ANS 1:-

1. There are 4 atoms at the corners of the cube which contributes to a single atom. ( 1 ÷8 × 8 corners = 1 atom)
2. There are 6 faces in a cube. An atom contribute 1/2 towards the unit cell. Therefore (1÷ 2 ×6 faces =3 atoms) .

ANS 2:- Body Centred Cubic Structure

At room temperatures, elements Li, Na, K, Rb, Ba, V, Cr and Fe have structures that can be described as body centre cubic (bcc) packing of spheres. The other two common ones are face centred cubic (fcc) and hexagonal closest (hcp) packing. This type of structure is shown by the diagram below.

In a crystal structure, the arrangement extends over millions and millions of atoms, and the above diagram shows the unit cell, the smallest unit that, when repeatedly stacked together, will generate the entire structure.

Actually, the unit we draw is more than a unit cell. We use the centre of the atoms (or spheres) to represent the corners of the unit cell, and each of these atoms are shared by 8 unit cells. There is a whole atom located in the centre of the unit cell.

Usually, the length of the cell edge is represented by a. The direction from a corner of a cube to the farthest corner is called body diagonal (bd). The face diagonal (fd) is a line drawn from one vertex to the opposite corner of the same face. If the edge is a, then we have:

fd2 = a2 + a2 = 2 a2

bd2 = fd2 + a2

= a2 + a2 + a2

= 3 a2

Atoms along the body diagonal (bd) touch each other. Thus, the body diagonal has a length that is four times the radius of the atom, R.

bd = 4 R

The relationship between a and R can be worked out by the Pythagorean theorem:

(4 R)2 = 3 a2

Thus,

4 R = sqrt(3) a

or

a = 4R/sqrt(3)

Recognizing these relationships enable you to calculate parameters for this type of crystal. For example, one of the parameter is the packing fraction, the fraction of volume occupied by the spheres in the structure.

Example 1

What is the packing fraction for a body centred packed structue?

Solution

Well, this means you should calculate the percentage of the volume occupied by the spheres in the packing.

Packing fraction = Vsphere / Vunit cell

= 2\*4/3 p R3 / (4/sqrt(3) R3)

= Ö3 p / 8 = 0.6802

ANS 3:- **Plastic deformation by Slip:**

Slip is defined as that mechanism of deformation where in one part of the crystal moves/ slips over another part along certain planes known as slip plane. Slip due to pure shearing stresses that are acting across the specimen irrespective of whether the crystal is subjected to tensile/ compressive stresses.

Representation of the greater resistance to slip along planes having lower atomic density due to necessity for side motion. Due to increase of tensile load, the blocks again divided and relative displacement has taken place. Slip can be imagined to a park of playing cards when they are shuffled. Slip occurs due to the movement of dislocations through the crystal that movement compared to the movement of an earthworm as it arches its back in order to move forward.

**Slip is governed by the following major rules:**

1. It occurs only along certain crystallographic planes and directions
2. Slip occurs only along the most closely packed set of planes
3. Slip direction is that direction on when the atoms are most closely spaced. Slip occurs on that system where the shear stress is maximum i.e., at 45o to the applied tensile load.

**Plastic deformation by twining:**

Zn, Tin, iron deform by twining.

In twinning each plane of atoms move through a definite distance and in the same direction. The extent of movement of each plane is proportional to its distance from the twining plane, as shown in fig. The distance moved by each successive atomic plane is greater than the previous plane by a few atomic spacings. When a shear stress is applied the crystal will twin about the twinning plane in such a way that the region to the left of the twinning plane is not deformed where as the region to the right is deformed. The atomic arrangement on either side of the twinned plane is in such a way they are mirror reflections of each other. Twins are known as anneling twins when they are produced during annealing heat treatment and mechanical twins when they are produced by mechanical deformation of metals.

