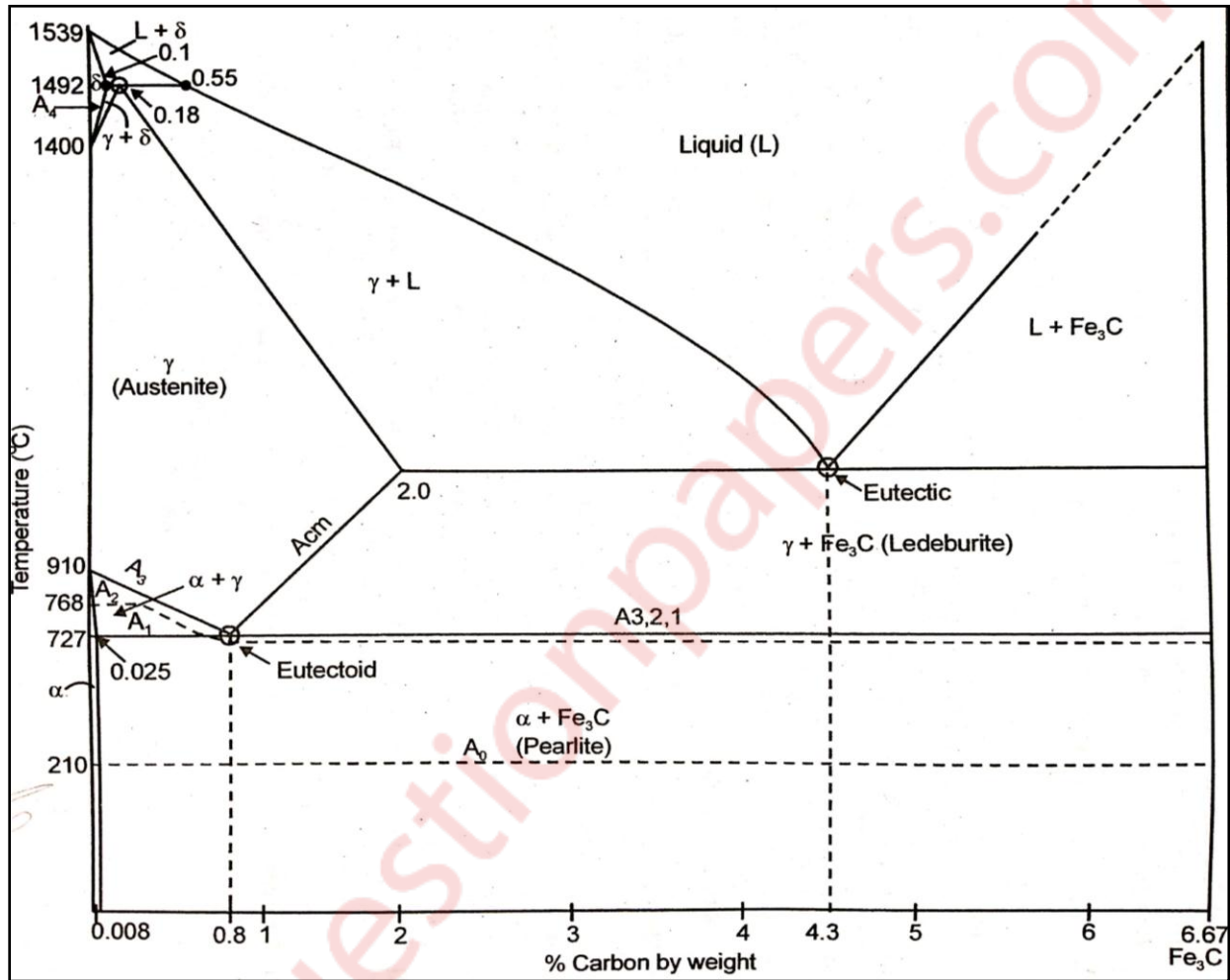


Fig: Iron-Iron Carbide Equilibrium Diagram

(B) Various Temperature lines in Iron-Iron Carbide Equilibrium Diagram:-

(1) A₀ (210°C):-

At this temperature line cementite changes from magnetic to non-magnetic character.

(2) A₁ (727°C):-

At this temperature, pearlite transforms to austenite during heating. This transformation occurs at a constant temperature of 727°C.

(3) A_2 :-

At this temperature line ferrite changes its property from magnetic to non-magnetic during heating. This line is at 0% C and 768°C temperature up to A_3 line then it is parallel to A_3 line up to 0.8% C and 727°C temperature and then it is constant at 727°C temperature up to 6.67% carbon.

(4) A_3 :-

At this temperature line the last trace of free ferrite gets dissolved to form 100% austenite. It decreases from 910°C temperature and 0% C to 727°C temperature and 0.8% C and then it is constant at 727°C temperature up to 6.67% C.

(5) A_{cm} :-

At this temperature line, the last trace of free cementite gets dissolved to form 100% austenite. It increases from 727°C temperature and 0.8% C to 1147°C temperature and 2.0% C.

(6) A_4 :-

At this temperature line, the last trace of austenite gets dissolved to form 100% δ -ferrite. It increases from 1400°C temperature and 0% C to 1492°C temperature and 0.1% C.

