SHAMBHUNATH INSTITUTE OF ENGINEERING AND TECHNOLOGY
Subject: Materials Engineering Subject Code: KME 303
B.Tech. – SEMESTER-III
FIRST SESSIONAL EXAMINATION, ODD SEMESTER, (2019-20)
Branch: Mechanical Engineering
Time –1hrs 30 min Maximum Marks – 30

SOLUTION

SECTION - A

Q1.

a) Classify various engineering materials.
Ans a): Materials are classified as follows:

Metals: These materials are characterized by high thermal and electrical conductivity; strong yet deformable under applied mechanical loads; opaque to light (shiny if polished). E.g.: aluminum, steel, brass, gold.

Ceramics: These are inorganic compounds, and usually made either of oxides, carbides, nitrides, or silicates of metals. Ceramics are typically partly crystalline and partly amorphous. Examples: glass, porcelain, many minerals.

Polymers: Polymers in the form of thermo-plastics (nylon, polyethylene, polyvinylchloride, rubber, etc.) consist of molecules that have covalent bonding within each molecule and van der Waals forces between them. Polymers in the form of thermo-sets (e.g., epoxy, phenolics, etc.) consist of a network of covalent bonds. They are based on H, C and other non-metallic elements. Polymers are amorphous, except for a minority of thermoplastics.

Composite materials: Composite materials are multiphase materials obtained by artificial combination of different materials to attain properties that the individual components cannot attain. The main classes of composites are metal-matrix, polymer-matrix, and ceramic-matrix.

Biomaterials: These are any type material that can be used for replacement of damaged or diseased human body parts. Primary requirement of these materials is that they must be biocompatible with body tissues, and must not produce toxic substances. Examples: Stainless steel, Co-28Cr-6Mo, Ti-6Al-4V, ultra high molecular weight poly-ethelene, high purity dense Al-oxide, etc.

b) Explain the term resilience.
Ans
b) This Energy stored by the body to regain its original shape is called Strain Energy. The strain Energy stored in a body due to the external loading is known as the Resilience.
Proof Resilience

The maximum amount of the strain energy can be stored in the body up to the elastic limit is defined as the Proof resilience.

c) What is the difference between crystalline and amorphous materials?

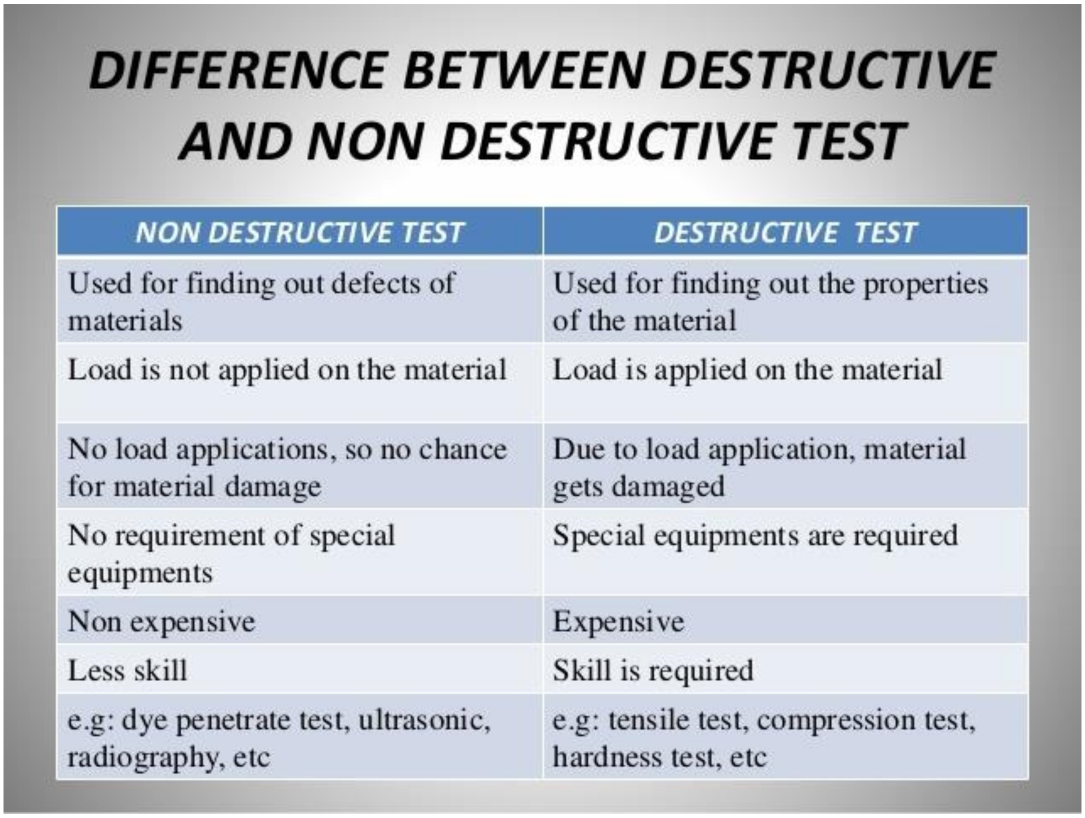
Difference between Crystalline and Amorphous	
CRYSTALLINE SOLIDS	AMORPHOUS SOLIDS
Atoms are arranged in regular 3 dimension	They do not have regular arrangement
Sharp melting point	No particular melting point
Anisotropic	Isotropic
True solid	Pseudo solid
Symmetrical	Unsymmetrical
More rigid	Less rigid
Long range order	Short range order
Example: Potassium nitrate, copper	Example: Cellophane, polyvinyl chloride

d) Explain Elasticity and plasticity.