**Mechanism of twinning:**

Partial dislocation line moves up (or) down by one plane each time the twinning dislocation goes round it. Twinning may be caused by impact, by thermal treatment (or) by plastic deformation.

| **Slip** | **Twinning** |
| --- | --- |
| 1. All atoms in one block move over the same distance | 1. Different planes of atoms moves fractional distances depending on their distance from the twinning plane. |
| 2. Under microscope, slip appears as thin line. | 2, It appears as broad lines (or) bands. |
| 3. There is very little change in lattice orientation. | 3. Lattice orientation changes in the twinned regions. |
| 4. It requires lower shear stress. | 4. It requires higher shear stress. |
| 5. Occurs in metals having more number of slip systems. | 5. Occurs in metals having less number of slip systems. |

ANS 4:- Carbonitriding is a metallurgical surface modification technique that is used to increase the surface hardness of a metal, thereby reducing wear.

During the process, atoms of carbon and nitrogen diffuse interstitially into the metal, creating barriers to slip, increasing the hardness and modulus near the surface. Carbonitriding is often applied to inexpensive, easily machined low carbon steel to impart the surface properties of more expensive and difficult to work grades of steel.[1] Surface hardness of carbonitrided parts ranges from 55 to 62 HRC.

Certain pre-industrial case hardening processes include not only carbon-rich materials such as charcoal, but nitrogen-rich materials such as urea, which implies that traditional surface hardening techniques were a form of carbonitriding.

Process

Carbonitriding is similar to gas carburization with the addition of ammonia to the carburizing atmosphere, which provides a source of nitrogen. Nitrogen is absorbed at the surface and diffuses into the workpiece along with carbon. Carbonitriding (around 850 °C / 1550 °F) is carried out at temperatures substantially higher than plain nitriding (around 530 °C / 990 °F) but slightly lower than those used for carburizing (around 950 °C / 1700 °F) and for shorter times. Carbonitriding tends to be more economical than carburizing, and also reduces distortion during quenching. The lower temperature allows oil quenching, or even gas quenching with a protective atmosphere.

Characteristics of carbonitrided parts

Carbonitriding forms a hard, wear-resistant case, is typically 0.07 mm to 0.5 mm thick, and generally has higher hardness than a carburized case. Case depth is tailored to the application; a thicker case increases the wear life of the part. Carbonitriding alters only the top layers of the workpiece; and does not deposit an additional layer, so the process does not significantly alter the dimensions of the part.

Maximum case depth is typically restricted to 0.75 mm; case depths greater than this take too long to diffuse to be economical. Shorter processing times are preferred to restrict the concentration of nitrogen in the case, as nitrogen addition is more difficult to control than carbon. An excess of nitrogen in the work piece can cause high levels of retained austenite and porosity, which are undesirable in producing a part of high hardness.

Advantages

Carbonitriding also has other advantages over carburizing. To begin, it has a greater resistance to softening during tempering and increased fatigue and impact strength. It is possible to use both carbonitriding and carburizing together to form optimum conditions of deeper case depths and therefore performance of the part in industry. This method is applied particularly to steels with low case hardenability, such as the seat of the valve. The process applied is initially carburizing to the required case depth (up to 2.5 mm) at around 900-955°C, and then carbonitriding to achieve required carbonitrided case depth. The parts are then oil quenched, and the resulting part has a harder case than possibly achieved for carburization, and the addition of the carbonitrided layer increases the residual compressive stresses in the case such that the contact fatigue resistance and strength gradient are both increased.

Applications

Typical applications for case hardening are gear teeth, cams, shafts, bearings, fasteners, pins, hydraulic piston rods, automotive clutch plates, tools, dies and tillage tools.

ANS 5:-

**Carburizing**

Carburizing, also referred to as Case Hardening, is a heat treatment process that produces a surface which is resistant to wear, while maintaining toughness and strength of the core. This treatment is applied to low carbon steel parts after machining, as well as high alloy steel bearings, gears, and other components.

Carburizing increases strength and wear resistance by diffusing carbon into the surface of the steel creating a case while retaining a substantially lesser hardness in the core. This treatment is applied to low carbon steels after machining.

Strong and very hard-surface parts of intricate and complex shapes can be made of relatively lower cost materials that are readily machined or formed prior to heat treatment.

Most carburizing is done by heating components in either a pit furnace, or sealed atmosphere furnace, and introducing carburizing gases at temperature. Gas carburizing allows for accurate control of both the process temperature and carburizing atmosphere (carbon potential). Carburizing is a time/temperature process; the carburizing atmosphere is introduced into the furnace for the required time to ensure the correct depth of case. The carbon potential of the gas can be lowered to permit diffusion, avoiding excess carbon in the surface layer.

