INTERNATIONAL INSTITUTE OF TECHNOLOGY & MANAGEMENT, MURTHAL SONIPAT
E-NOTES, SUBJECT: MATERIALS AND METALLURGY, COURSE: DIPLOMA
MECHANICAL ENGINEERING, SEM- 4TH
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CHAPTER -(Metal & Metallurgy)

INTRODUCTION

A material is a substance or mixture of substances that constitutes an object. Materials can be pure or impure, living or non-living matter. Materials can be classified based on their physical and chemical properties, or on their geological origin or biological function. Materials science is the study of materials and their applications.

Raw materials can be processed in different ways to influence their properties, by purification, shaping or the introduction of other materials. New materials can be produced from raw materials by synthesis.

HISTORY

The material of choice of a given era is often a defining point. Phrases such as Stone Age, Bronze Age, Iron Age, and Steel Age are historic, if arbitrary examples. Originally deriving from the manufacture of ceramics and its putative derivative metallurgy, materials science is one of the oldest forms of engineering and applied science. Modern materials science evolved directly from metallurgy, which itself evolved from mining and (likely) ceramics and earlier from the use of fire. A major breakthrough in the understanding of materials occurred in the late 19th century, when the American scientist Josiah Willard Gibbs demonstrated that the thermodynamic properties related to atomic structure in various phases are related to the physical properties of a material.

Important elements of modern materials science were products of the Space Race: the understanding and engineering of the metallic alloys, and silica and carbon materials, used in building space vehicles enabling the exploration of space. Materials science has driven, and been driven by, the development of revolutionary technologies such as rubbers, plastics, semiconductors, and biomaterials.

Before the 1960s (and in some cases decades after), many eventual materials science departments were metallurgy or ceramics engineering departments, reflecting the 19th and early 20th century emphasis on metals and ceramics. The growth of materials science in the United States was catalyzed in part by the Advanced Research Projects Agency, which funded a series of university-hosted laboratories in the early 1960s "to expand the national program of basic research and training. The field has since broadened to include every class of materials,including ceramics, polymers, semiconductors, magnetic materials, bi omaterials, and nanomaterials, generally classified into three distinct groups: ceramics, metals, and polymers. The prominent change in materials science during the recent decades is active usage of computer simulations to find new materials, predict properties, and understand phenomena.

SCOPE OF MATERIAL SCIENCE

Materials science is an interdisciplinary discipline and commonly termed as materials science and engineering, which involves the discovery and designing of new materials, with much emphasis on solids.

Today's research that deals with materials science, seeks to understand and influence the behaviour of materials at a variety of length scales, ranging from the atomic to the macroscopic levels, making use of practical, theoretical or computational tools as probes. The experimental researches include nano-science, biological materials, high-thermal materials, the interaction of laser-materials and electrochemical methods with several applications from medicine to renewable energy.

Classification of Engineering Materials

Basic Classification of Engineering Materials

Basically Engineering Materials can be classified into two categories-

1. Metals

2. Non-Metals

Metals

Metals are polycrystalline bodies which are having number of differentially oriented fine crystals. Normally major metals are in solid states at normal temperature. However, some metals such as mercury are also in liquid state at normal temperature. All metals are having high thermal and electrical conductivity. All metals are having positive temperature coefficient of resistance. Means resistance of metals increases with increase in temperature.

Examples of metals – Silver, Copper, Gold, Aluminum, Iron, Zinc, Lead, Tin etc. Metals can be further divided into two groups-

- 1. Ferrous Metals – All ferrous metals are having iron as common element. All ferrous materials are having very high permeability which makes these materials suitable for construction of core of electrical machines. Examples: Cast Iron, Wrought Iron, Steel, Silicon Steel, High Speed Steel, Spring Steel etc.

- 2. Non-Ferrous Metals - All non-ferrous metals are having very low permeability. Example: Silver, Copper, Gold, Aluminum etc.

Non-Metals

Non-Metal materials are non-crystalline in nature. These exists in amorphic or mesomorphic forms. These are available in both solid and gaseous forms at normal temperature. Normally all non-metals are bad conductor of heat and electricity. Examples: Plastics, Rubber, Leathers, Asbestos etc. As these non-metals are having very high resistivity which makes them suitable for insulation purpose in electrical machines.

Other classification of engineering materials:

Engineering materials can also be classified as below-

- Metals and Alloys
- Ceramic Materials
- Organic Materials

Metals and Alloys

Metals are polycrystalline bodies which are have number of differentially oriented fine crystals. Normally major metals are in solid states at normal temperature. However, some metals such as mercury are also in liquid state at normal temperature. Pure metals are having very a low mechanical strength, which sometimes does not match with the mechanical strength required for certain applications. To overcome this draw back alloys are used. Alloys are the composition of two or more metals or metal and non-metals together. Alloys are having good mechanical strength, low temperature coefficient of resistance. Example: Steels, Brass, Bronze, Gunmetal, Invar. Super Alloys etc.

Ceramic Materials

Ceramic materials are non-metallic solids. These are made of inorganic compounds such as Oxides, Nitrides, Silicates and Carbides. Ceramic materials possess exceptional Structural, Electrical, Magnetic, Chemical and Thermal properties. These ceramic materials are now extensively used in different engineering fields. Examples: Silica, glass, cement, concrete, garnet, Mgo, Cds, Zno, SiC etc.

Organic Materials

All organic materials are having carbon as a common element. In organic materials carbon is chemically combined with oxygen, hydrogen and other non-metallic substances. Generally organic materials are having complex chemical bonding. Example: Plastics, PVC, Synthetic Rubbers etc.

DIFFERENCE BETWEEN METALS AND NON METALS

Property	Metals	Non-metals
1. Nature	Metals are electropositive in nature	Non-metals are electronegative in nature
2. State	Metals are solid (except mercury)	Non-metals exist in all the three states, i.e., solid, liquid and gas.
3. Metallic	Metals are lustrous	Non-metals are non-lustorous. They cannot polished.
4. Ductility	Ductile	Non-ductile
5. Reaction with acids	Metals replaces hydrogen from acids and from salts.	Non-metals exits do not replace hydrogen from acids.
6. Reaction with oxygen in air	Metals forms basic oxides some of which to form alkalis.	Non-metals form acidic or neutral oxides.

Engineering Materials: Physical & Mechanical Properties

In this article we will discuss about the physical and mechanical properties of engineering materials.

Physical Properties of Engineering Materials:

These properties concerned with such properties as melting, temperature, electrical conductivity, thermal conductivity, density, corrosion resistance, magnetic properties, etc.

The more important of these properties will be considered as follows:

1. **Density**:

Density is defined as mass per unit volume for a material. The derived unit usually used by engineers is the kg/m^3. Relative density is the density of the material compared with the density of the water at 4°C.

The formulae of density and relative density are:
Density (p) = Mass (m)/volume (V)

Relative density (d) = Density of the material/Density of pure water at 4°C

2. Electrical Conductivity:
Figure shows a piece of electrical cable. In this example copper wire has been chosen for the conductor or core of the cable because copper has the property of very good electrical conductivity.

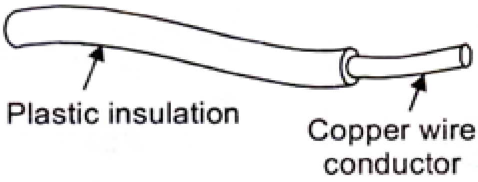


FIGURE : Electrical conductivity.

That is, it offers very little resistance to the flow of electrons (electric current) through the wire. A plastic materials such as polymerized has been chosen for the insulating sheathing surrounding the wire conductor.
This material has been chosen because it is such a bad conductor, where very few electrons can pass through it. Because they are very bad conductors they are called as insulators. There is no such thing as a perfect insulator, only very bad conductors. Pure metal shows this effect more strongly than alloys. However, pure metals generally have a better conductivity than alloys at room temperature. The conductivity of metals and metal alloys improves as the temperature falls.

Conversely, non-metallic materials used for insulators tend to offer a lower resistance to the passage of electrons and so become poorer insulators, as their temperatures rise. Glass, for example, is an excellent insulator at room temperature, but becomes a conductor if raised to red heat.

3. **Melting Temperature of Material:**
The melting temperatures and the recrystallisation temperatures have a great effect on the materials and the alloys of the materials properties and as a result on its applications.

4. **Semiconductors**:

In between conductors and insulators lies a range of materials known as semiconductors. These can be good or bad conductors depending upon their temperatures. The conductivity of semiconductor materials increases rapidly for relatively small temperature increases. This enables them to be used as temperature sensors in electronic thermometers.

Semiconductor materials are capable of having their conductors properties changed during manufacture. Examples of semiconductor materials are silicon and germanium. They are used extensively in the electronics industry in the manufacture of solid-state devices such as diodes, thermistors, transistors and integrated circuits.

5. Thermal Conductivity:

This is the ability of the material to transmit heat energy by conduction. Figure shows a soldering iron. The bit is made from copper which is a good conductor of heat and so will allow the heat energy stored in it to travel easily down to the tip and into the work being soldered. The wooden handle remains cool as it has a low thermal conductivity and resists the flow of heat energy.

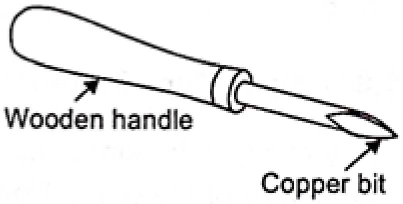


FIGURE : Thermal conductivity.

6. Fusibility:

This is the ease with which materials will melt. It can be seen from figure that solder melts easily and so has the property of high fusibility. On the other hand, fire bricks used for furnace linings only melt at very high temperatures and so have the properties of low fusibility.

Such materials which only melt a very high temperatures are called refractory materials. These must not be confused with materials which have a low thermal conductivity and used as thermal insulators. Although expanded polystyrene is an excellent thermal insulator, it has a very low melting point (high fusibility) and in no way can it be considered a refractory material.

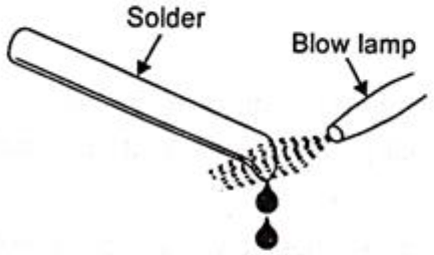


FIGURE : Solder melts at a low temperature and therefore it has a high fusibility.

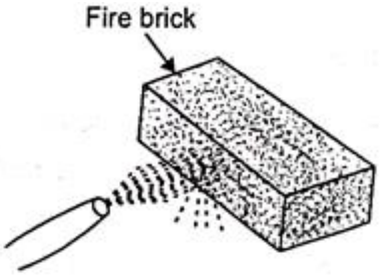


FIGURE : Fire brick only melts at very high temperatures and therefore it has a low fusibility and is called a refractory.

7. Reluctance (as Magnetic Properties):

Just as some materials are good or bad conductors of electricity, some materials can be good or bad conductors of magnetism. The resistance of magnetic circuit is referred to as reluctance.

