Council For Technical Education and Vocational Training

Narayani Polytechnic Institute

Bharatpur-10, Chitwan

A CLASS NOTE
ON
Material Science
FOR
DIPLOMA IN AUTOMOBILE ENGINEERING (II/I)

(Based on Revised curriculum)

BY

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Material Science
Unit: -1
Introduction

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Introduction To Material Science

Material science is a field that deals with the study of materials, their properties, structure, and behavior. It is an interdisciplinary field that includes elements of physics, chemistry, engineering, and biology. Material science has great importance in many areas of technology, industry, and research.

Importance and Scope of Material Science

Importance

1. *Designing new materials*: Material scientists work to develop new materials that have unique properties and characteristics. This includes developing materials that are stronger, lighter, more durable, and have improved thermal or electrical conductivity. These new materials can be used in a wide range of applications, from aerospace to medical devices.

2. *Improving existing materials*: Material science is also important for improving existing materials. Scientists work to optimize materials such as plastics, metals, and composites to make them stronger, more durable, and more efficient.

3. *Developing sustainable materials*: As concerns over the environment and climate change grow, material science is becoming increasingly important in developing sustainable materials. This includes developing materials that are renewable, biodegradable, and recyclable.

4. *Advancing technology:* Material science is critical in advancing technology, from developing new electronic devices to improving energy storage and conversion. Materials such as semiconductors, superconductors, and nanomaterials have transformed the electronics industry and are paving the way for new technologies such as quantum computing.

5. *Medical applications*: Material science is important in the development of medical devices, implants, and drug delivery systems. Scientists work to develop materials that are biocompatible, able to withstand bodily fluids, and can be tailored to specific medical needs.

Scope of Material Science

The scope of material science is vast and varied, encompassing numerous fields and industries. Some of the key areas where material science has a significant impact include:

1. *Aerospace and defense:* The aerospace and defense industries rely heavily on material science to develop lightweight, high-strength materials for use in aircraft, spacecraft, and other vehicles.

2. *Electronics and computing:* Material science is essential for developing new electronic and computing devices. Materials such as semiconductors, nanomaterials, and superconductors have revolutionized the electronics industry.

3. *Energy:* The development of new materials for energy storage and conversion is critical for addressing the world's energy needs. Material science is important for the development of batteries, fuel cells, and solar cells.

4. *Medical devices:* Material science plays a significant role in the development of medical devices such as implants, prosthetics, and drug delivery systems. Materials with specific properties such as biocompatibility, durability, and corrosion resistance are essential in this field.

5. *Automotive industry:* The automotive industry relies on material science to develop lightweight, high-strength materials for use in cars, trucks, and other vehicles. Materials such as carbon fiber composites, high-strength steels, and aluminum alloys are commonly used in this industry.

6. *Sustainable materials*: Material science is increasingly focused on the development of sustainable materials that are biodegradable, recyclable, and made from renewable sources.

Overall, material science has a broad scope and is critical to numerous fields and industries. The development of new materials with improved properties and sustainability is essential for addressing the challenges of the 21st century.

Classification of materials

Based on state:

Materials can be classified based on their physical state at room temperature into three categories:

A) Solid materials: Materials that have a definite shape and volume. Examples include metals, ceramics, and polymers.

B) Liquid materials: Materials that have a definite volume but take the shape of their container. Examples include water, oils, mercury and alcohol.

C) Gaseous materials: Materials that have no definite shape or volume and expand to fill the container they are in. Examples include air, helium, and carbon dioxide.

2. Classification of materials based on natural and artificial origin:

Materials can be classified based on their origin into two categories:

a) Natural materials: Materials that are obtained from natural sources. Examples include wood, stone, and cotton.

b) Artificial materials: Materials that are manufactured or synthesized by humans. Examples include plastics, synthetic fibers, and alloys.

3. Classification of materials based on metals and non-metals:
Materials can be classified based on their chemical properties into two categories:

a) Metals: Materials that have high electrical conductivity, ductility, malleability, and metallic luster. Examples include iron, aluminum, and copper.

b) Non-metals: Materials that have low electrical conductivity and are brittle in nature. Examples include carbon, sulfur, and oxygen.

Note: There is a third category called metalloids or semi-metals that have properties intermediate between metals and non-metals. Examples include silicon, germanium, and arsenic.

Properties of Materials

i. Physical properties
ii. Mechanical properties
iii. Electrical properties
iv. Magnetic properties
v. Thermal properties

Physical properties: luster, color, density

Physical properties are those properties of a material that can be observed or measured without changing the chemical composition of the material. Here are three common physical properties:

1. ***Luster***: Luster refers to the way a material reflects light. Materials can have a metallic luster, a glassy luster, or a dull or earthy luster.

2. *Color:* Color is another important physical property of a material. The color of a material can be affected by its chemical composition, crystal structure, and impurities.

3. ***Density:*** Density is the mass per unit volume of a material. It is an important physical property because it can be used to identify materials and to determine their purity. Materials with higher densities are generally heavier than those with lower densities.

Mechanical properties: plasticity, elasticity, ductility, malleability, toughness

Mechanical properties are those properties of a material that describe how it behaves under mechanical stress. Here are five common mechanical properties:

1. **Plasticity:** Plasticity refers to the ability of a material to deform permanently under stress. When a material is subjected to stress beyond its yield strength, it undergoes plastic deformation, which means it changes shape permanently.

2. **Elasticity:** Elasticity is the ability of a material to deform when subjected to stress and return to its original shape when the stress is removed. Materials with high elasticity are said to be "springy" or "flexible".

3. **Ductility:** Ductility refers to the ability of a material to be drawn or stretched under tension without breaking. Materials that are highly ductile can be drawn into wires or extruded into thin sheets.

4. **Malleability:** Malleability is the ability of a material to be hammered or pressed into thin sheets without breaking. Materials that are highly malleable can be shaped easily without cracking or breaking.

5. **Toughness:** Toughness refers to a material's ability to absorb energy before fracturing. Materials that are tough can withstand impacts or sudden shocks without breaking.

Electrical properties: conductivity and effect of temperature

Electrical properties are those properties of a material that describe how it conducts electricity. Here are two common electrical properties:

1. *Conductivity:* Conductivity is the ability of a material to conduct electrical current. Materials that are good conductors of electricity have a low resistance to the flow of electrical current. Examples of good conductors include metals such as copper, silver, and aluminum.

2. *Effect of temperature*: The electrical conductivity of a material can be affected by temperature. In general, the conductivity of metals decreases with increasing temperature, while the conductivity of semiconductors and insulators increases with increasing temperature. This is because at higher temperatures, electrons are more likely to be excited and break free from their bonds, causing an increase in the number of free charge carriers.

Magnetic properties: ferro-magnet, para-magnet, dia-magnet and hysteresis loss

Magnetic properties are those properties of a material that describe how it responds to magnetic fields. Here are four common magnetic properties:

1. *Ferromagnetism:* Ferromagnetic materials are strongly attracted to magnetic fields and can retain their magnetic properties even after the magnetic field is removed. Examples of ferromagnetic materials include iron, cobalt, and nickel.

2. *Paramagnetism*: Paramagnetic materials are weakly attracted to magnetic fields and lose their magnetism when the magnetic field is removed. Examples of paramagnetic materials include aluminum, platinum, and tungsten.

3. **Diamagnetism**: Diamagnetic materials are not attracted to magnetic fields and are actually slightly repelled by them. Examples of diamagnetic materials include copper, gold, and silver.

4. **Hysteresis loss:** Hysteresis loss is a type of energy loss that occurs when a ferromagnetic material is subjected to an alternating magnetic field. The energy is lost due to the friction between the magnetic domains in the material as they switch direction with the changing magnetic field.

Thermal properties: specific heat, latent heat and thermal expansion

Thermal properties are those properties of a material that describe how it behaves when subjected to changes in temperature. Here are three common thermal properties:

1. ***Specific heat***: Specific heat is the amount of heat energy required to raise the temperature of a material by one degree Celsius. Materials with high specific heat require more heat energy to raise their temperature, while materials with low specific heat require less energy.
2. ***Latent heat:*** Latent heat is the amount of heat energy required to change the phase of a material without changing its temperature. For example, when ice melts to form water, heat energy is absorbed by the ice, but the temperature remains constant until all the ice has melted.
3. ***Thermal expansion:*** Thermal expansion is the tendency of a material to expand or contract when subjected to changes in temperature. When a material is heated, its molecules vibrate more rapidly, causing the material to expand. Similarly, when a material is cooled, its molecules vibrate more slowly, causing the material to contract

Some important Meanings

1. Interdisciplinary: relating to more than one branch of knowledge.
2. Polymer: Polymer A substance made from long chains of repeating groups of atoms. Manufactured polymers include nylon, polyvinyl chloride (better known as PVC) and many types of plastics. Natural polymers include rubber, silk and cellulose (found in plants and used to make paper.

Material Science
Unit 2:
Arrangement of atoms

Contents

Crystalline and amorphous solids
Unit cell, coordination number, atomic packing factor
Crystal structure (BCC, FCC and HCP)
Crystal imperfection: Point defect, line and surface defect in brief

Crystal

These are solids which have a regular periodic arrangement in their component parties, bounded by flat faces, orderly arranged in reference to one another, which converge at the edges and vertices. A crystal is symmetrical about its certain elements like points, lines or planes and if it rotated about these elements, it is not possible to distinguish its new position from the original position.

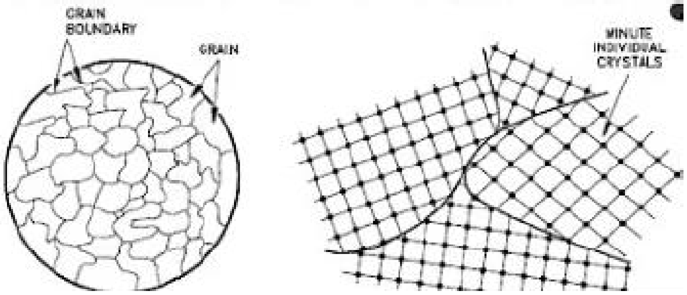


Fig: Crystal, grain and grain boundaries

Crystals can be found in a variety of natural and synthetic materials, including minerals, metals, salts, and organic compounds, and they exhibit a range of physical and chemical properties such as optical transparency, electrical conductivity, and mechanical strength. The study of crystals and their properties is known as crystallography.

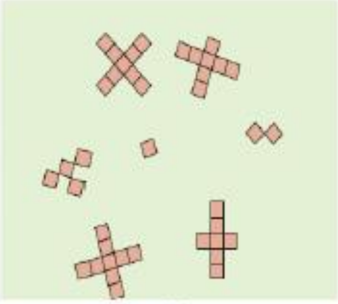
Crystalline and amorphous solids

Solids exist in nature in two principal forms: *crystalline* and *non-crystalline (amorphous)*, which differ substantially in their properties.

Crystalline Solids

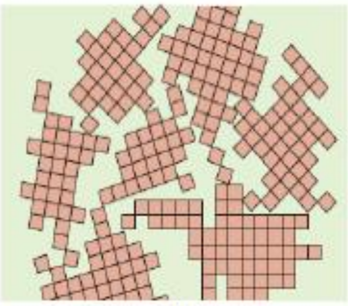
Most crystalline solids are made up of millions of tiny single crystals called grains which constitute what is called **microstructure** and are said to be **polycrystalline**. A crystalline material may be either in the form of *single crystal* or **an aggregate of many crystals** usually known as polycrystalline separated by well-defined boundaries called as grain boundaries. The properties of crystals depend on the electronic structure of atoms and the nature of their interactions in the crystal, on the spatial arrangement of their ions, atoms or molecules, and on the composition, size and shape of crystals.

Fig: Iron Pyrite Single Crystal



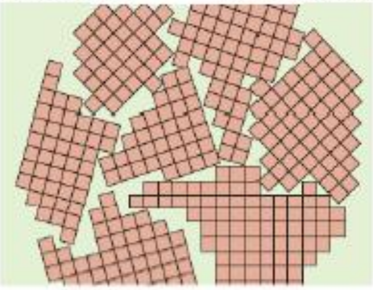
(a)

Fig: (*a*) Small crystallite nuclei.



(b)

Fig: (*b*) Growth of the crystallites

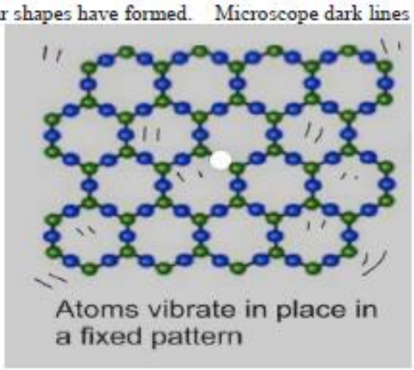


(c)

Fig: - (*c*) Upon completion of solidification grains having irregular shapes have formed.

(d)

Fig: - (*d*) The grain structure as it would appear under Microscope dark lines are grain boundaries.



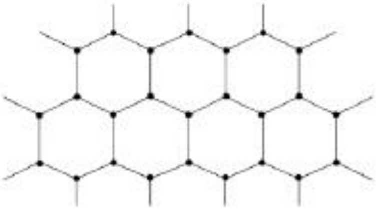


Fig. 3.2(b) **Crystalline (or highly ordered) structure**

crystalline solids have a distinct melting point. crystalline solids are typically more brittle than amorphous solids, which can exhibit greater toughness and elasticity.

Amorphous solids/ non-Crystalline

Non-crystalline solids *lack a systematic and regular arrangement of atoms* over *relatively large atomic distances*. Sometimes such materials are also called **amorphous** (meaning literally "without form"), or supercooled liquids, inasmuch as their atomic structure resembles that of a liquid.

In contrast, amorphous solids lack a long-range order in their arrangement of particles. Their constituent particles are arranged randomly or in a disordered fashion, which gives them a more irregular shape and lack of symmetry. Examples of amorphous solids include glass, rubber, and some plastics.

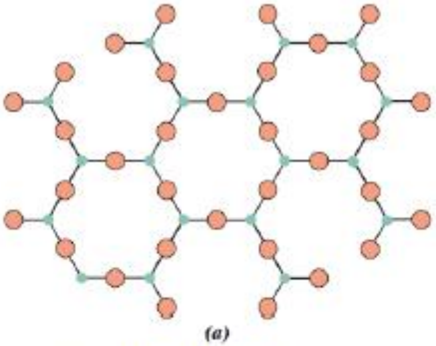


Fig: - (*a*) crystalline silicon dioxide

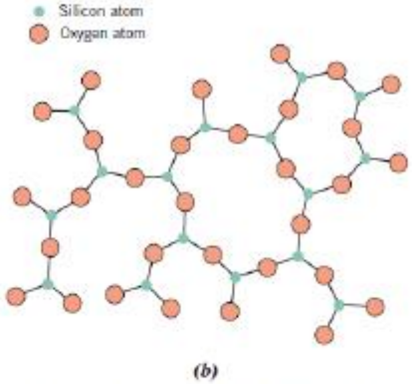
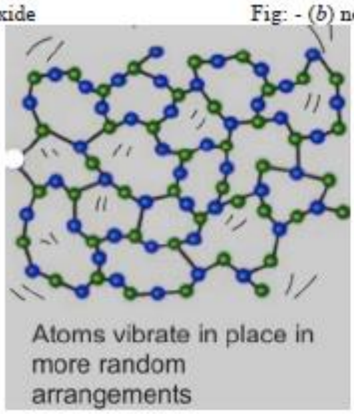


Fig: - (*b*) non-crystalline silicon dioxide



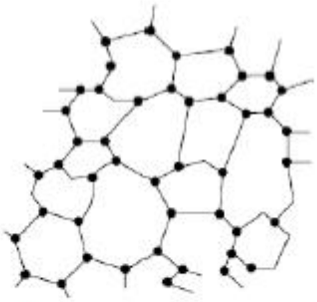


Fig. 3.2(a) Amorphous, or non-crystalline structure

Amorphous solids often soften and gradually deform when heated.

Crystal Structure

The atomic arrangement in crystal is called the crystal structure. In perfect crystal, there is a regular arrangement of atoms.

In a model of a crystal, ions i.e. (an atom or molecule with a net electric charge due to the loss or gain of one or more electrons.), atoms or molecules that constitute its structure can be imagined to be spheres which touch one another and are arranged regularly in different directions.

Space lattice + Basis = Crystal Structure

The crystal structure is obtained by placing the basis on each lattice point such that the center of the basis coincides with the lattice point.

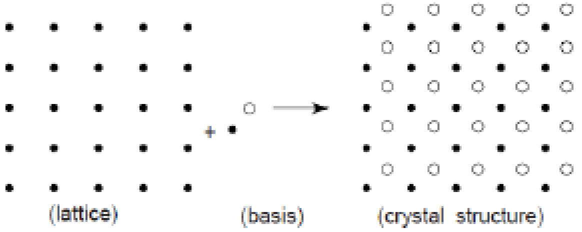


Figure: - Generation of crystal from lattice and basis

The generation of a crystal structure from a two-dimensional lattice is illustrated in Figure. **The basis consists of two atoms, represented by (o) and black dot (.)**, having orientation as shown in Figure The crystal structure is obtained by placing the basis on each lattice point such that the center of the basis coincides with the lattice point.

Thus, whereas a lattice is a mathematical concept, the crystal structure is a physical concept.

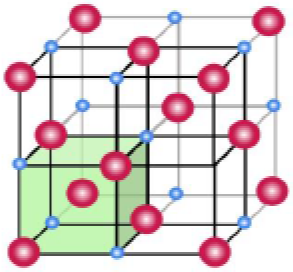
Basis

In crystallography, a basis (also called a motif or a lattice basis) refers to a set of atoms, molecules, or ions that occupy specific positions within the unit cell of a crystal. The basis defines the repeating pattern of the crystal lattice and the crystal structure.

In order to obtain a crystal structure, an atom or a group of atoms must be placed on each lattice point in a regular fashion. Such an atom or a group of atoms is called the *basis* and this acts as a building unit or a structural unit for the complete crystal structure.

Space lattice

The space lattice has been defined as an array of imaginary points which are so arranged in space that each point has identical surroundings.



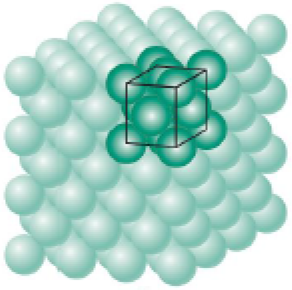
Crystal Lattice

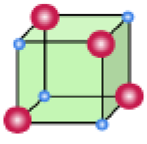
Unit cell, Coordination number, Atomic packing factor

Two other important characteristics of a crystal structure are the **coordination number** and the **atomic packing factor (APF).**

Unit Cell

The atomic order in crystalline solids indicates that small groups of atoms form a repetitive pattern. Thus, in describing crystal structures, it is often convenient to subdivide the structure into small repeat entities called **unit cells.**


(c)

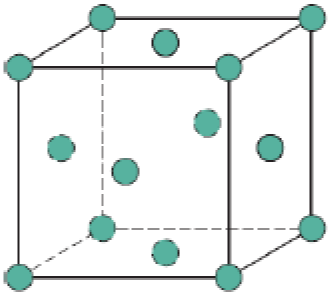

Unit Cell

Unit cells for most crystal structures are parallelepipeds or prisms having three sets of parallel faces; one is drawn within the aggregate of spheres (Figure 3.1*c*), which in this case happens to be a cube.

Co-ordination number

For metals, each atom has the same number of nearest-neighbor or touching atoms, which is the coordination number.

For face centered cubics, the coordination number is 12. This may be confirmed by examination of Figure 3.1*a*; the front face atom has four corner nearest-neighbor atoms surrounding it, four face atoms that are in contact from behind, and four other equivalent face atoms residing in the next unit cell to the front (not shown).



Atomic packing Factor (APF)

The APF is the sum of the sphere volumes of all atoms within a unit cell (assuming the atomic hard-sphere model) divided by the unit cell volume that is,

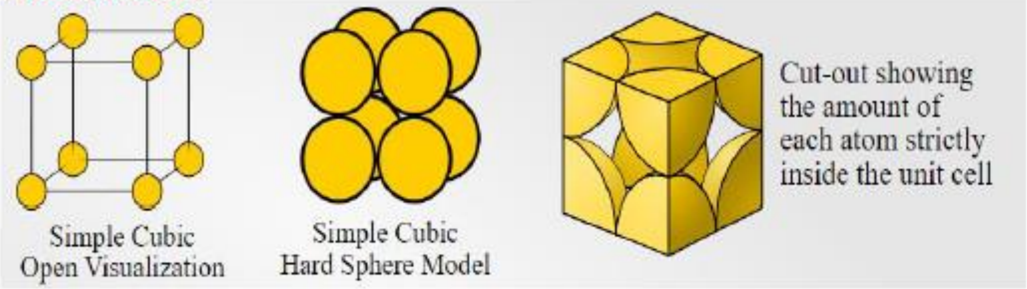
$$\text{APF} = \frac{\text{volume of atoms in a unit cell}}{\text{total unit cell volume}}$$

APF= (No. of atoms x volume of each atom)/ Volume of unit cell

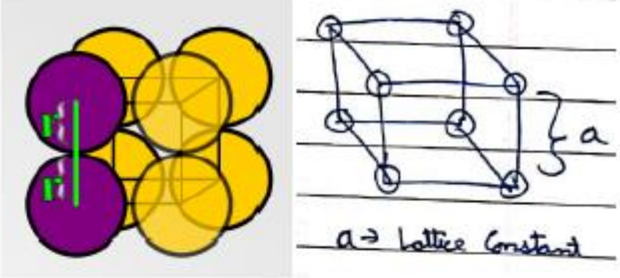
Crystal structure (SC, BCC, FCC and HCP)

The most common types of space lattices or crystal structure are :

1. Simple Cubic (SC)



It is also possible to have a unit cell that consists of atoms situated only at the corners of a cube. This is called the *simple cubic (SC) crystal structure.* The center of each atom coincides with different corners of the cube and the atoms touches each other.