After carburizing, the work is either slow cooled for later quench hardening, or quenched directly into oil. Quench selection is made to achieve the optimum properties with acceptable levels of dimensional change. Hot oil quenching may be used for minimal distortion, but may be limited in application by the strength requirements for the product. Alternatively, bearing races may be press quenched to maintain their dimensional tolerances, minimizing the need for excessive post heat treatment grinding. In some cases, product is tempered, then cryogenically processed to convert retained austenite to martensite, and then retempered.

Met lab has the ability to carburize and harden gears and other components that are small enough to be held in one's hand, up to 14' in diameter and 16' tall, weighing as much as 50,000 pounds. Shallow cases only 0.002 - 0.005", and deep cases, up to 0.350" have been specified and readily achieved.

The press quench located in the facility allows for the dimensional control, therefore precise hardening of gears and bearings up to 16" in diameter.

ANS 6:-

Nitriding is a heat treating process that diffuses nitrogen into the surface of a metal to create a case-hardened surface. These processes are most commonly used on low-carbon, low-alloy steels. They are also used on medium and high-carbon steels, titanium, aluminium and molybdenum. In 2015, nitriding was used to generate unique duplex microstructure (Martensite-Austenite, Austenite-ferrite), known to be associated with strongly enhanced mechanical properties [1]

Typical applications include gears, crankshafts, camshafts, cam followers, valve parts, extruder screws, die-casting tools, forging dies, extrusion dies, firearm components, injectors and plastic-mold tools.

The processes are named after the medium used to donate. The three main methods used are: gas nitriding, salt bath nitriding, and plasma nitriding.

Gas nitriding

In gas nitriding the donor is a nitrogen rich gas, usually ammonia (NH3), which is why it is sometimes known as ammonia nitriding.[2] When ammonia comes into contact with the heated work piece it dissociates into nitrogen and hydrogen. The nitrogen then diffuses onto the surface of the material creating a nitride layer. This process has existed for nearly a century, though only in the last few decades has there been a concentrated effort to investigate the thermodynamics and kinetics involved. Recent developments have led to a process that can be accurately controlled. The thickness and phase constitution of the resulting nitriding layers can be selected and the process optimized for the particular properties required.

The advantages of gas nitriding over the other variants are:

Precise control of chemical potential of nitrogen in the nitriding atmosphere by controlling gas flow rate of nitrogen and oxygen.

All round nitriding effect (can be a disadvantage in some cases, compared with plasma nitriding)

Large batch sizes possible - the limiting factor being furnace size and gas flow

With modern computer control of the atmosphere the nitriding results can be closely controlled

Relatively low equipment cost - especially compared with plasma

The disadvantages of gas nitriding are:

Reaction kinetics heavily influenced by surface condition - an oily surface or one contaminated with cutting fluids will deliver poor results

Surface activation is sometimes required to treat steels with a high chromium content - compare sputtering during plasma nitriding

Ammonia as nitriding medium - though not especially toxic it can be harmful when inhaled in large quantities. Also, care must be taken when heating in the presence of oxygen to reduce the risk of explosion

Salt bath nitriding

In salt bath nitriding the nitrogen donating medium is a nitrogen-containing salt such as cyanide salt. The salts used also donate carbon to the workpiece surface making salt bath a nitrocarburizing process. The temperature used is typical of all nitrocarburizing processes: 550–570 °C. The advantages of salt nitriding are that it achieves higher diffusion in the same period of time compared to any other method.

The advantages of salt nitriding are:

Quick processing time - usually in the order of 4 hours or so to achieve

Simple operation - heats the salt and workpieces to temperature and submerges until the duration has transpired.

The disadvantages are:

The salts used are highly toxic - Disposal of salts are controlled by stringent environmental laws in western countries and has increased the costs involved in using salt baths. This is one of the most significant reasons the process has fallen out of favor in recent decades.

Only one process possible with a particular salt type - since the nitrogen potential is set by the salt, only one type of process is possible

Plasma nitriding

Plasma nitriding, also known as ion nitriding, plasma ion nitriding or glow-discharge nitriding, is an industrial surface hardening treatment for metallic materials.