The good magnetic conductors have low reluctance and examples are the ferromagnetic materials which get their name from the fact that they are made from iron, steel and associated alloying elements such as cobalt and nickel. All other materials are non-magnetic and offer a high reluctance to the magnetic flux felid.

8. Temperature Stability:

Any changes in temperature can have very significant effects on the structure and properties of materials. However, there are several effects can appear with changes in temperature such as creep.

For example gas-turbine blades. The creep rate increases if the temperature is raised, but becomes less if the temperature is lowered.

Mechanical Properties of Engineering Materials:

These properties are concerned with the following properties:

1. Tensile Strength:

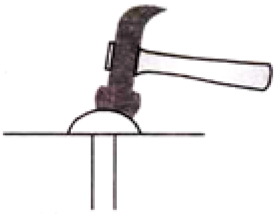
It is the ability of a material to withstand tensile (stretching) loads without breaking. As the force of gravity acting on the load is trying to stretch the rod, the rod is said to be in tension. Therefore, the material from which the rod is made needs to have sufficient tensile strength to resist the pull of the load. Strength is the ability of a material to resist applied forces without fracturing.

2. Toughness:

It is the ability of the materials to withstand bending or it is the application of shear stresses without fracture, so the rubbers and most plastic materials do not shatter, therefore they are tough. For example, if a rod is made of high-carbon steel then it will be bend without breaking under the impact of the hammer, while if a rod is made of glass then it will broke by impact loading.

3. Malleability:

It is the capacity of substance to withstand deformation under compression without rupture or the malleable material allows a useful amount of plastic deformation to occur under compressive loading before fracture occurs. Such a material is required for manipulation by such processes as forging, rolling and rivet heading.

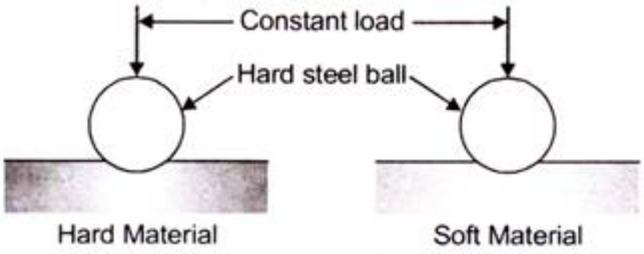


Malleability

4. Hardness:

It is the ability of a material to withstand scratching (abrasion) or indentation by another hard body, it is an indication of the wear resistance of the material.

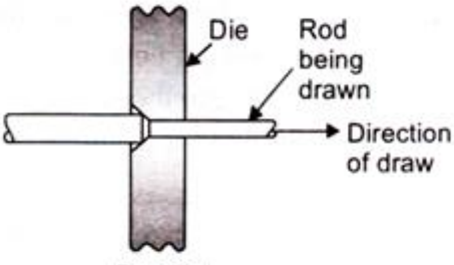
The ball only makes a small indentation in the hard material but it makes a very much deeper impression in the softer material.



Hardness

5. Ductility:

It refer to the capacity of substance to undergo deformation under tension without rupture as in wire drawing (as shown in figure), tube drawing operation. For more ductile material $\varepsilon_p > 15\%$, for less ductile material $\varepsilon_p > 5.1$ $\varepsilon_p < 15\%$.



Ductility

6. Stiffness:
It is the measure of a material’s ability not to deflect under an applied load.

For example, steel is very much stronger than cast iron, then the cast iron is preferred for machine beds and frames because it is more rigid and less likely to deflect with consequent loss of alignment and accuracy.

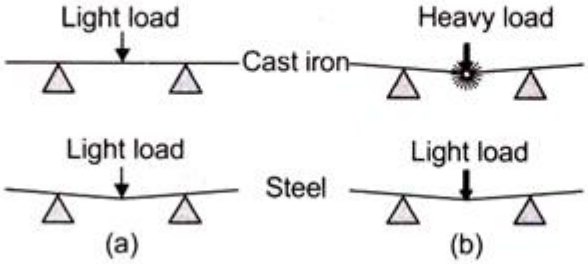


FIGURE : Stiffness (rigidity) :
(a) The tested materials deflect under a light load
(b) The tested materials deflect under a heavy load.

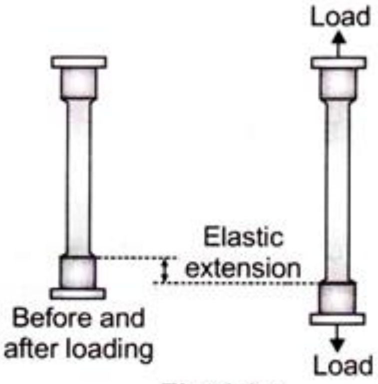
7. Brittleness:
It is the property of a material that shows little or no plastic deformation before fracture when a force is applied. Also it is usually said as the opposite of ductility and malleability.

For brittle material $\varepsilon_D < 5\%$.

$$\varepsilon_p = \frac{\Delta l}{l} = \frac{\text{Change in length}}{\text{Orginal length}}$$

8. Elasticity:
It is the ability of a material to deform under load and return to its original size and shape when the load is removed. If it is made from an elastic material it will

be the same length before and after the load is applied, despite the fact that it will be longer whilst the load is being applied. All materials possess elasticity to some degree and each has its own elastic limits.



Elasticity

9. Plasticity:

This property is opposite to elasticity, while the ductility and malleability are particular cases of the property of the plasticity. It is the state of a material which has been loaded beyond it elastic limit so as to cause the material to deform permanently.

Under such conditions the material takes a permanent set and will not return to its original size and shape when the load is removed. When a piece of mild steel is bent at right angles into the shape of a bracket, it shows the property of plasticity since it does not spring back strength again.

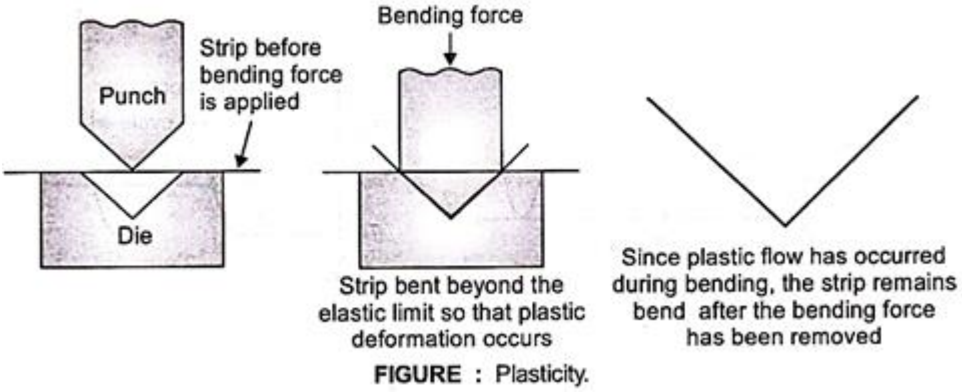


FIGURE : Plasticity.

10. Creep:

The permanent deformation (strain) of a material under steady load as a function of time is called creep.

Length of our waist belt increases after some duration, is due to creep effect.

Thermally actuated process, and hence is influenced by temperature. Appreciable at temperature above 0.4. T_m where T_m is melting point of material in degree kelvin.
Creep occurs at room temperature in many materials such as lead, zinc, solder wire (an alloy of Pb and Sn), white metals, rubber, plastics and leather etc. e.g. consider zinc where melting point is 420°C (693 K). Its creep rate is considerable above a temperature of (0.4 x 693 K = 277 K) is at about 4°C only.

11. Fatigue:
The behavior of materials under fluctuating and reversing loads (or stresses) is termed as fatigue. This behaviour is different from that under the steady load. Fatigue is, however, not a dynamic effect. The rate of loading is usually not a factor is fatigue behavior. Fatigue behavior is experienced by all materials whether metals, plastics, concretes, or composites.

Main Effects of Fatigue:

i. Loss of ductility,

ii. Loss of strength, and

iii. Enhanced uncertainty in strength and the service life of materials.

Materials Needs for the Industries of the Future

The materials needs of the IOF industries are documented in detail in the technology road maps, and the reader is referred to these road maps for listings and discussions of IOF materials needs. Only a sampling of the most important materials needs of the industries, especially the needs that are common to many industries, are included in this report. It summarizes important materials needs of the IOF industries, shows the relative importance of each crosscutting problem to individual industries, and lists one or two of the major problems facing each industry. The importance of each crosscutting materials problem to each industry is based on the prevalence of the problem in that industry and how well it is being addressed. Oak Ridge National Laboratory (ORNL) has performed an independent analysis of the materials needs of the IOF industries based on the road maps, and the results of their analysis were presented to the committee and included in the committee’s deliberations (Angelini, 1999).

Three things in stand out immediately. First, many of the industries have some similar, if not identical, needs. Thus, selecting truly crosscutting R&D should not be difficult. Second, many of the important materials needs are in areas that are considered uninteresting, unexciting, or not on the cutting edge of technology. This fact must be considered as OIT project mangers establish the scope and extent of R&D programs. Third, a few areas of materials research are extremely important to ALL of the industries. Progress in these areas would, therefore, have the biggest impact on energy savings and waste reduction. These areas (corrosion, wear, high-temperature materials [including refractories], and materials modeling/database development) are emphasized in this report.

Biomaterial

example of an application of biomaterials

A biomaterial is any substance that has been engineered to interact with biological systems for a medical purpose - either a therapeutic (treat, augment, repair or replace a tissue function of the body) or a diagnostic one. As a science, biomaterials is about fifty years old. The study of biomaterials is called biomaterials science or biomaterials engineering. It has experienced steady and strong growth over its history, with many companies investing large amounts of money into the development of new products. Biomaterials science encompasses elements of medicine, biology, chemistry, tissue engineering and materials science.

Applications

Biomaterials are used in:

- Joint replacements
- Bone plates
- Intraocular lenses (IOLs) for eye surgery
- Bone cement
- Artificial ligaments and tendons
- Dental implants for tooth fixation

- Blood vessel prostheses
- Heart valves
- Skin repair devices (artificial tissue)
- Cochlear replacements
- Contact lenses
- Breast implants

Biomaterials must be compatible with the body, and there are often issues of biocompatibility which must be resolved before a product can be placed on the market and used in a clinical setting. Because of this, biomaterials are usually subjected to the same requirements as those undergone by new drug therapies.

All manufacturing companies are also required to ensure traceability of all of their products so that if a defective product is discovered, others in the same batch may be traced.

Heart valves

In the United States, 49% of the 250,000 valve replacement procedures performed annually involve a mechanical valve implant. The most widely used valve is a bileaflet disc heart valve, or St. Jude valve. The mechanics involve two semicircular discs moving back and forth, with both allowing the flow of blood as well as the ability to form a seal against backflow. The valve is coated with pyrolytic carbon, and secured to the surrounding tissue with a mesh of woven fabric called Dacron (du Pont's trade name for polyethylene terephthalate). The mesh allows for the body's tissue to grow while incorporating the valve.