(C) Various phases existing in the Iron-Iron Carbide diagram:-

(1) α -Ferrite:-

Ferrite is interstitial solid solution of carbon in low-temperature B.C.C. α -iron. The solubility of carbon in α -iron at room temperature is 0.008% and increasing with increase in temperature to about 0.025% at 727°C.

(2) γ -Austenite:-

Austenite is an interstitial solid solution of carbon dissolved in F.C.C. γ -iron. Maximum solubility is 2% carbon at 1147°C temperature. The phase is stable only above 727°C.

(3) δ -Ferrite:-

It is an interstitial solid solution of carbon in high temperature B.C.C δ -iron.

(4) Cementite (Fe_3C):-

It is also called as carbide or iron carbide. It is an intermetallic compound of iron and carbon with fixed carbon content of 6.67% by weight. It is magnetic up to 210°C.

(5) Ledeburite:-

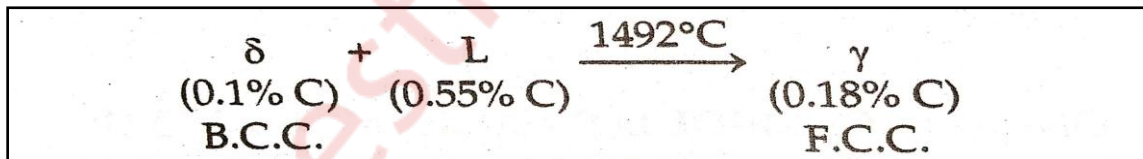
It is eutectic mixture of austenite and cementite. It contains 4.3% C at 1147°C temperature.

(6) Pearlite:-

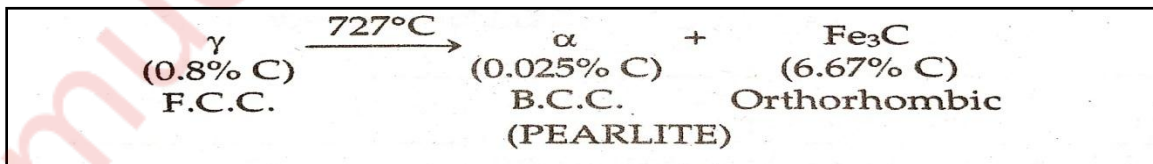
It is a eutectoid mixture containing 0.8% C and is formed at 727°C temperature on very slow cooling.

(D) Invariant Reactions:-

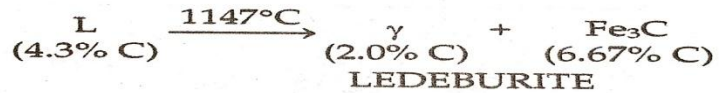
(1) Peritectic Transformation:-



(2) Eutectoid Transformation:-



(3) Eutectic Transformation:-



Q3] B] Describe cooling of 0.5% C steel at room temperature. Also find out the proportion of micro constituents in it at room temperature. (10)