Ans:

Elasticity is the property of a body to recover its original configuration (shape and size) when you remove the deforming forces. Plastic bodies do not show a tendency to recover to their original configuration when you remove the deforming forces. Plasticity is the property of a body to lose its property of elasticity and acquire a permanent deformation on the removal of deforming force.

e) Explain DT and NDT.

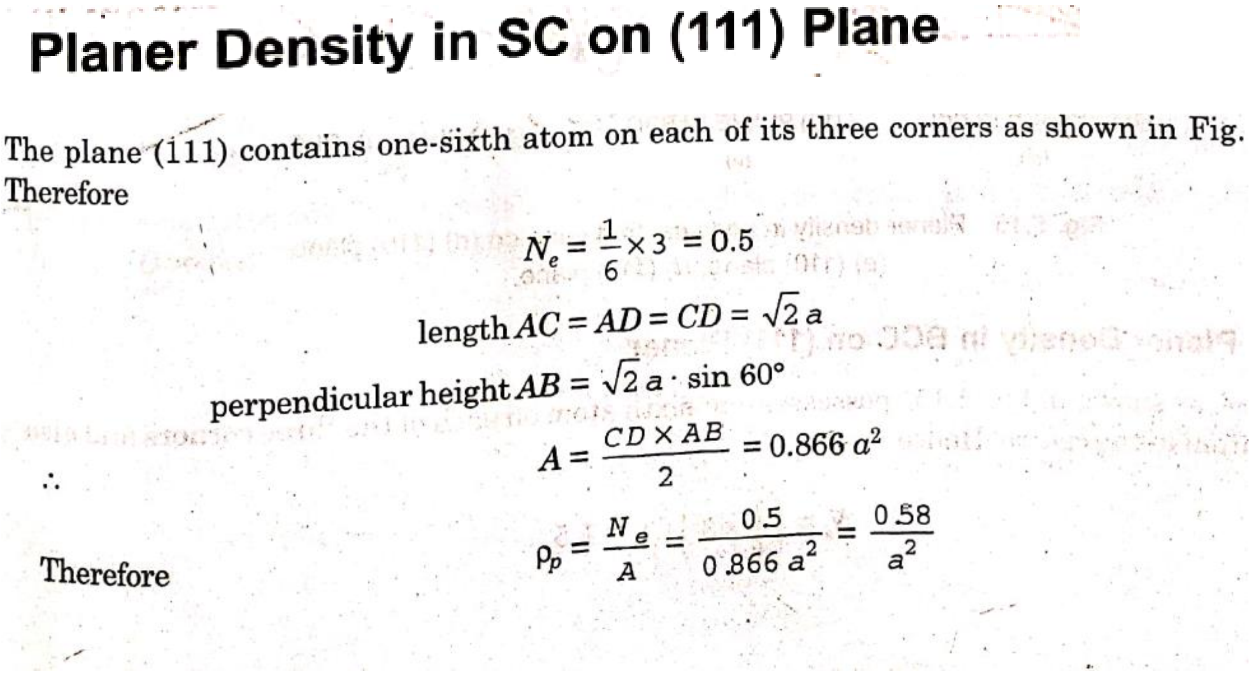


DIFFERENCE BETWEEN DESTRUCTIVE AND NON DESTRUCTIVE TEST

NON DESTRUCTIVE TEST	DESTRUCTIVE TEST
Used for finding out defects of materials	Used for finding out the properties of the material
Load is not applied on the material	Load is applied on the material
No load applications, so no chance for material damage	Due to load application, material gets damaged
No requirement of special equipments	Special equipments are required
Non expensive	Expensive
Less skill	Skill is required
e.g: dye penetrate test, ultrasonic, radiography, etc	e.g: tensile test, compression test, hardness test, etc

SECTION - B

Q 2. a. Calculate the planer density in SC (111) plane and BCC (110) plane.



Planer Density in SC on (111) Plane

The plane (111) contains one-sixth atom on each of its three corners as shown in Fig. Therefore

$$N_e = \frac{1}{6} \times 3 = 0.5$$

$$\text{length } AC = AD = CD = \sqrt{2}\,a$$

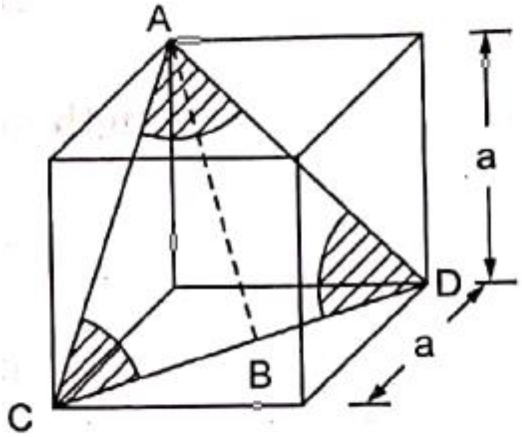
$$\text{perpendicular height } AB = \sqrt{2}\,a \cdot \sin 60°$$