Here, a= 2R
a= Lattice constant
R= Atom's Radius
Volume of atoms= $(4\pi r^3)/3$

Each of the atoms at the corner of the cube has 1/8 volume of its volume present inside the cubic cell.

The remaining volume of the atom is shared by its 7 neighboring unit cells.

No of atoms in one simple cube.

$$N = N_i + \frac{N_f}{2} + \frac{N_c}{8}$$

N_i = the number of interior atoms
N_f = the number of face atoms
N_c = the number of corner atoms

= (8/8) =1 atoms

APF (Atomic Packing Factor) = (Volume of Atoms/ Volume of unit cell)
= (No. of atoms x volume of each atom)/ Volume of unit cell

$$= \frac{1 \text{ x } (\frac{4\pi r3}{3})}{a3}$$

Substituting a= 2r in the equation,

$$= \frac{1 \text{ x } 4\pi r3}{3X(2r)3}$$

$$=\frac{4\pi r3}{3X8r3}$$

$$=\frac{\pi}{3X2}$$

$$=\frac{\pi}{6}$$

= 0.52

=0.52 x 100

=52%

2. Body centered cubic (BCC)

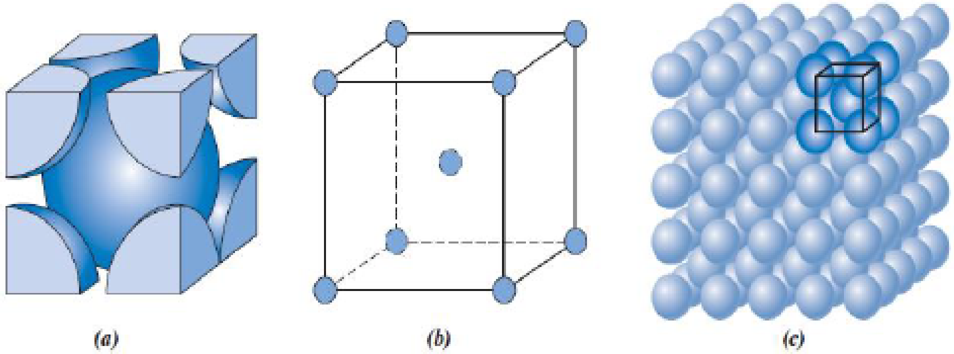


Figure (*a*) a hard-sphere unit cell representation.
Figure(*b*) a reduced sphere unit cell.
Figure (*c*) an aggregate of many atoms.

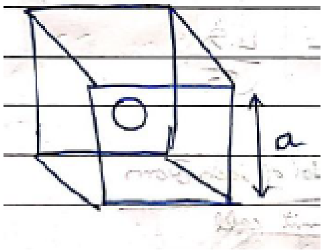
Let a = lattice constant
r = atomic radius

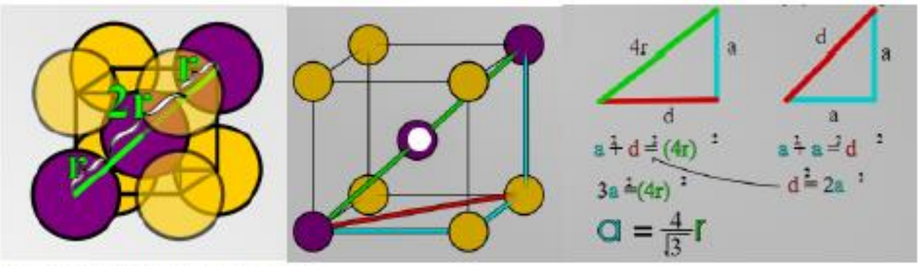
There is one full atom at the center and one atom at each of the eight corners.

$$N = N_i + \frac{N_f}{2} + \frac{N_c}{8}$$

$$= 1 + 0 + \frac{8}{8} = 2$$

Effective number of atoms inside each unit cell = 2 atoms





Here Lattice Constant a = 4r/$\sqrt{3}$

APF (Atomic Packing Factor) = (Volume of Atoms/ Volume of unit cell)

= (No. of atoms x volume of each atom)/ Volume of unit cell

$$= \frac{2 \text{ x } (\frac{4\pi r3}{3})}{a3}$$

Substituting a= 4r/$\sqrt{3}$ in the equation

$$= \frac{2 \text{ x } (\frac{4\pi r3}{3})}{\left(\frac{4r}{\sqrt{3}}\right)3}$$

$$=0.68$$
$$= 0.68 \text{ x } 100 \text{ \%}$$
$$= 68\%$$

3. Face centered cubic (FCC)

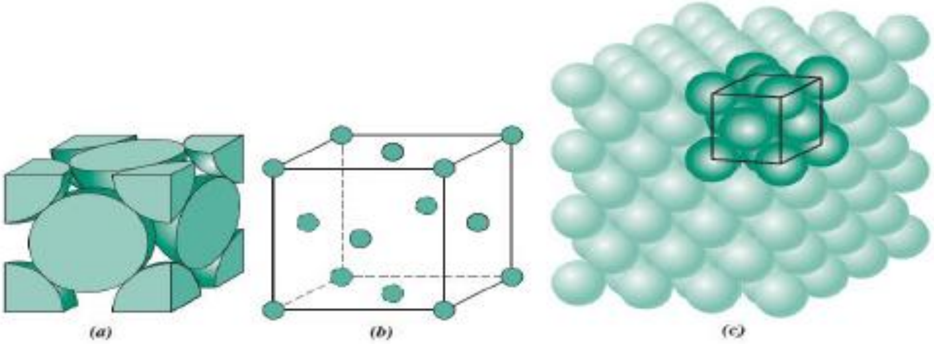
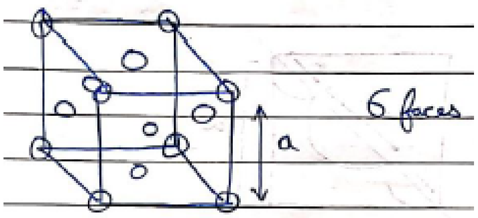


Figure (*a*) a hard-sphere unit cell representation.
Figure(*b*) a reduced sphere unit cell.
Figure (*c*) an aggregate of many atoms

One FCC unit cell has an atom at each corner of the cube and one atom at the center of each of the six faces.



There is only (1/8)th of each corner atom effectively inside the cell whereas ½ of the volume of each atom at the center of the faces are within the unit cell. The number of atoms per unit cell, *N*, can be computed using the following formula:

$$N = N_i + \frac{N_f}{2} + \frac{N_c}{8}$$

where

N_i = the number of interior atoms
N_f = the number of face atoms
N_c = the number of corner atoms

For the FCC crystal structure, there are eight corner atoms ($Nc = 8$), six face atoms ($N_f = 6$), and no interior atoms ($Ni = 0$). Thus, from Equation….

$$N = 0 + \frac{6}{2} + \frac{8}{8} = 4$$

Effective number of atoms inside each unit cell = 4 atoms

Let a = lattice constant
r = atomic radius
Here, lattice constant $a = 4r/\sqrt{2}$
Using Pythagoras Theorem, $h^2 = p^2 + b^2$
Therefore, $(4r)^2 = a^2 + a^2$
Or, $4r = \sqrt{a2 + a2}$
Or, $4r = \sqrt{2a2}$
Or, $4r = \sqrt{2}\ a$
hence $a = 4r/\sqrt{2}$
APF (Atomic Packing Factor) = (Volume of Atoms/ Volume of unit cell)
= (No. of atoms x volume of each atom)/ Volume of unit cell

$$= \frac{4 \times (\frac{4\pi r3}{3})}{a3} \ldots\ldots\ldots\ldots\ldots\ldots (i)$$

Substituting $a = 4r/\sqrt{2}$ in the equation (i)

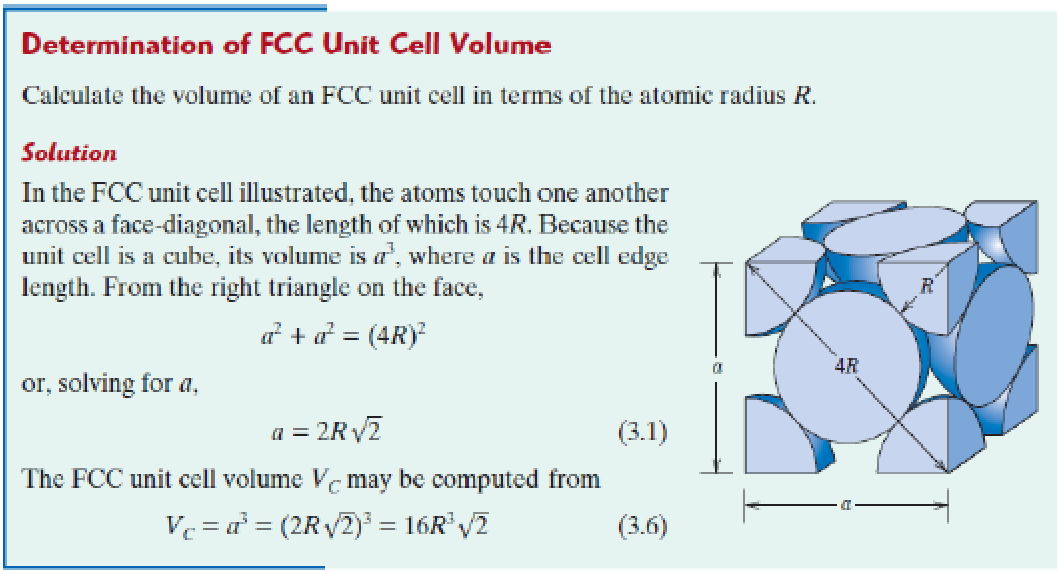
$$= \frac{4 \times (\frac{4\pi r3}{3})}{(\frac{4r}{\sqrt{2}})3}$$

$$= \frac{\frac{16\pi r3}{3}}{\frac{64r3}{2\sqrt{2}}}$$

=0.74

= 0.74 x 100 %

=74 %



Determination of FCC Unit Cell Volume

Calculate the volume of an FCC unit cell in terms of the atomic radius R.

Solution

In the FCC unit cell illustrated, the atoms touch one another across a face-diagonal, the length of which is $4R$. Because the unit cell is a cube, its volume is a^3, where a is the cell edge length. From the right triangle on the face,

$$a^2 + a^2 = (4R)^2$$

or, solving for a,

$$a = 2R\sqrt{2} \qquad (3.1)$$

The FCC unit cell volume V_C may be computed from

$$V_C = a^3 = (2R\sqrt{2})^3 = 16R^3\sqrt{2} \qquad (3.6)$$

Computation of the Atomic Packing Factor for FCC

Show that the atomic packing factor for the FCC crystal structure is 0.74.

Solution

The APF is defined as the fraction of solid sphere volume in a unit cell, or

$$\mathrm{APF} = \frac{\text{volume of atoms in a unit cell}}{\text{total unit cell volume}} = \frac{V_S}{V_C}$$

Both the total atom and unit cell volumes may be calculated in terms of the atomic radius R. The volume for a sphere is $\frac{4}{3}\pi R^3$, and because there are four atoms per FCC unit cell, the total FCC atom (or sphere) volume is

$$V_S = (4)\tfrac{4}{3}\pi R^3 = \tfrac{16}{3}\pi R^3$$

From Example Problem 3.1, the total unit cell volume is

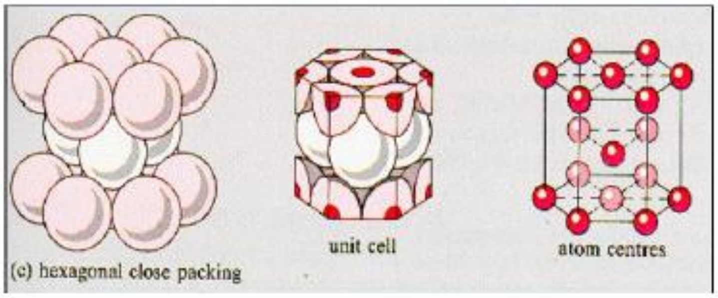
$$V_C = 16R^3\sqrt{2}$$

Therefore, the atomic packing factor is

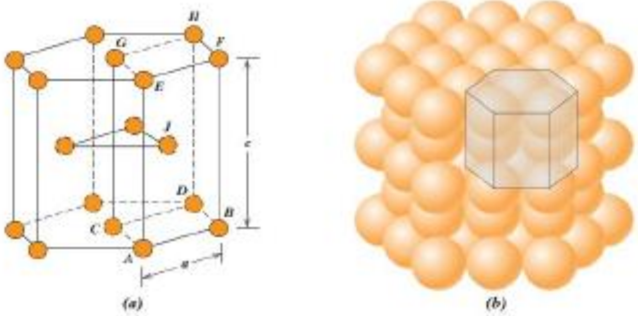
$$\mathrm{APF} = \frac{V_S}{V_C} = \frac{\left(\frac{16}{3}\right)\pi R^3}{16R^3\sqrt{2}} = 0.74$$

4. Hexagonal closed packed (HCP)

The HCP hexagonal closed packed cell has atoms at the center as well as at the corners hexagonal top face and base. Each of the 12 atoms at the corner of the top face and base are shared by 6HCP unit cells whereas the atoms at the center of the top face and base are each shared by only two-unit cells. There are also 3 full atoms within the volume of the unit cell.



(c) hexagonal close packing



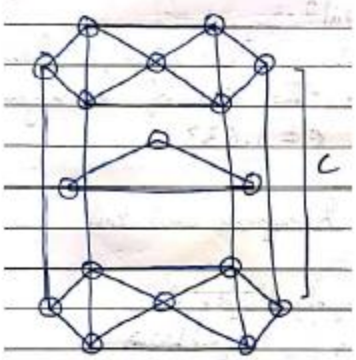
(a) a reduced-sphere unit cell
(b) and (*b*) an aggregate of many atoms.

$$N = N_i + \frac{N_f}{2} + \frac{N_c}{6}$$

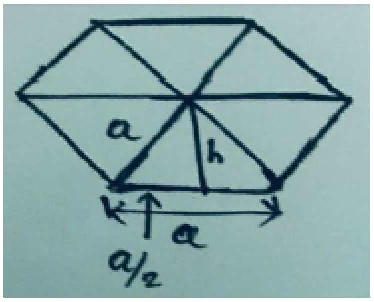
$$N = 3 + \frac{2}{2} + \frac{12}{6} = 6$$

No. of atoms in one HCP unit cell = 6 atoms
Since the corner atoms touch the neighboring atoms at their periphery.
We have a= 2r, and the ratio of height of hexagonal prism to the side of the hexagonal faces is given as C= 1.633a

Given c = 1.633a



To find the volume of hexagonal unit cell.
Volume of HCP unit cell = Area of hexagonal face X Height of the hexagonal prism



From figure,
Area of hexagonal face = area of each triangle x 6

$$\text{Area of triangle} = \frac{1}{2} \text{ b x h}$$

$$= \frac{1}{2} \text{ a x h}$$

To find height h of the triangle
Using Pythagoras theorem, $h^2 = p^2 + b^2$

$$P^2 = h^2 - b^2$$

$$= a^2 - (a/2)^2$$

$$= a^2 - (a^2/4)$$

$$= \frac{4a^2 - a^2}{4}$$

$$P^2 = (3a^2)/\ 4$$

$$P = h = \frac{a\sqrt{3}}{2}$$

$$\text{Area of triangle} = \frac{1}{2} \text{ a x h}$$

Substituting $h = \frac{a\sqrt{3}}{2}$

$$= \frac{1}{2} \text{ a x } \frac{a\sqrt{3}}{2}$$

$$= \frac{a^2\sqrt{3}}{4}$$

Area of hexagon= Area of triangle x No. of atoms in one HCP unit cell that is 6

$$= \frac{a^2\sqrt{3}}{4} \text{ x 6}$$

Volume of HCP Unit cell = (Area of hexagon) x (the ratio of height of hexagonal prism to the side of the hexagonal faces is given as C= 1.633a)

Volume of HCP Unit cell $= \frac{a^2\sqrt{3}}{4} \text{ x 6 x c}$

Substitute C= 1.633a

$$= \frac{a^2\sqrt{3}}{4} \text{ x } 6 \text{ x } 1.633a$$

APF (Atomic Packing Factor) = (Volume of Atoms/ Volume of unit cell)
= (No. of atoms x volume of each atom)/ Volume of unit cell

$$= \frac{6 \text{ x } (\frac{4\pi r3}{3})}{\frac{\sqrt{3}}{4} \text{ x } 6 \text{ x } 1.633 \text{ x } a^3}$$

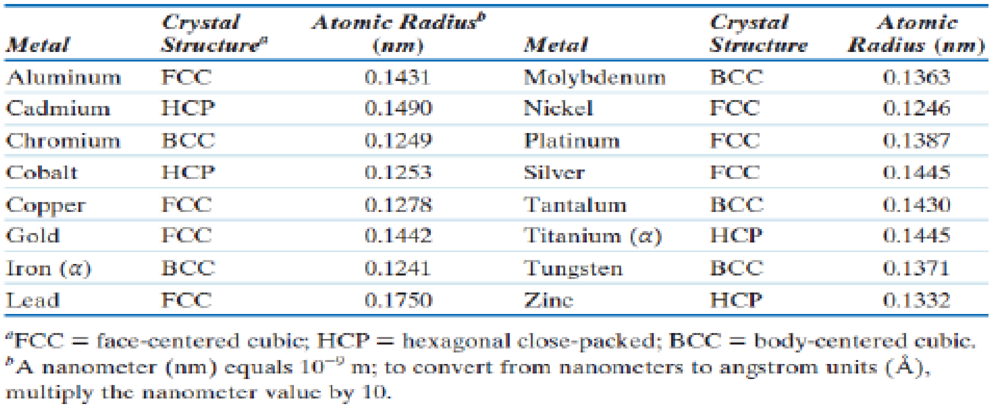
Here, atomic radius (r)= (a) lattice constant

= 0.74

=0.74 x 100%

=74%

Table Showing FCC, BCC and HCP Crystal Structure of Different Elements



Metal	Crystal Structure[a]	Atomic Radius[b] (nm)	Metal	Crystal Structure	Atomic Radius (nm)
Aluminum	FCC	0.1431	Molybdenum	BCC	0.1363
Cadmium	HCP	0.1490	Nickel	FCC	0.1246
Chromium	BCC	0.1249	Platinum	FCC	0.1387
Cobalt	HCP	0.1253	Silver	FCC	0.1445
Copper	FCC	0.1278	Tantalum	BCC	0.1430
Gold	FCC	0.1442	Titanium (α)	HCP	0.1445
Iron (α)	BCC	0.1241	Tungsten	BCC	0.1371
Lead	FCC	0.1750	Zinc	HCP	0.1332

[a] FCC = face-centered cubic; HCP = hexagonal close-packed; BCC = body-centered cubic.
[b] A nanometer (nm) equals 10^{-9} m; to convert from nanometers to angstrom units (Å), multiply the nanometer value by 10.

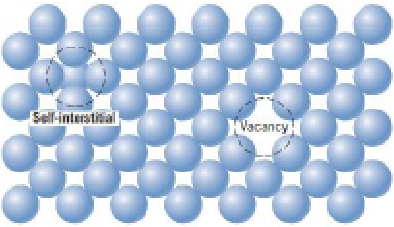
Crystal imperfection: Point defect, line and surface defect

Crystal imperfections are deviations or irregularities in the arrangement of atoms or molecules in a crystal lattice. There are several types of crystal imperfections, including point defects, line defects, and surface defects.

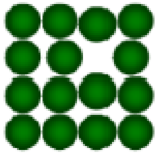
A *crystalline defect* refers to a lattice irregularity having one or more of its dimensions on the order of an atomic diameter.

A. **Point Defects** (those associated with one or two atomic positions)

A point defect is a crystal imperfection that occurs when there is a deviation from perfect lattice points in the crystal. Point defects include vacancies, interstitials, and substitutional impurities. A vacancy occurs when an atom is missing from its lattice site, an interstitial occurs when an extra atom is present in the interstitial space between the atoms, and substitutional impurities occur when atoms of a different element replace some of the atoms in the crystal lattice.

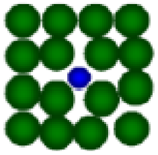


- Vacancies: This occurs when an atom or molecule is missing from its normal position within the crystal lattice, leaving an empty space or a "hole." Vacancies can occur naturally during crystal growth or can be induced by radiation or thermal energy.



