

MATERIAL TECHNOLOGY

(CBCGS MAY 2018)

Q1] Write notes on any four:-

Q1] a] smart materials.

(05)

Solution:-

Smart materials:-

(i) Smart materials are those that change one or more of their properties (shape, color, size, etc.) when subjected to an external stimulus.

(ii) These materials possess adaptive capabilities and perform better than ordinary materials. They are considered smart because of their in-built sensing and actuation capability.

(iii) Some applications of smart materials are shown below:

(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 in viscosity in response to electric/magnetic field.

Q1]b] Creep Test.

(05)

Solution:-

(i) The main type of creep testing machine that is most commonly used is a constant load creep testing machine. The constant load creep machine consists of a loading platform, foundation, fixture devices, and furnace.

(ii) The specimen to be tested is placed in the electric furnace where it is heated to a given temperature. The usual method of creep testing consists of subjecting the specimen to constant tensile stress at constant temperature and measuring the extent of deformation or strain with time.

(iii) The typical creep testing machine is shown in Fig.

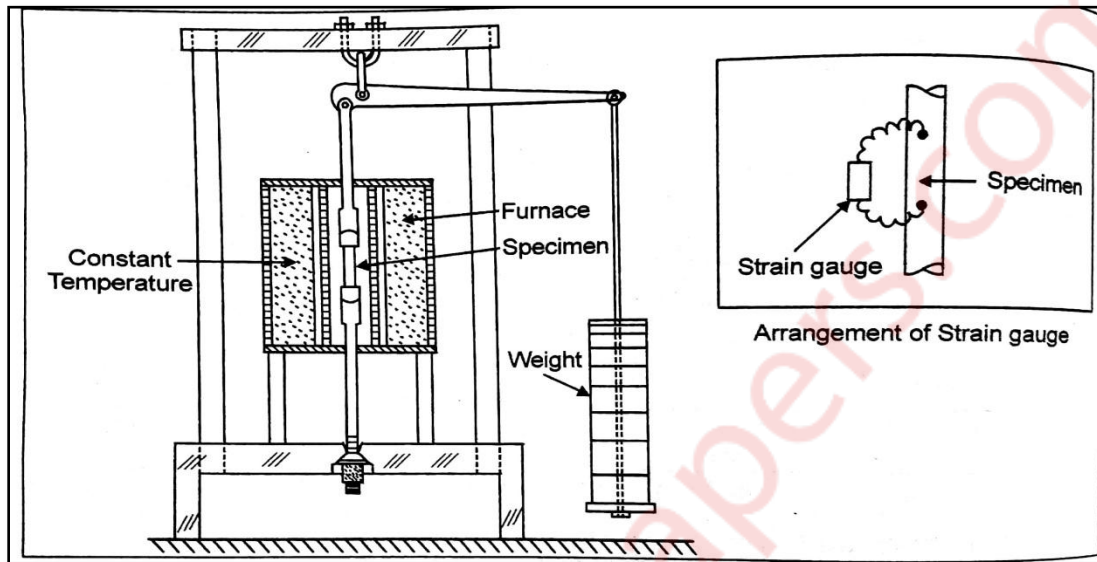


Fig: Creep Testing Machine

(iv) The time of each test may be a matter of hours, weeks, months or even years. The data is represented by plotting creep curve as deformation (or strain) and time at constant temperature and stress.

(v) The test specimen may be circular, square, or rectangular in cross-section. The strain is measured by the strain gauge.

Q1]c] Effect of alloying elements on properties of steel.

(05)

Solution:-

Listed below is a summary of the effects of various alloying elements on properties of steel:-

(i) Carbon:-

The basic metal, iron, is alloyed with carbon to make steel and has the effect of increasing the hardness and strength by heat treatment but the addition of carbon enables a wide range of hardness and strength.

(ii) Manganese:-

Manganese is added to steel to improve hot working properties and strength, toughness and hardenability.

(iii) Chromium:-

Chromium is added to steel to increase resistance to oxidation. This resistance as more chromium added.

(iv) Nickel:-

Nickel is added in large in large amounts, over 8%, to high chromium stainless steel to form the most important class of corrosion and heat resistant steels. These are the austenitic stainless steels, typified by 18-8, where the tendency of nickel to form austenite is responsible for great toughness and high strength at both high and low temperatures.

(v) Molybdenum:-

Molybdenum when added to chromium-nickel austenitic steels, improves resistance to pitting corrosion especially by chlorides and sulfur chemicals.

Q1]d] Critical resolved shear stress.

(05)

Solution`:-

(i) In response to an applied tensile or compressive stress, slip in single crystal commences on the most favorably oriented slip system when the resolved shear stress reaches some critical value, termed as 'Critical Resolved Shear Stress'.

$$(ii) \tau_{cr} = \sigma \cos \alpha \cos \beta$$

above equation gives shear stress resolved on the slip plane in slip direction.

(iii) If the slip direction is at right angles to the tensile axis i.e. $\alpha = 90^\circ$, then $\cos 90^\circ = 0$ that is why $\tau_{cr} = 0$.