Cooling of 0.5% C steel at room temperature :-

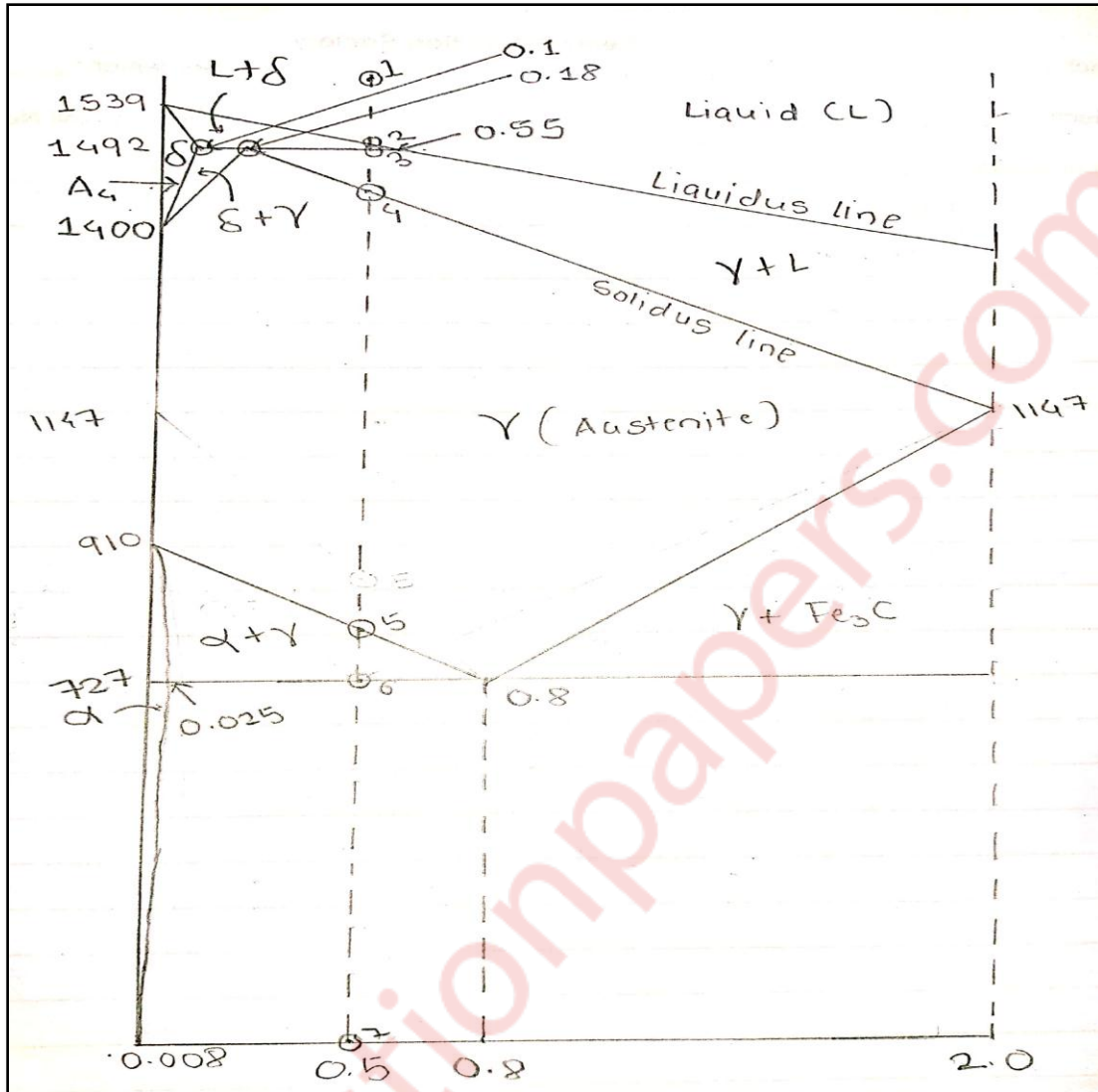


Fig: Steel portion of Iron-Iron Carbide Daigram

Fig shows steel portion of iron-iron carbide equilibrium diagram. In this diagram vertical line is drawn at 0.5% C steel from liquid state to room temperature.

The structural changes for this steel are marked at each point during cooling as follows:-

Point 1:- At point-1, the iron-carbon is in liquid state.

Point 2:- Up to point-2 alloy is in the liquid state. At point 2, solidification process starts and some part of the liquid is trying to convert into δ -ferrite.

Point 2-3:- Just below point 2, the liquid is trying to convert into δ -ferrite. This process continues until point 3. At point 3, there is a hyperperitectic reaction and it is possible to calculate exact percentage of liquid and δ -ferrite at 1492°C temperature. Lever arm for application of lever rule at 0.5% carbon and at 1492°C constant temperature is shown in fig (a)

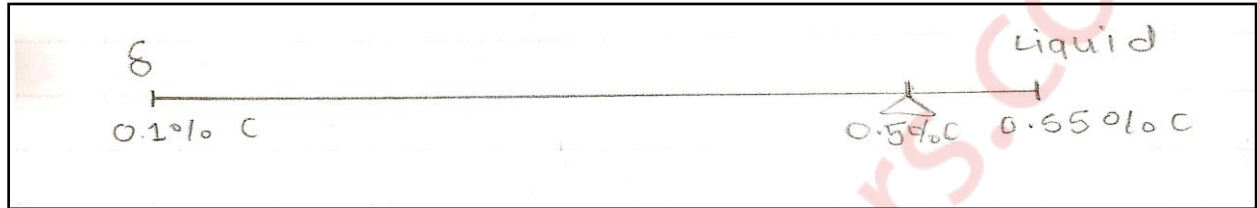


Fig (a)

$$\begin{aligned} \% \text{ Amount of } \delta &= \frac{\text{Opposite arm length}}{\text{Total arm length}} \times 100 \\ &= \frac{(0.55 - 0.5)}{(0.55 - 0.1)} \times 100 \\ &= 11.11\% \end{aligned}$$

$$\begin{aligned} \% \text{ Amount of liquid} &= \frac{(0.5 - 0.1)}{(0.55 - 0.1)} \times 100 \\ &= 88.88\% \end{aligned}$$

At point 3, at 1492°C temperature there is 11.11% δ -ferrite and 88.88% liquid in 0.5% C steel.

Point 3-4:- At point 3, 'Y' starts separating out at the grain boundaries of ' δ ' ferrite. From point 3 to 4, there is liquid and Y (austenite) and solidification process continued.

Point 4-5:- Point 4 is on solidus line. Up to this point solidification process continued and end on the point 4. Just below point 4, there is 100% austenite. From point 4 to 5 there is no change in the structure but only decrease in temperature. From point 4 to 5, there is 100% Y (austenite).

Point 5-6:- At point 5, α starts separating out at the grain boundaries of γ . As temperature decreases, amount of α -ferrite increases.

Point 6:- It is on eutectoid line. At 727°C constant temperature it is possible to apply lever rule for calculating exact percentage of α -ferrite and pearlite. Lever arm is shown in fig B.