Vacancy

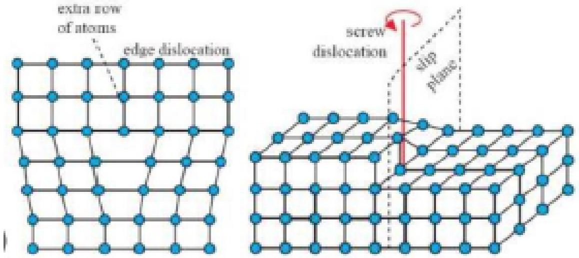
- Interstitials: This occurs when an atom or molecule is present at a position within the crystal lattice where it does not belong. This can also happen naturally or can be induced by external factors.

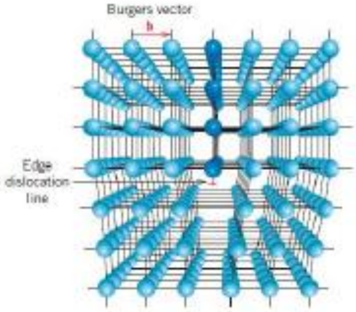


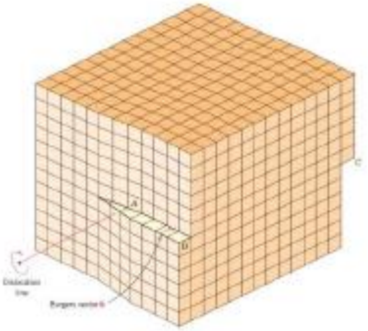
Interstitial impurity

B. Linear (or one-dimensional) Defects

A line defect is a crystal imperfection that occurs along a line or plane in the crystal lattice. Line defects include edge dislocations and screw dislocations. Edge dislocations occur when there is a misalignment of the crystal lattice along an edge, while screw dislocations occur when there is a twisting of the crystal lattice around a line.

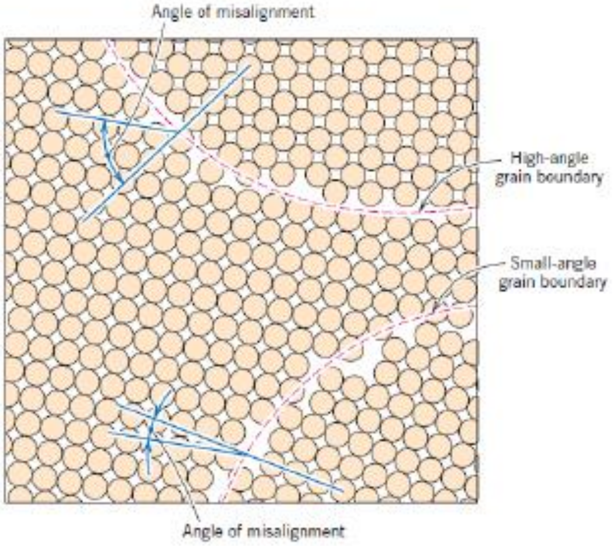






C. Surface Defects

These occur at the boundary between two crystals or at the surface of a single crystal. Surface defects can be caused by impurities, scratches, or other irregularities during crystal growth or by external factors like temperature or pressure.



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*****Thank You*****

Material Science
Unit 3:
Fracture

Contents

Introduction
Types of failure: Ductile, Brittle, Fatigue and Creep
Mechanism and remedies of Ductile and Brittle Fracture
Mechanism and remedies of Fatigue Failure

Introduction

Fracture

- Simple fracture – the separation of a body into two or more pieces in response to a static stress
- Propagation of cracks accompanies fracture
- Two general types of fracture
  - Ductile
    - Slow crack propagation
    - Accompanied by significant plastic deformation
    - Fails with warning
  - Brittle
    - Rapid crack propagation
    - Little or no plastic deformation
    - Fails without warning
- Ductile fracture generally more desirable than brittle fracture

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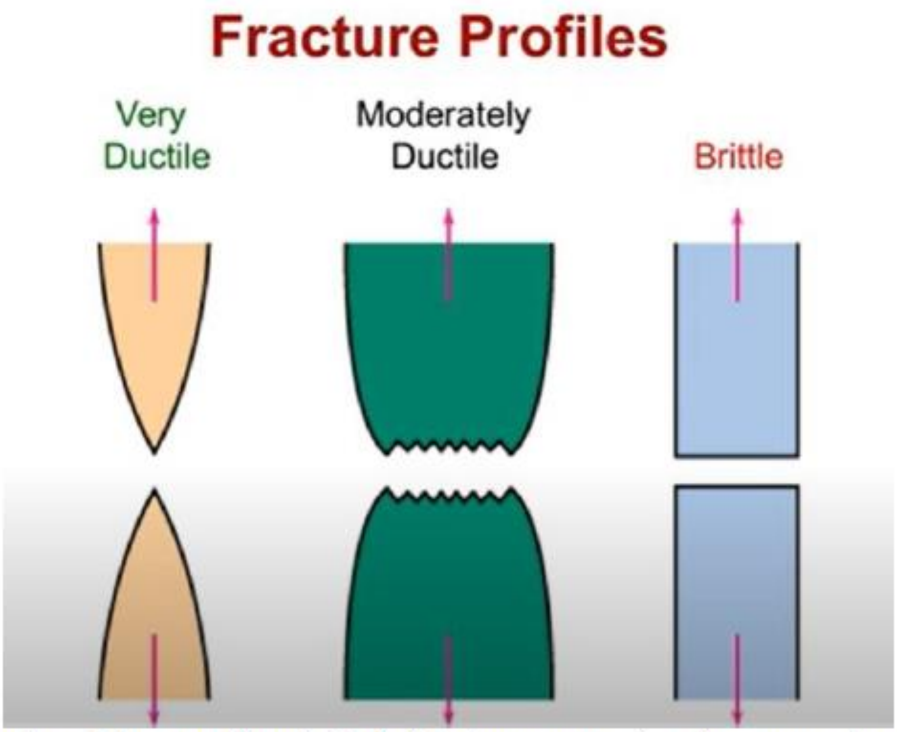


Simple fracture is the separation of a body into two or more pieces in response to an imposed stress that is static (i.e., constant or slowly changing with time) and at temperatures that are low relative to the melting temperature of the material.

Fracture is the separation or fragmentation (i.e. the process or state of breaking or being broken into fragments.) of a solid body into two or more parts under the action of load.
During fracture atomic bonds are broken and a new surface is formed.

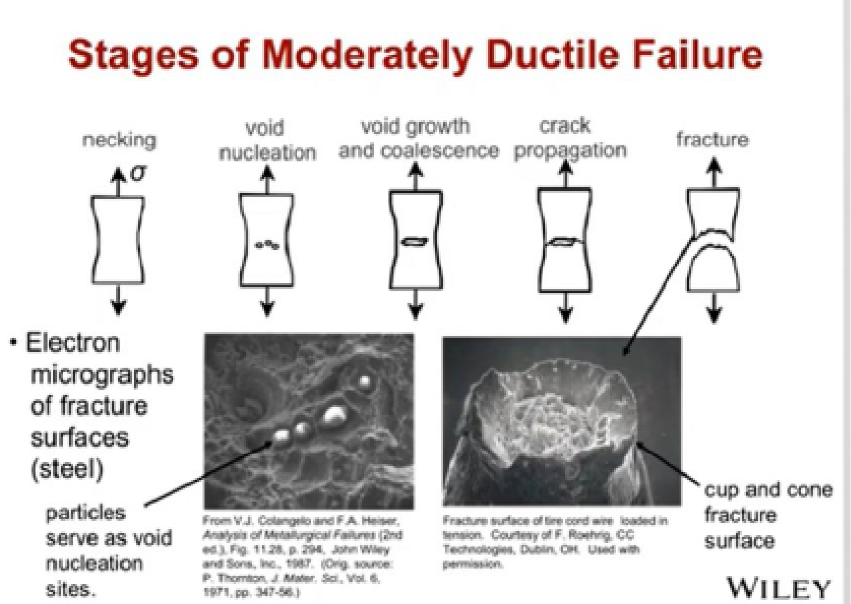
Fracture can also occur from fatigue (when cyclic stresses are imposed) and creep (time-dependent deformation, normally at elevated temperatures).

Types of failure:

1. Ductile failure
2. Brittle
3. Fatigue and
4. Creep

Ductile Failure

a. Highly ductile fracture
b. Moderately ductile fracture



From V.J. Colangelo and F.A. Heiser, *Analysis of Metallurgical Failures* (2nd ed.), Fig. 11.28, p. 294, John Wiley and Sons, Inc., 1987. (Orig. source: P. Thornton, *J. Mater. Sci.*, Vol. 6, 1971, pp. 347-56.)

Fracture surface of tire cord wire loaded in tension. Courtesy of F. Roehrig, CC Technologies, Dublin, OH. Used with permission.

Fig: - Stages of Moderately Ductile Fracture

Ductile failure in materials science refers to the mode of failure in which a material undergoes significant plastic deformation before ultimately fracturing. This type of failure occurs in materials that exhibit ductility, which is the ability of a material to deform under tensile stress without breaking.

It is characterized by an appreciable amount of plastic deformation. It proceeds relatively slowly and the fracture surface is dull in appearance.

a) **Highly ductile fracture:** Material necks down to a point fracture and yields to 100% reduction in cross- section area. Example- Soft metal like pure gold, lead.

b) **Moderately ductile fracture:**
Initial necking.
Small cavity formation.
Coalescence of cavities to form a crack.
Crack propagation.
Final shear fracture at a 45-degree angle relative to the tensile direction.

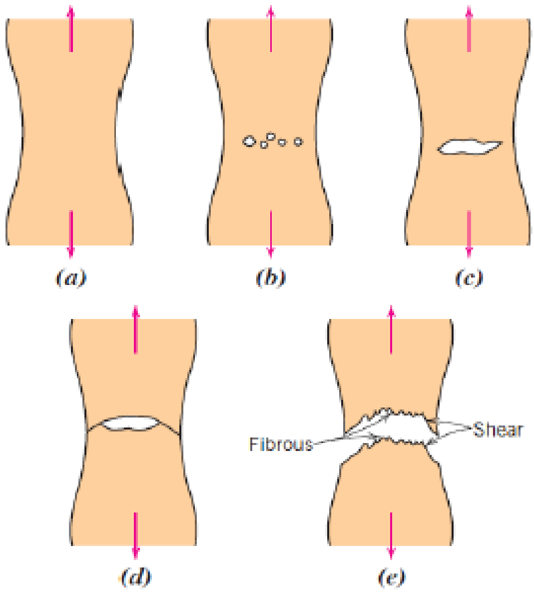


Fig: - (*a*) Initial necking.
Fig: - (*b*) Small cavity formation.
Fig (*c*) Coalescence of cavities to form a crack.
Fig: - (*d*) Crack propagation.
Fig:-(*e*) Final shear fracture at a 45-degree angle relative to the tensile direction.

Brittle failure

Brittle fracture in materials science refers to the mode of failure in which a material fractures without significant plastic deformation, often with little or no warning. This type of failure occurs in materials that are brittle, which means that they have low ductility and tend to fracture when subjected to stress.

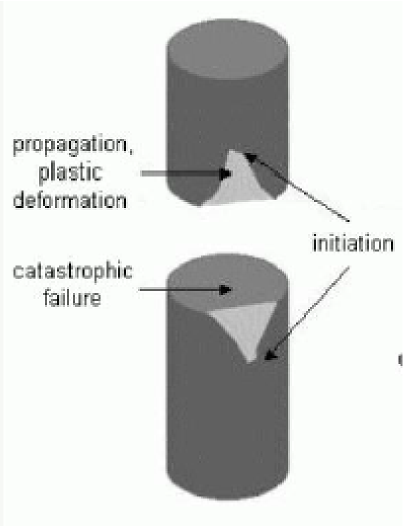
Unlike ductile failure, brittle failure occurs without significant plastic deformation, and it typically occurs at a stress level below the yield strength of the material. Brittle fractures often appear as clean, smooth surfaces perpendicular to the direction of the applied stress, and there is often little deformation or necking before fracture.

Fatigue failure

Fatigue in materials science refers to the progressive and localized damage that occurs in a material under cyclic loading conditions. It is a common mode of failure in engineering structures and is responsible for a significant percentage of mechanical failures. Fatigue failure is particularly relevant in applications involving repeated loading and unloading, such as in aircraft structures, bridges, and machine components.

Creep

Creep in materials science refers to the time-dependent deformation of a material under a constant load or stress. It is a common phenomenon in many engineering applications, particularly in high-temperature environments, where materials are subjected to sustained loads over extended periods.

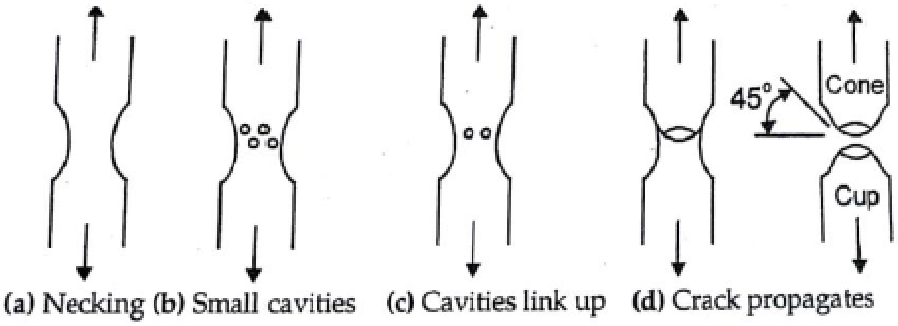


a) tensile / creep failure

Creep occurs when the material undergoes plastic deformation at a slow rate over time, even when the applied stress is below the yield strength of the material. This deformation is caused by the movement of defects, such as vacancies and dislocations, within the crystal lattice of the material.

Mechanism and remedies of Ductile Fracture

Ductile fracture occurs when a material is subjected to a tensile load and deforms plastically before breaking. In this type of fracture, the material undergoes significant plastic deformation before fracturing, which leads to necking and tearing. Ductile fracture is characterized by a dull, fibrous appearance and is commonly seen in metals such as steel, aluminum, and copper.



(a) Necking (b) Small cavities (c) Cavities link up (d) Crack propagates

Fig: Mechanism Showing Ductile Fracture

Necking

With elastic strain, the material becomes plastically deform and the neck form is shown in (a).

Small cavity formation

Within the neck, small cavities or voids are formed. These develops as a result of the stresses causing small particles of impurities or other discontinuities in the material to either fracture from the material matrix.

Formation of crack

These cavities then link up form an internal crack which spreads across the material in a direction at right angle to applied tensile stress. It is shown in (c).

Cup and cone fracture

The crack finally propagates to the material surface by sharing in a direction which is approximately 45° to the applied stress to give fracture as shown in (d).

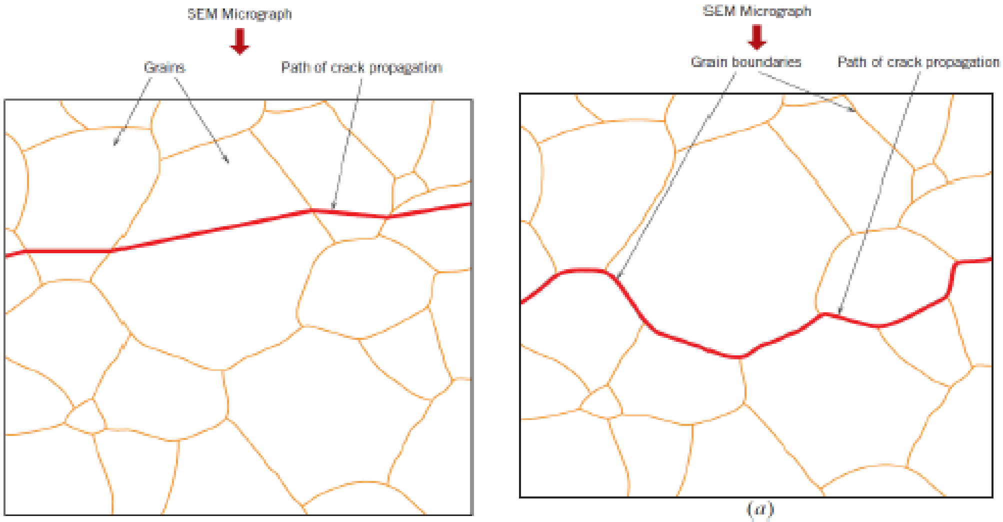
Remedies for Ductile Fracture

1. **Reduce the load rate**: Ductile fracture occurs due to high stress rates. Therefore, reducing the load rate can prevent ductile fracture.
2. **Improve material properties:** Ductile fracture can be prevented by improving the material's properties, such as increasing its ductility or toughness.
3. **Design modifications:** By modifying the design of the component, the stress concentration can be reduced. This can help prevent ductile fracture.

Mechanism and remedies Brittle Fracture

Brittle fracture occurs when a material fractures without significant plastic deformation. This type of fracture is characterized by a shiny, crystalline appearance and is often seen in materials with low ductility, such as ceramics and some types of polymers. Brittle fractures occur when a material is subjected to a sudden, high-stress load, such as an impact or a sudden change in temperature.

The direction of crack motion is very nearly perpendicular to the direction of the applied tensile stress and yields a relatively flat fracture surface.



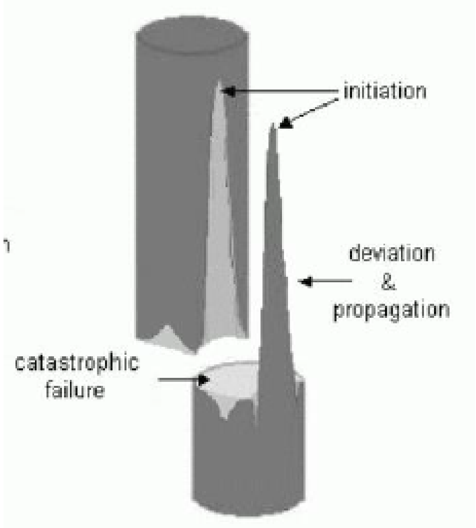
a. Schematic cross-section profile showing crack propagation along grain boundaries for intergranular fracture.
b. Schematic cross-section profile showing crack propagation through the interior of grains for trans granular fracture.

Remedies for Brittle Fracture

1. **Improve material properties:** Brittle fracture can be prevented by improving the material's properties, such as increasing its ductility or toughness.
2. **Reduce the stress concentration:** Brittle fracture occurs due to stress concentration. Therefore, reducing the stress concentration can prevent brittle fracture.
3. **Increase the operating temperature:** Brittle fracture occurs at low temperatures. Therefore, increasing the operating temperature can help prevent brittle fracture.

Mechanism and remedies of Fatigue Failure

Fatigue failure is a type of failure that occurs due to repeated cyclic loading on a material, which leads to a gradual accumulation of damage over time. The mechanism of fatigue failure involves three stages: ***initiation, propagation, and final fracture.***



b) fatigue failure

Initiation

During the initiation stage, small cracks or defects form on the surface of the material due to cyclic loading. These cracks may be too small to detect and can occur even at low stress levels.

Propagation

During the propagation stage, the cracks continue to grow under cyclic loading, which can cause the material to weaken and lose its structural integrity.

Final Fracture

Finally, the material experiences final fracture when the crack reaches a critical size, causing the material to fail suddenly.

The remedies for fatigue failure include:

1. **Material selection:** Choosing a material that has high fatigue resistance can help prevent fatigue failure.

2. **Design modifications:** Design modifications such as reducing stress concentrations, altering the shape or size of the component, and providing fillets or radii can help prevent fatigue failure.
3. **Surface treatments**: Surface treatments such as shot peening or polishing can help prevent fatigue failure by improving the surface quality of the material and reducing stress concentrations.
4. **Regular inspection and maintenance:** Regular inspection and maintenance can help detect and repair any cracks or defects before they become critical and cause fatigue failure.
5. **Load reduction:** Reducing the magnitude or frequency of cyclic loading can help prevent fatigue failure.

Material Science

Unit 4
Testing of metals

Contents

Types of testing
Non-destructive testing and their uses: X-ray, ultrasonic, magnetic tests
Destructive testing
- Tensile test
- Fatigue test
- Hardness test: Brinell, Vicker and Rockwell
- Impact test: Charpy and Izod

Non-destructive testing and their uses: X-ray, ultrasonic, magnetic tests

Introduction

Non-Destructive Tests: The specimen is not destroyed and can be used after the test. Examples of nondestructive tests are the magnetic dust method, penetrating liquid method, ultrasonic test and radiography. All these non-destructive tests are used to detect various types of flaws on the surface or internal inclusions of impurities.

X-ray

This method is used to check internal cracks, defects in materials and welds. Nowadays, radiography techniques are finding more extensive applications in the field of physical metallurgy and in the treatment of various diseases. Rays are absorbed by the materials through which they are passed in the proportion of their density. The rays, after passing through the components, show a picture on a fluorescent screen or on a photographic plate. The cracks, blow holes and cavities appear lighter, whereas inclusions of impurities appear darker than the metal component. Developed photographic film show lighter and darker areas to represent the radiograph of defects in the component.