(iv) If slip plane is parallel to the tensile axis i.e. $\beta = \cos 90^\circ = 0$ that is why $\tau_{cr} = 0$.

(v) If both the slip plane and slip direction are inclined at an angle of 45° to the tensile axis, then $\tau_{cr} = \sigma \cos 45^\circ \cos 45^\circ = \sigma \times \frac{1}{\sqrt{2}} \times \frac{1}{\sqrt{2}} = \frac{\sigma}{2}$

(vi) We can that for all combinations of β and α , the critical resolved shear stress will always be less than $\frac{\sigma}{2}$ i.e. half the tensile stress.

Q1]e] Classification of stainless steels.

(05)

Solution:-

(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 0.15% 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 (0.08 – 0.2%) 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] What do you understand by Composite material? Explain their properties and applications. (10)

Solution:-

(i) 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.

(ii) Each of the various components retains its identity in the composite and maintains its characteristic structure and properties.

(iii) Composite materials generally possess stiffness, strength, high temperature performance, corrosion resistance, hardness, and conductivity.

(iv) 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.

Properties of composites:-

(i) Tensile strength of composite is four to six times greater than conventional materials like steel, aluminium, etc.

(ii) Improved torsion stiffness and impact properties.

(iii) Higher fatigue endurance limit (up to 60% of the ultimate tensile strength).

(iv) Composites are less noisy while in operation and provide lower vibration transmission.

(v) Long life offers excellent fatigue, impact, environmental resistance and reduced maintenance.

Applications of composites:-

(i) Composites are suitable for aerospace applications which required light weight, stiffness and fatigue resistance.

(ii) Sporting equipment such as golf club shafts, baseball bats, fishing rods and tennis rackets.

(iii) Bicycle frames are also available in a variety of fibrous composites.

(iv) Composites are useful in an automobile such as body panels, drive shafts, springs, bumpers, oil pans, instruments panels and engine covers.

Q2]b] What is fatigue? Explain fatigue testing in detail.

(10)

(A) Fatigue:-

(i) With frequent stress fluctuations, the material may fail at stress level far below its static ultimate tensile strength is called as 'Fatigue Failure'.

(ii) 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.

(iii) Fatigue failure occurs in aircraft, compressors, pumps, turbines, etc., subject to repeated loading and vibration.