In plasma nitriding, the reactivity of the nitriding media is not due to the temperature but to the gas ionized state. In this technique intense electric fields are used to generate ionized molecules of the gas around the surface to be nitrided. Such highly active gas with ionized molecules is called plasma, naming the technique. The gas used for plasma nitriding is usually pure nitrogen, since no spontaneous decomposition is needed (as is the case of gas nitriding with ammonia). There are hot plasmas typified by plasma jets used for metal cutting, welding, cladding or spraying. There are also cold plasmas, usually generated inside vacuum chambers, at low pressure regimes.

Usually steels are beneficially treated with plasma nitriding. This process permits the close control of the nitrided microstructure, allowing nitriding with or without compound layer formation. Not only is the performance of metal parts enhanced, but working lifespans also increase, and so do the strain limit and the fatigue strength of the metals being treated. For instance, mechanical properties of austenitic stainless steel like resistance to wear can be significantly augmented and the surface hardness of tool steels can be doubled.

A plasma nitrided part is usually ready for use. It calls for no machining, or polishing or any other post-nitriding operations. Thus the process is user-friendly, saves energy since it works fastest, and causes little or no distortion.

This process was invented by Dr. Bernhardt Berghaus of Germany who later settled in Zurich to escape Nazi persecution. After his death in late 1960s the process was acquired by Klockner group and popularized globally.

Plasma nitriding is often coupled with physical vapor deposition (PVD) process and labeled Duplex Treatment, with enhanced benefits. Many users prefer to have a plasma oxidation step combined at the last phase of processing to produce a smooth jet black layer of oxides which is resistant to wear and corrosion.

Since nitrogen ions are made available by ionization, differently from gas or salt bath, plasma nitriding efficiency does not depend on the temperature. Plasma nitriding can thus be performed in a broad temperature range, from 260 °C to more than 600 °C.[4] For instance, at moderate temperatures (like 420 °C), stainless steels can be nitrided without the formation of chromium nitride precipitates and hence maintaining their corrosion resistance properties.

In the plasma nitriding processes, nitrogen gas (N2) is usually the nitrogen carrying gas. Other gasses like hydrogen or Argon are also used. Indeed, Argon and H2 can be used before the nitriding process during the heating of the parts to clean the surfaces to be nitrided. This cleaning procedure effectively removes the oxide layer from surfaces and may remove fine layers of solvents that could remain. This also helps the thermal stability of the plasma plant, since the heat added by the plasma is already present during the warm up and hence once the process temperature is reached the actual nitriding begins with minor heating changes. For the nitriding process H2 gas is also added to keep the surface clear of oxides. This effect can be observed by analyzing the surface of the part under nitriding (see for instance.

Materials for nitriding

Examples of easily nitridable steels include the SAE 4100, 4300, 5100, 6100, 8600, 8700, 9300 and 9800 series, UK aircraft quality steel grades BS 4S 106, BS 3S 132, 905M39 (EN41B), stainless steels, some tool steels (H13 and P20 for example) and certain cast irons. Ideally, steels for nitriding should be in the hardened and tempered condition, requiring nitriding to take place at a lower temperature than the last tempering temperature. A fine-turned or ground surface finish is best. Minimal amounts of material should be removed post nitriding to preserve the surface hardness.

Nitriding alloys are alloy steels with nitride-forming elements such as aluminum, chromium, molybdenum and titanium.

ANS 7:-

Crystallization

Crystallization is the (natural or artificial) process by which a solid forms, where the atoms or molecules are highly organized into a structure known as a crystal. Some of the ways by which crystals form are precipitating from a solution, freezing, or more rarely deposition directly from a gas. Attributes of the resulting crystal depend largely on factors such as temperature, air pressure, and in the case of liquid crystals, time of fluid evaporation.

Crystallization occurs in two major steps. The first is nucleation, the appearance of a crystalline phase from either a supercooled liquid or a supersaturated solvent. The second step is known as crystal growth, which is the increase in the size of particles and leads to a crystal state. An important feature of this step is that loose particles form layers at the crystal's surface lodge themselves into open inconsistencies such as pores, cracks, etc.