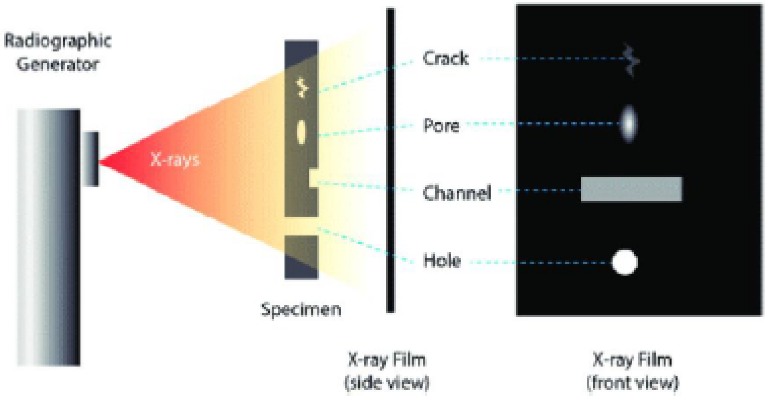
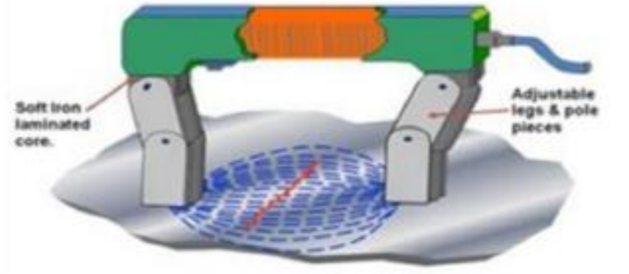


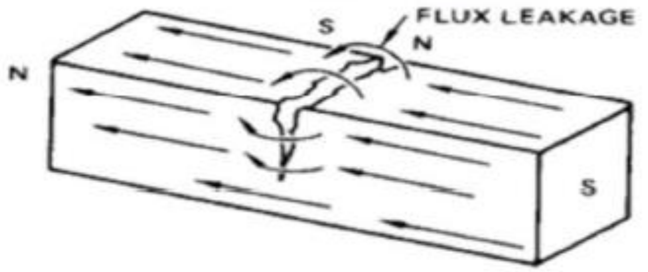
Fig: X-ray method of testing material defects

In X-ray photography, X-rays after allowing through the blow hole in a casting, will be absorbed to a lesser extent than X-rays which allowed to pass through sound metal. X-ray absorption measurement can be used to detect the fault in the specimen. X-rays are useful only for small thickness materials as their penetration power is less than that of gamma rays.

Magnetic Test

This method is restricted to magnetic materials e.g., iron, nickel, cobalt, etc. This test is based on the principle that if there is a flaw in the magnetic material through which a magnetic field is allowed to pass, the lines of magnetic force or flux will be distorted near the flaw and lines of magnetic flux will be uniform for magnetic materials which are defect free. *This test is performed by magnetizing the substance and then immersing the substance (test piece) in a bath of kerosene oil containing iron oxide powder*. One can also use the colored powder. If a crack or void lies across the path of the magnetic flux, each side of the crack or void becomes a magnetic pole which attracts iron powder. The accumulation of iron dust on the crack portion of the sample reveals the crack. This test can detect both internal and external defects. One can detect the cracks caused by quenching, fatigue failure in welding, blow holes in castings and grinding operations by this method. *Magnaflux* is the equipment used for this test.





Ultrasonic Test

High frequency ultrasonic (sound) waves are applied to the test piece by a Piezoelectric crystal. If the test piece is free from cracks, or flawless, then it reflects ultrasonic waves without distortion. If there are any flaws in the specimen, the time taken by the ultrasonic waves will be less as the reflection of these waves will be from flaw points and not from the bottom of the specimen. Cathode ray oscilloscope (CRO) is used to receive the sound signals, whose time base circuit is connected to it. Knowing the time interval between the transmission of the sound pulse and the reception of the echo signal, we can calculate the depth of the crack. This test is a very fast method of inspection and often used to test aerospace components and automobiles. This test is generally used to detect internal cracks like shrinkage cavities, hot tears, zones of corrosion and non-metallic inclusions.

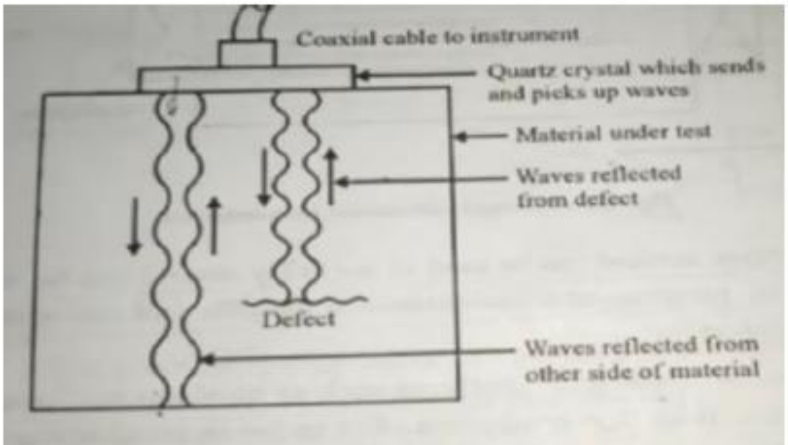


Fig. 4.4 : Detection of defects by ultrasonic waves.

Destructive testing

In this type of testing, the specimen or the component is destroyed and cannot be reused. The tests are conducted on similar specimens and under the same conditions. Tensile test, hardness test, impact test, fatigue test, creep test, etc. are examples of destructive test.

Tensile test

In engineering, tension test is widely used to provide basic design information on the strength of the materials. In the tension test a specimen is subjected to a continually increasing uniaxial tensile force while simultaneous observations are made of the elongation of the specimen. A stress-strain curve is plotted from the load-elongation measurements. The parameters which are used to describe the stress-strain curve of a material are the tensile strength, yield strength or yield point, percent elongation and reduction of area. The first two are strength parameters; the last two indicate ductility.

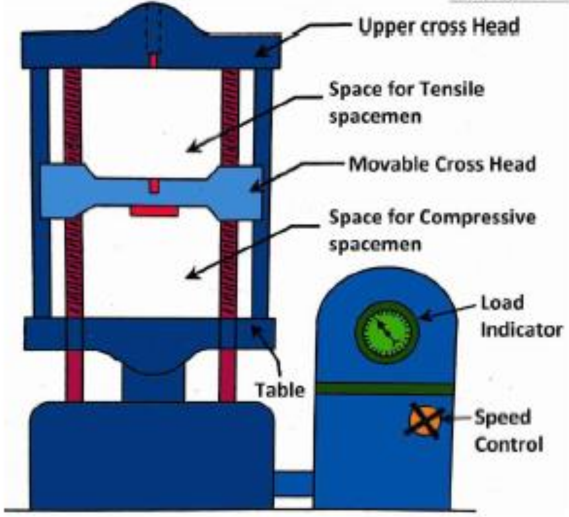


Figure: - Universal Testing Machine

Apparatus:

Universal Testing machine, Dial gauge, Vernier calliper and scale.

A - Elastic Limit
B - Upper Yield Stress
C - Lower Yield Stress
D -Ultimate Stress
E -Breaking Stress

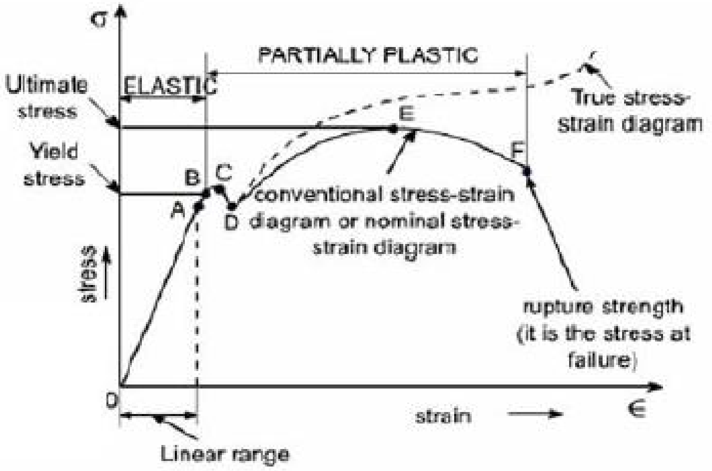
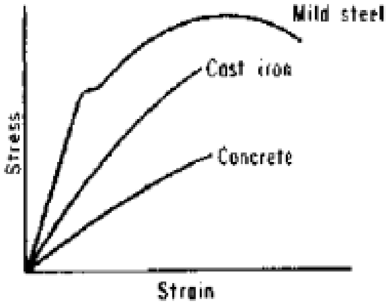


Fig: - Stress-Strain Curve



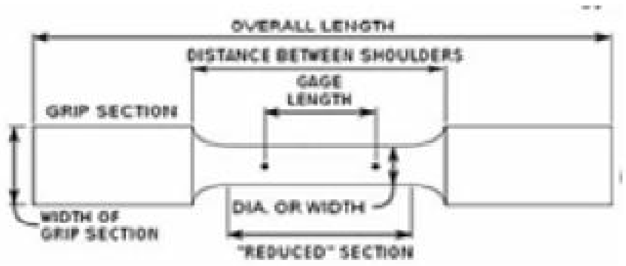


Fig: - Test Specimen

Percentage increase in Length = $[(L_f - L_i)/L_i]*100$

Ultimate Tensile Stress, $\sigma_u = F_{max} / A$

Yield Stress, $\sigma_y = F_y/A_i$

Breaking Stress, $\sigma_b = F_b/A_i$

Fatigue Test

Machines which may be used for making fatigue tests under cycles of repeated or reversed stress are usually classified according to the type of stress produced:

Rotating Beam Fatigue Test

The most common test loading for fatigue testing is pure bending, because it is easy to apply. A circular specimen is gripped in collets (Fig.). Figure shows the test specimen and main features of the testing machine. The test machine has high speed electrical motor with a speed of 1000 rpm. Next to the motor there is a large bearing, which relieves the motor from large bending moment which is applied to the specimen. A collet is attached with a rotating lever arm which is further connected with a small bearing. A force is applied on the bearing, which causes the specimen to bend. The upper surface of the specimen will be under tension, whereas the lower surface in compression. Since the specimen is rotated by a motor, the surface of specimen is subjected to alternate tensile and compressive stresses. The revolution counter reader provided with the machine records the number of cycles applied and when the specimen breaks then the counter automatically disengages. Truly, the disengaging device is designed to stop the testing machine itself.

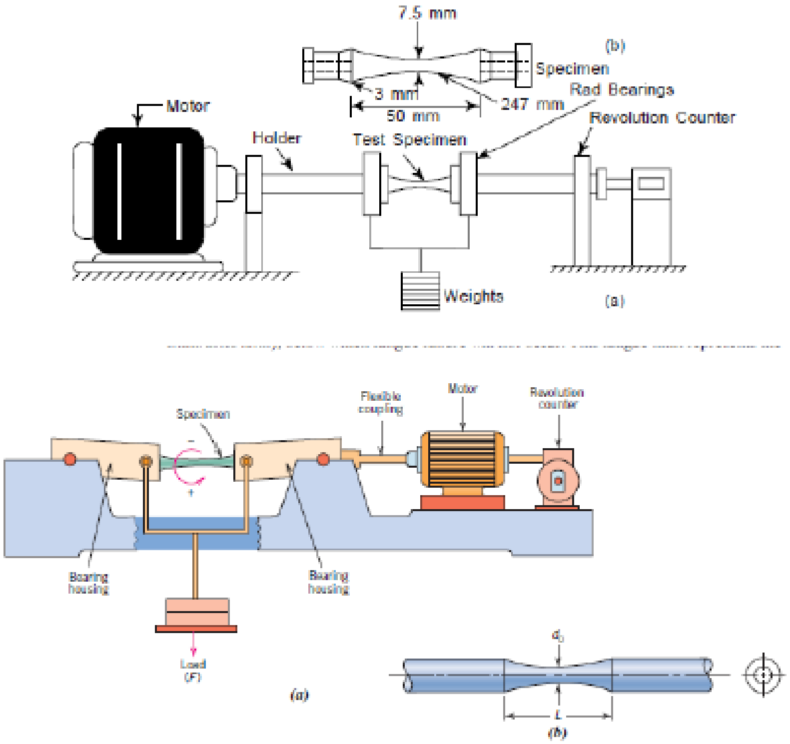


Fig: Rotating Beam Fatigue Test

In order to obtain the fatigue limit, i.e., endurance limit of a metal, it is necessary to prepare a number of specimens which are representative of that metal. The first specimen of metal is tested at a relatively high stress so that the failure will occur at a small number of applications of the stress. The other specimens of the metal are tested relatively at a lower stress than the previous one.

With the decrease in stress value, the life of specimen increased. The number of repetitions required to produce rupture, i.e., fracture increases as the stress decreases. Specimen with stress below the endurance limit will not rupture.

The life of the specimen is expressed in number of cycles required up to failure at maximum applied force. The results of fatigue tests are commonly plotted on diagrams in which values of stress are plotted as ordinates and values of cycles of stress for rupture as abscissae.

The curve is called *S-N* diagram, where *S*-stands for stress and *N* for number of cycles (Fig. 8.16). These diagrams are drawn using semi-logarithmic plotting, i.e., plotting '*N*' on logarithmic scale.

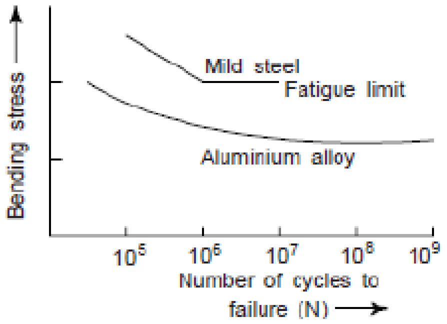


Fig. 8.16 S-N Diagram

Wohler's Fatigue Test

Figure shows a diagrammatic sketch of Wohler fatigue testing machine. In this machine, the specimen in the form of cantilever forms the extension of a shaft which is driven by an electric motor. Through a ball bearing, dead loading is applied to the specimen. When the machine is in action i.e., it runs, the specimen rotates and the fibers of the specimen are subjected to reversed stresses. In some instances, the specimen is tapered or a two-point loading is applied to obtain a uniform surface stress over a considerable length of specimen.

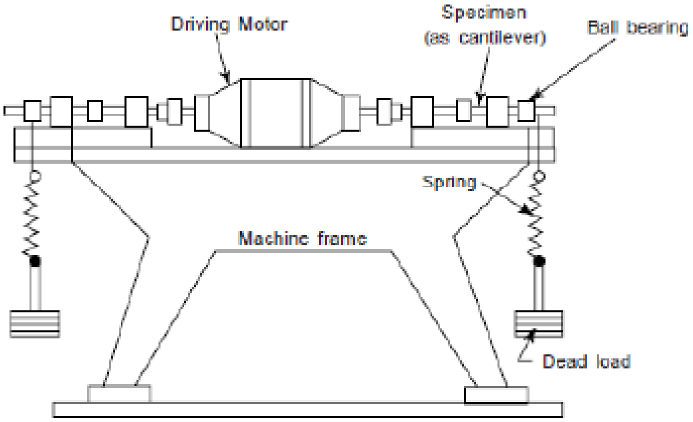


Fig. 8.17 Wohler fatigue testing machine

To cause failure the number of cycles vary with applied stress. When stress is higher, fewer are the cycles required for causing the fracture. Obviously, a stress is reached below which fracture would not take place within the limits of a standard test and this is termed as 'endurance limit'. The length of such a standard test depends on the material being tested and types of loading. Usually, it is of the order of 500,000 cycles for very hard steels, 5,000,000 for soft steels; 10,000,000 for cast steel and cast iron; and for nonferrous metals and alloys from 1,000,000 to about 50,000,000. If the fracture does not take place within these limits, then it is understood that it will not take place at all. There are certain well-defined characteristics for fatigue failures of metallic materials. The fractured surface frequently exhibits two distinct zones. One can find the cause of the failure by careful examination of such a failure. There is a smooth part usually showing concentric markings starting from a nucleus stress raiser, and rougher part often presenting crystalline faces.

Hardness test: Brinell, Vickers and Rockwell

Hardness

This is the property of a material (metal) by virtue of it is able to resist abration, indentation (or penetration) and scratching by harder bodies. It is the resistance of a material to permanent deformation of the surface. In other words, one can define it as the resistance of the metal to penetration by an indentor.

Brinell Test

The Brinell hardness test is a method used to determine the hardness of a material. It involves indenting the surface of a material with a specified load and measuring the diameter of the resulting indentation. This test is primarily used for metals and alloys, although it can also be applied to some non-metallic materials.

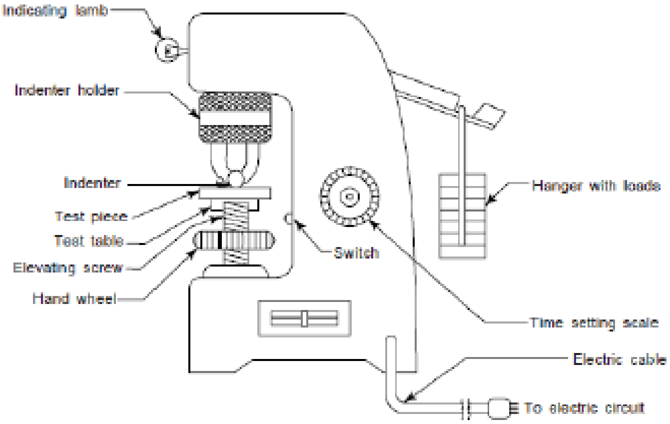


Fig. 8.30 Brinell hardness testing machine

Brinell Hardness Test is used to determine the Hardness Number of hard, moderately hard, and soft material Eg: Brass, Bronze, Aluminium, Gold, Copper, Etc. Very hard material and Brittle material cannot be tested by Brinell hardness tester.

Principle

Brinell hardness number (BHN) is obtained by the ratio of the calculated load and the spherical area of the Indentation or Impression made on the specimen by the corresponding Indenter Ball.

Apparatus:

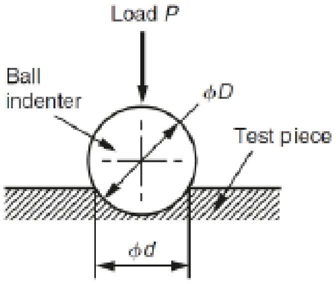
i) Brinell hardness testing machine and Brinell Microscope
ii) Ball Indentor of diameter 2.5mm and 5mm
iii) Specimens (Mild steel, Brass, Copper, Aluminium)

Formula:

Brinell hardness number (BHN) =

$$\frac{2P}{\pi D[D-\sqrt{D^2-d^2}}$$

Where,



D = Diameter of ball indentor in mm
d= Diameter of Indentation in mm
P= Load applied in 'N'
d=MSR+ (CVSD×LC)

Observations / Tabular Column:

Sl. No.	Material	Ball Diameter "D" in mm	Applied load "P" in Kg	Applied load "P" in N	BHN (N/mm^2)
1					
2					
3					

Result: Brinell hardness number (BHN) of a given specimen is ______________

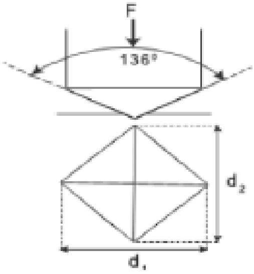
VICKER'S HARDNESS TEST

Very Hard materials (e.g. Mild steel, case hardened steel, etc.) can be tested by the Vicker's method. If the moderately hard materials like Brass, Copper and Aluminium are tested in this machine, the indentor makes a deep impression. Hence, a proper indentation cannot be made on the specimen and a correct value of the hardness cannot be obtained for these materials by V. H. Test.

This test is similar to Brinell hardness test similar relationship and eliminates most of the errors. A regular pyramid having a square base and smoothened off diamond point is pressed in the material to be tested under a load "F". The produced impression is projected onto a focusing screen and the diagonals of the impression are measured by means of the measuring equipment. Due to small impressions, it is very suitable for testing polished and hardened material surfaces. This test is rapid, accurate.

Formula:

Vickers Hardness Number (VHN) $=\frac{2P\sin\frac{\theta}{2}}{d^2}$



Where,
P= Load applied in 'N'
$d=(d_1+d_2)/2$
$\theta = 136^0$ (angle between two opposite faces of indentation)

Principle

The required load as calculated by P/d_2 ratio is applied on the specimen for a standard time of 8-10 Seconds and BHN is calculated by the ratio of load and the spherical area of indentation. The diameter of the indentation is measured on the focusing screen of the machine.