(B) Fatigue Testing:-

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

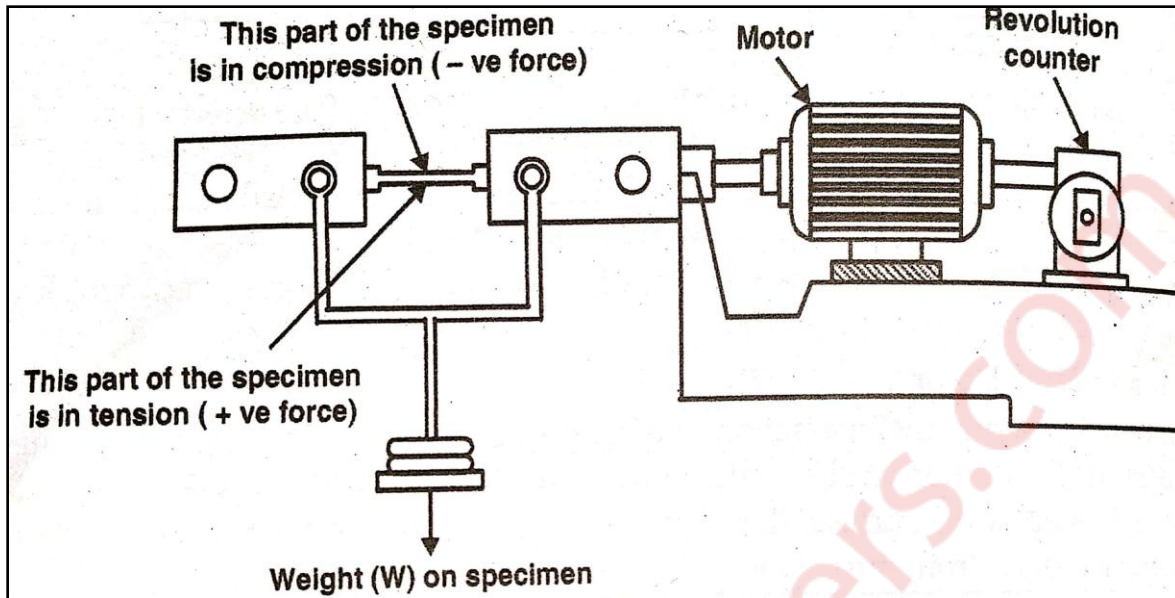


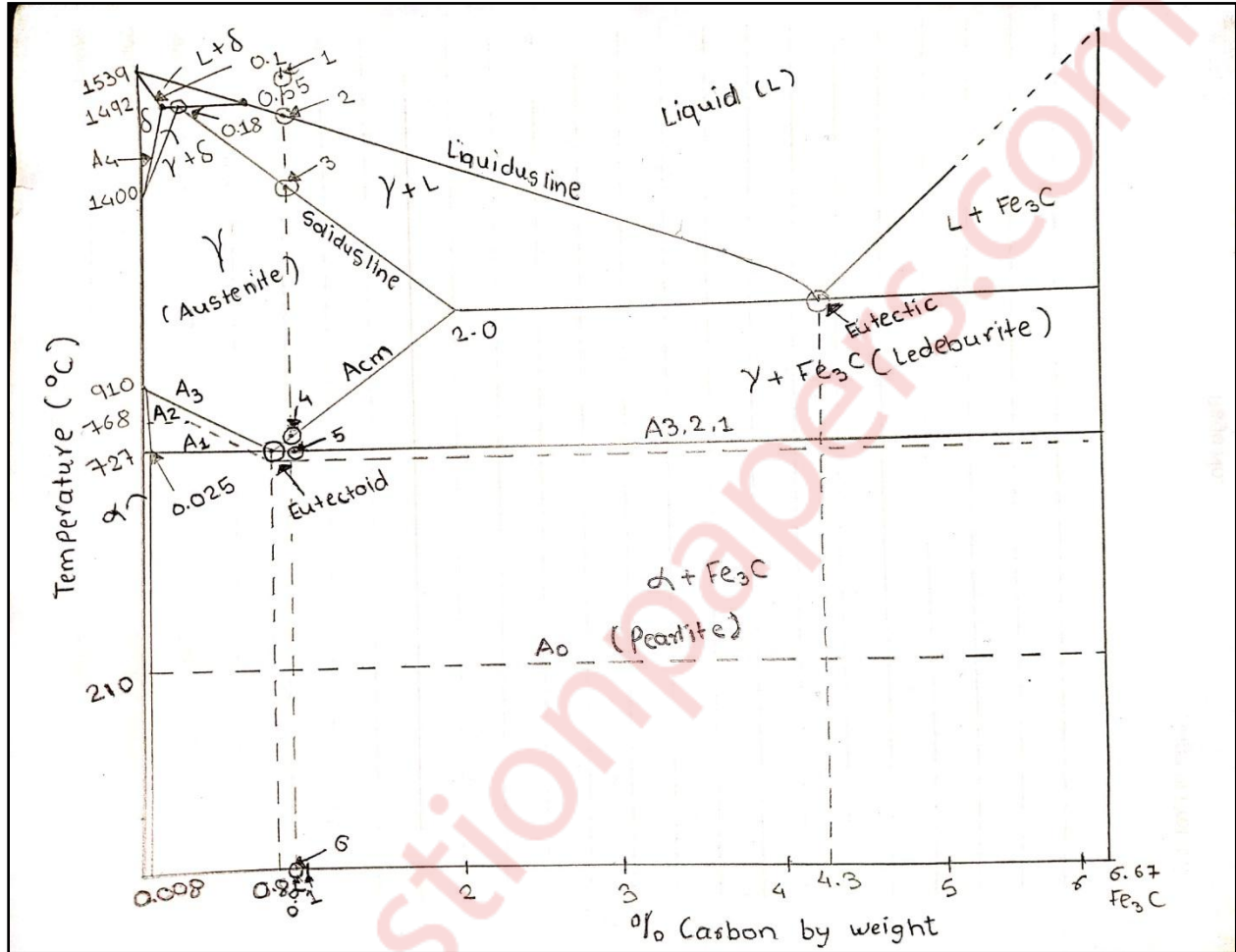
Fig: Rotating Beam Fatigue Testing Machine

- (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.
- (5) The fatigue test is normally conducted using at least 8-12 specimens in order to provide sufficient information for the interpretation of fatigue behavior of the tested material.

Q3]a] Draw Fe-Fe₃C Diagram and explain cooling of 0.9% C alloy in the Fe-Fe₃C diagram.

(10)

Solution:-



Fig(a): Fe-Fe₃C Diagram with 0.9% cooling

The above Fig. shows Fe-Fe₃C equilibrium diagram. In this diagram vertical line is drawn at 0.9% 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 alloy is in the liquid state.

Point 2: From point 1 to point 2 alloy is in the liquid state.

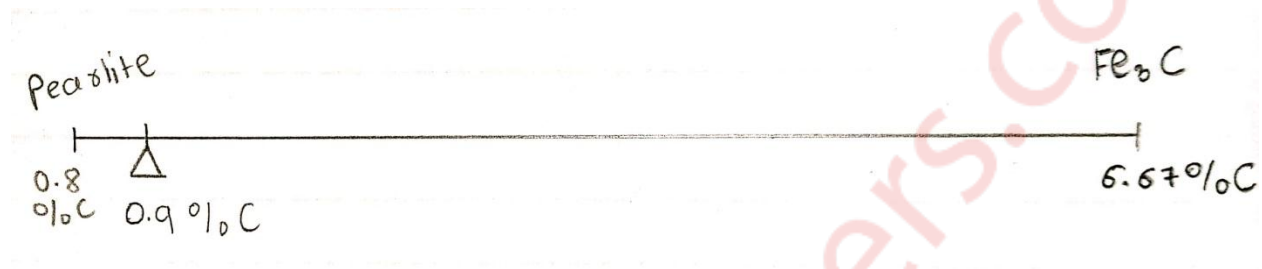
At point 2, solidification process starts and liquid is trying to solidify into Y-phase.