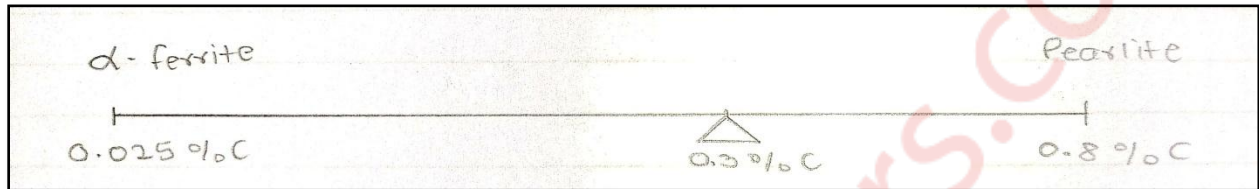


Fig (B)

$$\% \text{ Amount of } \delta = \frac{\text{Opposite arm length}}{\text{Total arm length}} \times 100$$

$$= \frac{(0.8 - 0.5)}{(0.8 - 0.025)} \times 100$$

$$= 38.70\%$$

$$\% \text{ Amount of liquid} = \frac{(0.5 - 0.025)}{(0.8 - 0.025)} \times 100$$

$$= 61.30\%$$

At point 6, at 727°C constant temperature, there is 38.70% α -ferrite and 61.30% pearlite at 0.5% carbon steel.

Q4] A) What is fatigue of metals? Explain the method of testing the metals for fatigue. Discuss the various methods used to increase fatigue life of a component. (10)

(A) 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.

(B) Fatigue Testing:-

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

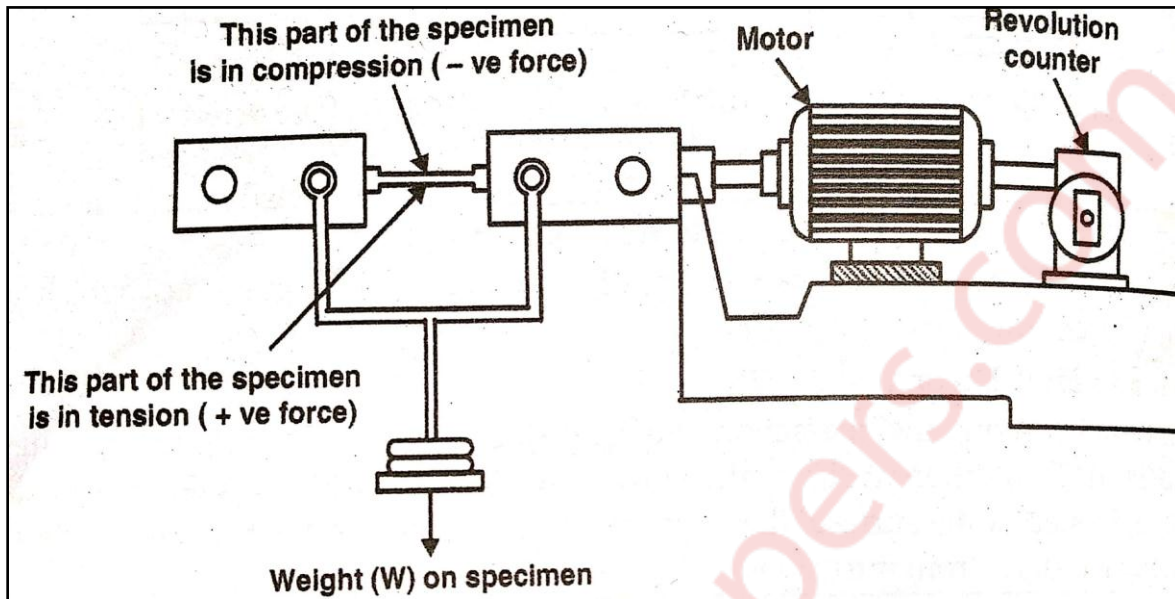


Fig: Rotating Beam Fatigue Testing Machine

- (1) 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.
- (2) 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.
- (3) 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.
- (4) 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.

(C) Methods used to increase fatigue life of a component:-

(i) Case Hardening:-

Case hardening is a technique by which both surface hardness and fatigue life are enhanced for steel alloys. This is accomplished by a carburizing or nitriding process whereby a component is exposed to a carbonaceous or nitrogenous atmosphere at an elevated temperature.

(ii) Shot Peening:-

shot peening allows an increased amount of stress to achieve the same component metal fatigue life. Shot peening extends the life of any part if the existing stress level is maintained.

Q4] B) What is hardenability? What are factors affecting hardenability? Explain Jominy End Quench test.

(10)

Solution:-

(A) Hardenability:-

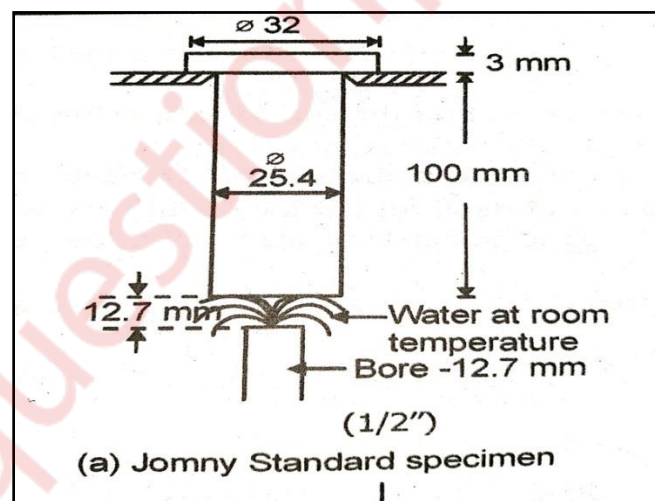
The hardenability of metal alloy is the depth to which a material is hardened after putting it through a heat treatment process. It is the capability of an alloy to be hardened by heat treatment.