Observations / Tabular Column:

Sl. No.	Material	Applied Load "P" in Kg	Applied Load "P" in N	Indentation		VHN (N/mm^2)
				d_1	d_2	
1						
2						
3						

Result: Vickers hardness number (VHN) of a given specimen is ____________

Rockwell Hardness Test

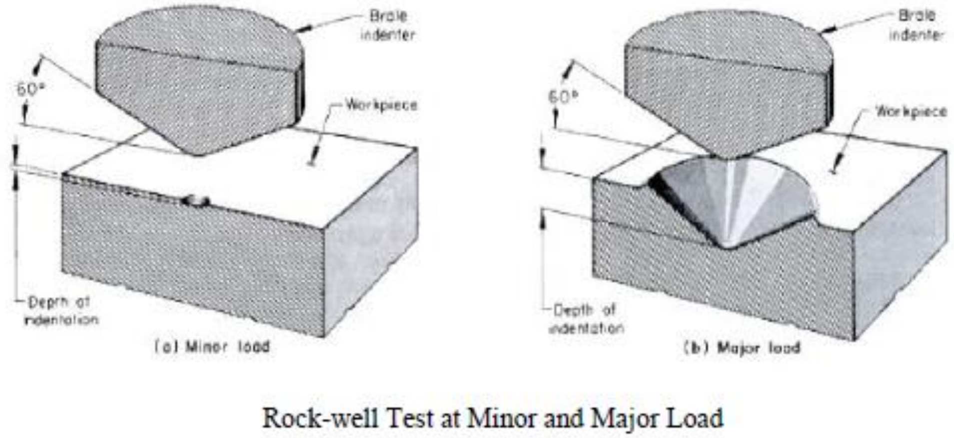
Rockwell test is developed by the Wilson instrument co U.S.A in 1920. This test is an indentation test used for smaller specimens and harder materials. In this test indentor is forced into the surface of a test piece in two operations, measuring the permanent increase in depth of an indentation from the depth increased from the depth reached under a datum load due to an additional load. Measurement of indentation is made after removing the additional load. Indentor used is the cone having an angle of 120 degrees made of black diamond.

Principle:

A standard load (Based on type of material) is applied through a standard indentor (cone or ball indentor) for a standard duration of time. The hardness number is directly obtained in the experiment.

Specification:

Rockwell hardness tester gives the direct reading of hardness number on a dial provided with the machine. The specimen may be cylinder, cube, thick or thin metallic sheets.



(a) Minor load

(b) Major load

Rock-well Test at Minor and Major Load

Observations / Tabular Column:

Sl. No	Material	Indentor	Load Applied "P" in N		RHN
			Minor	Major	
1					
2					
3					

Impact test: Charpy and Izod
In the field of material science, the term "impact" typically refers to the forceful collision or contact between two objects. It specifically relates to the study of how materials respond to such collisions and the resulting effects on their properties.

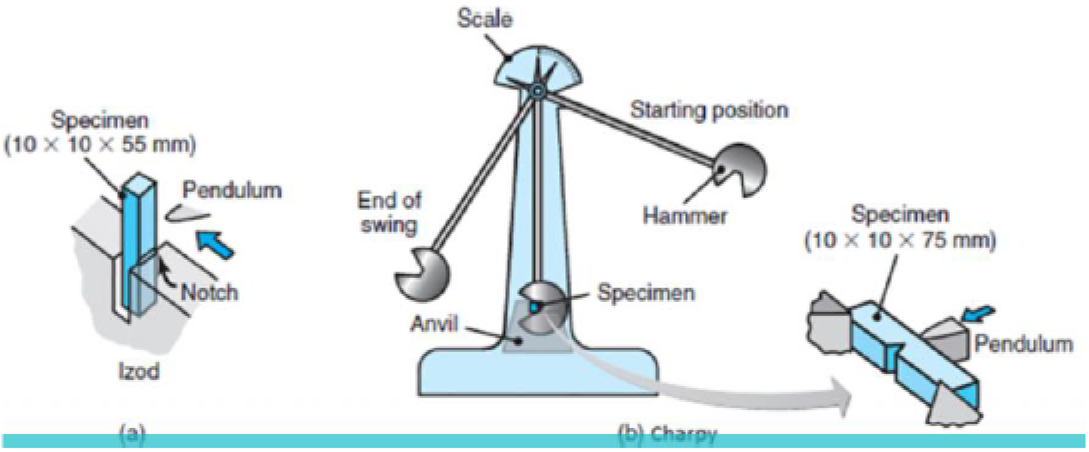
IZOD Impact Test
A pendulum type single blow impact test in which the specimen, usually notched, is fixed at one end and free at other end Specimen is broken by a falling pendulum. The energy absorbed as measured by the subsequent rise of the pendulum is a measure of impact strength or notch toughness.

Notch
A slot or groove of specified characteristics intentionally cut in a test piece so as to concentrate the stress localizing the rupture.

Notch Toughness
The high resistance of the material to fracture under suddenly applied loads at any Stress raiser such as notch.

Toughness
The ability of the material to absorb energy and deform plastically before fracture. It is usually measured by the energy absorbed in a notched impact test like Charpy and Izod tests. The area under the stress -strain curve in a tensile test is also a measure of toughness and as such is proportional to the combined effects of tensile strength and ductility.

The Izod impact energy (I) i.e, the energy required to break the specimen is obtained directly from the test. The depth below the notch and the breadth of the specimen is measured (i.e d and b). The effective cross-sectional area below the notch is obtained (A=bd ,mm^2) hence, specific Impact factor=If=I/A Joules /mm^2.



(a)

(b) Charpy

Fig: - Charpy and Izod Test Setup

Specification:
Specimen size= 75*10*10
Type of notch = V- Notch
Angle of notch= 45o
Depth of notch= 2mm

Observations / Tabular Column:

Sl. No	Material	Breadth 'b' in mm	Depth Below the notch 'd' in mm	Area 'A' in mm²	Impact Energy 'I' in Joules	Impact Strength 'K' in J/ mm²
1						
2						
3						

Formula:
Breadth= MSR+ (CVD*LC) = ...mm
Depth = MSR+ (CVD*LC) = ...mm
Area = Depth * Breadth
Impact Strength, K = I/ A =........... J/ mm²

Result: Impact strength of a given specimen in
Izod is ______________
Charpy is ______________

Material Science
Unit 5
Steels and cast iron

Contents

Micro constituents in iron and cooling curve
Effect of carbon in iron
Difference between steels and cast iron
Types of steels: HSLA steel, stainless steel, tool steel
Types of cast iron: Grey, white, malleable, ductile
Various steel making processes: Bessemer, Open hearth, Duplex

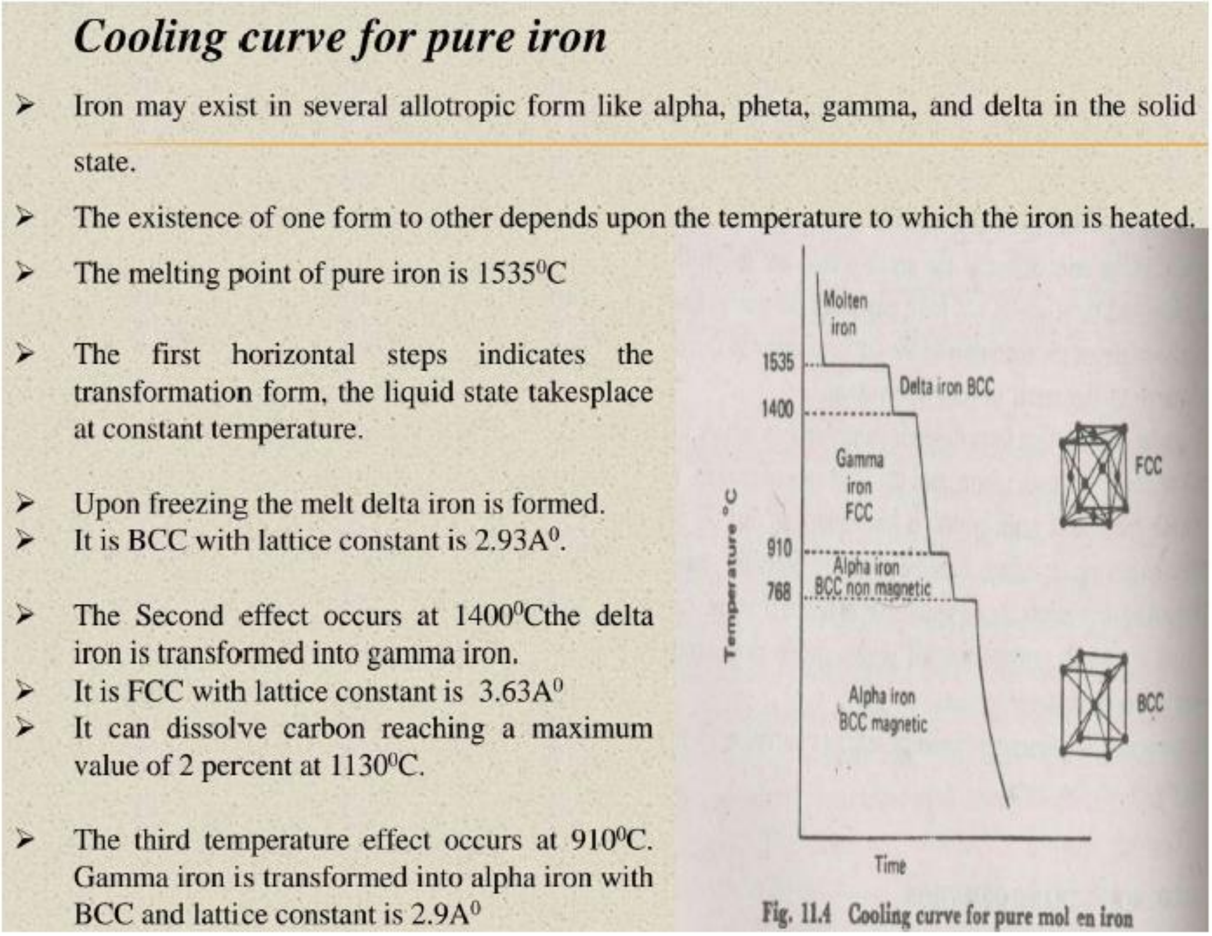
Introduction to steel and cast iron

Steels and cast iron are both important materials widely used in various industries due to their exceptional mechanical properties, versatility, and cost-effectiveness. They are primarily composed of iron (Fe) with varying amounts of carbon (C) and other alloying elements, which give them distinct properties suitable for specific applications. Let's briefly introduce each of these materials.

Steel: Steel is an alloy of iron and carbon, with carbon content typically ranging from 0.2% to 2.1% by weight. However, steel can also contain small amounts of other elements, such as manganese, silicon, and various trace elements, to further enhance its properties. The carbon content and the presence of other elements influence the mechanical properties of steel, making it highly customizable for different applications.

Cast Iron: Cast iron is also an alloy of iron and carbon, but it contains a higher carbon content than steel, usually between 2.1% to 4%. The increased carbon content results in a brittle material that lacks the ductility of steel but offers superior compressive strength and wear resistance. The higher carbon content in cast iron promotes the formation of graphite flakes during solidification, which gives it its characteristic grey appearance. This graphite microstructure also helps in reducing the likelihood of cracks propagating through the material.

Micro constituents in Iron and Cooling curve



Cooling curve for pure iron

- Iron may exist in several allotropic form like alpha, pheta, gamma, and delta in the solid state.
- The existence of one form to other depends upon the temperature to which the iron is heated.
- The melting point of pure iron is 1535^0C
- The first horizontal steps indicates the transformation form, the liquid state takesplace at constant temperature.
- Upon freezing the melt delta iron is formed.
- It is BCC with lattice constant is $2.93A^0$.
- The Second effect occurs at 1400^0Cthe delta iron is transformed into gamma iron.
- It is FCC with lattice constant is $3.63A^0$
- It can dissolve carbon reaching a maximum value of 2 percent at 1130^0C.
- The third temperature effect occurs at 910^0C. Gamma iron is transformed into alpha iron with BCC and lattice constant is $2.9A^0$

Fig. 11.4 Cooling curve for pure mol en iron

Fig: Schematic diagram of pure iron cooling curve

Following listed below are the Micro-Constituents in Iron (Fe).

1. **α-ferrite**

- *Alpha-ferrite is Interstitial* solid solution of Carbon in BCC iron (Fe).
- Stable form of iron at room temperature to 912 C.
- The maximum solubility of Carbon is 0.022 wt.% at 727°C.
- Transforms to FCC γ-austenite phase at 912 °C.
- It dissolves only 0.008 % C at room temperature.

Properties it is ductile, highly magnetic and it has a low tensile strength of approximately 2800 Kg/cm2. Its soft phase.

2. γ-austenite

- ***Gamma-austenite is Interstitial*** solid solution of Carbon in FCC Fe.
- The maximum solubility of Carbon is 2.14 wt. % at 1147°C.
- Transforms to BCC δ-ferrite at 1395 °C.
- Is not stable below the eutectic temperature (727 ° C) unless cooled rapidly.
- It is stable above 727°C.
- This phase plays an important role in the phase transformations of steels.
- High formability, most of heat treatments begin with this single phase.
- It is normally not stable at room temperature. But, under certain conditions it is possible to obtain austenite at room temperature.
- FCC structure

Properties it is generally soft, ductile, non- magnetic and it is denser than ferrite.

3. δ-ferrite

- **Delta Ferrite is Solid solution of Carbon in BCC Fe (Iron).**
- The same structure as α-ferrite.
- Stable only at high Temperature, above 1395 °C.
- Melts at 1539 °C.
- Maximum carbon solubility: 0.09-0.10 wt.%.
- BCC structure
- Paramagnetic

4. Cementite (Fe3C)

- This intermetallic compound is metastable,
- It is a product which contains 6.67% carbon and 93.33% iron by weight.
- It is found in steel containing over 0.8% carbon when it cools.
- The amount of cementite increases with increasing the percentage of carbon in iron.
- It is very hard, brittle intermetallic compound of iron & carbon, can strengthen steels, with chemical formula **Fe3C.**
- Cementite (Fe3C) contains 6.67 % C.

It is the hardest structure that appears on the diagram, exact melting point unknown.

5. Pearlite

- Pearlite is a structure (i.e., consists of two phases) consists of alternate layers of ***ferrite and cementite*** in the proportion 87:13 by weight.
- It is formed from austenite at eutectoid temperature (A1) 727°C upon slow cooling.
- Pearlite is the eutectoid mixture containing 0.80 % C and is formed at 723°C on very slow cooling.
- It is a very fine plate like or lamellar mixture of ferrite and cementite.

Properties it is strong metal phase, may be cut reasonably well with cutting tool and it has tensile strength of 8750 Kg/cm2.

6. Ledeburite

- Is the eutectic mixture of ***austenite and cementite***.
- It contains 4.3 percent Carbon and is formed at 1130°C.

7. Martensite

Martensite is a super-saturated solid solution of carbon in ferrite. It is formed when steel is cooled so rapidly that the change from austenite to pearlite is suppressed (growth less).

Effect of carbon in iron

The addition of carbon to iron has a profound impact on the properties and behavior of the resulting material, leading to the formation of different types of steel. The carbon content in iron can range from very low (wrought iron) to high (cast iron), and each variation has distinct characteristics. Here are the key effects of carbon in iron:

Strength and Hardness: Carbon in iron acts as a strengthening agent, making the material harder and more robust. As the carbon content increases, the steel's hardness and strength also increase, making it suitable for various structural applications.

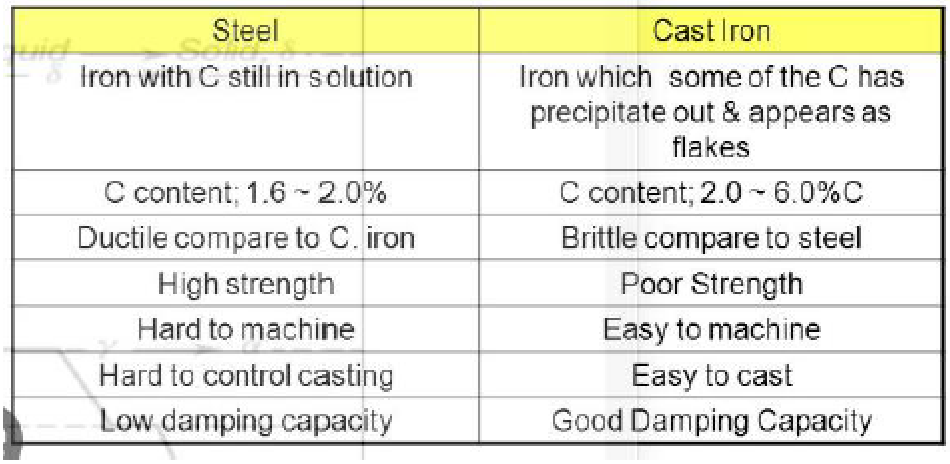
Affects melting points: Carbon raises the melting point of iron, which is essential for industrial processes like casting and welding.

Ductility and Malleability: Lower carbon content in iron contributes to its ductility and malleability, making it easier to shape and form into various objects.

Reduces Toughness: While carbon enhances strength, it can reduce the toughness and impact resistance of the iron. This is particularly evident in high-carbon steels, which tend to be more brittle.

Corrosion Resistance: The addition of carbon can improve the material's resistance to corrosion, particularly in stainless steels where the presence of chromium helps form a protective oxide layer.

Difference between steels and cast iron



Steel	Cast Iron
Iron with C still in solution	Iron which some of the C has precipitate out & appears as flakes
C content; 1.6 ~ 2.0%	C content; 2.0 ~ 6.0%C
Ductile compare to C. iron	Brittle compare to steel
High strength	Poor Strength
Hard to machine	Easy to machine
Hard to control casting	Easy to cast
Low damping capacity	Good Damping Capacity

Fig: - Table showing difference between steel and cast iron

Types of steels: HSLA steel, stainless steel, tool steel

High-Strength Low-Alloy Steel (HLSA)

HSLA steel is a type of carbon steel that contains small amounts of alloying elements such as vanadium, niobium, titanium, and others. These alloying elements enhance the steel's strength, hardness, and wear resistance while maintaining good formability. HSLA steels are commonly used in the construction of bridges, buildings, and various structural components where high strength and lightweight properties are desired.

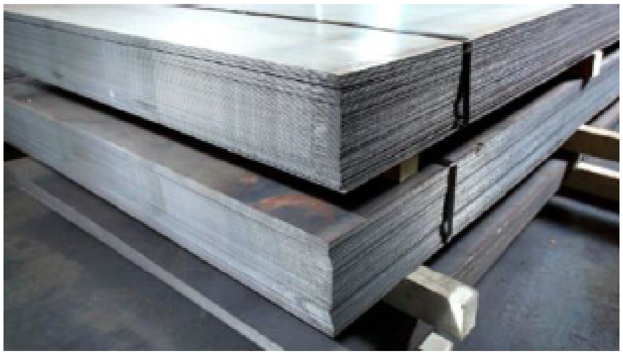


Fig: - HLSA Steel

High Speed Steel (HSS)

High Speed Steel consist of carbon steel alloyed with tungsten or molybdenum, together with percentages of chromium, vanadium and cobalt. The alloying elements raise the temperature at which tempering occurs, allowing HSS to be used at temperatures up to about 650°C. Their hardness is limited to 750 HV, adequate for machining most of the common metals, including alloy steels in their unhardened forms.

Stainless Steel

Stainless steel is a corrosion-resistant alloy of iron with a minimum of 10.5% chromium content. The presence of chromium creates a protective oxide layer on the surface, making it highly resistant to rust and corrosion in various environments. Stainless steel comes in various grades with different compositions to suit specific applications, such as kitchen utensils, medical instruments, industrial equipment, and architectural structures.

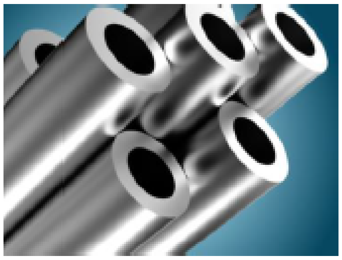


Fig: - Stainless Steels

Tool Steel

Tool steel is a specialized type of steel designed for the production of tools, dies, and cutting implements. It is known for its high hardness, wear resistance, and ability to retain its shape at elevated temperatures. Tool steels often contain alloying elements like tungsten, vanadium, and molybdenum, which contribute to their exceptional properties. Different grades of tool steel are used for specific tooling applications, such as high-speed cutting tools, molds, and dies for metalworking and plastic molding industries.

Fig: - Tool Steels

Each of these types of steels has distinct properties that make them suitable for various industrial applications. Engineers and material specialists carefully choose the appropriate type of steel based on the specific requirements of a project or product, considering factors like strength, corrosion resistance, wear resistance, formability, and cost.

Types of cast iron: Grey, white, malleable, ductile

Cast iron is a family of ferrous alloys that contains more than 2% carbon (by weight) and varying amounts of silicon. The different types of cast iron are classified based on their microstructure and properties. Here are the four main types of cast iron:

Grey Cast Iron

Grey cast iron is the most common type of cast iron. It has a graphite microstructure, which appears as flakes distributed throughout the iron matrix. The presence of graphite flakes gives it its characteristic gray color. Grey cast iron is relatively brittle, making it unsuitable for applications requiring high impact resistance. However, it has excellent compressive strength, good machinability, and is widely used in various applications such as engine blocks, pipes, and automotive components.

Fig: - Grey Cast Iron

White Cast Iron

White cast iron has a different microstructure compared to grey cast iron. It contains cementite, a hard and brittle compound of iron and carbon, instead of graphite. This gives white cast iron its white appearance. White cast iron is extremely hard and wear-resistant but lacks ductility and toughness. It is often used for applications where high abrasion resistance is needed, such as in mining and crushing machinery.