Skin repair

Most of the time, ‘artificial’ tissue is grown from the patient’s own cells. However, when the damage is so extreme that it is impossible to use the patient's own cells, artificial tissue cells are grown. The difficulty is in finding a scaffold that the cells can grow and organize on. The characteristics of the scaffold must be that it is biocompatible, cells can adhere to the scaffold, mechanically strong and biodegradable. One successful scaffold is a copolymer of lactic acid and glycolic acid.

Compatibility

Biocompatibility is related to the behavior of biomaterials in various environments under various chemical and physical conditions. The term may refer to specific properties of a material without specifying where or how the material is to be used. For example, a material may elicit little or no immune response in a given organism, and may or may not able to integrate with a particular cell type or tissue. Immuno-informed biomaterials that direct the immune response rather than attempting to circumvent the process is one approach that shows promise.The ambiguity of the term reflects the ongoing development of insights into how biomaterials interact with the human body and eventually how those interactions determine the clinical success of a medical device (such as pacemaker or hip replacement). Modern medical devices and prostheses are often made of more than one material—so it might not always be sufficient to talk about the biocompatibility of a specific material.

Biopolymers

Biopolymers are polymers produced by living organisms. Cellulose and starch, proteins and peptides, and DNA and RNA are all examples of biopolymers, in which the monomeric units, respectively, are sugars, amino acids, and nucleotides. Cellulose is both the most common biopolymer and the most common organic compound on Earth. About 33% of all plant matter is cellulose.

SEMICONDUCTOR

Semiconductors are the materials which have a conductivity between conductors (generally metals) and non-conductors or insulators (such ceramics). Semiconductors can be compounds such as gallium arsenide or pure elements, such as germanium or silicon. Physics explains the theories, properties and mathematical approach governing semiconductors.

Examples of Semiconductors:

Gallium arsenide, germanium, and silicon are some of the most commonly used semiconductors. Silicon is used in electronic circuit fabrication and gallium arsenide is used in solar cells, laser diodes, etc.

Properties of Semiconductors

Semiconductors can conduct electricity under preferable conditions or circumstances. This unique property makes it an excellent material to conduct electricity in a controlled manner as required.

Unlike conductors, the charge carriers in semiconductors arise only because of external energy (thermal agitation). It causes a certain number of valence electrons to cross the energy gap and jump into the conduction band, leaving an equal amount of unoccupied energy states, i.e. holes. Conduction due to electrons and holes are equally important.

- Resistivity: 10^{-5} to 10^{6} Ωm
- Conductivity: 10^{5} to 10^{-6} mho/m
- Temperature coefficient of resistance: Negative
- Current Flow: Due to electrons and holes

Types of Semiconductors

Semiconductors can be classified as:

- Intrinsic Semiconductor
- Extrinsic Semiconductor

Intrinsic Semiconductor

An intrinsic type of semiconductor material is made to be very pure chemically. It is made up of only a single type of element.

tors (a) In absence of electric field (b) In presence of electric Field
Germanium (Ge) and Silicon (Si) are the most common type of intrinsic semiconductor elements. They have four valence electrons (tetravalent). They are bound to the atom by covalent bond at absolute zero temperature.

When the temperature rises, due to collisions, few electrons are unbounded and become free to move through the lattice, thus creating an absence in its original position (hole). These free electrons and holes contribute to the conduction of electricity in the semiconductor. The negative and positive charge carriers are equal in number.

The thermal energy is capable of ionizing a few atoms in the lattice, and hence their conductivity is less.

In intrinsic semiconductors, current flows due to the motion of free electrons as well as holes. The total current is the sum of the electron current I_e due to thermally generated electrons and the hole current I_h

Total Current (I) = $I_e + I_h$

For an intrinsic semiconductor, at finite temperature, the probability of electrons to exist in conduction band decreases exponentially with increasing bandgap (E_g)

$n = n_0 e^{-Eg/2.Kb.T}$

Where,

- Eg = Energy bandgap

- K_b = Boltzmann's constants

Extrinsic Semiconductor

The conductivity of semiconductors can be greatly improved by introducing a small number of suitable replacement atoms called IMPURITIES. The process of adding impurity atoms to the pure semiconductor is called DOPING. Usually, only 1 atom in 10^7 is replaced by a dopant atom in the doped semiconductor. An extrinsic semiconductor can be further classified into:

- N-type Semiconductor
- P-type SemiconductorClassification of Extrinsic Semiconductor

N-Type Semiconductor

- Mainly due to electrons
- Entirely neutral
- $I = I_h$ and $n_h >> n_e$
- Majority – Electrons and Minority – Holes

When a pure semiconductor (Silicon or Germanium) is doped by pentavalent impurity (P, As, Sb, Bi) then, four electrons out of five valence electrons bonds with the four electrons of Ge or Si.

The fifth electron of the dopant is set free. Thus the impurity atom donates a free electron for conduction in the lattice and is called "Donar".

Since the number of free electron increases by the addition of an impurity, the negative charge carriers increase. Hence it is called n-type semiconductor.

Crystal as a whole is neutral, but the donor atom becomes an immobile positive ion. As conduction is due to a large number of free electrons, the electrons in the n-type semiconductor are the MAJORITY CARRIERS and holes are the MINORITY CARRIERS.

P-Type Semiconductor

- Mainly due to holes
- Entirely neutral
- $I = I_h$ and $n_h >> n_e$
- Majority – Holes and Minority – Electrons

When a pure semiconductor is doped with a trivalent impurity (B, Al, In, Ga) then, the three valence electrons of the impurity bonds with three of the four valence electrons of the semiconductor.

This leaves an absence of electron (hole) in the impurity. These impurity atoms which are ready to accept bonded electrons are called “Acceptors“.

With the increase in the number of impurities, holes (the positive charge carriers) are increased. Hence, it is called p-type semiconductor.

Crystal as a whole is neutral, but the acceptors become an immobile negative ion. As conduction is due to a large number of holes, the holes in the p-type semiconductor are MAJORITY CARRIERS and electrons are MINORITY CARRIERS.

Difference between Intrinsic and Extrinsic Semiconductors

Intrinsic Semiconductor	Extrinsic Semiconductor
Pure semiconductor	Impure semiconductor
Density of electrons is equal to the density of holes	Density of electrons is not equal to the density of holes
Electrical conductivity is low	Electrical conductivity is high
Dependence on temperature only	Dependence on temperature as well as on the amount of impurity
No impurities	Trivalent impurity, pentavalent impurity

Applications of Semiconductors

Let us now understand the uses of semiconductors in daily life. Semiconductors are used in almost all electronic devices. Without them, our life would be much different.

Their reliability, compactness, low cost and controlled conduction of electricity make them ideal to be used for various purposes in a wide range of components and devices. transistors, diodes, photosensors, microcontrollers, integrated chips and much more are made up of semiconductors.

Uses of Semiconductors in Everyday life

- Temperature sensors are made with semiconductor devices.
- They are used in 3D printing machines
- Used in microchips and self-driving cars
- Used in calculators, solar plates, computers and other electronic devices.
- Transistor and MOSFET used as a switch in Electrical Circuits are manufactured using the semiconductors.

Industrial Uses of Semiconductors

The physical and chemical properties of semiconductors make them capable of designing technological wonders like microchips, transistors, LEDs, solar cells, etc.

The microprocessor used for controlling the operation of space vehicles, trains, robots, etc is made up of transistors and other controlling devices which are manufactured by semiconductor materials.

Importance of Semiconductors

Here we have discussed some advantages of semiconductors which makes them highly useful everywhere.

- They are highly portable due to the smaller size
- They require less input power
- Semiconductor devices are shockproof
- They have a longer lifespan
- They are noise-free while operating

CHAPTER -(Crystallography)

INTRODUCTION

A crystal or crystalline solid is a solid material whose constituents (such as atoms, molecules, or ions) are arranged in a highly ordered microscopic structure, forming a crystal lattice that extends in all directions. In addition, macroscopic single crystals are usually identifiable by their geometrical shape, consisting of flat faces with specific, characteristic orientations. The scientific study of crystals and crystal formation is known as crystallography. The process of crystal formation via mechanisms of crystal growth is called crystallization or solidification.

Types of solids

On the basis of the arrangement of constituent particles, the solids are classified into two categories, namely:

- Amorphous Solids
- Crystalline Solids

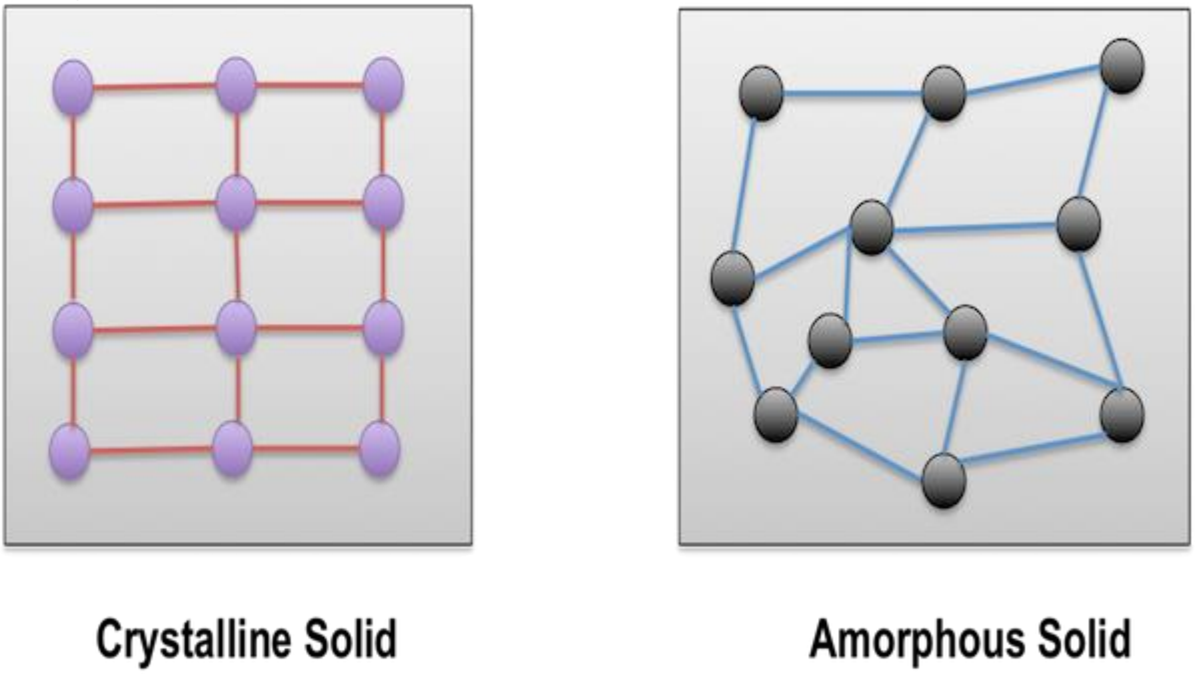


Image 1: Arrangement of Atoms

Amorphous Solids

The solids in which the constituent particles of matter are arranged in a random manner are called amorphous solids. It is a non-crystalline solid with no proper arrangement of atoms in the solid lattice. In other words, we can define amorphous solids as materials which don’t have certain organized arrangement of atoms and molecules. Most solids are amorphous in nature and are utilized in many sectors as well. One of the most common examples of amorphous solids is glass, which is used widely in the manufacturing sector.