(B) Factors affecting hardenability:-

- (a) The mean composition of the steel.
- (b) The homogeneity of austenite.
- (c) The grain size of the austenite.
- (d) The undissolved carbides and nitrides in the austenite.

(C) Jominy End Quenched test:-

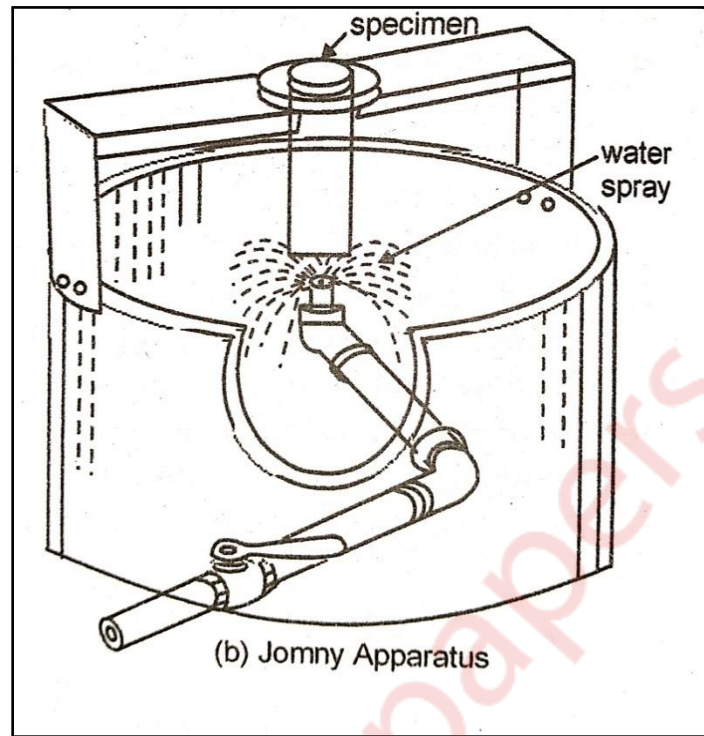
(1) In this test, the specimen dimensions and test conditions are standardized as per A.S.T.M. The specimen is of cylindrical shape with 25.4 mm diameter and approximately 100 mm in length has machined shoulder at one end as shown in fig (a).



(2) The specimen is heated up to austenite temperature and held at constant temperature for 1 hour and quickly transferred to a fixture (quenching jig).

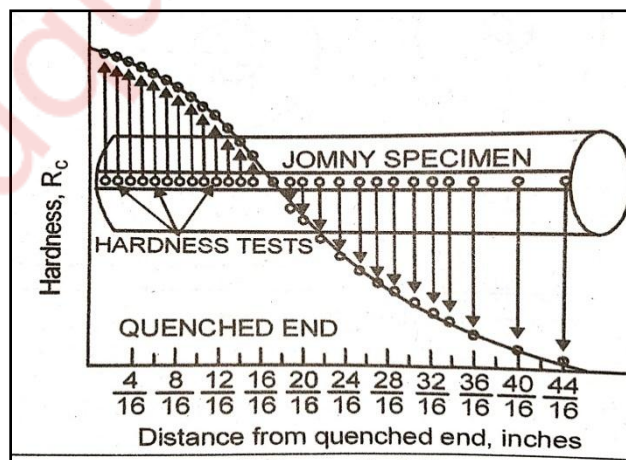
(3) Water is pumped through the jet at the bottom of the specimen. Free height of water is adjusted approximately 65 mm. Water is allowed to flow from the bottom end through a pipe inside

diameter of 12.7 mm for about 20 minutes. The pressurized water forms a complete umbrella over the bottom surface of the specimen as shown in fig (b).



(4) The cooling rate is maximum at the quenched end of the specimen where usually full hardening occurs and reduces steadily towards air cooled i.e. all possible rates of cooling from water quenching to air cooling are obtained on single test piece.

(5) After quenching, Two flat surfaces are ground opposite to each other along the length of the specimen. The hardness is measured at intervals of 1.6 mm distance from the quenched end. The hardness values are plotted as a function of distance from the quenched end and resulting curve is called jominy hardenability curve.



Q5] A] How is surface hardening is different from case hardening? Discuss any one of the case hardening methods in detail. (10)

Solution:-

Case hardening may be defined as a process of hardening a ferrous material in such a manner that the surface layer known as a case, is substantially harder than the remaining material known as the core. This can be achieved by two different methods.

(a) Changing the chemical composition at the surface of the steel. It is called case hardening method.

(b) Without changing the chemical composition at the surface of the steel. It is called surface hardening.

Method of case hardening:-

Nitriding :-

(A) Principle of Nitriding:-

Nitriding is a case hardening process by which nitrogen contents at the surface of the steel is increased. It is based on the fact that active nitrogen can be absorbed by ferrite phase of iron and certain other metallic elements.