Fig: - White Cast Iron

Malleable Cast Iron

Malleable cast iron is created by heat-treating white cast iron or cast iron with high carbon content (around 2-4%) in a controlled manner. This process converts the cementite microstructure into irregularly shaped nodules of graphite within the iron matrix. Malleable cast iron combines some of the properties of both grey and white cast iron. It is more ductile and impact-resistant than white cast iron but retains some of the hardness and wear resistance. Malleable cast iron is used for applications requiring a combination of strength, toughness, and machinability.

Fig: - Malleable Cast Iron

Ductile Cast Iron (Nodular Cast Iron or Spheroidal Graphite Iron)

Ductile cast iron is characterized by the presence of spherical nodules or graphite in its microstructure, which gives it the name "spheroidal graphite iron." The graphite nodules provide greater ductility and toughness compared to grey cast iron, making ductile cast iron highly suitable for applications that require high strength, good impact resistance, and dimensional stability. It is used in a wide range of applications, including automotive parts, pipes, gears, and machinery components.

Fig: - Ductile Cast Iron

Each type of cast iron has its unique set of properties, making them suitable for different industrial applications based on their mechanical and chemical characteristics. The choice of cast iron type depends on the specific requirements and conditions of the application at hand.

Various steel making processes: Bessemer, Open hearth, Duplex

Various steelmaking processes have been used historically, but with advancements in technology, some of them have become less common or obsolete. However, they still provide valuable insights into the evolution of steel production. Let's explore three significant steelmaking processes: Bessemer, Open Hearth, and Duplex.

Bessemer Process

The Bessemer process, invented by Sir Henry Bessemer in the 1850s, was a crucial development in the mass production of steel. ***It involved blowing air through molten pig iron to remove impurities and excess carbon***. The high-pressure air oxidized the impurities, converting them into slag, and also burned off excess carbon to produce steel. The process was fast and efficient, enabling large-scale steel production.

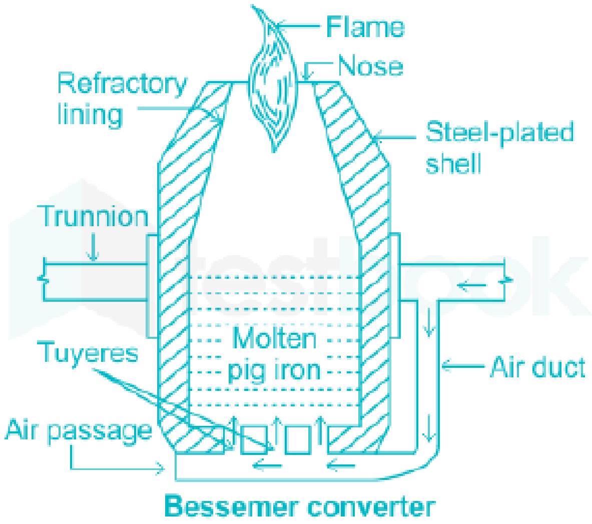


Fig: - Schematic of Bessemer Process

However, the Bessemer process had limitations. It was best suited for low-impurity pig iron, and it couldn't handle iron ores with high phosphorus and sulfur content. As a result, the process was gradually replaced by more advanced methods like the Open-Hearth process and the Basic Oxygen Process (BOP).

Open Hearth Process

The Open-Hearth process, also known as the Siemens-Martin process, was another significant steelmaking method developed in the 1860s. ***It involved heating a mixture of pig iron, scrap steel, and iron ore in a large furnace called an open hearth***. The process was slower than the Bessemer process, but it allowed for more precise control over the composition of the steel, making it suitable for a wider range of iron ores.

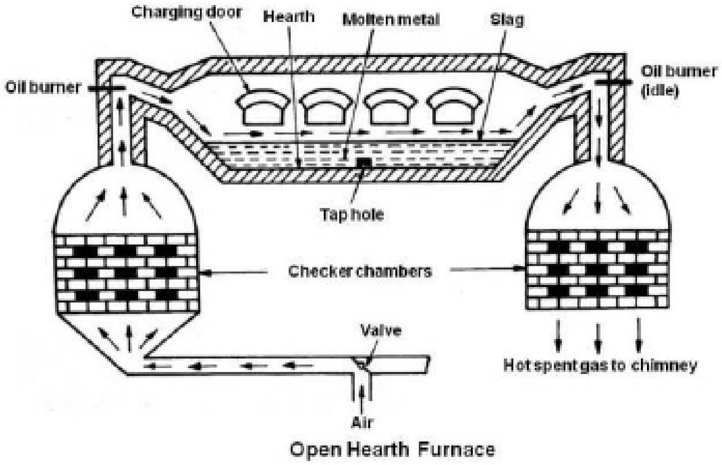


Fig: - Schematic of Open-hearth process of steel manufacturing

The Open-Hearth process became a dominant steelmaking method in the late 19th and early 20th centuries and remained in use until the mid-20th century. It was eventually replaced by more efficient processes like the Basic Oxygen Process and Electric Arc Furnace.

Duplex Process

The Duplex process is a combination of the Bessemer and Open-Hearth processes, developed in the late 19th century. In this method, pig iron is initially refined using the Bessemer converter to remove impurities and excess carbon quickly. Then, the partially refined steel is transferred to an Open-Hearth furnace for further refining and adjustment of its chemical composition.

The Duplex process aimed to combine the advantages of both the Bessemer and Open-Hearth processes while mitigating their respective limitations. However, it required additional equipment and was more complex than other methods, which led to its decline with the rise of newer steelmaking technologies.

Assignment for Students

Write at least ten differences between Steel and cast iron.

********Thank you********

Material Science
Unit-6
Heat Treatment Process

Contents

Purpose of heat treatment
Annealing
Normalizing
Quenching
Tempering
Surface hardening: Nitriding and Carburizing

Introduction To Heat Treatment Process

Heat treatment refers to the heating and cooling operations required to alter the properties of metals, alloys plastic and ceramic materials. Changes in material's properties result from changes made in microstructure of the material. Heat treatment can be applied to ingots, castings, semi-finished products, welded joints and various elements of machines and instruments.

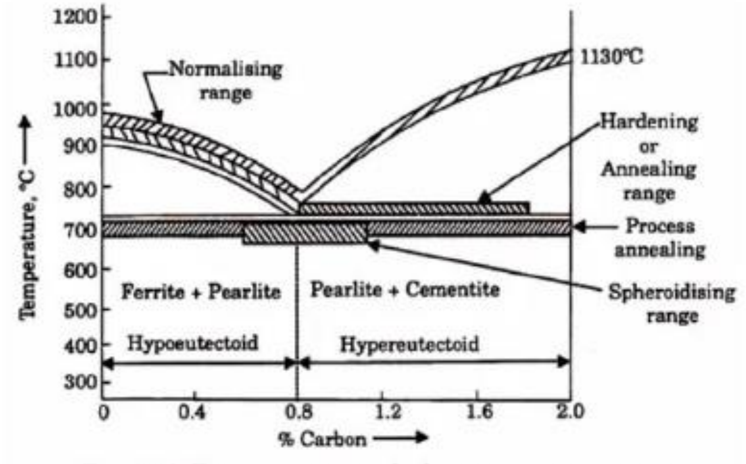
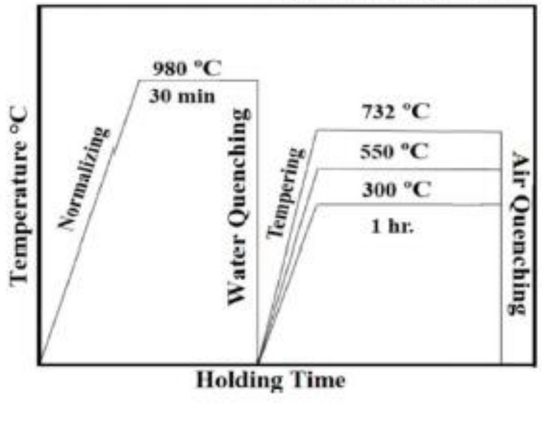


Fig. 5.16. Temperature range for heat treatment processes.



Purposes of Heat Treatment

- The purpose of heat treatment is to achieve any one or more objectives cited as follows:
- To remove strain hardening of a cold worked metal and to improve its ductility.
- To relieve internal stresses set up during cold-working, casting, welding and hot-working treatments.
- To remove gases from castings, to soften a metal to improve its machinability, and to increase the resistance to wear, heat and corrosion.
- To improve the cutting ability, i.e., hardness of a steel tool, to improve grain structure after hot working a metal and to remove effects of previously performed heat-treatment operations.
- To improve magnetization property, especially of steels, for producing permanent magnets.
- To refine grain structure after hot working a metal.
- To soften and toughen a high carbon steel piece.
- To produce a single-phase alloy in stainless steel, and to produce a hard, wear resistant case on a tough core of a steel part.
- To harden non-ferrous metals and alloys, especially aluminum alloys and to produce a single-phase alloy in stainless steel.
- To produce a hard, wear resistant case on a tough core of a steel part and to toughen a hardened steel piece at the cost of its hardness.

Heat Treatment Process / Types of Heat Treatment Process

The principal kinds of heat treatment are:

1. Annealing
2. Normalizing
3. Quenching
4. Tempering
5. Surface hardening: Nitriding and Carburizing

Annealing

This operation removes all structural imperfections by complete recrystallization. This operation is often utilized in low and medium carbon steels that will be machined or will experience extensive plastic deformation during a forming operation. This operation consists of:

a. Heating the hypoeutectoid steel to about 50-70°C above the upper critical temperature *(*for hypoeutectoid steels*)* and by the same temperature above the lower critical temperature for hypereutectoid steels until equilibrium is achieved. This ensures that the metal is heated thoroughly and phase transformation has taken place throughout the whole volume.

b. The alloy is then furnace cooled; i.e., the heat-treating furnace is turned off and both furnace and steel cool to room temperature at the same rate, which takes several hours. The microstructural product of full anneal is coarse pearlite (in addition to any proeutectoid phase) that is relatively soft and ductile. The full-annealing cooling procedure is time consuming; however, a microstructure having small grains and a uniform grain structure result.

Process Annealing or Partial Annealing

This is a heat treatment that is used to negotiate the effects of cold work, i.e., to soften and increase the ductility of a previously strain hardened metal. Process annealing is commonly utilized during fabrication procedures that require extensive plastic deformation, to allow a continuation of deformation without fracture or excessive energy consumption. It is the recrystallization of cold work, i.e., recovery and recrystallization processes are allowed to occur.

Process annealing or sub-critical annealing which is done on coldworked low carbon steel sheet, wire or tubing to relieve internal stresses and to soften the material. The process is as follows:

i. The steel is heated to 550-650°C, which is just below the lower critical temperature on iron-carbon diagram for steel.

ii. Stresses throughout the metal are relieved and recrystallization causes new grains to form and grow. Changes taking place during

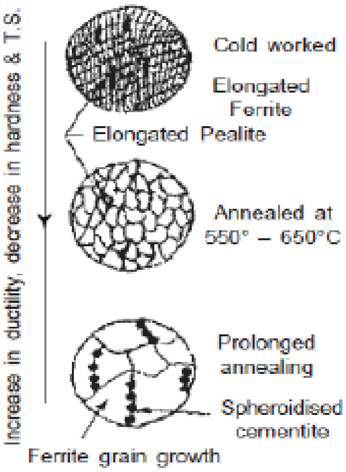


Fig: - Changes for low carbon steel in process annealing

Patening

It is mainly applied to medium to high carbon steels prior to drawing of wire or between drafts. This mainly increases ductility for wire drawing. The process is as follows:

i. Heating to a temperature above the transformation range and *then* cooling to a temperature below that range in air or in a bath of molten lead or salt maintained at a temperature appropriate to the carbon content of the steel and the properties required of the finished product.

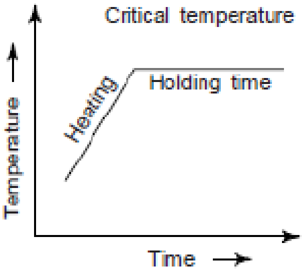


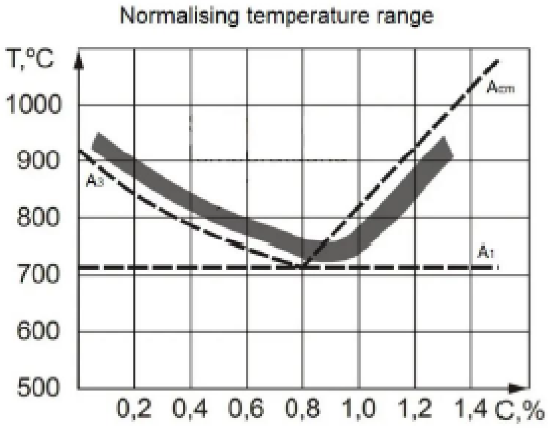
Fig. 10.3 Processannealing

Double Annealing:

It is quite useful for steel castings. It removes the strains. It coalesces the sulphide films (which embrittle the steel) in the ferrite and produces homogeneity by rapid diffusion. The steel is ultimately obtained with refined grains and in soft condition.

Normalizing

This is used as a finishing treatment for carbon steels giving higher strength than annealing. There is no serious loss of ductility too. ***Heating and soaking in this process is same as in the full annealing but part is allowed to cool in air so that cooling rate is much faster***.



An annealing heat treatment called normalizing is used to refine the grains (i.e., to decrease the average grain size) and produce a more uniform and desirable size distribution. Fine grained pearlite steels are tougher than coarse-grained ones. The fine grain structure increases the yield and ultimate strengths, hardness and impact strength. Normalizing is accomplished by heating at approximately 55 to 85°C above the upper critical temperature, which is, of course, dependent on composition. Normalizing often applied to castings and forgings is stress relieving process. To some extent, it increases strength of medium carbon steel. It improves machinability, when applied to low carbon steel.

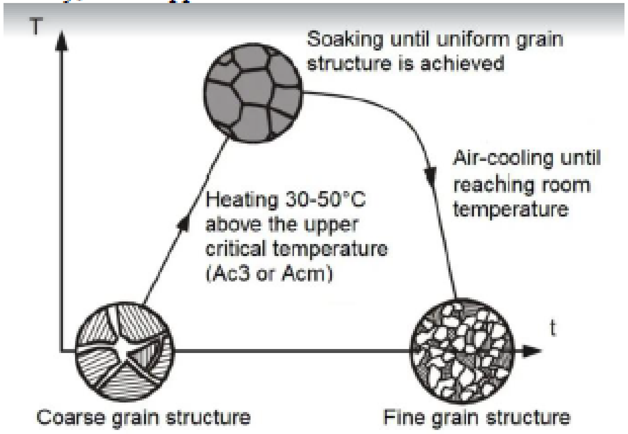


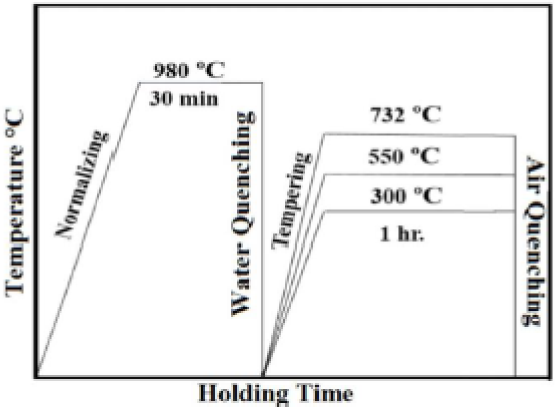
Fig: - Process Normalizing

The advantages of this method are:

- In comparison to fully annealed material, normalizing produces stronger material.
- Normalizing refines the grains.
- Normalizing produces homogenized structure.
- Normalizing is used to improve properties of steel castings instead of hardening and tempering.
- Strength and hardness are increased.
- Better surface finish is obtained in machining.
- Resistance to brittle fracture is increased in hot-rolled steel.
- Crack propagation is checked.

Quenching

"**Severity of quench**" is widely used to express the rate of cooling. Interestingly, the more rapid the quench, the more severe the quench. *Water, oil and air are the three most common quenching media*. Out of these three, *water produces the most severe quench followed by oil, which is most effective than air*. Quenching is a step in many heat treatment processes that involves heating the part to the required temperature and immersing it in a quenching medium to quickly cool it. Other heat treatment processes often follow quenching, such as aging, tempering, or annealing to achieve the desired results.



Oil quenches are found suitable for the heat treating of many alloy steels.

A water quench is too severe for higher. Carbon steels, because cracking and wrapping may be produced.

Air cooling of austenitized plain carbon steels ordinarily produces an almost totally pearlitic structure.

Tempering

Tempering and ageing are the kinds of heat treatment which are applied to hardened alloys; they involve certain phase transformations which make the metal structure approach the equilibrium. *Tempering is a type of heat treatment used to increase the toughness of certain metals, most commonly iron-based alloys like steel*. The metal being treated, using this process, *is heated under its critical point temperature and then air-cooled*.

The tempering temperature depends on the application of the metal and the desired outcome. For instance, drill bits are tempered at a lower temperature than mattress springs.

Tempering releases the stresses and reduces the brittleness. Tempering causes the transformation of the martensite into less brittle structure, i.e., a fine pearlistic structure termed as troostite. Troostitie is much tougher, although somewhat softer than martensite. Most c.s. cutting tools have this type of structure. Once the tempering temperature has been reached, it is normal to quench the steel.

Surface hardening: Nitriding and Carburizing

Surface hardening is a process where the surface of the metal is hardened without changing the bulk properties. The main purpose of surface hardening is to improve the metal's wear resistance, fatigue strength, and corrosion resistance. In this process, a thin layer of harder metal is deposited on the surface of the metal. Surface hardening of articles, like most methods of surface strengthening (chemical heat treatment, strain hardening, knurling, etc.) offers an additional advantage that large compressive stresses appear in the surface layers of hardened articles.

Carburizing

This is another method of surface hardening. The composition of surface layers is changed. ***This process is usually carried out on a steel containing less than 0.2% carbon.*** Carburizing is usually employed for treating certain types of machine elements which have to have a wear-resistance working surface and tough core, gear wheels, shafts, pins, camshafts, cams, worms, etc.

The initial medium for carburizing (carbon saturation) is usually called a carburizer. Two methods of carburizing are in use: in ***a solid and in a gaseous carburizer***. In both cases, however, the carburizing process passes through a gaseous phase. The most popular solid carburizer consists ***of charcoal*** with an addition of ***20-25% barium carbonate*** to intensify the process and of 3-5% of CaCO3 to prevent the carburizer particles from caking.

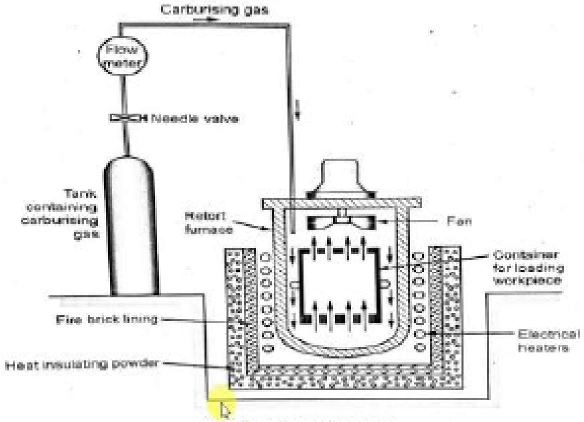


Fig. 6.2 : Gas carburizing

Nitriding

This is the process of diffusion saturation of steel surface with nitrogen. The component is heated in a mixture of ammonia and hydrogen so that nitrogen diffuses into the surface layers and hard nitride compounds are formed. *The process is employed for increasing the wear resistance and endurance limit of machine elements (crankshafts, cylinder sleeves, worm gears, shafts, etc.)*

In a nitriding process, *the component is heated in a mixture of ammonia and hard nitride compounds are formed*. Common nitriding is carried out at *a temperature of 500-600°C* in a muffle or container through which dissociating ammonia is being passed. This process is used with those alloys of steel which contain elements that form stable nitrides, e.g., chromium, molybdenum, tungsten, vanadium, aluminum, etc. It is probable that the reaction of ammonia dissociation takes place at the steel surface; nitrogen ions are absorbed by the surface and then diffuse into the depth of the metal. The time taken for nitrogen to react with the steel surface is about 100 hours.

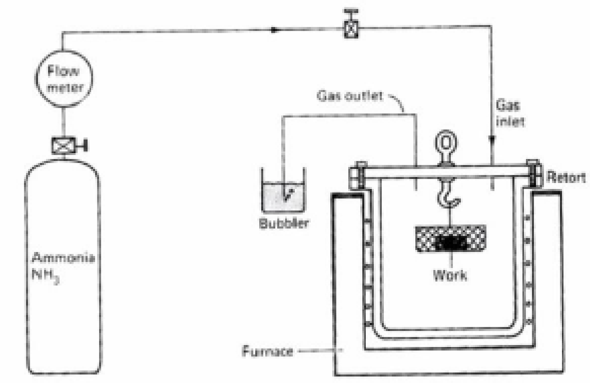


Fig: -Nitriding

If ammonia is heated in an isolated volume, only the reaction 2NH3=N2 + 3H2 is possible and the molecular nitrogen formed by this reaction cannot diffuse into the metal without being ionized. The depth to which the nitrides are formed depend on the temperature and time allowed for the reaction, and in normal conditions, it is unlikely to exceed 0.7 mm.