Examples: Plastics, Glass, Rubber, Metallic Glass, Polymers, Gel etc.

Uses of Amorphous Solids

There are many applications of amorphous solids, some of them are:

- The glass is widely used in packaging (food jars, cosmetics box, and soft-drink bottles), making tableware (utensils), in the construction of buildings windows, lighting, and shelves) etc.
- Rubber is mainly used in manufacturing of tires, footwear, ropes, camp cloth and as a raw material for several industries
- Use of polymer can be seen in manufacturing of pipes, medicines and as a raw ingredient for many factories
- Amorphous silicon is considered as the best photovoltaic material to convert sunlight into electricity

Crystalline Solids

The solids in which the constituent particles of matter are arranged and organized in a specific manner are called Crystalline Solids. These solids contain crystals in their structure and each crystal has definite geometry. Adding further, as crystalline solids have low potential energy, they are the most stable form of solids. Almost all solids fall in the category of crystalline solids including metallic elements (iron, silver, and copper) and non-metallic elements (Phosphorus, Sulphur, and iodine). Also several compounds like sodium chloride, zinc sulphide and naphthalene build crystalline solids.
Examples: Quartz, Calcite, Sugar, Mica, Diamonds etc.

Uses of Crystalline Solids

There are many applications of crystalline solids, some are:

- Diamond is the most decent example of crystalline solids and is widely used in making beautiful jewelry items
- Quartz is extensively used in manufacturing of watches and clocks
- Many crystalline solids are used as a raw material in many industries

Definition of crystallography

It is a branch of science in which structure of crystals, external or internal symmetries and properties of crystals are studied.

Space lattice (or) crystal lattice.

In a solid crystalline material, the atoms or molecules are arranged regularly and periodically in three dimensions. If each such unit of atoms or atom in a crystal is replaced by a point in space, then the resultant points in space are called space lattice.

Unit Cell

The smallest repeating unit of the crystal lattice is the unit cell, the building block of a crystal.
The unit cells which are all identical are defined in such a way that they fill space without overlapping. The 3D arrangement of atoms, molecules or ions inside a crystal is called a *crystal lattice.* It is made up of a large number of unit cells. One of the three constituent particles takes up every lattice point.

A unit cell can either be primitive cubic, body-centered cubic (BCC) or face-centered cubic (FCC). In this section, we will discuss the three types of the unit cell in detail.

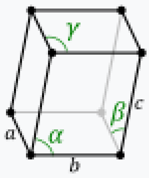
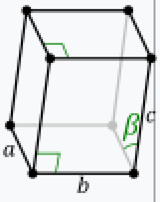
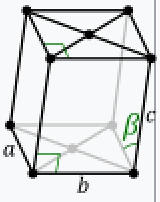
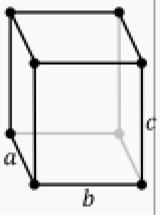
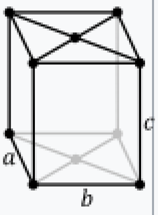
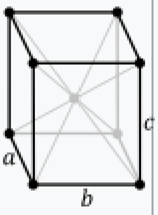
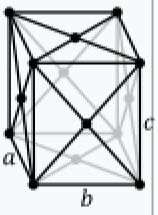
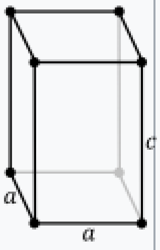
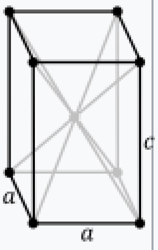
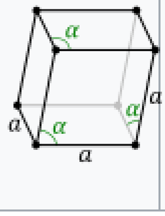
Types of Unit Cell

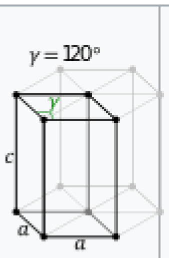
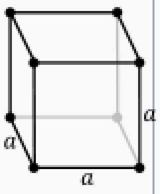
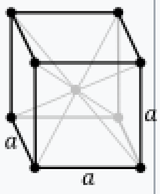
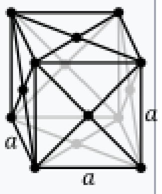
A large number of unit cells together make a crystal lattice. Constituent particles like atoms, molecules are also present. Each lattice point is occupied by one such particle.

1. *Primitive Cubic Unit Cell*
2. *Body-centered Cubic Unit Cell*
3. *Face centered cubic unit cell*

Lattice systems

Lattice systems are a grouping of crystal structures according to the axial system used to describe their lattice. Each lattice system consists of a set of three axes in a particular geometric arrangement. All crystals fall into one of seven lattice systems. They are similar to, but not quite the same as the seven crystal systems.

Crystal family	Lattice system	Schönflies	14 Bravais Lattices			
			Primitive	Base-centered	Body-centered	Face-centered
triclinic		C_i				
monoclinic		C_{2h}				
orthorhombic		D_{2h}				
tetragonal		D_{4h}				
hexagonal	rhombohedral	D_{3d}				

	hexagonal	D_{6h}				
cubic		O_h				

The simplest and most symmetric, the cubic or isometric system, has the symmetry of a cube, that is, it exhibits four threefold rotational axes oriented at 109.5° (the tetrahedral angle) with respect to each other. These threefold axes lie along the body diagonals of the cube. The other six lattice systems, are hexagonal, tetragonal, rhombohedral (often confused with the trigonal crystal system), orthorhombic, monoclinic and triclinic.

Bravais lattices

Bravais lattices, also referred to as space lattices, describe the geometric arrangement of the lattice points, and therefore the translational symmetry of the crystal. The three dimensions of space afford 14 distinct Bravais lattices describing the translational symmetry. All crystalline materials recognized today, not including quasicrystals, fit in one of these arrangements. The fourteen three-dimensional lattices, classified by lattice system, are shown above.

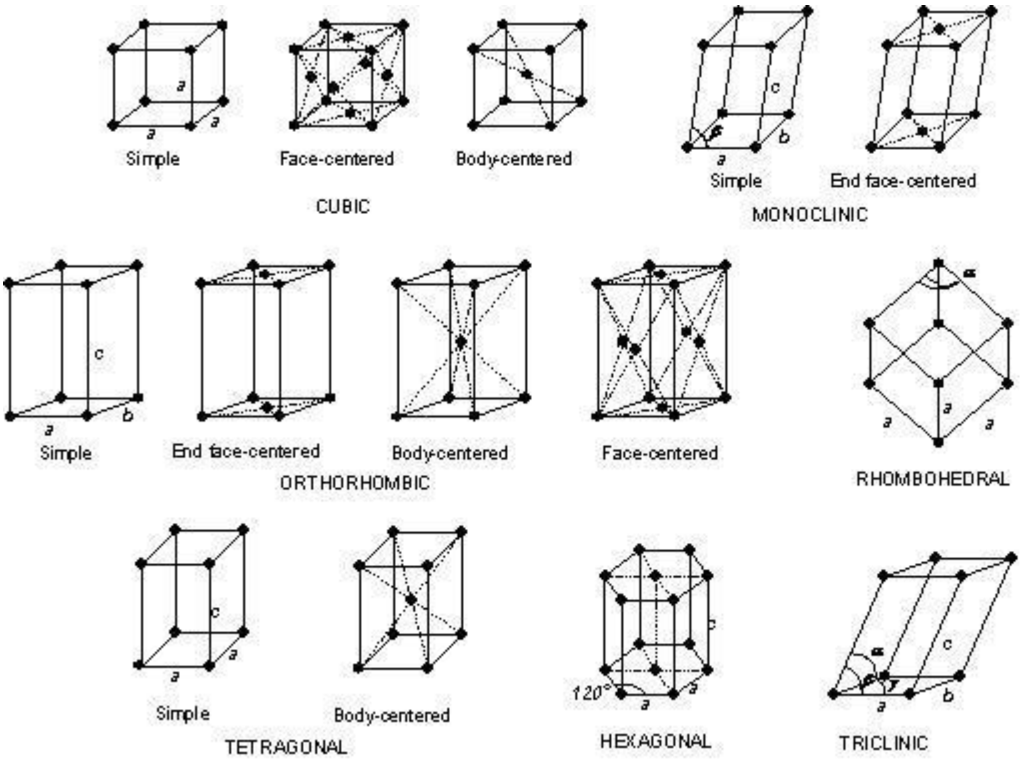
The crystal structure consists of the same group of atoms, the basis, positioned around each and every lattice point. This group of atoms therefore repeats indefinitely in three dimensions according to the arrangement of one of the Bravais lattices. The characteristic rotation and mirror symmetries of the unit cell is described by its crystallographic point group.

Crystal systems

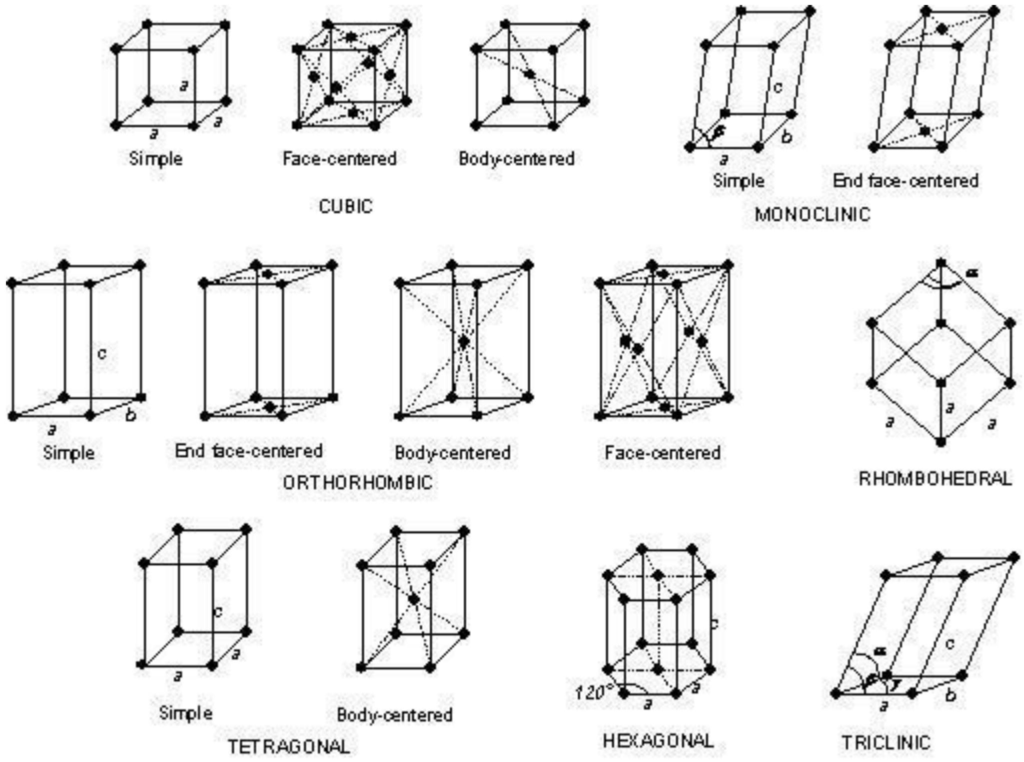
A crystal system is a set of point groups in which the point groups themselves and their corresponding space groups are assigned to a lattice system. Of the 32 point groups that exist in three dimensions, most are assigned to only one lattice system, in which case the crystal system and lattice system both have the same name. However, five point groups are assigned to two lattice systems, rhombohedral and hexagonal, because both lattice systems exhibit threefold rotational symmetry. These point groups are assigned to the trigonal crystal system.