∴

$$A = \frac{CD \times AB}{2} = 0.866\,a^2$$

Therefore

$$\rho_p = \frac{N_e}{A} = \frac{0.5}{0.866\,a^2} = \frac{0.58}{a^2}$$



(111) PLANE IN SC

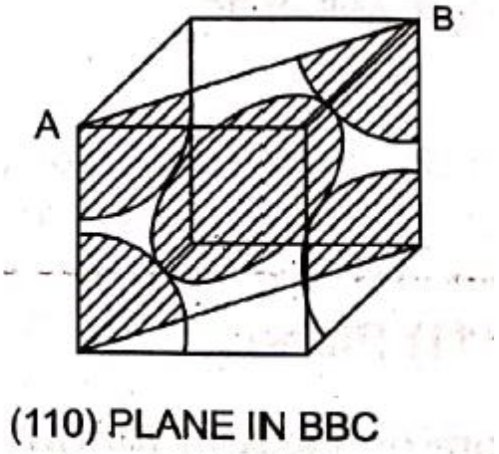
Planer Density in BCC on (110) Plane

$$N_e = \left(\frac{1}{4} \times 4\right) + 1 = 2$$

length $AB = \sqrt{2}\, a$

$$A = a\sqrt{2}\, a = \sqrt{2}\, a^2$$

$$\rho_p = \frac{N_e}{A} = \frac{2}{\sqrt{2}\, a^2} = \frac{1.414}{a^2}$$



(110) PLANE IN BBC

Q 2. b. Explain annealing process in detail.
Ans:

Annealing

Annealing is a heat treatment process which alters the microstructure of a material to change its mechanical or electrical properties. Typically, in steels, annealing is used to reduce hardness, increase ductility and help eliminate internal stresses.

Benefits

Annealing will restore ductility following cold working and hence allow additional processing without cracking. Annealing may also be used to release mechanical stresses induced by grinding, machining etc. hence preventing distortion during subsequent higher temperature heat treatment operations. In some cases, annealing is used to improve electrical properties.

Application & materials

One of the main applications of annealing is reversing the effects of work hardening. During cold forming, drawing, bending etc. the material can become hardened to the point where further working can be impossible or result in cracking. An annealing operation at this stage will make the material more ductile, permitting further forming. In a similar manner, annealing is utilized to remove the internal stresses which occur when welds solidify.

Besides steels, other metals may also benefit from annealing such as copper, aluminium, and brass.

Process details

Annealing is a generic term and can be further classified according to temperature and atmosphere.

For steels, subcritical annealing takes place at 1000°F – 1200°F, so there is no crystal structure change. Intermediate annealing is carried out at 1200°F – 1400°F, so there is some transformation to austenite and full annealing involves completely austenitizing the work at 1500°F – 1700°F.

Parts can be annealed in a vacuum or reducing atmosphere where a bright surface finish is needed. Annealing in air is employed where surface finish is not an important factor and an endothermic/neutral atmosphere may be used during annealing to control decarburisation.

Q2. c. Explain the following hardening process: i) Martempering and ii) Austempering.
Ans:

Austempering

Austempering is a heat treating process for medium-to-high carbon ferrous metals which produces a metallurgical structure called bainite. It is used to increase strength, toughness, and reduce distortion. Parts are heated to the hardening temperature, then cooled rapidly enough to a temperature above the martensite start (Ms) temperature and held for a time sufficient to produce the desired bainite microstructure.

Benefits

Austempering is a hardening process for metals which yields desirable mechanical properties including:

- Higher ductility, toughness, and strength for a given hardness.
- Resistance to shock
- Reduced distortion, specifically with thin parts.

Application & materials

Austempering is primarily used to harden medium to high carbon steels in the range of 35-55 HRC when toughness is required with the additional benefit of a reduction in distortion. The process is widely used in the automotive industry for clips and other parts where maximum flexibility and toughness are required.

The range of austempering applications generally encompasses parts fabricated from sheet or strip of small cross section. Austempering is particularly applicable to thin section carbon steel parts requiring exceptional toughness.

Austempering is most effective on medium to high carbon ferrous alloys and ductile iron castings, such as SAE 1045 to 1095, 4130, 4140, 5160, 6150 (C45 to C100, 25CrMo4, 42CrMo4, 50CrV4) and for hardness requirements needed in between HRC 38-52.

Process details

Steel is austempered by:

- Heating to a temperature within the austenitising range, usually 790°-915°C (1450 -1675°F).
- Quenched in a bath (molten salt, or occasionally oil) maintained at a constant temperature, usually in the range of 260°-370°C (500-700°F).
- Held for a time to allow transformation to a bainite microstructure.
- Cooled to room temperature.

Martempering/Marquenching

Marquenching/Martempering is a form of heat treatment applied as an interrupted quench of steels typically in a molten salt bath at a temperature right above the martensite start temperature. The purpose is to delay the cooling for a length of time to equalise the temperature throughout the piece. This will minimise distortion, cracking and residual stress.

Benefits

Reduced cracking due to thermal stress. Reduced residual stress in the quenched part section for parts with varying geometry, size, or weight.

Application & materials

Since marquenching lowers the residual thermal stress, it is used for parts with complex geometries, diverse weights, and section changes.

Marquenching is used primarily to minimise distortion and eliminate cracking. Alloy steels are generally more adaptable to marquenching. In general, any steel part or grade of steel responding to oil quenching can be marquenched to provide similar physical properties.

Process details

Marquenched parts are tempered in the same manner as conventional quenched parts.

Steel is marquenched and tempered by:

- Quenching from the austenitising temperature into a hot fluid medium at a temperature usually above the martensitic range;
- Holding in the quenching medium until the temperature throughout the steel is substantially uniform;
- Cooling at a moderate rate to prevent large differences between the outside and the centre of the section; and
- Tempering in conventional fashion.

Q 2.d. Differentiate between: i) Ductility and brittleness and ii) Toughness and hardness.