The majority of minerals and organic molecules crystallize easily, and the resulting crystals are generally of good quality, i.e. without visible defects. However, larger biochemical particles, like proteins, are often difficult to crystallize. The ease with which molecules will crystallize strongly depends on the intensity of either atomic forces (in the case of mineral substances), intermolecular forces (organic and biochemical substances) or intramolecular forces (biochemical substances).

Crystallization is also a chemical solid–liquid separation technique, in which mass transfer of a solute from the liquid solution to a pure solid crystalline phase occurs. In chemical engineering, crystallization occurs in a crystallizer. Crystallization is therefore related to precipitation, although the result is not amorphous or disordered, but a crystal.

Time-lapse of growth of a citric acid crystal. The video covers an area of 2.0 by 1.5 mm and was captured over 7.2 min.

The crystallization process consists of two major events, nucleation and crystal growth which are driven by thermodynamic properties as well as chemical properties. In crystallization Nucleation is the step where the solute molecules or atoms dispersed in the solvent start to gather into clusters, on the microscopic scale (elevating solute concentration in a small region), that become stable under the current operating conditions. These stable clusters constitute the nuclei. Therefore, the clusters need to reach a critical size in order to become stable nuclei. Such critical size is dictated by many different factors (temperature, super saturation, etc.). It is at the stage of nucleation that the atoms or molecules arrange in a defined and periodic manner that defines the crystal structure — note that "crystal structure" is a special term that refers to the relative arrangement of the atoms or molecules, not the macroscopic properties of the crystal (size and shape), although those are a result of the internal crystal structure.

The crystal growth is the subsequent size increase of the nuclei that succeed in achieving the critical cluster size. Crystal growth is a dynamic process occurring in equilibrium where solute molecules or atoms precipitate out of solution, and dissolve back into solution. Supersaturation is one of the driving forces of crystallization, as the solubility of a species is an equilibrium process quantified by Ksp. Depending upon the conditions, either nucleation or growth may be predominant over the other, dictating crystal size.

Many compounds have the ability to crystallize with some having different crystal structures, a phenomenon called polymorphism. Each polymorph is in fact a different thermodynamic solid state and crystal polymorphs of the same compound exhibit different physical properties, such as dissolution rate, shape (angles between facets and facet growth rates), melting point, etc. For this reason, polymorphism is of major importance in industrial manufacture of crystalline products. Additionally, crystal phases can sometimes be interconverted by varying factors such as temperature.

In nature

Snowflakes are a very well-known example, where subtle differences in crystal growth conditions result in different geometries.

Crystallized honey

There are many examples of natural process that involve crystallization.

Geological time scale process examples include:

Natural (mineral) crystal formation (see also gemstone);

Stalactite/stalagmite, rings formation.

Human time scale process examples include:

Honey crystallization (nearly all types of honey crystallize).

Methods

Crystal formation can be divided into two types, where the first type of crystals are composed of a cation and anion, also known as a salt, such as sodium acetate. The second type of crystals are composed of uncharged species, for example menthol.[1]

Crystal formation can be achieved by various methods, such as: cooling, evaporation, addition of a second solvent to reduce the solubility of the solute (technique known as antisolvent or drown-out), solvent layering, sublimation, changing the cation or anion, as well as other methods.

The formation of a supersaturated solution does not guarantee crystal formation, and often a seed crystal or scratching the glass is required to form nucleation sites.

A typical laboratory technique for crystal formation is to dissolve the solid in a solution in which it is partially soluble, usually at high temperatures to obtain supersaturation. The hot mixture is then filtered to remove any insoluble impurities. The filtrate is allowed to slowly cool. Crystals that form are then filtered and washed with a solvent in which they are not soluble, but is miscible with the mother liquor. The process is then repeated to increase the purity in a technique known as recrystallization.

For biological molecules in which the solvent channels continue to be present to retain the three dimensional structure intact, microbatch[2] crystallization under oil and vapor diffusion[3] methods have been the common methods.