Crystal structure

We know that crystal structure deals with the atomic arrangement in the solid crystal structure show the regular three-dimensional pattern of atoms. In geometric terms, crystal structure is known as space lattice or point lattice.



We know that crystal structure deals with the atomic arrangement in the solid crystal structure show the regular three-dimensional pattern of atoms. In geometric terms, crystal structure is known as space lattice or point lattice.



Types of crystal structure:

There are four types of crystal structure as given below:

- Simple Cubic Crystal Structure (SC)
- Body-Centered Crystal Structure (BCC)
- Face Centered Crystal Structure (FCC)
- Hexagonal close packed structure (HCP)

1. Simple Cubic Crystal Structure (SC) :
In this type of crystal structure, one atom is situated at each corner of the unit cell as shown in the figure. In the simple cubic crystal structure, the total number eight.
Simple cubic crystal structure does not have an atom at the center of the unit cell or faces of the unit cell. Now we can say that the average number of atoms per unit in a simple cubic crystal structure one. This type of crystal structure does not exist in any engineering material.

2. Body-Centered Crystal Structure (BCC) :
In body centered crystal structure, one atom is placed at each corner of the unit cell like a simple cubic crystal structure but, in addition to this, there is one atom at the center of the unit cell. A body-centered crystal structure is more complex as compared to the simple cubic crystal structure. Center atom in the body centered crystal structure does not come in contact with another atom, hence it remains unshared. An average number of atoms per unit cell in body centered crystal structure is two. Metals like Li, K, Na, V, Ta, etc. has this type of crystal structure.

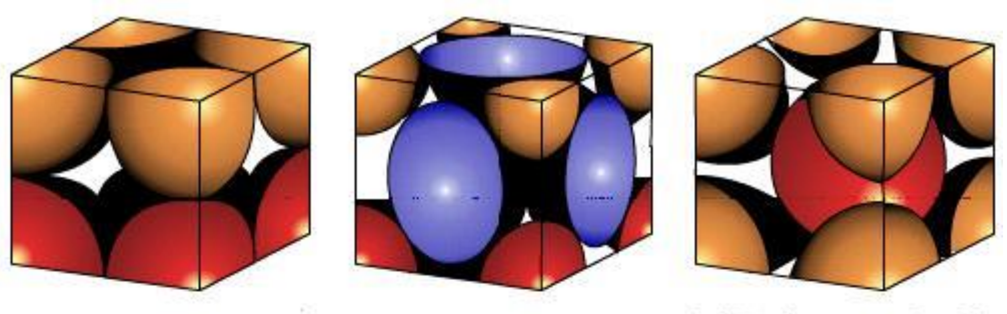
3. Face Centered Crystal Structure (FCC) :
In the face-centered crystal structure, an atom is placed at each corner of the unit cell that is eight corner atoms. One atom is placed at each face center that is six face atoms. In Face centered crystal structure, there is no center atom. In this type of crystal structure, an average number of atoms per unit cell is four. Metals like Cu, Ag, Al, Ca, Pt, etc. contain this type of crystal structure.

4. Hexagonal close packed structure (HCP) :
In Hexagonal close packed structure, crystal structure shows one atom at each corner of the hexagon. Therefore, there are 12 corner atoms in the hexagonal close packed structure. Also, there is one atom on each face of the hexagon. Interior three atoms in the hexagon remain unshared. In hexagonal close packed structure, an average number of atoms per unit cell is six. Metal like Zn, Co, Cd, Mg, Be, Ca, etc. has this type of crystal structure.

Number of atoms per unit cell

A large number of unit cells together make a crystal lattice. Constituent particles like atoms, molecules are also present. Each lattice point is occupied by one such particle.

1. *Primitive Cubic Unit Cell*
2. *Body-centered Cubic Unit Cell*
3. *Face centered cubic unit cell*



(a) Simple cubic (b) Face centred cubic (c) Body centred cubic

Three dimensional view showing the number of atoms per unit cell

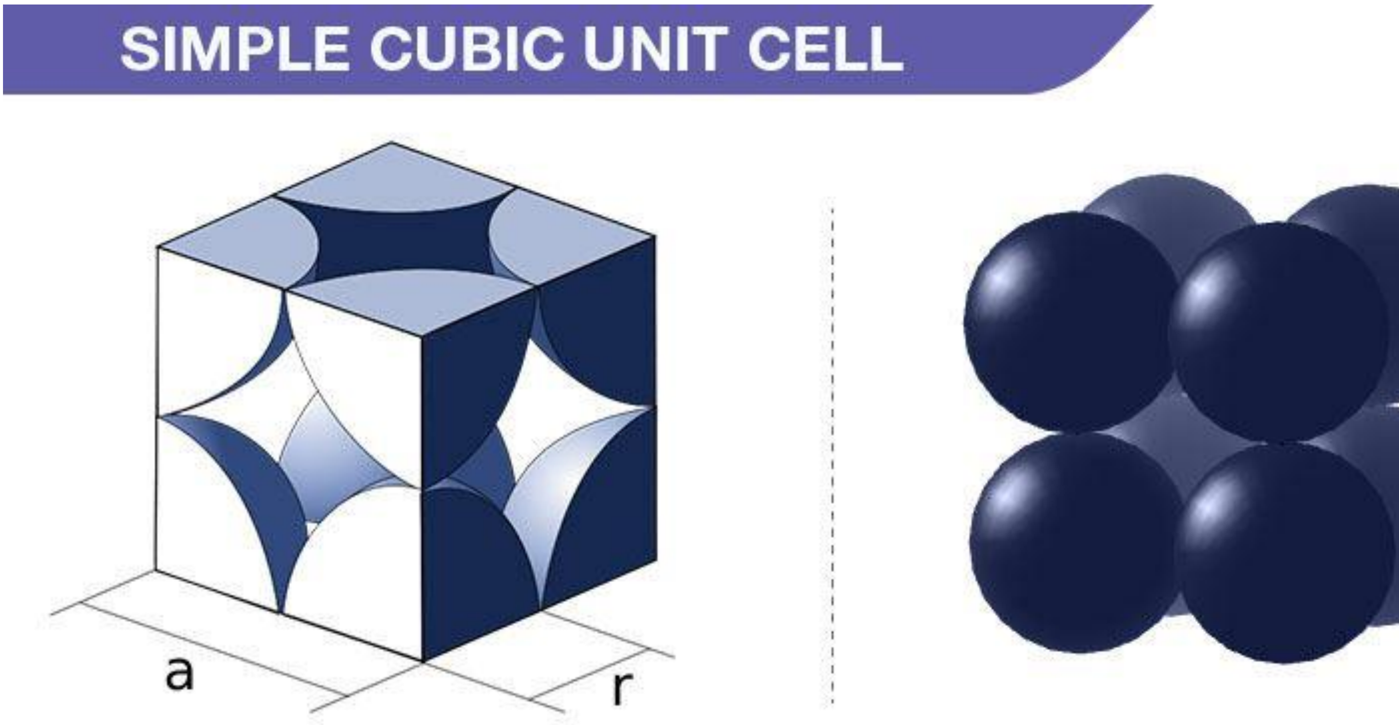
Types of Unit Cell

1. Primitive Cubic Unit Cell

In the primitive cubic unit cell, the atoms are present only at the corners. Every atom at the corner is shared among 8 adjacent unit cells. There are 4 unit cells in the same layer and 4 in the upper (or lower) layer. Therefore, a particular unit cell has the only 1/8th of an atom. Each small sphere in the following figure represents the center of a particle that occupies that particular position and not its size. This structure is known as an *open structure*.

1. The atoms in the primitive cubic unit cell are present only at the corners
2. Every atom at the corner is shared among eight adjacent unit cells
3. Four unit cells are present in the same layer
4. Four unit cell in the upper/lower layer
5. Therefore a particular unit cell has the only 18th of an atom
6. Each small sphere in the following figure represents the center of a particle which occupies that particular position and not its size

Below is an open structure



simple cubic unit cell

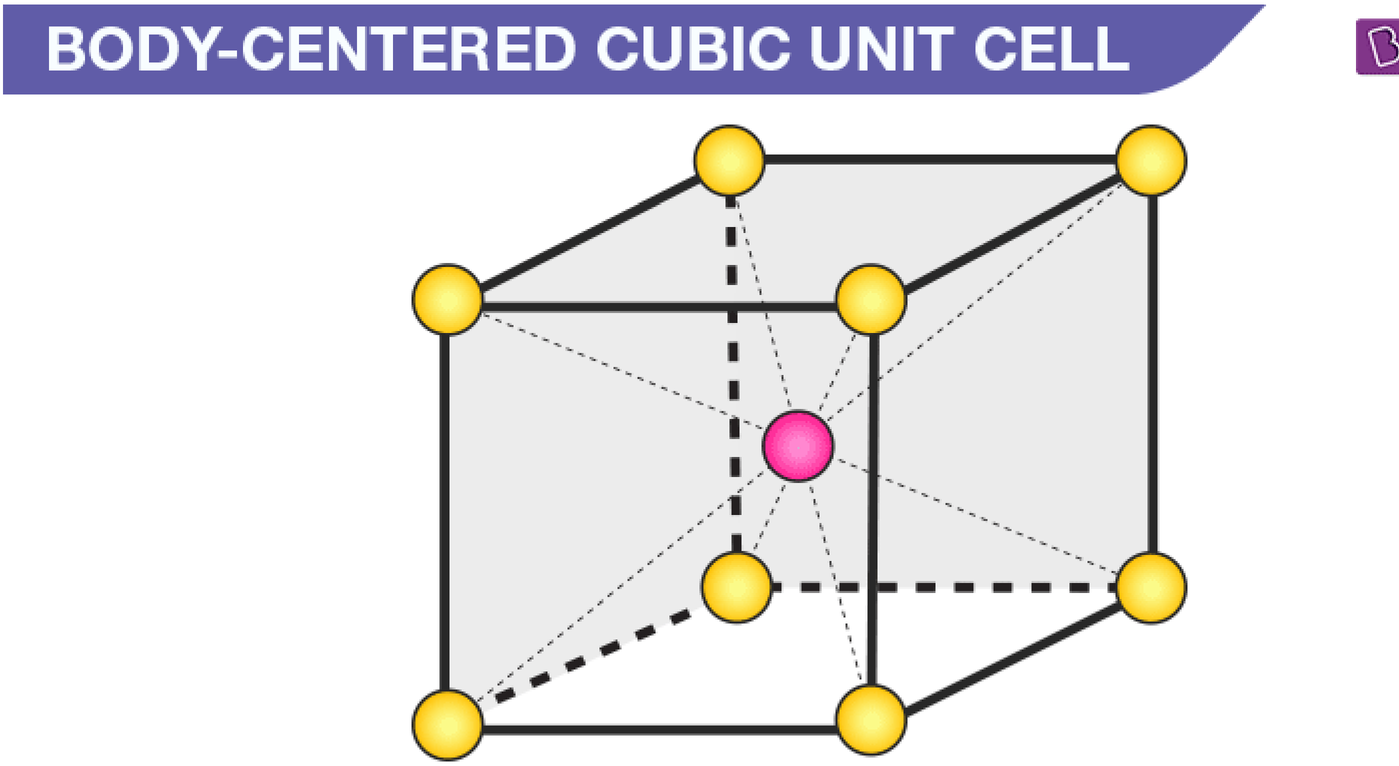
In each cubic unit cell, there are 8 atoms at the corners. Therefore, the total number of atoms in one unit cell is

8 × 1/8 = 1 atom.