(B) Nitriding Process:-

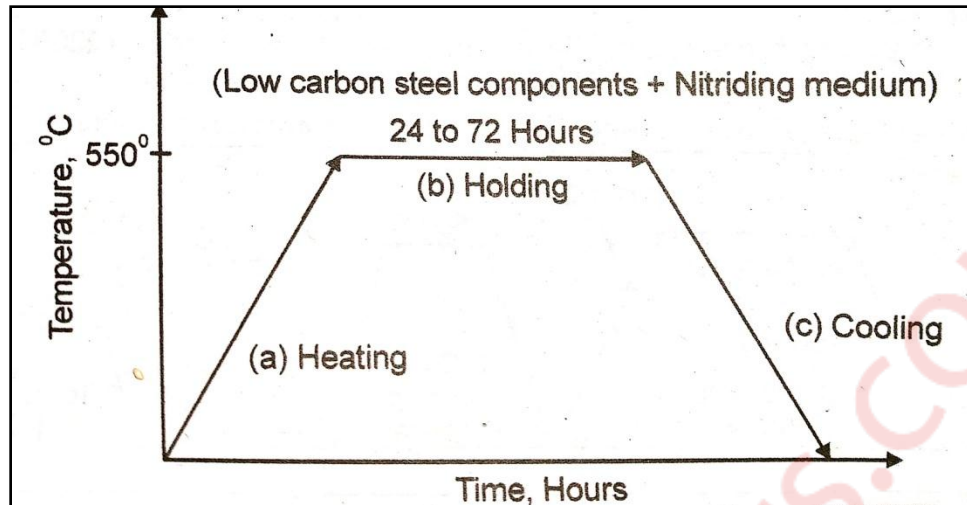


Fig: Nitriding Process

(1) In this process low carbon steel components are heated in contact with a source of atomic nitrogen at a temperature of 550°C. The atomic nitrogen diffuses into steel and combines with iron and certain alloying elements present in steel and forms respective nitrides. This nitride increase the hardness and wears resistance of steels.

(2)The steel components are held at a constant temperature 550°C for 24 to 72 hours for the addition of atomic nitrogen layer on surfaces up to room temperature.

Q5] b] A continuous and aligned fibre-reinforced composite is to be produced consisting of 30 vol% aramid fibres in polycarbonate matrix. Find the modulus of composite in longitudinal direction. (Given: modulus of elasticity of aramid fibre = 131GPa, modulus of elasticity for polycarbonate = 2.4GPa) (05)

Solution:-

Given:

$$E_f = 131 \text{ GPa}$$

$$V_f = 30\% = 0.3$$

$$E_m = 2.4 \text{ GPa}$$

Modulus of elasticity of the composite in the longitudinal direction is calculated using equation,

$$E_{Cl} = E_m \cdot V_m + E_f \cdot V_f \dots\dots\dots(1)$$

We know that the composite consists of only matrix and fibre phases that is $V_m + V_f = 1$

$$V_m + 0.3 = 1$$

$$V_m = 0.7$$

Putting value of V_m and all the values in equation (1),

$$E_{Cl} = (2.4 \times 0.7) + (131 \times 0.3)$$

$$E_{Cl} = 40.98 \text{ GPa}$$

Modulus of elasticity of the composite in the longitudinal direction is 40.98 GPa.

Q5] c) What are smart materials? Discuss few applications for smart materials? (05)

Solution:-

(A) Smart materials:-

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

(B) Applications:-

(1) Piezoelectric:-

Generate an electric charge in response to applied mechanical stress and vice versa.

(2) Magnetostrictive:-

Change in dimension of ferromagnetic material in magnetic field and vice versa

(3) Phase transition dependent:-

“Remembers” its original shape and after being deformed returns to its original shape when heated.

(4) Electro/Magneto Rheological Materials:-

Change is viscosity in response to electric/magnetic field

Q6] a] Nano materials and their synthesis routes.

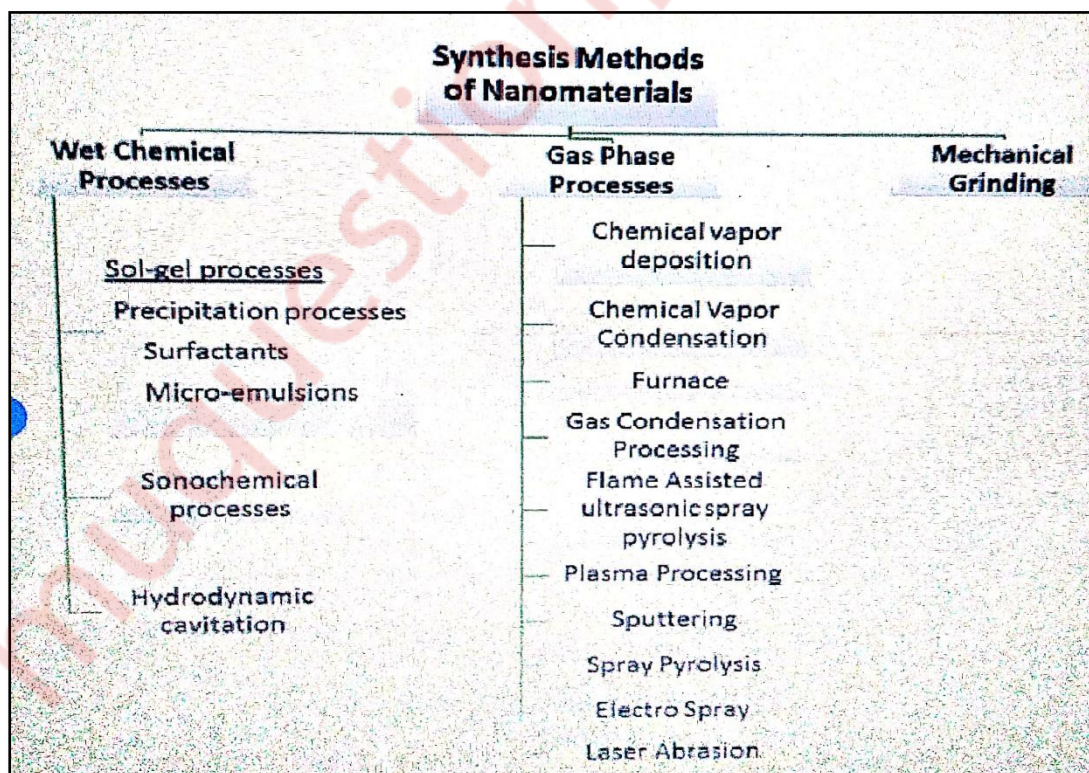
(05)