Point 2-3: Just below point 2, solidification process starts and liquid is converted into 100% solid this point is on the solidus line.

Point 3-4: At point 3, liquid is converted into 100% γ (austenite). There is no change in structure from point 3 to point 4.

Point 4-5: At point 4, Fe_3C starts separating out on the grain boundaries of austenite. As the temperature decreases, the amount of Fe_3C increases and austenite decreases.

Point 5: It is on eutectoid line and at 727°C constant temperature. The lever rule can be applicable at this constant temperature to calculate exact percentage of pearlite and Fe_3C . Fig (b) shows lever arm at 0.9% C steel and 727°C constant temperature.



Fig(b): Lever Arm at 727°C Constant temperature

$$\begin{aligned} \% \text{ Amount of pearlite} &= \frac{\text{Opposite arm length}}{\text{Total arm length}} \times 100 \\ &= \frac{(6.67 - 0.9)}{(6.67 - 0.8)} \times 100 \\ &= 98.29\% \end{aligned}$$

$$\% \text{ Amount of } \text{Fe}_3\text{C} = \frac{(0.9 - 0.8)}{(6.67 - 0.8)} \times 100 = 1.71\%$$

At point 5, as per lever rule, there is 98.29% pearlite and 1.71% Fe_3C .

Point 5-6: Just below point 5, γ is not stable and by eutectoid transformation convert into pearlite. cooling from point 5 to point 6 does not result in significant change in structure. The same structure is observed at room temperature.

Q3]b] How are dislocations regenerated at Frank Reed Source? Explain with neat diagram. (10)

Solution:-

(i) The method by which dislocations could be generated from existing dislocations was proposed by Frank and Reed and is commonly called as Frank Reed source.

(ii) As the dislocations are moved by applying stress, their density increases (i.e. they regenerate) if they come across any obstacle such as second phase particles, precipitate particles, a local stress field in the lattice, grain boundaries or impurity particles.

(iii) In presence of such obstacles, the dislocation forms loops (mixed dislocations) around the obstacles. This clearly indicates that the dislocation density increases during plastic deformation.

(iv) Steps to regenerate dislocations:-

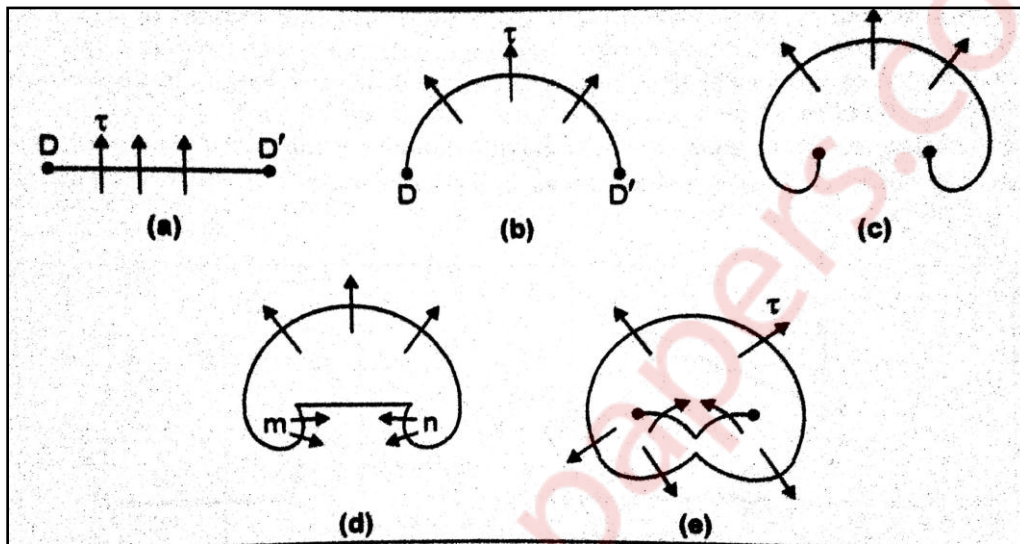


Fig: Frank Reed Source

(a) Consider a dislocation line DD' lying in a slip plane. The dislocation line leaves the slip plane at points D and D' .

(b) If D and D' were nodes where the dislocation in the plane of the paper intersects dislocations in other slip planes or the anchoring could be caused by impurity atoms. If shear stress ' τ ' act in slip plane, the dislocation line produces a slip. It is given in equation.

(c) The maximum value of shear stress is required when dislocation becomes semi-circle so that ' R ' has a minimum value $\frac{1}{2}$.

$$\tau = \frac{Gb}{l}$$

Where,

τ = Shear stress

b = Berger vector

G = Dislocation density

L = Spacing between two jogs

(d) Beyond this point, 'R' will increase and dislocation loop will continue to expand under decreasing ' τ '. When loop reaches the segments at 'm' and 'n' will meet and touches each other and form new dislocations. 'm' and 'n' are edge orientation but of opposite sign.