2. Body-centered Cubic Unit Cell (BCC)

A BCC unit cell has atoms at each corner of the cube and an atom at the center of the structure. The diagram shown below is an open structure. According to this structure, the atom at the body center wholly belongs to the unit cell in which it is present.

1. In BCC unit cell every corner has atoms.
2. There is one atom present at the center of the structure
3. Below diagram is an open structure
4. According to this structure atom at the body centers wholly belongs to the unit cell in which it is present.



Body centered Cubic (BCC) Unit Cell

Number of Atoms in BCC Cell:

Thus, in a BCC cell, we have:

- 8 corners × 1/8 per corner atom = 8 × 1/8 = 1 atom
- 1 body center atom = 1 × 1 = 1 atom

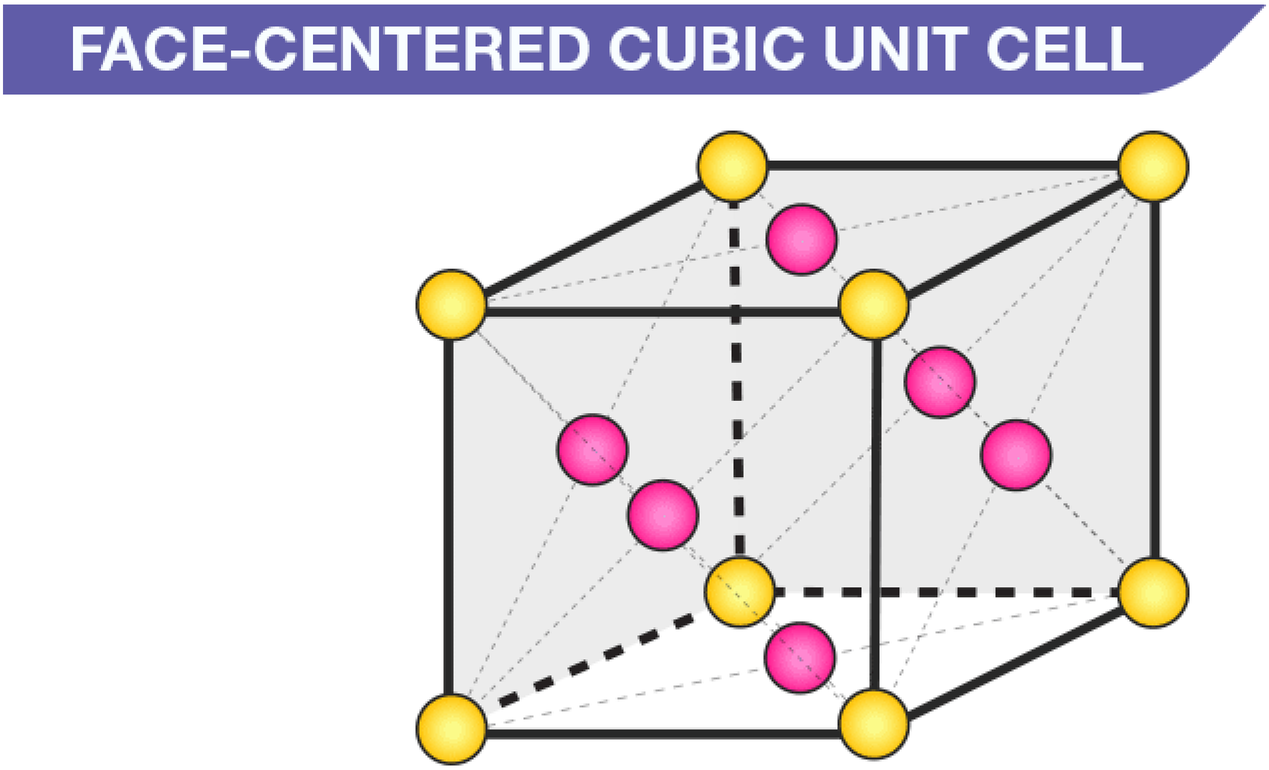
Therefore, the total number of atoms present per unit cell = 2 atoms.

3. Face-centered Cubic Unit Cell (FCC)

An FCC unit cell contains atoms at all the corners of the crystal lattice and at the center of all the faces of the cube. The atom present at the face-center is shared between 2 adjacent unit cells and only 1/2 of each atom belongs to an individual cell.

1. In FCC unit cell atoms are present in all the corners of the crystal lattice
2. Also, there is an atom present at the center of every face of the cube
3. This face-center atom is shared between two adjacent unit cells
4. Only 12 of each atom belongs to a unit cell

The diagram shown below is an open structure.



face centered cubic unit cell

Number of Atoms in BCC Cell

a) 8 corners × 18 per corner atom = 8 × 18 = 1 atom
b) 6 face-centered atoms × 12 atom per unit cell = 3 atoms

Hence the total number of atoms in a unit cell = 4 atoms

Thus, in a face-centered cubic unit cell, we have:

- 8 corners × 1/8 per corner atom = 8 × 1/8 = 1 atom
- 6 face-centered atoms × 1/2 atom per unit cell = 3 atoms

Therefore, the total number of atoms in a unit cell = 4 atoms.

Atomic packing factor

In crystallography, atomic packing factor (APF), packing efficiency or packing fraction is the fraction of volume in a crystal structure that is occupied by constituent particles. It is a dimensionless quantity and always less than unity.

In atomic systems, by convention, the APF is determined by assuming that atoms are rigid spheres. The radius of the spheres is taken to be the maximum value such that the atoms do not overlap. For one-component crystals (those that contain only one type of particle), the packing fraction is represented mathematically by

APF =N particle X V particle / V unit~cell

where N_{particle} is the number of particles in the unit cell, V_{particle} is the volume of each particle, and $V_{\text{unit cell}}$ is the volume occupied by the unit cell. It can be proven mathematically that for one-component structures, the most dense arrangement of atoms has an APF of about 0.74 (see Kepler conjecture), obtained by the close-packed structures. For multiple-component structures (such as with interstitial alloys), the APF can exceed 0.74.

The atomic packing factor of a unit cell is relevant to the study of Materials Science, where it explains many properties of materials. For example, metals with a high atomic packing factor will have a higher "workability" (malleability or ductility), similar to how a road is smoother when the stones are closer together, allowing metal atoms to slide past one another more easily.

Simple cubic

For a simple cubic packing, the number of atoms per unit cell is one. The side of the unit cell is of length 2r, where r is the radius of the atom.

APF = Volume of atoms per unit cell/Volume of unit cell

= 0.52

Body-centered cubic[edit]

BCC structure

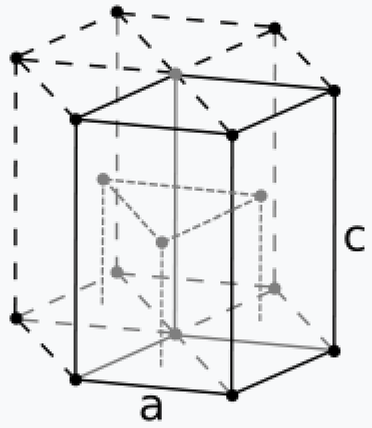
The primitive unit cell for the body-centered cubic crystal structure contains several fractions taken from nine atoms (if the particles in the crystal are atoms): one on each corner of the cube and one atom in the center. Because the volume of each of the eight corner atoms is shared between eight adjacent cells, each BCC cell contains the equivalent volume of two atoms (one central and one on the corner).

Each corner atom touches the center atom. A line that is drawn from one corner of the cube through the center and to the other corner passes through 4r, where r is the radius of an atom. By geometry, the length of the diagonal is $a\sqrt{3}$. Therefore, the length of each side of the BCC structure can be related to the radius of the atom by

APF = Volume of atoms per unit cell/Volume of unit cell

= 0.68

Hexagonal close-packed



HCP structure

For the hexagonal close-packed structure the derivation is similar. Here the unit cell (equivalent to 3 primitive unit cells) is a hexagonal prism containing six atoms (if the particles in the crystal are atoms). Indeed, three are the atoms in the middle layer (inside the prism); in addition, for the top and bottom layers (on the bases of the prism), the central atom is shared with the adjacent cell, and each of the six atoms at the vertices is shared with other five adjacent cells. So the total number of atoms in the cell is 3 + (1/2)×2 + (1/6)×6×2 = 6. Each atom touches other twelve atoms.

APF = Volume of atoms per unit cell/Volume of unit cell

= 0.73

DEFORMATION

The change in dimensions of forms of matter under the action of applied forces is called ‘deformation’. It is caused either by the mechanical action of external forces or by various physical and physio-chemical processes. To form various metallic shapes the deformation of metals is necessary. The deformed or mechanically worked metals are much superior to cast metals from which they are produced.