*****Thank You*****

Material Science
Unit-7
Engineering Materials

Contents

Ferrous alloys
Non-ferrous alloys
Polymers: Properties, classification and uses
Rubber: Properties and uses
Ceramics: Properties, classification and uses
Composite materials: properties, classification and uses
Glass: properties, classification and uses

Introduction

Engineering materials refers to the group of materials that are used in the construction of manmade structures and components. The primary function of an engineering material is to withstand applied loading without breaking and without exhibiting excessive deflection.

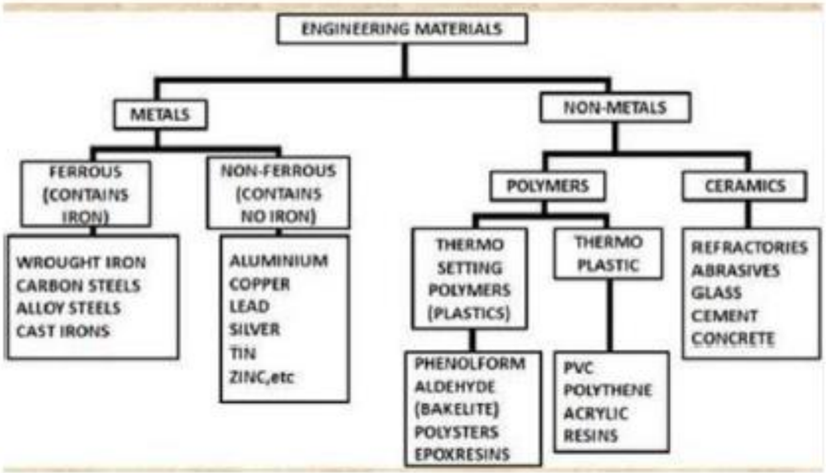
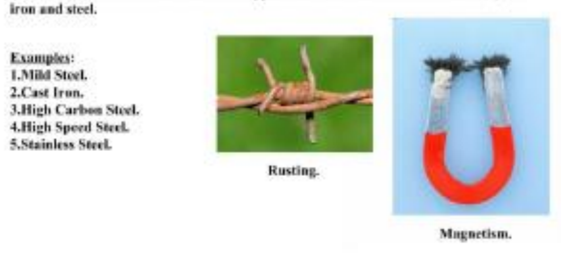


Fig: - Classifications of Engineering Materials

Ferrous Alloys

Ferrous alloys have iron as the base element. These alloys and include steels and cast irons. Ferrous alloys are the most common metal alloys in use due to the abundance of iron, ease of production, and high versatility of the material. The biggest disadvantage of many ferrous alloys is low corrosion resistance.

Carbon is an important alloying element in all ferrous alloys. In general, higher levels of carbon increase strength and hardness, and decrease ductility and weldability.



Ferrous metals:

Ferrous metals are metals that consist mostly of iron and small amounts of other elements. Ferrous metals are prone to rusting if exposed to moisture. Ferrous metals can also be picked up by a magnet. The rusting and magnetic properties in ferrous metals are both down due to the iron. Typical ferrous metals include mild steel, cast iron and steel.

Examples:

1.Mild Steel.
2.Cast Iron.
3.High Carbon Steel.
4.High Speed Steel.
5.Stainless Steel.

Ferrous Metals.

Metal Type.	Metal Uses.	Melting Point.
Mild Steel. A ductile and malleable metal. Mild steel will rust quickly if it is in frequent contact with water.	Used as Nuts and bolts, Building girders, car bodies, gates, etc.	1600°C

Ferrous Metals.

Metal Type.	Metal Uses.	Melting Point.
Cast Iron. Is a very strong metal when it is in compression and is also very brittle. It consists of 93% iron and 4% carbon plus other elements.	Used as car Brake discs, car cylinders, metalwork vices, manhole covers, machinery bases eg: The pillar drill.	1200°C

Ferrous Metals.

Metal Type.	Metal Uses.	Melting Point.
High Speed Steel. HSS is a metal containing a high content of tungsten, chromium and vanadium. However it is very brittle but is also very resistant to wear.	Used for drill bits and lathe cutting tools. It is used where high speeds and high temperatures are created.	1400°C

Metal Type.	Metal Uses.	Melting Point.
Stainless Steel. Stainless steel is very resistant to wear and water corrosion and rust. Properties – It is an alloy of iron with a typical 18% chromium 8% nickel and 8% magnesium content.	Used for kitchen sinks, cutlery, teapots, cookware and surgical instruments.	1400°C

Fig: - Ferrous Metals/Alloys

Non-ferrous alloys

Non ferrous metal alloys are metals that are a mixture of two or more metals. Non-ferrous metals or alloys is defined as are materials that are not iron-based like their ferrous counterparts.
Example Brass, Bronze and Solder

Metal Type.	**Metal Uses.**	**Melting Point.**
Brass. **Brass is a mixture of copper and zinc. Copper is the main component, and brass is usually classified as a copper alloy. The color of brass varies from a dark reddish brown to a light silvery yellow. Brass is stronger and harder than copper, but not as strong or hard as steel. It is easy to form into various shapes, a good conductor of heat, and generally resistant to corrosion from salt water.**	**Brass is used to make water fittings, screws, radiators, musical instruments, and cartridge casings for firearms.**	**940°C**




Metal Type.	**Metal Uses.**	**Melting Point.**
Bronze. **Bronze is a metal alloy consisting primarily of copper, usually with tin as the main additive. It is a hard and brittle metal. It has a very high resistance to corrosion.**	**Used for ship propellers and underwater fittings. Also used for statues and medals.** -	**950°C**



Metal Type.	**Metal Uses.**	**Melting Point.**
Solder. **Solder is a fusible metal alloy used to join together metal work pieces and having a melting point below that of the work pieces. It is an alloy of Lead and Tin.**	**Solder is used for electronics, plumbing, jewelry making and repair processes where metal parts cannot be effectively or safely welded.**	200°C



Non-ferrous metals are metals that do not have any iron in them at all. This means that Non-ferrous metals are not attracted to a magnet and they also do not rust in the same way when exposed to moisture. Typical Non-ferrous metals include copper, aluminium (coke cans), tin and zinc.

Examples:

1. **Aluminium.**
2. **Copper.**
3. **Zinc.**
4. **Tin.**
5. **Lead.**
6. **Silver.**
7. **Gold.**
8. **Magnesium.**

Metal Type.	Metal Uses.	Melting Point.
Aluminium. It tends to be light in colour although it can be polished to a mirror like appearance. It is very light in weight.	Used for saucepans, cooking foil, window frames, ladders, expensive bicycles.	660°C

Metal Type.	Metal Uses.	Melting Point.
Copper. It is a ductile and malleable metal. It is often red / brown in colour. It is a very good conductor of heat and electricity.	Used for plumbing, electric components, cookware and roof coverings.	1084°C

Metal Type.	Metal Uses.	Melting Point.
Zinc. It is very resistant to corrosion from moisture. However zinc is a very weak metal and is used mainly for coating steel.	Used as a coating on screws, steel buckets etc It is also used to galvanize steel.	419°C

Metal Type.	Metal Uses.	Melting Point.
Tin. It is a very ductile and very malleable metal. It is resistant to corrosion from moisture. It is bright silver in appearance. Tinplate is steel with a tin coating.	Used as a coating on food cans, beer cans. Used as whistles, tin foil and soldering.	231°C



Metal Type.	Metal Uses.	Melting Point.
Lead. It is a soft, malleable metal. It is also counted as one of the heavy metals. Lead has a bluish-white color after being freshly cut, but it soon tarnishes to a dull grayish color when exposed to air.	Used for roof flashing. Also used for batteries and for X-ray protection. Lead is used for its weight in many ways.	327°C



Metal Type.	Metal Uses.	Melting Point.
Silver. A soft, white, lustrous transition metal, it has the highest electrical conductivity of any element and the highest thermal conductivity of any metal. The metal occurs naturally in its pure, free form.	Used for jewelry and high quality cutlery. Also used for currency coins and sports trophies. Used in mirrors as a reflective metal.	961°C





Metal Type.	Metal Uses.	Melting Point.
Gold. Gold is a dense, soft, shiny, malleable and ductile metal. Pure gold has a bright yellow color and luster traditionally considered attractive, which it maintains without oxidizing in air or water. Gold resists attacks by individual acids It won't tarnish, discolor, crumble, or be affected by most solvents.	Used mainly for jewelry. Also used in computers as a conductor. Used for its reflective powers to protect satellites.	1337°C



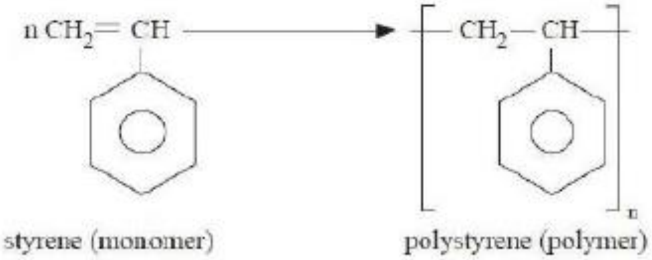

Metal Type.	Metal Uses.	Melting Point.
Magnesium. Magnesium is a fairly strong, silvery-white, light-weight metal (one third lighter than aluminum) that slightly tarnishes when exposed to air. In a powder, this metal heats and ignites when exposed to moisture and burns with a white flame.	Magnesium is used in pyrotechnic (i.e. fireworks). It is alloyed with other metals to make them lighter and more easily welded.	648°C

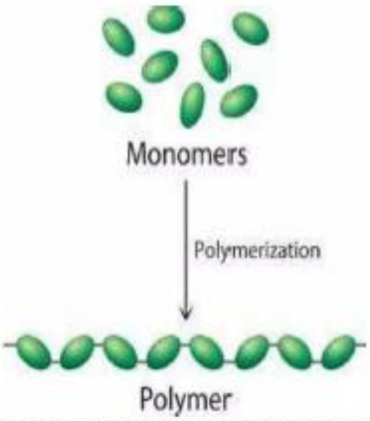


Polymers

Polymers are very large molecules made when hundreds of monomers join together to form long chain. The word polymer comes from Greek words **Poly** means many and **Mer** means part. Polymer is used as a synonym for plastic. All plastics are polymers but all polymers are not plastics.

$$N(CH_2\text{-}CH_2) \longrightarrow (\text{-}CH_2\text{-}CH_2\text{-})_s$$





Styrene is a *monomer*, which is defined as "any molecule that can be converted to a polymer by combining with other molecules of the same or different type.

Properties of Polymer

Physical Properties

- As chain length and cross-linking increase, the tensile strength of the polymer increases.
- Polymers do not melt, and they change state from crystalline to semi-crystalline.

Chemical Properties

- Compared to conventional molecules with different side molecules, the polymer is enabled by hydrogen bonding and ionic bonding resulting in better cross-linking strength.
- Dipole-dipole bonding side chains enable the polymer for high flexibility.
- Polymers with Van der Waals forces linking chains are known to be weak but give the polymer a low melting point.

Optical Properties

- Due to their ability to change their refractive index with temperature, as in the case of PMMA and HEMA: MMA, they are used in lasers for applications in spectroscopy and analytical applications.

Classification and uses of polymer

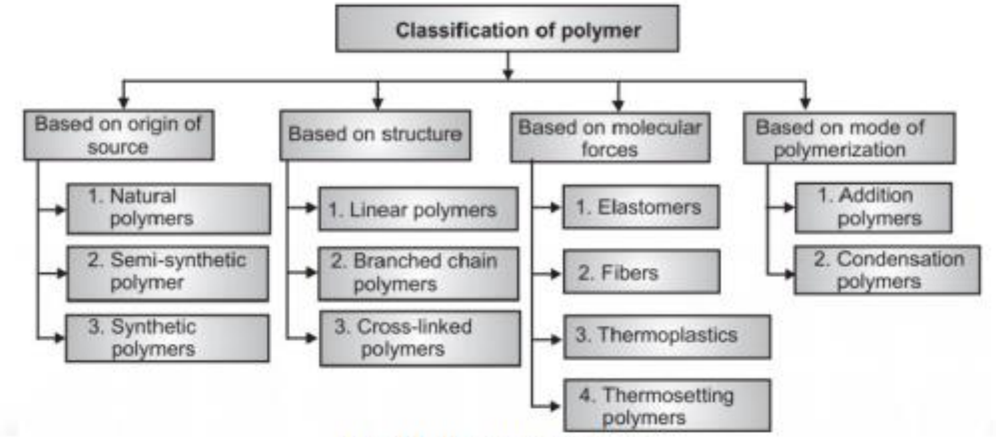


Fig: -Classifications of polymer

Classification Based on The Basis of Their Occurrence (Based on Sources)

Natural Polymers

They occur naturally and are found in plants and animals. Naturally occurring polymers, including rubber, cotton, wood, hair, silk and cellulose, Cellulose (found in wood, cabbages, cotton, and linen) is composed of long chains of sugar rings. For example, proteins, starch, cellulose and rubber. To add up, we also have biodegradable polymers called biopolymers.

Semi-synthetic Polymers

They are derived from naturally occurring polymers and undergo further chemical modification. For example, cellulose nitrate and cellulose acetate. These polymers either have bock bone of any natural polymer and the pendant groups are substituted to make it perform better properties or have one of its components as natural polymer and other as synthetic, e.g.: -grafted copolymers of starch and polyacrylamides, silicones etc.

Synthetic Polymers

These are human-made polymers. Plastic is the most common and widely used synthetic polymer. It is used in industries and various dairy products. For example, nylon-6, 6, polyether, etc. Synthetic polymers are widely used as plastics (polyethylene, polyvinylchloride = PVC) synthetic fibers (nylon, polyester), and synthetic rubber.

Classification Based on The Chemical Nature of Polymer

Organic Polymer

That is based on a carbon chain. The ability of the carbon atom to from macromolecule by covalently bonding with other carbon atoms as well as oxygen, sulfur, and nitrogen forms the basis for the wide variety of organic polymers.

Inorganic Polymers

Inorganic polymers display remarkable high temperature resistance. Silicone and other elements, can form long - chain molecules, these inorganic polymers frequently exhibit properties which are quite different from those displayed by organic polymer.

Classification Based on The Structural Shape of Molecules

Linear Polymers

Linear Polymers are those in which the Mer unit are joined together end to end in single chains. These long chains are flexible. For linear polymers, there may be extensive. van der waols and hydrogen bonding between the chains. Examples of linear polymers are polyvinyl chloride (PVC), poly ethylene, polystyrene, poly methyl metha crylate (PMMA), nylon, and the fluorocarbons.

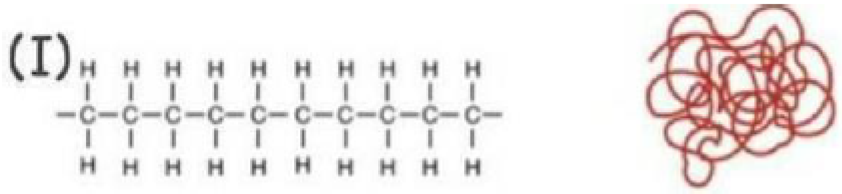
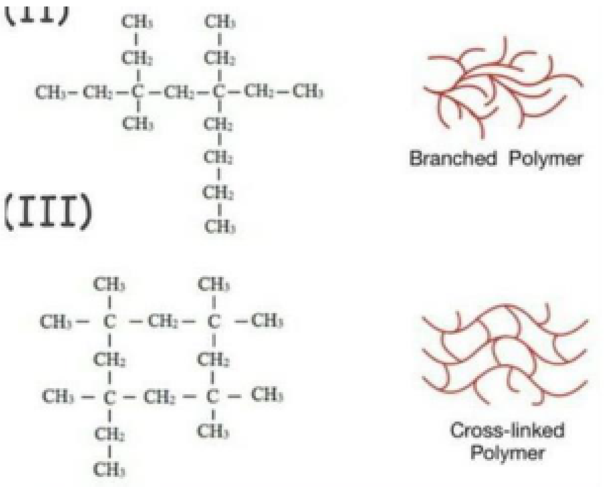


Fig: - Linear polymer

Branched polymers

This type of structure can occur with linear polymers as well as with other types, it consists of side branches of similar structure attached to the main chain. The branches polymers canisters to be part of the main - chain molecule, result from side reaction that occurs during the synthesis of the polymer. The chain packing efficiency is reduced with the formation of side branched which results in a lowering of the polymer density.



Uses of Polymer

we will list some of the important uses of polymers in our everyday life.

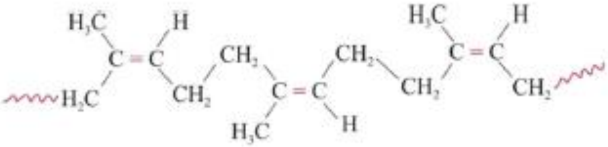
- Polypropene finds usage in a broad range of industries, such as textiles, packaging, stationery, plastics, aircraft, construction, rope, toys, etc.
- Polystyrene is one of the most common plastics actively used in the packaging industry. Bottles, toys, containers, trays, disposable glasses and plates, TV cabinets and lids are some of the daily-used products made up of polystyrene. It is also used as an insulator.
- The most important use of polyvinyl chloride is the manufacture of sewage pipes. It is also used as an insulator in electric cables.
- Polyvinyl chloride is used in clothing and furniture and has recently become popular for the construction of doors and windows as well. It is also used in vinyl flooring.
- Urea-formaldehyde resins are used for making adhesives, moulds, laminated sheets, unbreakable containers, etc.
- Glyptal is used for making paints, coatings and lacquers.
- Bakelite is used for making electrical switches, kitchen products, toys, jewellery, firearms, insulators, computer discs, etc.

Common Uses for Polymeric Materials	
Packaging	Paint
Bottles	Automative parts
Surgical sutures	Housewares: tupperwares, plates, cups
Electric components	Fabric
Contact lenses	Rubber
Adhesive	Pipes
Medical supplies: bone cement, blood bags	Plastic bags

Rubber

Rubber is a polymer that has the primary property to stretch and shrink. It is an elastomer that can come back to its original shape after being deformed. It is made by polymerization of isoprene (22 methyl-1,31,3-butadiene).

Natural rubber is extracted from the bark of a rubber tree. In order, to meet its huge demand, rubber was synthesized artificially, and this led to a revolution in the field of polymers.



Natural Rubber

The synthetic rubbers are artificial elastomers that are synthesised from petroleum products.They have double tensile strength than natural rubber. They are primarily derivatives of 1,31,3-butadiene. Synthetic rubber is of two types: **Homopolymer** (one monomeric repeating unit) and **Copolymer** (more than one monomeric repeating unit).

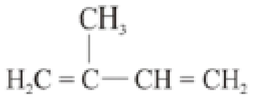
Chloroprene

2 - Chloro -1,3- Buta diene

Neoprene

$$nCH_2=\overset{Cl}{\overset{|}{C}}-CH=CH_2 \xrightarrow{\text{Polymerisation}} \left[CH_2-\overset{Cl}{\overset{|}{C}}=CH-CH_2\right]_n$$

The monomer of natural rubber is Isoprene (22-methyl, 1−31−3, Butadiene). The polymer of this isoprene is known as natural rubber, and its chemical name is 'cis – 1,41,4 – polyisoprene'.



Isoprene

$$H_2C=\overset{CH_3}{\overset{|}{C}}-CH=CH_2$$

Properties of Rubber

Rubber is a versatile and elastomeric material that exhibits several unique properties, making it useful in a wide range of applications. Here are some key properties of rubber:

1. **Elasticity:** Rubber is highly elastic, meaning it can undergo significant deformation when subjected to stress and then return to its original shape when the stress is removed. This property allows rubber to absorb and dissipate energy, making it suitable for applications requiring shock absorption, vibration isolation, and flexibility.
2. **Flexibility:** Rubber is flexible and can be easily bent or stretched without breaking. It can withstand repeated bending and twisting without permanent deformation, which makes it ideal for applications where a material needs to accommodate movement or conform to various shapes.
3. **Resilience:** Rubber exhibits excellent resilience, which refers to its ability to recover its shape after deformation. When compressed or stretched, rubber stores energy, and upon release of the stress, it rapidly returns to its original shape. This property enables rubber to provide cushioning and impact resistance.
4. **Low Thermal Conductivity:** Rubber is a poor conductor of heat, meaning it has low thermal conductivity. This property makes rubber useful for insulation purposes, as it helps prevent the transfer of heat or cold. Rubber is commonly used in applications such as seals, gaskets, and insulation materials.
5. **Electrical Insulation:** Rubber has high electrical resistance, making it an excellent electrical insulator. It is widely used in electrical and electronic applications to provide insulation and prevent the flow of electric current.
6. **Chemical Resistance:** Rubber exhibits good resistance to many chemicals, oils, and solvents. This property makes it suitable for use in gaskets, seals, and other applications where exposure to harsh chemicals is expected.
7. **Waterproof and Weather Resistant:** Rubber is inherently water-resistant and can withstand exposure to moisture and varying weather conditions. It is commonly used in products such as rain boots, waterproof clothing, and seals for plumbing and automotive applications.
8. **Abrasion Resistance:** Rubber has good resistance to wear and abrasion, which allows it to withstand friction and contact with rough surfaces. This property makes rubber suitable for applications involving tires, conveyor belts, footwear, and other products subjected to constant wear.