(d) Now loop can continue to expand under increased shear stress and pinned segments DD' is in a position to repeat the process.

This process can be repeated over and over again at a single source, each time producing dislocation loop which produces a slip of one Berger vector along the slip plane.

Q4]a] Draw and explain construction of Time Temperature Transformation (TTT) diagram. Also indicate various cooling patterns on the diagram. (10)

Solution:-

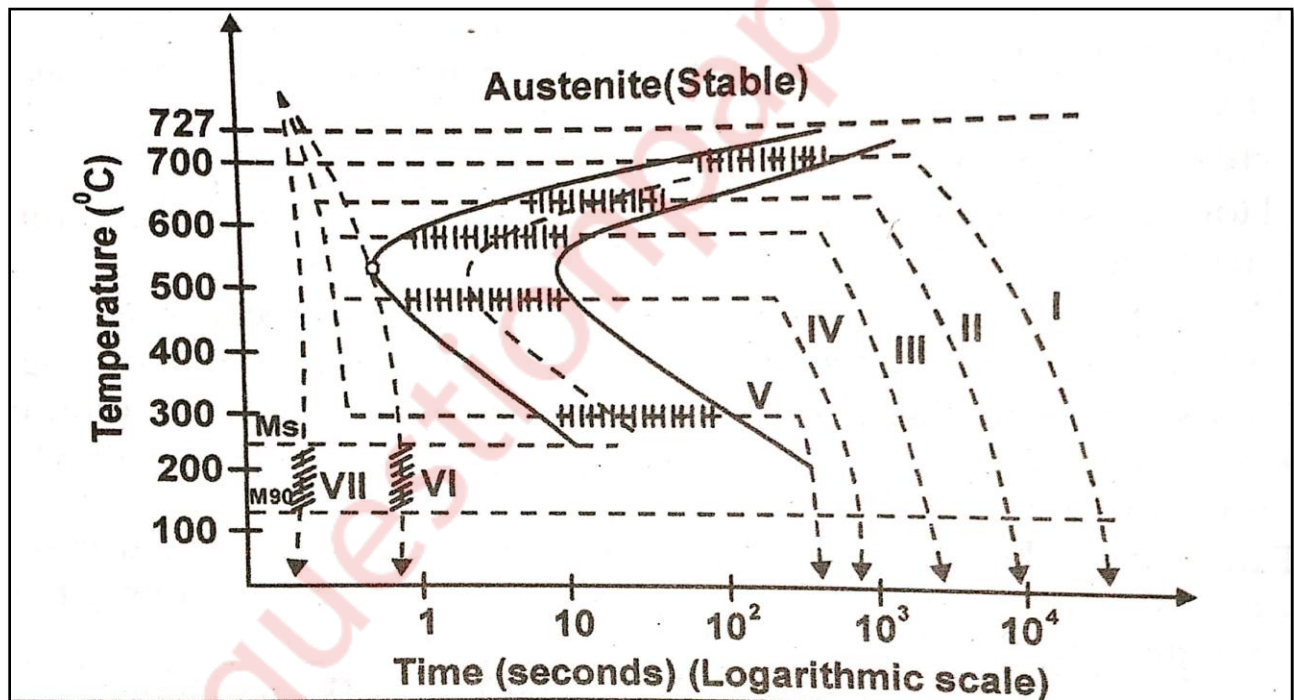


Fig :- Time-Temperature-Transformation (TTT) diagram

(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 pearlite.

(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.

Q4]b) Derive an expression for Griffith theory of brittle fracture. Explain Orowan's Modification. (10)

Solution:-

(A) Derivation of Expression for Griffith Theory:-

Suppose we have an elliptical internal crack as shown in Fig. The elastic strain energy that has been released per unit volume by the crack

$$= \frac{1}{2} \times \text{Stress} \times \text{Strain}$$

For each upper and lower surfaces of crack.

(1) Total elastic energy per unit volume (U_e) when crack introduced is,

$$\begin{aligned}
 U_e &= \left(\frac{\pi}{4} 4c^2 \times t \right) \times \frac{1}{2} \times \sigma \times \frac{\sigma}{E} \times 2 \\
 &= (\pi c^2 \times t) \times \frac{\sigma^2}{E} \quad (t = 1 \text{ unit thickness}) \\
 U_e &= \frac{\pi c^2}{E} \times \sigma^2
 \end{aligned}$$

(2) Total surface Energy ($U\sigma$):

Taking into consideration, the plastic deformation of the surface of crack requiring energy 'p' per unit area, the total energy required to create the crack is,

$$U\sigma = 4C[\gamma + p]$$

Where,

γ = Energy required producing unit area of the new surface.

(3) The change in energy during crack forms (ΔU):

ΔU = Total surface energy + Elastic energy released

$$\Delta U = 4C[\gamma + p] + \left[-\frac{\pi c^2}{E} \times \sigma^2 \right]$$

Negative (-) sign of elastic energy indicates that elastic energy stored in the material is released as crack forms

$$\Delta U = 4C[\gamma + p] - \frac{\pi c^2 \sigma^2}{E} \quad \dots\dots(1)$$

The critical value can be found by setting $\frac{d\Delta U}{dc} = 0$.