Solution:-

Nanomaterials:-

Nanostructured materials or Nanomaterials may be defined as those materials whose structural element clusters, crystallites or molecules have dimensions in the 1 to 100 nm range.

Synthesis of Nanomaterials:-



Solution:-

(B) Creep Curve and Stages of Creep:-

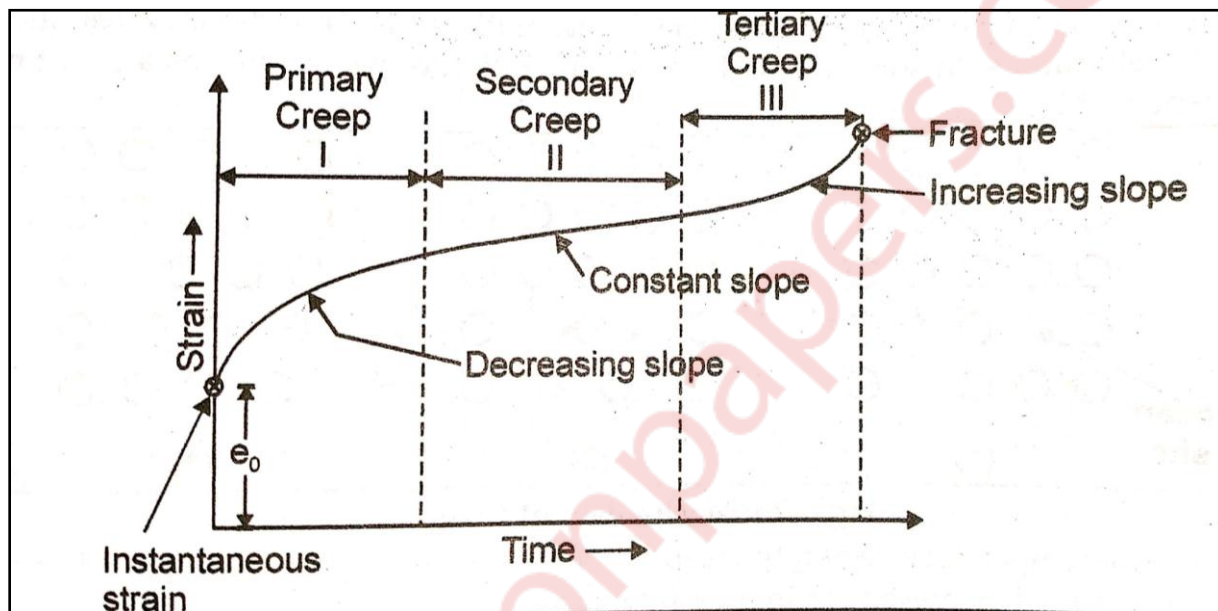


Fig: Creep Curve

(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 secondary or steady state creep, 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.

(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 the void formation and extensive crack formation occurs.

Q6] c] Dislocations and strain hardening.

(05)

Solution:-

(i) Dislocations:-

A dislocation is a linear or one-dimensional defect around which some of the atoms are misaligned.

There are two types of dislocations, screw and edge dislocation.

(1) Edge dislocation:-

If one of the planes is not continuous from top to bottom or bottom to top and ends part way within the crystal, it is called as edge dislocation.

(2) Screw dislocation:-

If the plane of atoms follows dislocation in a helical or screw path then it is called as screw dislocation.

(ii) Strain hardening:-

(1) Strain hardening or work hardening is a phenomenon which results in an increase in hardness and strength of metal when subjected to plastic deformation at a temperature lower than the recrystallization range (cold working).