Ans: Differences between ductility and brittleness

Ductility	Brittleness
Ductility is defined as the ability of solid material to plastically deform to a larger extent before fracture when it is subjected to external tensile loading.	Brittleness is defined as the tendency of solid material to undergo negligible plastic deformation before fracture when it is subjected to external tensile loading.
Solid material having high ductility is called Ductile Material.	Solid material that shows brittleness is called Brittle Material.
Percentage elongation of the ductile materials	Percentage elongation of the brittle materials

before fracture under tensile testing is higher.	before fracture under tensile testing is very less.
Ductile materials fail gradually by neck formation under the action of external tensile loading.	Brittle materials fail by sudden fracture (without any warning such as necking).
Energy absorbed by ductile materials before fracture under tensile testing is more.	Brittle materials absorb very small energy before fracture.
Various metal forming operations (such as rolling, forging, drawing, bending, etc.) can be performed on ductile materials.	Forming operations cannot be easily performed on brittle materials. For example, brittle material cannot be drawn into wire.
Ductile materials show longer life when subjected to fatigue loading.	Brittle materials fail faster when subjected to fatigue loading.
Examples of ductile material: • Mild steel • Aluminum • Copper • Tin	Examples of brittle material: • Cast iron • Ceramics such as glass, cement, concrete, etc. • Stone

Hardness is the measurement of how much a material resists to penetration from a semi-static force. It is tested for with an indenter hardness machine usually (but not solely) by measuring the size of the indentation after releasing the load.

The most well known of the hard materials is diamond. It is so hard it is usually used as the penetration material (for the Vickers Hardness, for example). A typically soft material is aluminum metal, or any plastic. Hardness correlates well with scratch proof ability meaning that harder materials are harder to scratch.

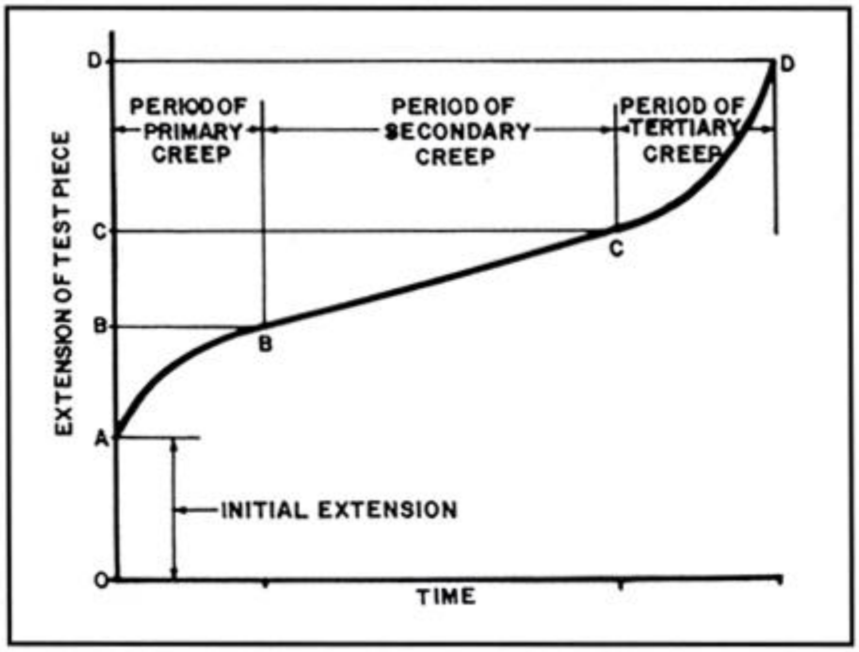
Toughness is the ability of a material to absorb energy when impacted. It is tested with impact Charpy or Izod testing machines by measuring how much a predetermined weight will rise after impacting and breaking the piece under test. The height correlates to how much energy the weight has left in its motion so it is an indication of how much energy the material can absorb.

Materials known to be very tough are stainless steels and titanium alloys. Materials known to be very fragile (the opposite of tough) are ceramics such as glasses or porcelain.

SECTION - C

Q 3.a) Explain creep. What are the different stages in the creep curve?

Ans: Creep may be defined as a time-dependent deformation at elevated temperature and constant stress. It is a time- dependent deformation under a certain applied load. Generally occurs at high temperature (thermal creep), but can also happen at room temperature in certain materials (e.g. lead or glass), albeit much slower. As a result, the material undergoes a time dependent increase in length, which could be dangerous while in service.



Creep Stages
- Primary Creep: starts at a rapid rate and slows with time.
- Secondary Creep: has a relatively uniform rate.
- Tertiary Creep: has an accelerated creep rate and terminates when the material breaks or ruptures.

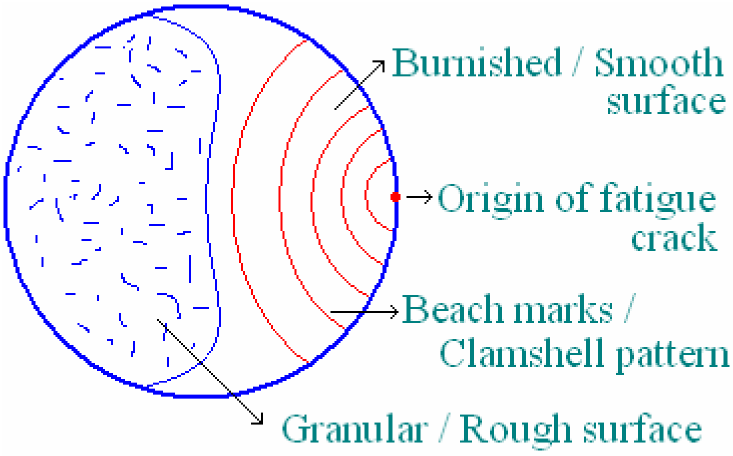
It is associated with both necking and formation of grain boundary voids.
Characteristics of Creep
- Creep in service is usually affected by changing conditions of loading and temperature
- The number of possible stress-temperaturetime combinations is infinite.
- The creep mechanisms is often different between metals, plastics, rubber, concrete.