Set $\frac{d\Delta U}{dc} = 0$ in equation (1) for critical value, (Taking derivative with respect to 'c')

$$4[\gamma + p] = \frac{2\pi c \sigma^2}{E}$$

$$\sigma^2 = \frac{4[\gamma + p] \cdot E}{2\pi c}$$

$$\sigma_{\text{crit.}} = \sqrt{\frac{2 E [\gamma + p]}{\pi c}}$$

This is the required equation.

(B) Orowan's Modification:-

(i) The metal is considered to contain small, weak regions, which may be areas of favorable orientation for slip or areas of high-stress concentration due to metallurgical notches such as inclusions.

(ii) If the loading or the stress is such that the total plastic strain in the weak region exceeds the critical value, a crack is formed.

Q5]a] Explain slip and twin mechanism of plastic deformation. (10)

Solution:-

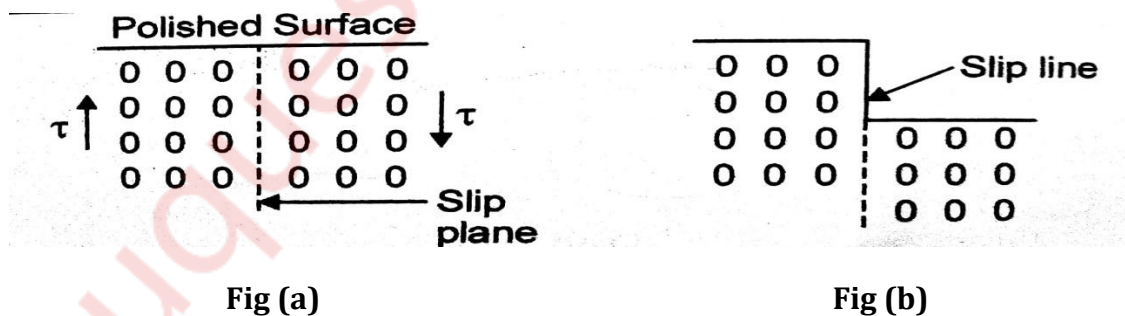
(A) Slip Mechanism:-

(i) Slip is a mechanism of deformation where one part of crystal moves, glides or slips over another part of along certain planes known as slip plane. Slip occurs when shear stress applied exceeds a critical value.

(ii) During slip, each atom usually moves a same integral number of atomic distances along the slip plane producing a step, but the orientation of the crystal remains the same. Steps observable under the microscope as straight lines are called slip lines.

(iii) Fig (a) shows the slip process under a shear load in a single crystal. Because of plastic deformation, the crystal is divided into layers or slip blocks which are displaced in reference to each other and are separated by thin layers in which a considerable displacement of atoms takes place.

(iv) In Fig. (a), a shear stress is applied to a metal cube with a top polished surface. Slip occurs when the shear stress exceeds a critical value. The atoms move an integral number of atomic distances along slip plane, and step is produced in the polished surface as shown in Fig. (b)



(B) Twin Mechanism:-

(i) Twinning is that process by which a portion of crystal takes up an orientation which makes that portion a mirror image of parent crystal.

(ii) Twins may be produced by mechanical deformation, or as the result of annealing following plastic deformation.

(iii) the first types of twins are known as mechanical twins, the latter termed as annealing twins. Mechanical twins are produced in BCC and HCP metals under conditions of rapid rate of loading, i.e. shock loading and decreased temperature.

(iv) However, FCC metals are not ordinarily considered to deform by mechanical twinning, although gold-silver alloys twin fairly readily at low temperature.

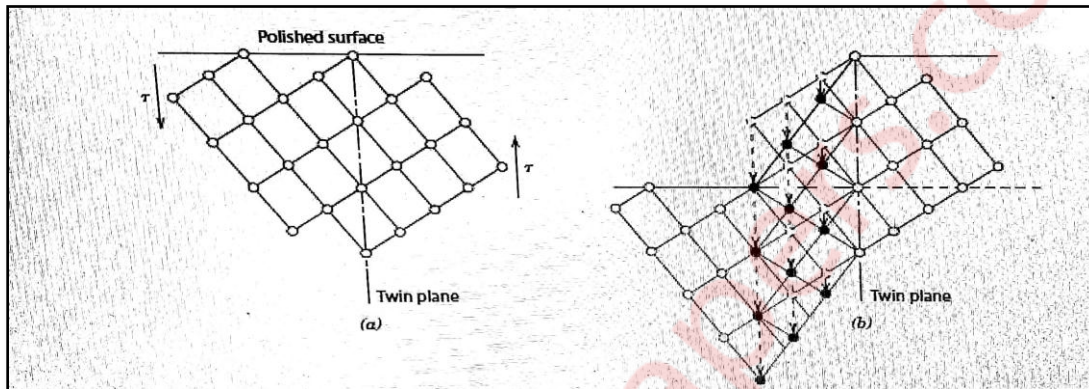


Fig: Twinning Process

Q5]b] Classify Crystal Imperfections. Distinguish between Edge and Screw dislocation.