9. **Tensile Strength:** Rubber has moderate tensile strength, meaning it can resist stretching or pulling forces. Reinforcing rubber with materials like fibers or fillers can significantly enhance its tensile strength, making it suitable for applications requiring high strength and durability.
10. **Damping and Noise Reduction:** Rubber has excellent damping properties, meaning it can absorb and dissipate energy, reducing vibrations and noise. It is commonly used in automotive suspensions, anti-vibration mounts, and shock absorbers to dampen vibrations and provide a smoother ride.

Uses of Rubber

Rubber is used in different fields, such as transportation, automobiles, chemicals, agriculture, and many more. Let's discuss them:

1. **The tires and tube** industries are one of the biggest consumers of rubber. Natural rubber is further mixed with synthetic products to make them more durable.
2. Rubbers are used in different **automobile** sectors. **Natural rubber** is used to make seals and different forms of padding for various automobile parts. For example, it is used to create pads of the brakes and seals of the windows and windshields of cars.
3. Rubber is used to make **airbags** in cars that protect riders from accidental injuries.
4. **Clothing:** Natural rubber in its fibrous form is elastic, which is used to manufacture tight-fitting and expandable clothing such as swimsuits and cycling shorts.
5. **Flooring:** Rubber is used in making flooring in many commercial places, kitchens, and even playgrounds. It provides a surface that provides padding and is both slip-resistant and waterproof. It is very easy to maintain and is long-lasting.
6. **Gaskets:** Gaskets are used in between two or more mechanical parts to prevent leakage or to fill irregular space between them.
7. **Erasers:** This rubber product could "rub" away marks made from pencils on paper, thus giving the material its name.
8. **Ancient Uses:** Ancient Mesoamerican civilizations used natural rubber to make waterproof shoes and bottles. Not only that but it was also used to create a sports ball in a game that is very similar to modern-day basketball, football.
9. **Adhesives and Coatings:** In its latex form, rubber is used as an adhesive or a protective coating for many surfaces.
10. **Rubber Gloves** are a very famous rubber product as using them is always preferred for keeping our hands safe and sanitary.

Ceramics

Ceramics refer to a broad category of materials that are made from non-metallic, inorganic compounds, primarily consisting of clay minerals and other additives. Ceramics are all around us. This category of materials includes things like tile, bricks, plates, glass, and toilets.

Properties of Ceramics

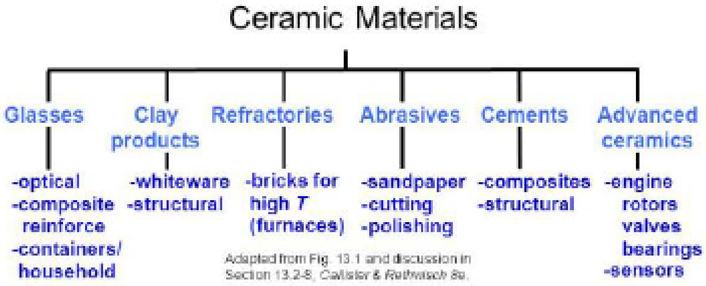
Ceramics exhibit a range of unique properties that make them valuable materials in various applications. Here are some key properties of ceramics:

1. **Hardness:** Ceramics are known for their high hardness and are often harder than metals or polymers. This property makes ceramics resistant to scratching, wear, and deformation. It allows ceramics to maintain their shape and structural integrity even under high loads or abrasive conditions.
2. **High Temperature Resistance:** Ceramics possess excellent resistance to high temperatures. They can withstand extreme heat without softening or melting, making them suitable for applications in environments with elevated temperatures. This property is crucial for applications such as gas turbines, kiln linings, and high-temperature processing.

3. **Strength and Stiffness:** Ceramics have high strength and stiffness, providing them with excellent load-bearing capabilities. They can withstand significant compressive forces, making them suitable for structural applications where strength and rigidity are essential.
4. **Chemical Resistance:** Ceramics exhibit strong chemical resistance, making them resistant to corrosion, oxidation, and chemical attack. They can withstand exposure to harsh chemicals and aggressive environments, making them suitable for use in chemical processing, corrosion-resistant coatings, and biomedical implants.
5. **Electrical Insulation:** Ceramics are typically excellent electrical insulators, meaning they do not conduct electricity. This property makes ceramics valuable for electrical and electronic applications, where insulation is required to prevent the flow of electric current and provide electrical insulation.
6. **Low Thermal Conductivity:** Ceramics generally have low thermal conductivity, meaning they are poor conductors of heat. This property makes ceramics effective thermal insulators, allowing them to retain or resist the transfer of heat. It is advantageous in applications such as kiln linings, furnace insulation, and thermal barriers.
7. **Low Thermal Expansion:** Ceramics often have low coefficients of thermal expansion, which means they expand or contract minimally with changes in temperature. This property makes ceramics useful in applications requiring dimensional stability over a wide temperature range, such as in precision instruments and high-temperature environments.
8. **Biocompatibility:** Some ceramics, such as certain forms of alumina and zirconia, exhibit excellent biocompatibility, meaning they are well-tolerated by living tissues and can be used in biomedical applications. These ceramics are used in dental implants, joint replacements, and other medical devices.
9. **Transparency:** Certain ceramics, such as alumina and sapphire, can be highly transparent to visible light or specific wavelengths. This property makes them valuable in applications such as optoelectronics, laser systems, and transparent armor.
10. **Aesthetic Appeal:** Ceramics offer a wide range of aesthetic possibilities. They can be easily shaped, glazed, and decorated, resulting in visually appealing and decorative objects.

Classifications of Ceramics

Ceramics can be classified into various categories based on different criteria, such as composition, microstructure, and application. Here are some common classifications of ceramics:



Adapted from Fig. 13.1 and discussion in Section 13.2-6, *Callister & Rethwisch 8e.*

1. **Traditional Ceramics:** These ceramics are based on inorganic, non-metallic materials and are typically made from clay and other minerals. Traditional ceramics include pottery, bricks, tiles, and porcelain.

2. **Structural Ceramics:** These ceramics are designed to have high mechanical strength and are used in applications where the material needs to withstand heavy loads and harsh environments. Examples include alumina (aluminum oxide), zirconia, silicon carbide, and silicon nitride.
3. **Refractory Ceramics:** Refractory ceramics are specifically formulated to withstand high temperatures without deforming or melting. They are used in kilns, furnaces, and other high-temperature applications. Common refractory ceramics include alumina, magnesia, and chromia.
4. **Whitewares:** Whitewares refer to ceramics that are typically white or light-colored and are used for domestic and decorative purposes. Examples include tableware, sanitaryware, and decorative ceramics.
5. **Technical Ceramics:** Technical ceramics, also known as advanced or engineered ceramics, are designed with specific properties to meet demanding industrial applications. They often possess excellent mechanical, thermal, electrical, or chemical properties. Technical ceramics include materials such as alumina, zirconia, silicon nitride, and boron nitride.
6. **Porous Ceramics:** Porous ceramics have a high porosity and are used for applications such as filtration, catalysis, and as lightweight structural materials. Materials like alumina, silica, and carbon can be used to create porous ceramics.

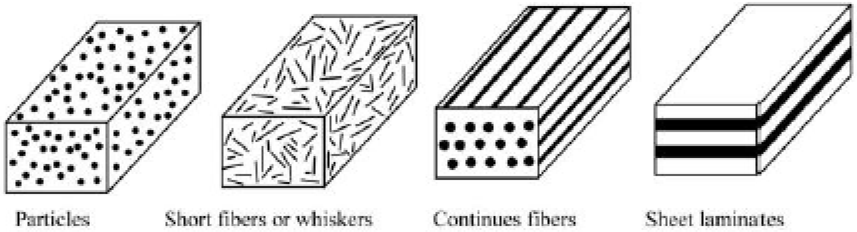
Uses of Ceramics

Ceramics have a wide range of uses across various industries due to their unique properties. Here are some common applications of ceramics:

1. **Construction:** Ceramics such as bricks, tiles, and cement are widely used in the construction industry for building materials. They provide durability, resistance to high temperatures, and aesthetic appeal.
2. **Electronics:** Ceramics are essential in the electronics industry for components such as capacitors, resistors, and insulators. They have excellent electrical properties, high thermal stability, and can withstand harsh operating conditions.
3. **Aerospace and Defense:** Ceramics play a crucial role in aerospace and defense applications due to their high strength, lightweight nature, and resistance to extreme temperatures. They are used in components like turbine blades, heat shields, radomes, and armor.
4. **Automotive:** Ceramics are used in various automotive applications, such as catalytic converters, spark plugs, sensors, and engine components. They offer high-temperature resistance, wear resistance, and electrical insulation properties.
5. **Medical and Dental:** Ceramics find extensive use in the medical and dental fields. Bio-ceramics like hydroxyapatite and bio glass are used for bone grafts, dental implants, and prosthetics due to their biocompatibility and ability to integrate with living tissue.
6. **Chemical Industry:** Ceramics are used in the chemical industry for applications like corrosion-resistant linings, catalyst supports, and filtration systems. They can withstand harsh chemical environments and maintain their structural integrity.
7. **Energy Generation:** Ceramics are employed in various energy generation technologies. For instance, they are used in the production of gas and steam turbines, fuel cells, and solar panels due to their high-temperature resistance, electrical properties, and corrosion resistance.
8. **Cookware and Kitchenware:** Ceramics like porcelain and stoneware are commonly used in cookware and kitchenware due to their heat resistance, non-reactivity with food, and aesthetic appeal.
9. **Art and Decor:** Ceramics have a long history in artistic and decorative applications. They are used for pottery, sculptures, tiles, and decorative objects due to their malleability, ability to hold intricate shapes, and the wide range of colors and finishes they can achieve.

Composite Materials

Composite materials are materials that are composed of two or more different constituent materials, each retaining their distinct properties. These constituent materials work together synergistically, resulting in a composite material with enhanced or unique properties compared to its individual components.



Properties

Composite materials are widely used in various industries due to their desirable properties. Here's an overview of composite materials, their properties.

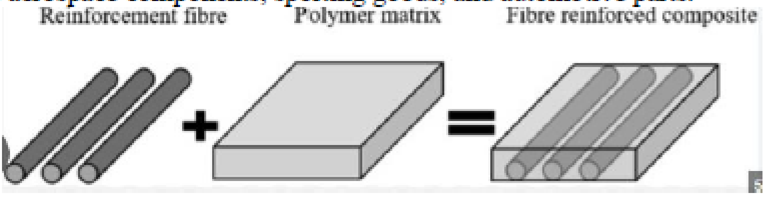
1. **Strength and Stiffness:** Composites can possess high strength and stiffness due to the reinforcement materials incorporated into the matrix material.
2. **Lightweight:** Composites are often lighter than traditional materials such as metals, which makes them advantageous in applications where weight reduction is crucial, such as aerospace and automotive industries.
3. **Durability:** Composites can exhibit excellent resistance to corrosion, chemicals, and fatigue, resulting in increased lifespan and reduced maintenance requirements.
4. **Tailored Properties:** The properties of composites can be tailored by selecting different combinations of matrix and reinforcement materials, allowing for customization to meet specific application requirements.
5. **Thermal and Electrical Conductivity:** Composites can have varying degrees of thermal and electrical conductivity, depending on the choice of constituent materials.

Classifications

Composite materials can be classified based on the type of reinforcement used, the nature of the matrix material, and the structural arrangement of the constituents. Common classifications include:

Fiber-Reinforced Composites

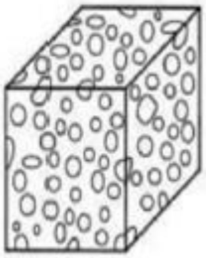
These composites consist of a matrix material reinforced with high-strength fibers, such as carbon fibers, glass fibers, or aramid fibers. Fiber-reinforced composites offer high strength-to-weight ratios and are used in applications like aerospace components, sporting goods, and automotive parts.



Fiber reinforced composite

Particle-Reinforced Composites

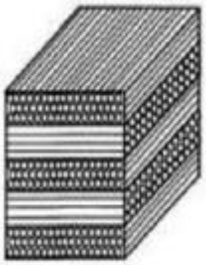
Particle-reinforced composites involve the dispersion of small particles, such as ceramics or metals, into a matrix material. They offer improved properties like increased hardness, wear resistance, and thermal stability. Examples include metal matrix composites used in the automotive and aerospace industries.



Particulate composite

Laminate Composites

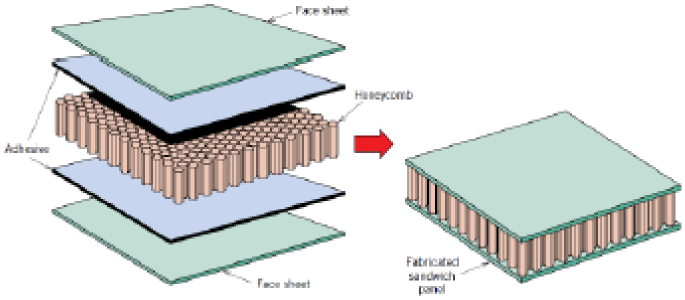
Laminate composites are composed of multiple layers of different materials bonded together. Each layer may have different properties, resulting in tailored characteristics. Laminate composites are used in aircraft structures, marine applications, and sporting goods.



Laminated composite

Structural Composites

These composites consist of a combination of different reinforcing materials, such as fibers, particles, and laminates, to create materials with superior mechanical properties. They find applications in load-bearing structures like bridges, buildings, and wind turbine blades.



Schematic diagram showing the construction of a honeycomb core sandwich panel.

Uses of Composite Materials

Aerospace and Aviation: Composite materials are extensively used in the aerospace industry for aircraft components like wings, fuselage sections, and tail structures. The high strength-to-weight ratio of composites helps reduce fuel consumption and increase aircraft performance.
Automotive: Composite materials are used in automotive applications to reduce weight and improve fuel efficiency. They are used in body panels, chassis components, and interior parts.

Construction: Composite materials find applications in construction for structural elements, bridges, reinforcement bars, and corrosion-resistant pipes.

Sports and Recreation: Composite materials are used in sporting goods like tennis rackets, golf clubs, bicycle frames, and helmets. The lightweight and high strength of composites improve performance and durability.

Marine: Composite materials are used in boat hulls, decks, and masts due to their resistance to corrosion and ability to withstand harsh marine environments.

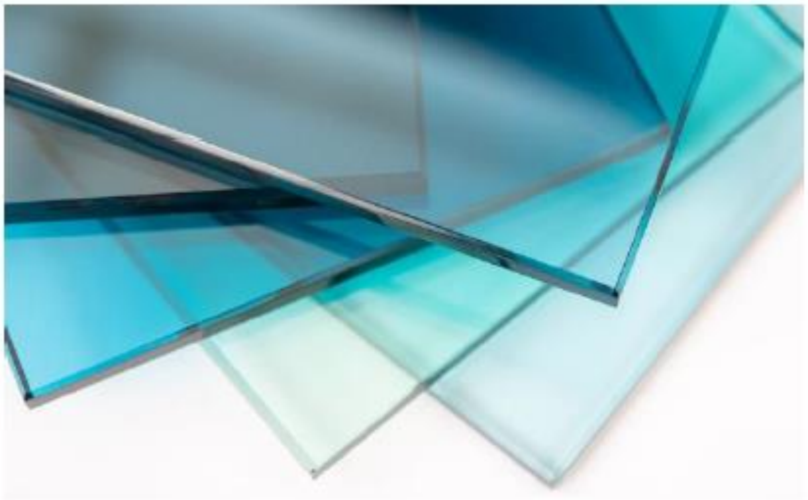
Energy: Composites are used in wind turbine blades, solar panels, and energy storage systems due to their lightweight nature, strength, and resistance to environmental degradation.

Medical: Composite materials find applications in the medical field for prosthetics, orthopedic implants, and dental structures. They offer biocompatibility and the ability to match the mechanical properties of natural tissues.

Consumer Goods: Composites are used in various consumer goods such as furniture, appliances, electronics, and musical instruments due to their aesthetic appeal, durability, and design flexibility.

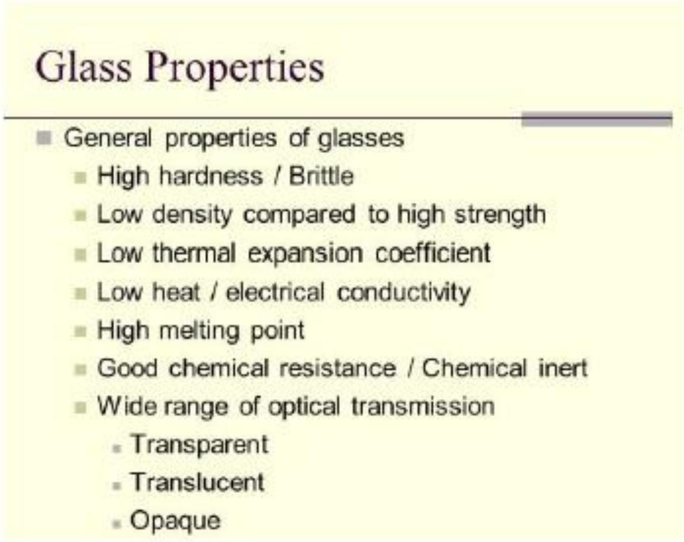
Glass

Glass is a non-crystalline, amorphous solid that is often transparent and has widespread practical, technological, and decorative usage in, for example, window panes, tableware, and optoelectronics. The most familiar, and historically the oldest, types of manufactured glass are "silicate glasses" based on the chemical compound silica (silicon dioxide, or quartz), the primary constituent of sand. The term *glass*, in popular usage, is often used to refer only to this type of material, which is familiar from use as window glass and in glass bottles.



Properties of Glasses

In general, glass is a hard and brittle substance that is usually transparent or translucent. It may be comprised of a fusion of sand, soda, lime, or other materials. The most common glass forming process heats the raw materials until they become molten liquid, then rapidly cools the material to create hardened glass.



Glass Properties

- General properties of glasses
  - High hardness / Brittle
  - Low density compared to high strength
  - Low thermal expansion coefficient
  - Low heat / electrical conductivity
  - High melting point
  - Good chemical resistance / Chemical inert
  - Wide range of optical transmission
    - Transparent
    - Translucent
    - Opaque

Classifications of Glasses

Glasses are classified based on other ingredients which change its properties. The following is a list of the more common types of silicate glasses and their ingredients, properties, and applications.

Soda-lime-silica glass or soda glass or soft glass or **window glass**: Silica (SiO_2) + sodium oxide (Na_2O) + lime (CaO) + Magnesia (MgO) + Alumina (Al_2O_3). Is transparent, easily formed and most suitable for window glass. It has a high thermal expansion and poor resistance to heat (500–600 °C).

Borosilicate glass or Pyrex glass: silica (SiO_2) + boron trioxide (B_2O_3) + soda (Na_2O) + alumina (Al_2O_3). Stands heat expansion much better than window glass. Used for chemical glassware, cooking glass, car head lamps, etc. Borosilicate glasses (e.g. Pyrex, Duran) have as main constituents' **silica** and **boron trioxide**.

Lead-oxide glass or **crystal glass or lead glass**: silica (SiO_2) + lead oxide (PbO) from red lead Pb_3O_4+ potassium oxide (K_2O) from K_2CO_3+ soda (Na_2O) from Na_2CO_3+ zinc oxide (ZnO) + alumina (Al_2O_3). Because of its high density (resulting in a high electron density), it has a high refractive index, high dispersion, high electrical resisatnce, high homogeneity, does not undergo devitrification, cut off harmful UV radiation. making the look of glassware more brilliant (called "crystal", though of course it is a glass and not a crystal).

Safety glass: It is classified into **laminated safety glass and heat strengthened or tempered safety glass**. **Laminated safety glass** is made by bonding two sheets of ordinary glass with a thin layer of vinyl plastic between them. Poly vinyl butyral (PVB) is used as a bonding agent between two or more layers of glass. An important property of safety glass is that when it is broken, the fragments are held in place by the interlayer. The glass pieces do not fly off that is it is shatter-proof.

Tempered safety glass is obtained by heating a single sheet of glass to just below its fusion point and then quenching I in oil, air or molten salt. It does not get fractured easily and is capable of withstanding mechanical and thermal shocks. If the outer surface breaks the pieces does not fly and the broken pieces have no sharp edges.

Safety glass is used for the manufacture of doors, windows shield of automobiles, ships, aero planes and furnaces. A sandwich effect is produced where in the outer surface cools rapidly and is in a state of compression.

Uses of Glasses

Glass is used in the following non-exhaustive list of products:

- Packaging (jars for food, bottles for drinks, flacon for cosmetics and pharmaceuticals)
- Tableware (drinking glasses, plate, cups, bowls)
- Housing and buildings (windows, facades, conservatory, insulation, reinforcement structures)
- Interior design and furniture's (mirrors, partitions, balustrades, tables, shelves, lighting)
- Appliances and Electronics (oven doors, cook top, TV, computer screens, smart-phones)
- Automotive and transport (windscreens, backlights, light weight but reinforced structural components of cars, aircrafts, ships, etc.)
- Medical technology, biotechnology, life science engineering, optical glass
- Radiation protection from X-Rays (radiology) and gamma-rays (nuclear)
- Fiber optic cables (phones, TV, computer: to carry information)
- Renewable energy (solar-energy glass, wind turbines)

*****Thank You*****

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