Q3. b) What is fatigue and fatigue limit? Explain in detail.

Ans:

Fatigue

Fatigue Failures occurring under conditions of dynamic or alternating loading are called fatigue failures, presumably because it is generally observed that these failures occur only after a considerable period of service. Fatigue failure usually occurs at stresses well below those required for yielding, or in some cases above the yield strength but below the tensile strength of the material. These failures are dangerous because they occur without any warning. Typical machine components subjected to fatigue are automobile crank-shaft, bridges, aircraft landing gear, etc. Fatigue failures occur in both metallic and non-metallic materials, and are responsible for a large number fraction of identifiable service failures of metals. The fatigue crack nucleates at the stress concentration. Generally, the fatigue fracture surface is perpendicular to the direction of an applied stress. A fatigue failure can be recognized from the appearance of the fracture surface, which shows a smooth and polished surface that corresponds to the slow growth of crack, when the crack faces smoothen out by constant rubbing against each other and a rough/granular region corresponds to the stage of fast growth, after critical conditions is attained where member has failed in a ductile manner when cross section was no longer able to carry the applied load. The region of a fracture surface that formed during the crack propagation step may results in characteristic pattern of concentric rings spread over the smooth region of the fracture surface, known as beach marks or striations, radiating outward from the point of initiation of the failure, as shown in figure. Beach marks (also known as clamshell pattern) are macroscopic dimensions and may be observed with the unaided eye. These markings are found for components that experienced interruptions during the crack propagation stage. Each beach mark band represents a period of time over which crack growth occurred. On the other hand fatigue striations are microscopic in size and subject to observation with the electron microscope (either TEM or SEM). The relatively widely spaced striations are caused by variations in the stress amplitude during the life of the component. On a much finer level, a large number of striations may be sometimes being seen. The width of each striation here is equal to the distance by which the crack grows during one cycle. Any point with stress concentration such as sharp corner or notch or metallurgical inclusion can act as point of initiation of fatigue crack. FigurE:



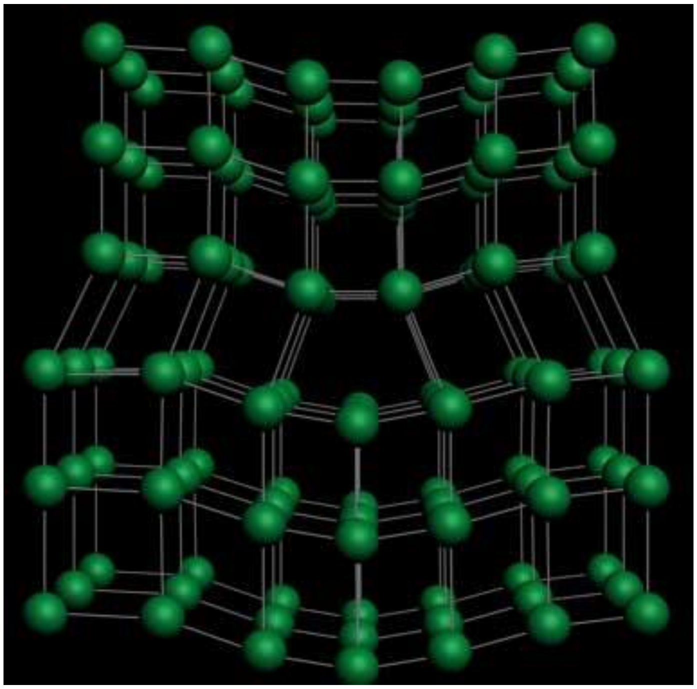
Schematic of fatigue fracture surface. Three basic requisites for occurrence of fatigue fracture are: (a) a maximum tensile stress of sufficiently high value (b) a large enough variation or fluctuation in the applied stress and (c) a sufficiently large number of cycles of applied stress. The stress cycles that are evident in fatigue studies are characterized using many parameters, such as mean stress, alternating stress, stress ratio and amplitude ratio.

Q 4.a) Explain with simple sketches the following: a) Edge dislocation and b) Screw dislocation.