ANS 8:- HOMOGENEOUS NUCLEATION 2.1 Generals This chapter deals with the simplest nucleation event, namely the homogeneous nucleation of solid crystals during the freezing of a pure metal. On completion, the student should be able to:  Explain the term homogeneous, as applied to nucleation events,  Understand the concept of a critical size or radius, r\* and a critical free energy to nucleation,

Differentiate between unstable clusters (or embryos) and stable nuclei,  Derive expressions for r\* and ΔG\* in terms of volume free energy, ΔGv and undercooling, ΔT.  Recall that r\* ∞ 1/ΔT and ΔG\* ∞ 1/ΔT 2. The chapter starts by explaining that a driving force for solidification, ΔGv exists below the equilibrium melting temperature, Tm and that this is approximately proportional to the degree of undercooling ΔT. Solidification and melting can be defined as “Transformation between crystallographic and non-crystallographic states of a metal and alloy”. These transformations are of course basic to such technological applications as: 1. Ingot casting. 2. Foundry casting. 3. Continuous casting. 4. Single-crystal growth for semiconductors. 5. Directionally solidified composite alloys, and more recently rapidly solidified alloys and glasses. Another important and complex solidification and melting process, often neglected in textbooks on solidification, concerns the process of fusion welding. An understanding of the mechanism of solidification and how it is affected by such parameters such as: a. Temperature distribution. b. Cooling rate and alloying. Are important in the control of mechanical properties of cast metals and fusion welds? It is the objective of this chapter to develop some of the basic concepts of solidification and apply these to some of the most important practical processes such as ingot casting, continuous casting and fusion welding

ANS 9:- Miller Indices

Rules for Miller Indices:

Determine the intercepts of the face along the crystallographic axes, in terms of unit cell dimensions.

Take the reciprocals

Clear fractions

Reduce to lowest terms

For example, if the x-, y-, and z- intercepts are 2, 1, and 3, the Miller indices are calculated as:

Take reciprocals: 1/2, 1/1, 1/3

Clear fractions (multiply by 6): 3, 6, 2

Reduce to lowest terms (already there)

Thus, the Miller indices are 3,6,2. If a plane is parallel to an axis, its intercept is at infinity and its Miller index is zero. A generic Miller index is denoted by .

If a plane has negative intercept, the negative number is denoted by a bar above the number. Never alter negative numbers. For example, do not divide -1, -1, -1 by -1 to get 1,1,1. This implies symmetry that the crystal may not have!

Some General Principles

If a Miller index is zero, the plane is parallel to that axis.

The smaller a Miller index, the more nearly parallel the plane is to the axis.

The larger a Miller index, the more nearly perpendicular a plane is to that axis.

Multiplying or dividing a Miller index by a constant has no effect on the orientation of the plane

Miller indices are almost always small.

Why Miller Indices?

Using reciprocals spares us the complication of infinite intercepts.

Formulas involving Miller indices are very similar to related formulas from analytical geometry.

Specifying dimensions in unit cell terms means that the same label can be applied to any face with a similar stacking pattern, regardless of the crystal class of the crystal. Face 111 always steps the same way regardless of crystal system.

ANS 10:- 1. **Recovery**: This usually occurs at low temperatures and involves motion and annihilation of

point defects as well as annihilation and rearrangement of dislocations resulting in the formation

of subgrains and subgrain boundaries (e.g., tilt and/or twist low-angle boundaries). A distinctive

feature of the recovery process is that it does not involve any change in the grain structure of the

cold-worked metal, the only changes taking place are the dislocation arrangements within the

existing grains. Small changes in hardness that are sometimes observed during recovery can

be attributed to the decrease in the dislocation and point defect density and to the growth of

the subgrains.

2. **Recrystallization**: If increased thermal activation is available (i.e., if the temperature is

raised) nucleation and growth of strain-free grains in the deformed matrix will take place. As

these grains grow, the dislocations in the matrix are annihilated at the boundaries of the newlyformed

grains. Strength and hardness decrease considerably and ductility increases. The

lowest temperature at which stress-free grains appear in the structure of a previously plastically

deformed metal is termed the recrystallization temperature. This depends upon the grain size,

the severity of plastic deformation, and the presence of solute atoms or second phase particles.

The recrystallization temperature is usually 1/3-1/2 the absolute melting point of the

material.