Types of Metal Deformation:

The metal deformations are of the following two types:

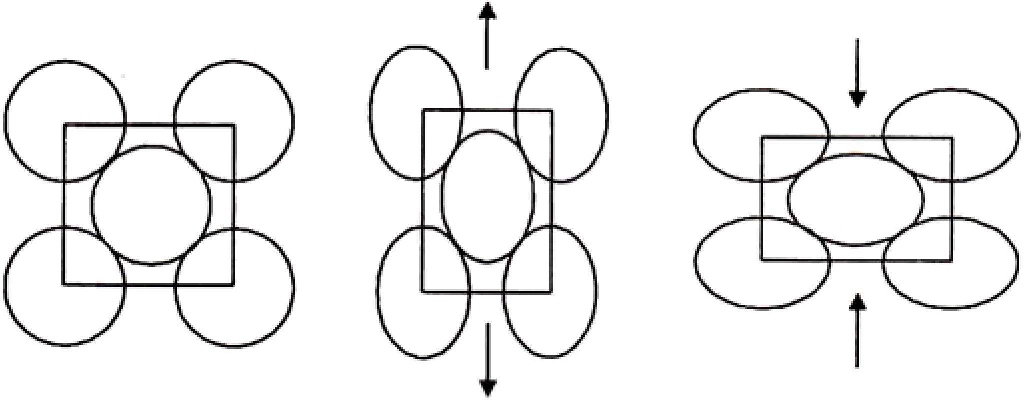
1. Elastic deformation, and
2. Plastic deformation.

1. Elastic Deformation:

Elastic deformation is the deformation which disappears when the load is removed. It precedes (takes place before) plastic deformation. This deformation occurs when a stress is applied on a metal piece.

Figs. 3.1 [(i), (ii), (iii)] shows form of the atoms before loading, after loading in tension and compression respectively. When a tensile load is applied, the piece becomes slightly longer whereas a compressive load shortens the piece.

On removal of load (tensile or compressive) the metal piece or specimen regains its original shape (dimension). Within the elastic range, the strain is result of a slight elongation of the unit cell in the direction of the tensile load, or a slight contraction in the direction of compressive load.



(i) Before loading (ii) Loading in tension (iii) Loading in compression

Fig. 3.1. Elastic deformation.

For elastic deformation, the strain is nearly proportional to stress. The ratio between stress and strain under elastic deformation is known as modulus of elasticity or Young’s modulus (E). It is a characteristic of the type of the metal and its magnitude depends upon the force of attraction between atoms of a metal. Shear stresses are also set up in crystal structures in engineering applications. These produce displacement of one plane of atoms relative to the adjacent plane of atoms. The elastic strain is defined as the tangent of the shear angle. The ratio between shear stress and shear strain is known as shear modulus of rigidity (C).

2. Plastic Deformation:

It is the deformation which persists even after the load is removed. Plastic deformation is observed at stresses exceeding the elastic limit. In contrast of elastic deformation, which depends primarily on stress in the simplest cases, plastic deformation is typically a function of stress, temperature, and the rate of straining.

Plastic deformation is associated with the displacement of the atoms within the grains and causes ultimately permanent changes in shape of the material. Tensile, compressive and torsional stresses can cause plastic deformation.

Plastic deformation process is generally applied in important metallurgical operations of shaping. The operations include rolling of boiler plates, drawing of wire, extrusion of telephone cables, stamping of automobile parts etc.

In metals the plastic deformation generally takes place by the process of “slipping”.

Slip:

Slip is defined as a shear deformation that moves atoms by many interatomic distances in one crystal plane over the atoms of another crystal plane. Fig. 3.2 shows the slip process under a shear load (in a single crystal). Because of plastic deformation, the crystal is divided into layers or slip blocks which are displaced in reference to each other and are separated by thin layers in which a considerable displacement of atoms has taken place.

These intermediate layers with strongly distorted lattices are called “slip planes”. Slip occurs more readily along certain crystal directions and planes than along others. This is shown in Fig. 3.3 where a single crystal HCP metal was deformed plastically.

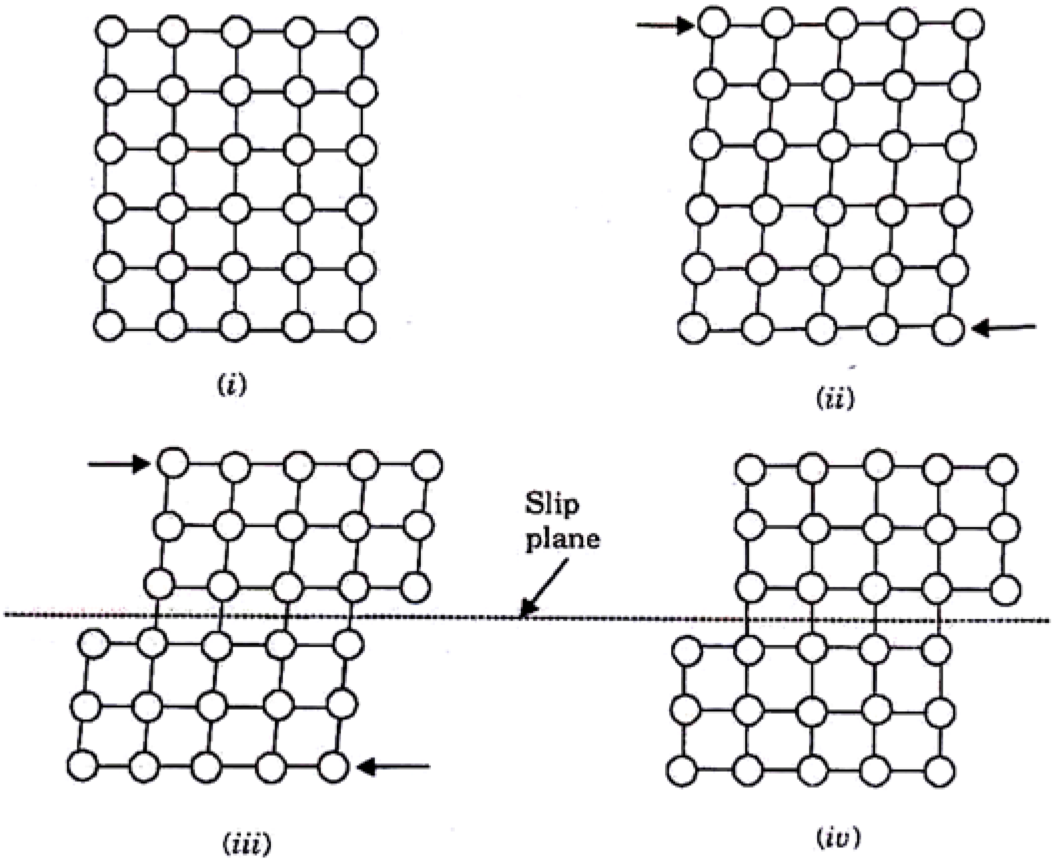


Fig. 3.2. Slip process.

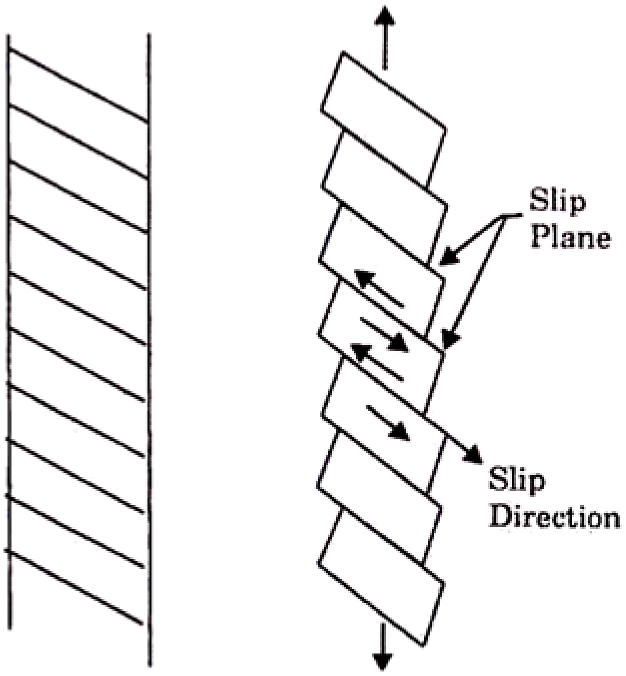


Fig. 3.3.

Critical Resolved Shear Stress

Twinning:

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

Deformation by twinning is most common in HCP metals and its effects on others is to move parts of the grains such that they acquire favourable orientation for the slip to occur. Twinning is produced suddenly and is accompanied with sound. The well-known cry of tin is the result of twinning.

Fig. 3.6 shows the classical atomic picture of twinning. The twinning plane is at right angle to the paper. If a shear stress is applied, the crystal will turn about the twinning plane. The region to the left of the twinning plane is un-deformed. To the right of this plane, the planes of atoms have sheared in such a way as to make the lattice a mirror image across the twin plane.

The mechanism of twinning may thus be described as the simple sliding of one plane of atoms over the next, the extent of movement of each plane being proportional to its distance from the twinning plane. Fig. 3.7 shows the schematic representation of twinning.

In case of slip, the offset is a multiple of interatomic spacing, but in twinning the offset produced by sliding of one plane against its neighbour is a fraction of a unit slip. This causes a difference in the orientation between the twinned and untwined regions in the crystal and on polishing and etching these can be easily differentiated under the microscope.

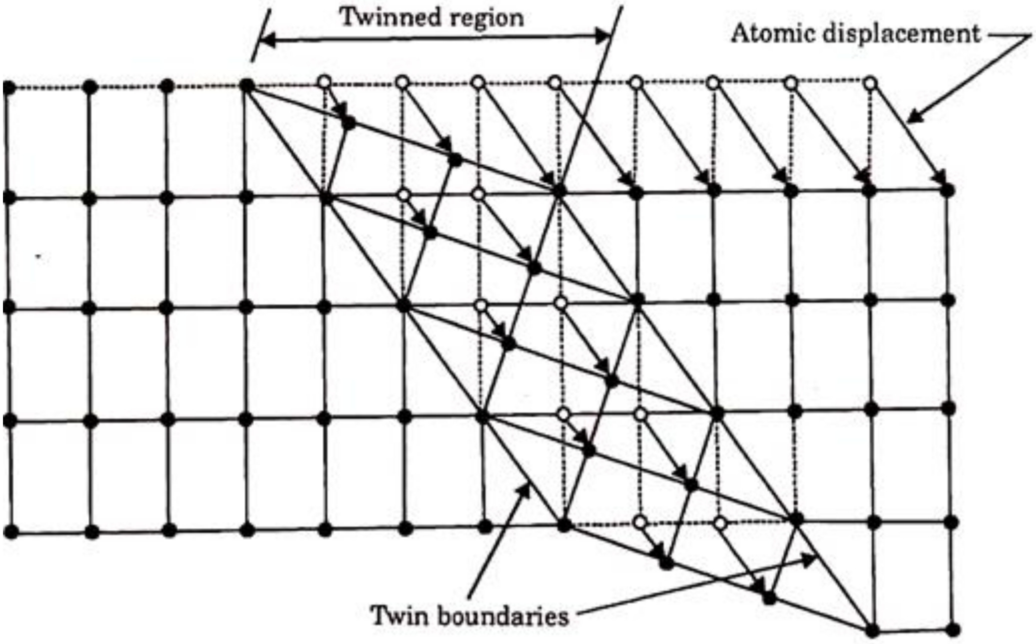


Fig. 3.6. Twinning.