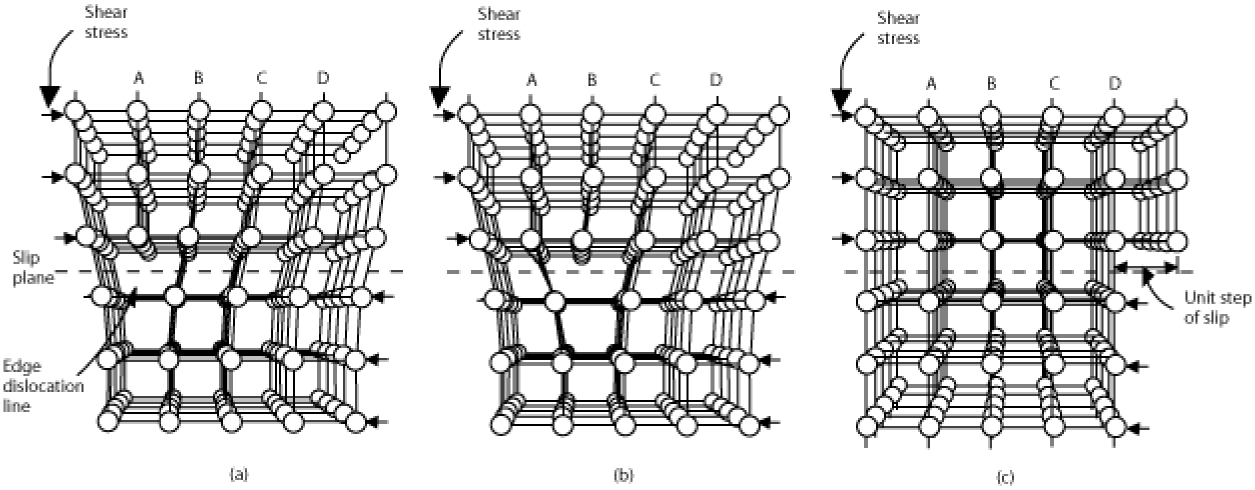
Ans:

EdgeDislocations

The edge defect can be easily visualized as an extra half-plane of atoms in a lattice. The dislocation is called a line defect because the locus of defective points produced in the lattice by the dislocation lie along a line. This line runs along the top of the extra half-plane. The inter-atomic bonds are significantly distorted only in the immediate vicinity of the dislocation line.



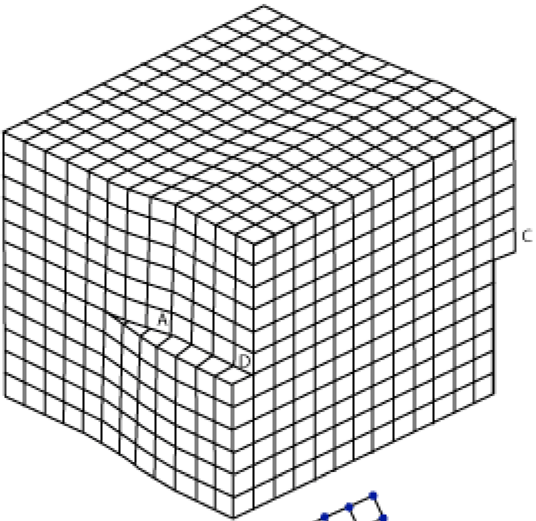
Understanding the movement of a dislocation is key to understanding why dislocations allow deformation to occur at much lower stress than in a perfect crystal. Dislocation motion is analogous to movement of a caterpillar. The caterpillar would have to exert a large force to move its entire body at once. Instead it moves the rear portion of its body forward a small amount and creates a hump. The hump then moves forward and eventual moves all of the body forward by a small amount.

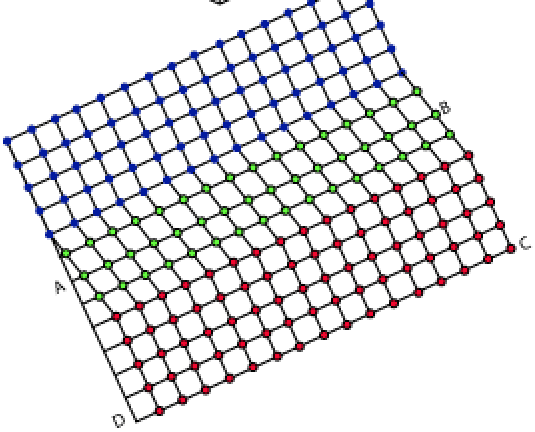


As shown in the set of images above, the dislocation moves similarly moves a small amount at a time. The dislocation in the top half of the crystal is slipping one plane at a time as it moves to the right from its position in image (a) to its position in image (b) and finally image (c). In the process of slipping one plane at a time the dislocation propagates across the crystal. The movement of the dislocation across the plane eventually causes the top half of the crystal to move with respect to the bottom half. However, only a small fraction of the bonds are broken at any given time. Movement in this manner requires a much smaller force than breaking all the bonds across the middle plane simultaneously.

ScrewDislocations

There is a second basic type of dislocation, called screw dislocation. The screw dislocation is slightly more difficult to visualize. The motion of a screw dislocation is also a result of shear stress, but the defect line movement is perpendicular to direction of the stress and the atom displacement, rather than parallel. To visualize a screw dislocation, imagine a block of metal with a shear stress applied across one end so that the metal begins to rip. This is shown in the upper right image. The lower right image shows the plane of atoms just above the rip. The atoms represented by the blue circles have not yet moved from their original position. The atoms represented by the red circles have moved to their new position in the lattice and have reestablished metallic bonds. The atoms represented by the green circles are in the process of moving. It can be seen that only a portion of the bonds are broke at any given time. As was the case with the edge dislocation, movement in this manner requires a much smaller force than breaking all the bonds across the middle plane simultaneously.