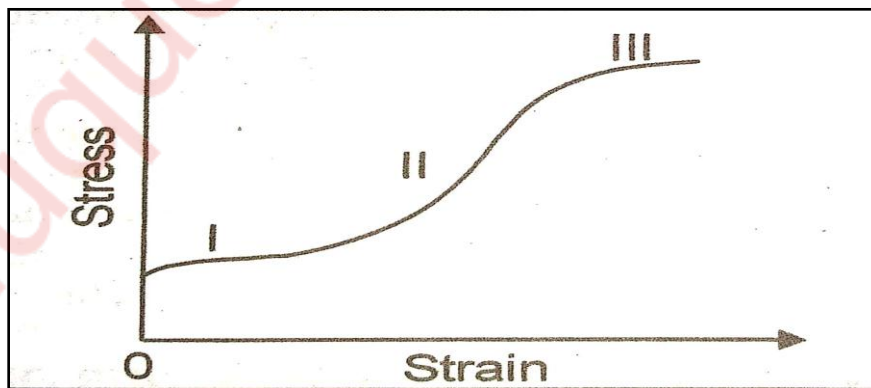


Fig: Strain Hardening

(2) The three stages of strain hardening are as follows:-

(i) Stage - I [Easy Glide Region]

(ii) - II [Linear Hardening Region]

(iii) Stage - III [Parabolic Hardening Region]

Q6] d] Isomorphous phase diagram.

(05)

Solution:-

Isomorphous phase diagram:-

These diagrams are of a loop type and are obtained for two metals having complete solubility in the liquid state as well as solid state. For examples Cu-Ni, Au-Ag, Au-Cu, Mo-W, etc.

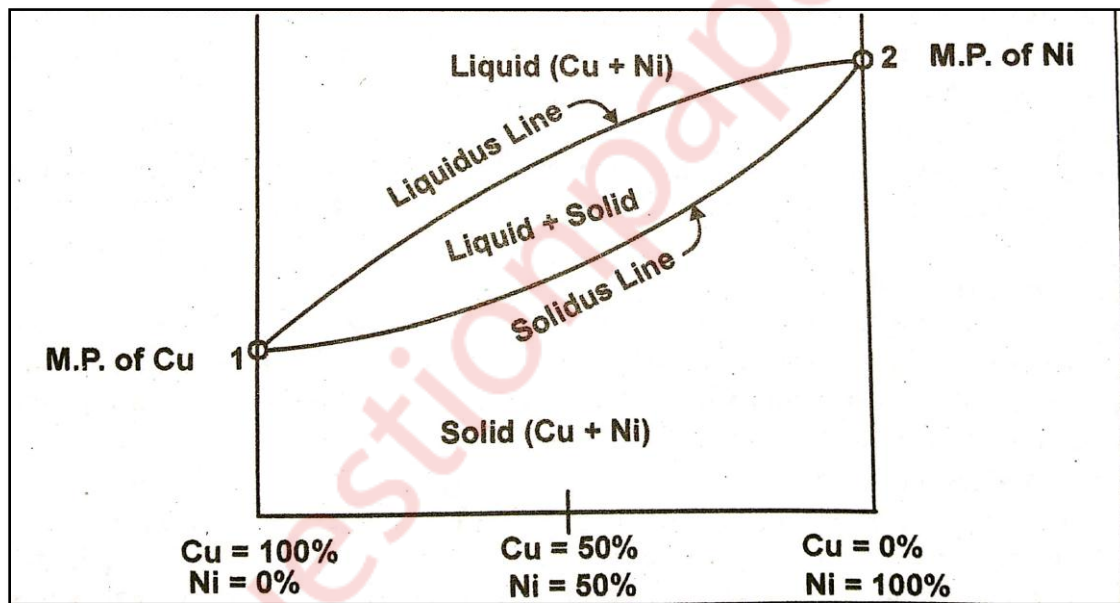


Fig: Isomorphous Phase Diagram

Fig shows Cu-Ni diagram in which at a point '1' 'Cu' is pure and at point '2' 'Ni' is pure. Above liquidus line, Cu and Ni are completely soluble in liquid form and below solidus line, Cu and Ni are having a complete solubility in solid form. Between liquidus and solidus line it is in the combined liquid and solid form.

Q6] e] Retained austenite.

(05)

Solution:-

Retained austenite:-

- (1) Austenite that does not transform to martensite upon quenching is called retained austenite.
 - (2) Thus, retained austenite occurs when steel is not quenched to the M_f or martensite finish, temperature that is low enough to form 100% martensite. Because the M_f is below room temperature in alloys containing more than 0.30% carbon, significant amounts of untransformed or retained austenite may be present, intermingled with martensite at room temperature.
 - (3) Retained austenite is a specific crystalline form of iron and steel. The amount of retained austenite is a function of the carbon content, alloy content (especially nickel and manganese), quenched temperature and subsequent thermal and/or mechanical treatments.
 - (4) Depending on the steel chemistry and specific heat treatment, the retained austenite level in the case can vary from over 50% of the structure to nearly zero. While large amounts of retained austenite (>15%) can be detected and estimated by optical microscope.
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Q6] f] MR fluids.

(05)

Solution:-

- (1) A magnetorheological fluid (MR fluid, or MRF) is a type of smart magnetic fluid in a carrier fluid, usually a type of oil. When subjected to a magnetic field, the fluid greatly increases its apparent viscosity, to the point of becoming a viscoelastic solid.
 - (2) Importantly, the yield stress of the fluid when in its active ("on") 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.
 - (4) MR fluid is different from a ferrofluid which has smaller particles. MR fluid particles are primarily on the micrometre-scale and are too dense for Brownian motion to keep them suspended (in the lower density carrier fluid).
 - (5) Ferrofluid particles are primarily nanoparticles that are suspended by Brownian motion and generally will not settle under normal conditions. As a result, these two fluids have very different applications.
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