(10)

Solution:-

(A) Classification of crystal imperfections:-

(i) Point Defects:

- (a) Vacancies
- (b) Interstitialcy
- (c) Impurity Atoms
- (d) Frenkel Imperfection
- (e) Schottky Imperfection

(ii) Line Defects:

- (a) Edge dislocations
- (b) Screw dislocations

(iii) Planer or surface defects:

- (a) Grain Boundaries
- (b) Tilt Boundaries
- (c) Twin Boundaries

(iv) Volume defects:

- (a) Inclusions
- (b) Voids

(B) Difference between Edge and Screw Dislocation:-

Edge Dislocation	Screw Dislocation
(i) 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.	(i) If the plane of atoms follows dislocation in a helical or screw path then it is called as screw dislocation
(ii) The relation between dislocation line and berger vector (b) is perpendicular to each other.	(ii) The relation between dislocation line and berger vector (b) is parallel to each other.
(iii) The direction of dislocation line movement relative to berger vector is parallel.	(iii) The direction of dislocation line movement relative to berger vector is perpendicular.
(iv) It is occurring due to glide and climbs motion.	(iv) It is occurring due to glide motion.
(v) Edge dislocations are of two types positive and negative dislocation.	(v) Screw Dislocations are of two types clockwise and anti-clockwise dislocation.

Q6] Write short notes on any four.

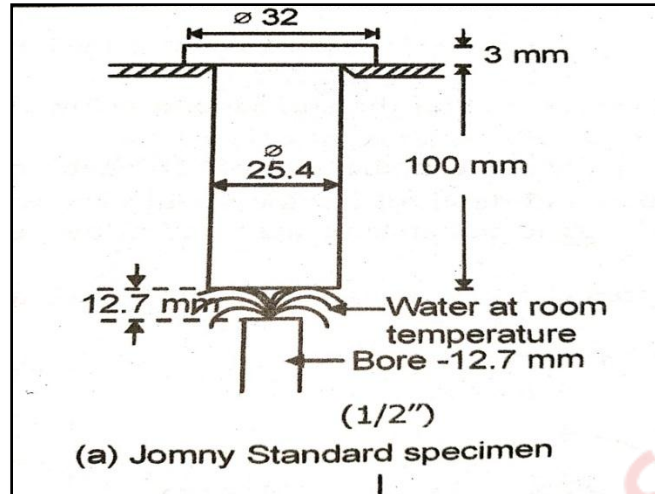
Q6]a] Hardenability test.

(05)

Solution:-

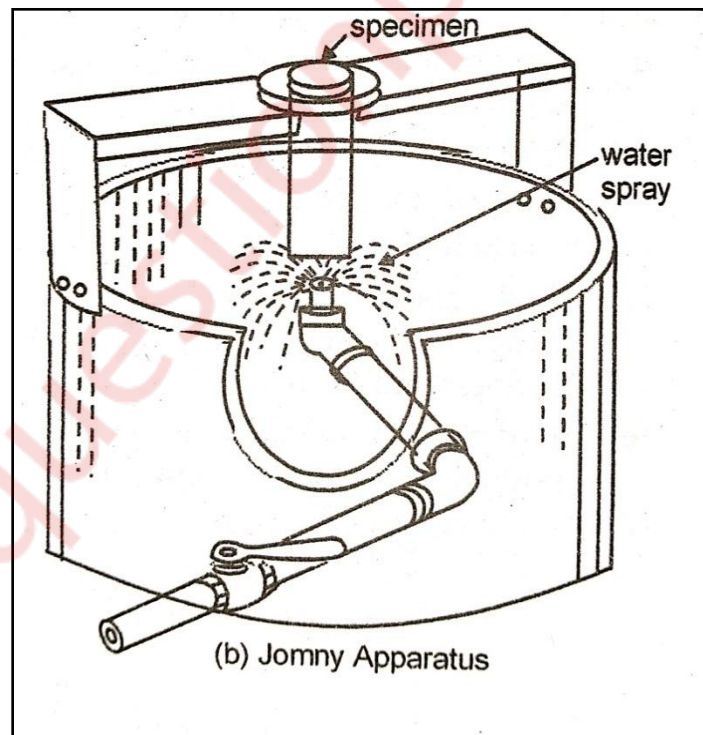
Jominy End Quenched test:-

(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).



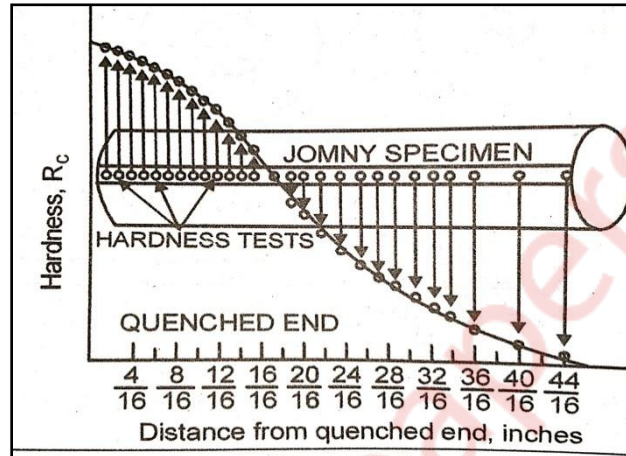
(2) The specimen is heated up to austenite temperature and held at constant temperature for 1 hour and quickly transferred to a fixture (quenching jig).