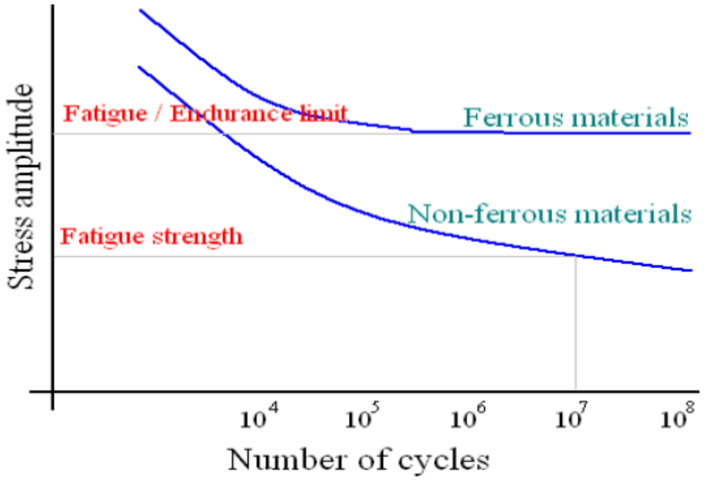


If the shear force is increased, the atoms will continue to slip to the right. A row of the green atoms will find there way back into a proper spot in the lattice (and become red) and a row of the blue atoms will slip out of position (and become green). In this way, the screw dislocation will move upward in the image, which is perpendicular to direction of the stress.

Q4. b) Discuss the mechanism of fatigue failure. Suggest the methods to improve the fatigue life.

Fatigue testing – Data presentation

- Fatigue test, usually, involves applying fluctuating load cyclically.
- A specimen of rotating beam type is often used because of its simplicity.
- Fatigue data is usually presented by plotting maximum stress (*S*) against number of cycles to fracture (*N*), using a logarithmic scale for the latter variable.



S-N curve can be represented by the Basquin equation:

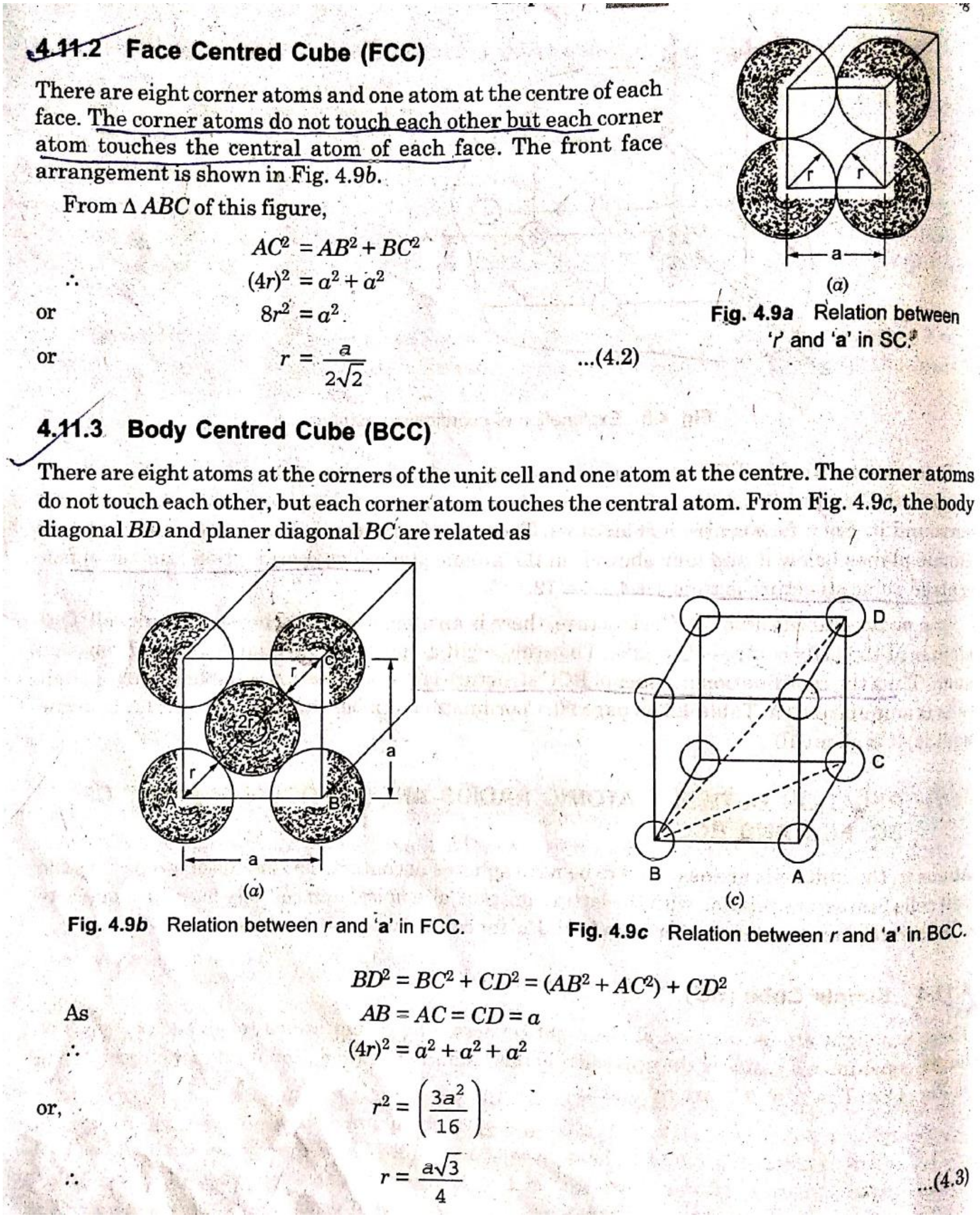
$$N\sigma_a^p = C$$

Fatigue – Crack initiation & propagation

- Fatigue failure consists of four stages: (a) crack initiation – includes the early development of fatigue damage that can be removed by suitable thermal anneal (b) slip-band crack growth – involves the deepening of initial crack on planes of high shear stress (stage-I crack growth) (c) crack growth on planes of high tensile stress – involves growth of crack in direction normal to maximum tensile stress (stage-II crack growth) (d) final ductile failure – occurs when the crack reaches a size so that the remaining cross-section cannot support the applied load.