ANS 11:- 3. Grain Growth: If a recrystallized material is further annealed at the same temperature or at a higher temperature grain growth usually occurs. Boundaries between annealed grains migrate

and larger grains grow by an increase in the average grain size (or a decrease in the ASTM grain

size number, n). Grain growth depends on the fact that the grain boundary energy of the

material is reduced due to the decrease in grain boundary area for a given volume of material.

The effect of recovery, recrystallization and grain growth on grain size, internal stress and

strength (or hardness) of a plastically deformed material.

Measurement of Hardness

Throughout this experiment, hardness measurements will be made using a Rockwell

hardness tester. A 1/16" steel ball indentor with either a 60 or 100 kg load corresponds to the

Rockwell F or Rockwell B scales. Hardness value may be calculated from the load applied

Divided by the surface area of the indentation. However, the instrument you will use is

calibrated to read hardness values directly. Consult with the instructor before operating the

hardness tester. You should run a hardness test on the test standard for the particular scale

being used before and after each set of measurements. At least three hardness measurements

should be made on a smooth surface of each specimen to achieve statistical significance. If your

hardness values fall below 20 or above 100, you need to change hardness scales.

ANS 12:- **Cyaniding**

a method of case hardening involving the diffusion of carbon and nitrogen into the surface layer of steel in cyanide-salt baths at temperatures of 820°–860°C (medium-temperature cyaniding) or 930°–950°C (high-temperature cyaniding). Its principal purpose is to increase the hardness, wear resistance, and fatigue limit of steel products.

During cyaniding, the cyanide salts are oxidized with the liberation of atomic carbon and nitrogen, which diffuse into the steel. In medium-temperature cyaniding, the cyanide layer formed, containing 0.6–0.7 percent C and 0.8–1.2 percent N, has a thickness of 0.15 to 0.6 mm, while in high-temperature cyaniding (a method often used instead of carburizing), the cyanide layer, containing 0.8–1.2 percent C and 0.2–0.3 percent N, has a thickness of 0.5 to 2 mm. After cyaniding, a product undergoes hardening and low-temperature tempering.

The disadvantages of cyaniding are high cost and the toxicity of the cyanide salts, the latter necessitating the adoption of special measures to protect workers and the environment. The difference between cyaniding and nitrogen case hardening (or carboni-triding) is that in the latter the diffusion of nitrogen and carbon is achieved from a gaseous medium.The Iron–Iron Carbide (Fe–Fe3C) Phase Diagram

ANS 13:- **The Iron-Carbon Equilibrium Diagram**  
It should first be pointed out that the normal equilibrium diagram really represents the metastable equilibrium between iron and iron carbide (cementite). Cementite is metastable, and the true equilibrium should be between iron and graphite. Although graphite occurs extensively in cast irons (2-4 wt % C), it is usually difficult to obtain this equilibrium phase in steels (0.03-1.5 wt %C). Therefore, the metastable equilibrium between iron and iron carbide should be considered, because it is relevant to the behavior of most steels in practice.

The much larger phase field of γ-iron (austenite) compared with that of α-iron (ferrite) reflects the much greater solubility of carbon in γ-iron, with a maximum value of just over 2 wt % at 1147°C (E, Fig.1). This high solubility of carbon in γ-iron is of extreme importance in heat treatment, when solution treatment in the γ-region followed by rapid quenching to room temperature allows a supersaturated solid solution of carbon in iron to be formed.

The α-iron phase field is severely restricted, with a maximum carbon solubility of 0.02 wt% at 723°C (P), so over the carbon range encountered in steels from 0.05 to 1.5 wt%, α-iron is normally associated with iron carbide in one form or another. Similarly, the δ-phase field is very restricted between 1390 and 1534°C and disappears completely when the carbon content reaches 0.5 wt% (B).

There are several temperatures or critical points in the diagram, which are important, both from the basic and from the practical point of view.