(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.



Q6]b] Martempering.

(05)

Solution:-

(i) Martempering is a heat treatment for steel involving austenitization followed by step quenching, at a rate fast enough to avoid the formation of ferrite, pearlite or bainite to a temperature slightly above the martensite (M_s) point.

(ii) After heating the steel component to the austenitic temperature, it is quenched rapidly by avoiding the nose of the TTT diagram to a temperature between the nose and M_s temperature.

(iii) The component is held in bath until it reaches the temperature of the medium and then it is cooled further to room temperature in air or sometimes in oil.

(iv) Austenite is transformed into martensite during cooling up to room temperature.

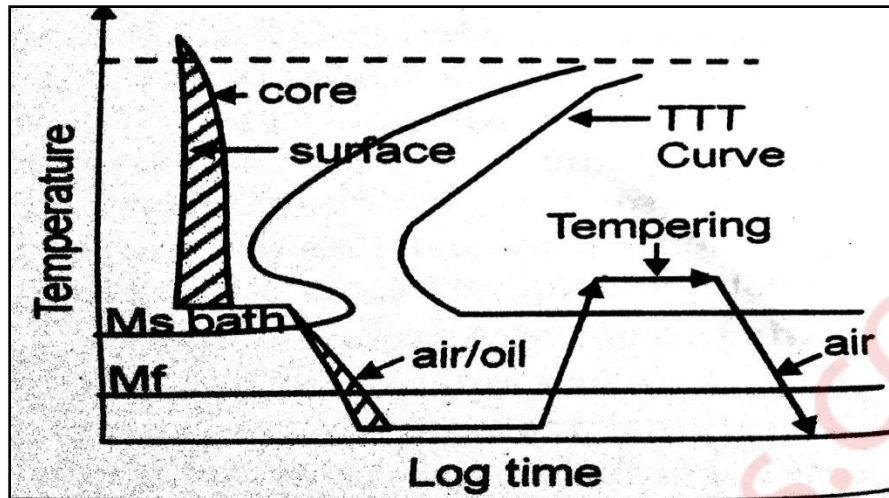


Fig: Martempering Process

Q6]c] Synthesis of Nanomaterials.

(05)

Solution:-

(i) Different Methods (Top-down and Bottom up approaches). Growth Kinetics (Cluster Formation followed by Nucleation and Growth) Synthesis of Nanomaterials Design and preparation of nanoparticles with high functionality i.e., to fabricate nanomaterials which have the suitable properties for applications The fabrication of nanomaterials of tailored properties involve the control of Size, shape, structure, composition and purity of their constituents.

(ii) Nanoparticle Synthesis Bottom-Up approach (or self-assembly approach) Top-Down approach. Bottom up approach refers to the build up of a material from the bottom: atom by atom, molecule by molecule. Atom by atom deposition leads to formation of Self- assembly of atoms/molecules and clusters. These clusters come together to form self- assembled monolayers on the surface of substrate. Top down approach refers to slicing or successive cutting of a bulk material to get nano sized particle. There are two approaches for synthesis of nanomaterials and the fabrication of nano structures.

(iii) Mechanical methods: - cutting , etching, grinding - ball milling } Lithographic techniques: - Photo Lithography - Electron Beam Lithography. Physical and chemical processing methods: Physical techniques- Physical Vapor Deposition (PVD): involves condensation of vapor phase species - Evaporation (Thermal , e-beam) - Sputtering - Plasma Arcing, - Laser ablation, Chemical techniques- CVD: Deposition of vapor phase of reaction species - PECVD(RF-PECVD,MPECVD) Self-assembled Monolayer : Electrolytic deposition, Sol-gel method, Microemulsion route, pyrolysis.

(iv) Physical processing methods: Bottom-Up approach Top-Down approach All the synthesis/deposition techniques are divided into two categories based on the phase of starting

material All the Bottom-up techniques, the starting material is either gaseous state or liquid state of matter In Top-down techniques, the starting material is solid state.

Q6]d] Recrystallization annealing

(05)

Solution:-

Recrystallization annealing is an annealing process applied to cold-worked metal to obtain nucleation and growth of new grains without phase change. This heat treatment removes the results of the heavy plastic deformation of highly shaped cold formed parts. Following are the stages of 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.

Q6]e] Rule of mixtures for composites.

(05)

Solution:-

(i) 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.

(ii) These rule-of mixtures equations predict that the elastic modulus should fall between an upper bound and lower bound.

(iii) For upper bound the equation is,

$$E_c(u) = E_m V_m + E_p V_p$$

(iv) For lower bound the equation is,

$$E_c(l) = \frac{E_m E_p}{V_m E_p + V_p E_m}$$

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.

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