Q5.a) Derive the expression for relation between atomic radius and lattice constant in case of (a) BCC and (b) FCC.

Ans:



4.11.2 Face Centred Cube (FCC)

There are eight corner atoms and one atom at the centre of each face. The corner atoms do not touch each other but each corner atom touches the central atom of each face. The front face arrangement is shown in Fig. 4.9*b*.

From Δ *ABC* of this figure,

$$AC^2 = AB^2 + BC^2$$

$$\therefore \quad (4r)^2 = a^2 + a^2$$

or $$8r^2 = a^2.$$

or $$r = \frac{a}{2\sqrt{2}} \qquad \text{...(4.2)}$$

Fig. 4.9*a* Relation between '*r*' and 'a' in SC.

4.11.3 Body Centred Cube (BCC)

There are eight atoms at the corners of the unit cell and one atom at the centre. The corner atoms do not touch each other, but each corner atom touches the central atom. From Fig. 4.9*c*, the body diagonal *BD* and planer diagonal *BC* are related as

Fig. 4.9*b* Relation between *r* and 'a' in FCC.

Fig. 4.9*c* Relation between *r* and 'a' in BCC.

$$BD^2 = BC^2 + CD^2 = (AB^2 + AC^2) + CD^2$$

As $$AB = AC = CD = a$$

$$\therefore \quad (4r)^2 = a^2 + a^2 + a^2$$

or, $$r^2 = \left(\frac{3a^2}{16}\right)$$

$$\therefore \quad r = \frac{a\sqrt{3}}{4} \qquad \text{...(4.3)}$$

Q5. b) Give classification of imperfections. Explain Frenkel's and Schottky's defects.

Ans: Point defects explain about the imperfections of solids along with the types of point defects. Crystalline solids are formed by joining a large number of small crystals. Different types of defects are found in crystals after the process of crystallization.

Point defects are accounted for when the crystallization process occurs at a very fast rate. These defects mainly happen due to deviation in the arrangement of constituting particles. In a crystalline solid, when the ideal arrangement of solids is distorted around a point/ atom it is called a point defect.

Defects or Imperfections in crystalline solid can be divided into four groups namely line defects, point defects, volume defects and surface defects. Historically, crystal point defects were first regarded in ionic crystals, not in metal crystals that were much simpler.

There are 3 types of point defects:

1. Stoichiometric defect
2. Frenkel defect
3. Schottky defect

1. Stoichiometric Defect:

In this kind of point defect, the ratio of positive and negative ions (Stoichiometric) and electrical neutrality of a solid is not disturbed. Sometimes it is also known as intrinsic or thermodynamic defects.

Fundamentally, they are of two types:

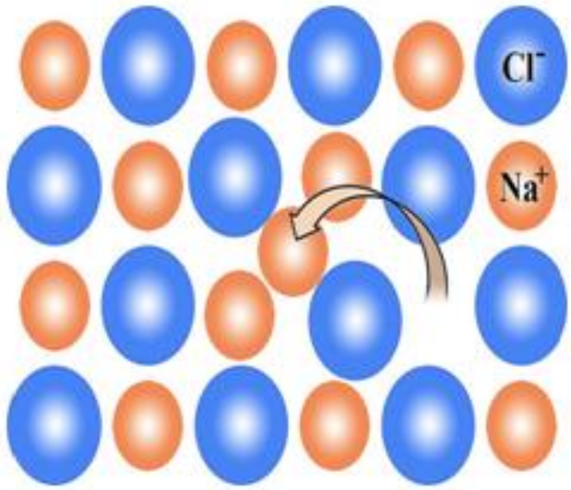
- *Vacancy defect:* When an atom is not present at their lattice sites, then that lattice site is vacant and it creates a vacancy defect. Due to this, the density of a substance decreases.
- *Interstitial defect:* It is a defect in which an atom or molecule occupies the intermolecular spaces in crystals. In this defect, the density of the substance increases.

A non-ionic compound mainly shows vacancy and interstitial defects. An ionic compound shows the same in Frenkel and Schottky defect.

2. Frenkel Defect:

In ionic solids generally, the smaller ion (cation) moves out of its place and occupies an intermolecular space. In this case, a vacancy defect is created on its original position and the interstitial defect is experienced at its new position.

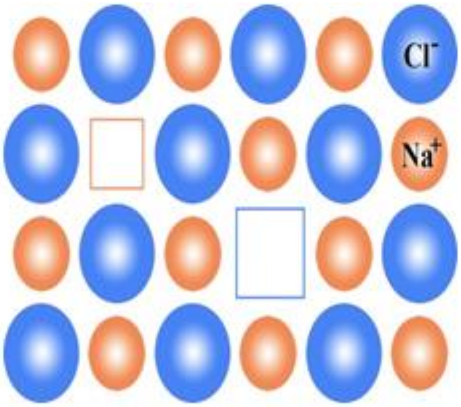
- It is also known as dislocation defect.
- The density of a substance remains unchanged.
- It happens when there is a huge difference in the size of anions and cations.
- *Example:* ZnS and AgCl.



Frenkel defect

3. Schottky Defect

- This kind of vacancy defects is found in Ionic Solids. But in ionic compounds, we need to balance the electrical neutrality of the compound so an equal number of anions and cations will be missing from the compound.
- It reduces the density of the substance.
- In this, the size of cations and anions are of almost the same.



Schottky defect