* Firstly, there is the A1, temperature at which the eutectoid reaction occurs (P-S-K), which is 723°C in the binary diagram.
* Secondly, there is the A3, temperature when α-iron transforms to γ-iron. For pure iron this occurs at 910°C, but the transformation temperature is progressively lowered along the line GS by the addition of carbon.
* The third point is A4 at which γ-iron transforms to δ-iron, 1390°C in pure iron, hut this is raised as carbon is added. The A2, point is the Curie point when iron changes from the ferro- to the paramagnetic condition. This temperature is 769°C for pure iron, but no change in crystal structure is involved. The A1, A3 and A4 points are easily detected by thermal analysis or dilatometry during cooling or heating cycles, and some hysteresis is observed. Consequently, three values for each point can be obtained. Ac for heating, Ar for cooling and Ae (equilibrium}, but it should be emphasized that the Ac and Ar values will be sensitive to the rates of heating and cooling, as well as to the presence of alloying elements.

The great difference in carbon solubility between γ- and α-iron leads normally to the rejection of carbon as iron carbide at the boundaries of the γ phase field. The transformation of γ to α - iron occurs via a eutectoid reaction, which plays a dominant role in heat treatment.

The eutectoid temperature is 723°C while the eutectoid composition is 0.80% C(s). On cooling alloys containing less than 0,80% C slowly, hypo-eutectoid ferrite is formed from austenite in the range 910-723°C with enrichment of the residual austenite in carbon, until at 723°C the remaining austenite, now containing 0.8% carbon transforms to pearlite, a lamellar mixture of ferrite and iron carbide (cementite). In austenite with 0,80 to 2,06% carbon, on cooling slowly in the temperature interval 1147°C to 723°C, cementite first forms progressively depleting the austenite in carbon, until at 723°C, the austenite contains 0.8% carbon and transforms to pearlite.

Steels with less than about 0.8% carbon are thus hypo-eutectoid alloys with ferrite and pearlite as the prime constituents, the relative volume fractions being determined by the lever rule which states that as the carbon content is increased, the volume percentage of pearlite increases, until it is 100% at the eutectoid composition. Above 0.8% **C**, cementite becomes the hyper-eutectoid phase, and a similar variation in volume fraction of cementite and pearlite occurs on this side of the eutectoid composition.

The three phases, ferrite, cementite and pearlite are thus the principle constituents of the infrastructure of plain carbon steels, provided they have been subjected to relatively slow cooling rates to avoid the formation of metastable phases.

**The austenite- ferrite transformation**

Under equilibrium conditions, pro-eutectoid ferrite will form in iron-carbon alloys containing up to 0.8 % carbon. The reaction occurs at 910°C in pure iron, but takes place between 910°C and 723°C in iron-carbon alloys.

However, by quenching from the austenitic state to temperatures below the eutectoid temperature Ae1, ferrite can be formed down to temperatures as low as 600°C. There are pronounced morphological changes as the transformation temperature is lowered, which it should be emphasized apply in general to hypo-and hyper-eutectoid phases, although in each case there will be variations due to the precise crystallography of the phases involved. For example, the same principles apply to the formation of cementite from austenite, but it is not difficult to distinguish ferrite from cementite morphologically.

**The austenite-cementite transformation**

The Dube classification applies equally well to the various morphologies of cementite formed at progressively lower transformation temperatures. The initial development of grain boundary allotriomorphs is very similar to that of ferrite, and the growth of side plates or Widmanstaten cementite follows the same pattern. The cementite plates are more rigorously crystallographic in form, despite the fact that the orientation relationship with austenite is a more complex one.

As in the case of ferrite, most of the side plates originate from grain boundary allotriomorphs, but in the cementite reaction more side plates nucleate at twin boundaries in austenite.

**The austenite-pearlite reaction**

Pearlite is probably the most familiar micro structural feature in the whole science of metallography. It was discovered by Sorby over 100 years ago, who correctly assumed it to be a lamellar mixture of iron and iron carbide.

Pearlite is a very common constituent of a wide variety of steels, where it provides a substantial contribution to strength. Lamellar eutectoid structures of this type are widespread in metallurgy, and frequently pearlite is used as a generic term to describe them.

These structures have much in common with the cellular precipitation reactions. Both types of reaction occur by nucleation and growth, and are, therefore, diffusion controlled. Pearlite nuclei occur on austenite grain boundaries, but it is clear that they can also be associated with both pro-eutectoid ferrite and cementite. In commercial steels, pearlite nodules can nucleate on inclusions.