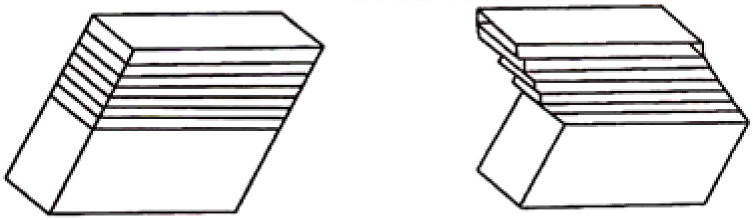


Fig. 3.7. Schematic representation of twinning.

Fracture

It is the separation of an object or material into two or more pieces under the action of stress. The fracture of a solid usually occurs due to the development of certain displacement discontinuity surfaces within the solid. If a displacement develops perpendicular to the surface of displacement, it is called a normal tensile crack or simply a crack; if a displacement develops tangentially to the surface of displacement, it is called a shear crack, slip band, or dislocation.[1]

Brittle fractures occur with no apparent deformation before fracture; ductile fractures occur when visible deformation does occur before separation. Fracture strength or breaking strength is the stress when a specimen fails or fractures.

There are two types of fractures :

Brittle fracture

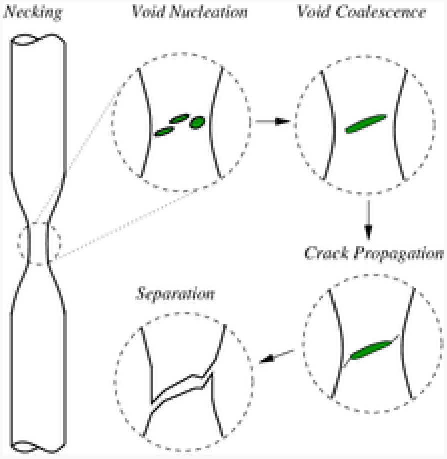
In brittle fracture, no apparent plastic deformation takes place before fracture. Brittle fracture typically involves little energy absorption and occurs at high speeds—up to 2133.6 m/s (7000 ft/s) in steel. In most cases brittle fracture will continue even when loading is discontinued.

In brittle crystalline materials, fracture can occur by cleavage as the result of tensile stress acting normal to crystallographic planes with low bonding (cleavage planes). In amorphous solids, by contrast, the lack of a crystalline structure results in a conchoidal fracture, with cracks proceeding normal to the applied tension.

Ductile fracture

In ductile fracture, extensive plastic deformation (necking) takes place before fracture. The terms rupture or ductile rupture describe the ultimate failure of ductile materials loaded in tension. The extensive plasticity causes the crack to propagate slowly due to the absorption of a large amount of energy before fracture.

Ductile failure of a specimen strained axially



Schematic representation of the steps in ductile fracture (in pure tension)

Fatigue

In materials science, fatigue is the weakening of a material caused by cyclic loading that results in progressive and localised structural damage and the growth of cracks. Once a fatigue crack has initiated, each loading cycle will grow the crack a small amount, typically producing striations on some parts of the fracture surface. The crack will continue to grow until it reaches a critical size, which occurs when the stress intensity factor of the crack exceeds the fracture toughness of the material, producing rapid propagation and typically complete fracture of the structure.

Stages of fatigue

Crack initiation :- The formation of initial cracks preceding fatigue failure is a separate process consisting of four discrete steps in metallic samples. The material will develop cell structures and harden in response to the applied load. This causes the amplitude of the applied stress to increase given the new restraints on strain. These newly formed cell structures will eventually break down with the formation of persistent slip bands (PSBs). Slip in the material is localized at these PSBs, and the exaggerated slip can now serve as a stress concentrator for a crack to form.

Crack growth:- Most of the fatigue life is generally consumed in the crack growth phase. The rate of growth is primarily driven by the range of cyclic loading although additional factors such as mean stress, environment, overloads and underloads can also affect the rate of growth. Crack growth may stop if the loads are small enough to fall below a critical threshold.Fatigue cracks can grow from material or manufacturing defects from as small as 10 μm.

Creep (deformation)

In materials science, creep (sometimes called cold flow) is the tendency of a solid material to move slowly or deform permanently under the influence of persistent mechanical stresses. It can occur as a result of long-term exposure to high levels of stress that are still below the yield strength of the material. Creep is more severe in materials that are subjected to heat for long periods and generally increases as they near their melting point.

The rate of deformation is a function of the material's properties, exposure time, exposure temperature and the applied structural load. Depending on the magnitude of the applied stress and its duration, the deformation may become so large that a component can no longer perform its function — for example creep of a turbine blade will cause the blade to contact the casing, resulting in the failure of the blade. Creep is usually of concern to engineers and metallurgists when evaluating components that operate under high stresses or high temperatures. Creep is a deformation mechanism that may or may not constitute a failure mode. For example, moderate creep in concrete is sometimes welcomed because it relieves tensile stresses that might otherwise lead to cracking.

Introduction of Metal and Alloys :

Metals are generally hard, opaque and shiny materials that exhibit good electrical and thermal conductivity.

An alloy is a mixture or metallic solid solution composed of two or more elements.

History and development of iron and steel :

The history of the modern steel Industry began in the late 1850s; steel has become a staple of the world's industrial economy. This article is intended only to address the business, economic and social dimensions of the industry, since the bulk production of steel began as a result of Henry Bessemer's development of the Bessemer converter, in 1857. Previously, steel was very expensive to produce, and only used in small, expensive items, such as knives, swords and Armor.

In Mesopotamia (Iraq) there is evidence people were smelting Iron around 5000 BC. Artefacts made of smelted Iron have been found dating from about 3000 BC in Egypt and Mesopotamia. ... The origin of the chemical symbol Fe is from the Latin word meaning Iron. The word Iron itself comes from 'iron' in Anglo-Saxon.

Different iron ores :

The Iron minerals that are at present used as ores are hematite, magnetite, limonite, and siderite; also, occasionally ankerite, goethite, and turgid. Hematite is the most important Iron ore.

Raw Material in production of iron and steel :

The three raw materials used in making pig iron (which is the raw material needed to make steel) are the processed iron ore, coke (residue left after heating coal in the absence of air, generally containing up to 90% carbon) and limestone ($caco_3$) or burnt lime (Cao), which are added to the blast furnace at intervals.

Basic Process of iron making and steel making :

Primary steel making involves converting liquid iron from a blast furnace and steel scrap into steel via basic oxygen steel making, or melting scrap steel or direct reduced iron (ORI) in an electric arc furnace

Iron is manufactured in a blast furnace. First, Iron ore is mixed with coke and heated to form an Iron-rich clinker called 'sinter'. Sintering is an important part of the overall process as it reduces waste and provides an efficient raw material for iron making. Coke is produced from carefully selected grades of coal.

Classification of iron and steel :

Steel is graded as a way of classification and is often categorized into four groups- Carbo n, Alloy, Stainless, and Tool. Carbon Steels only contain trace amounts of elements besides carbon and iron. This group is the most common, accounting for 90% of steel production

Iron is categorized as (i) pure Iron, (ii) wrought Iron, (iii) cast Iron, (iv) pig Iron, and (v) direct reduced Iron. These types of Iron are shown in Fig 1. Pure Iron is a term used to describe new Iron produced in an electric arc furnace where temperatures sufficient to melt the Iron can be achieved.

Cast iron:

Cast Iron, an alloy of Iron that contains 2 to 4 percent carbon, along with varying amounts of silicon and manganese and traces of impurities such as sulphur and phosphorus. It is made by reducing iron ore in a blast furnace.

Different types of cast iron:

White cast iron

When the white cast iron is fractured, white coloured cracks are seen throughout because of the presence of carbide impurities. White cast iron is hard but brittle. It has lower silicon content and melting point.

Grey cast iron

Grey is the most versatile and widely used cast iron. The presence of carbon leads to formation graphite flakes that does not allow cracks to pass through, when the material breaks. Instead, as material breaks the graphite initiates numerous new cracks. The fractured cast iron is grey is colour, which also gives it the name. The graphite flakes make the grey cast iron exhibit low resistance. They also lack elasticity and have low tensile strength.

Malleable cast iron

Malleable cast iron is basically white iron that undergoes heat treatment to convert the carbide into graphite. The resultant cast iron has properties that vary from both grey and white cast iron. In malleable cast iron, the graphite structure is formed into irregularly shaped spheroidal particular rather than flakes that are usually present in grey cast iron.

Ductile cast iron

Ductile cast iron is yet another type of ferrous alloy that is used as an engineering material in many applications. To produce ductile iron, small amount of magnesium is added to the molten iron, w alters the graphite structure that is formed.

Uses of cast iron

For making cisterns, water pipes, gas pipes and sewers, manhole covers and sanitary fittings. For making ornamental castings such as brackets, gates, lamp posts, spiral staircases, etc. For making parts of machinery which are not subject to heavy shocks. For manufacturing compression members like column in building’ s, bases of colulllils ,etc.

For preparing agricultural implements.

For preparing rail chairs, carriage wheels.

Steel and Alloy steel

Alloy steel is steel that is alloyed with a variety of elements in total amounts between 1.0% and 50% by weight to improve its mechanical properties.

Alloy steels are broken down into two groups: low alloy steels and high alloy steels. The difference between the two is disputed

Classification of Plain Carbon Steels

The only other elements allowed in plain carbon steel are: manganese (1.65% max), silicon (0.60% max), and copper (0.60 %) Steel with a low carbon content has the same properties as iron, soft but easily formed

Properties and usage of different type of Plain Carbon Steels

Carbon steel or plain-carbon steel, is a metal alloy. It is a combination of two elements, iron and carbon. Other elements are present in quantities too small to affect its properties. The only other elements allowed in plain- carbon steel are: manganese (1.65% max), silicon (0.60% max), and copper (0.60% max).

Steel and cast iron, both Fe - C alloys or compounds, and not just *iron* made the difference to the bronze tools and weapons in use before the iron age. Note, however, that bronze products were used for a long time parallel to steel products.

The industrial revolution in the 19th century has one of its deeper roots in the discovery of how steel could be mass produced; and the car industry, for example, is still perfectly impossible without steel but quite possible without Silicon.

Effect of Various alloys on properties of steel

Steel is a combination of iron and carbon. Steel is alloyed with various elements to improve physical properties and to produce special properties such as resistance to corrosion or heat. Specific effects of the addition of such elements are outlined below:

Carbon (C)

The most important constituent of steel. It raises tensile strength, hardness, and resistance to wear and abrasion. It lowers ductility, toughness and machinability.

Chromium (CR)

Increases tensile strength, hardness, hardenability, toughness, resistance to wear and abrasion, resistance to corrosion, and scaling at elevated temperatures.

Cobalt (CO)

Increases strength and hardness and permits higher quenching temperatures and increases the red hardness of high speed steel. It also intensifies the individual effects of other major elements in more complex steels.

Columbium (CB)

Used as stabilizing elements in stainless steels. Each has a high affinity for carbon and forms carbides, which are uniformly dispersed throughout the steel. Thus, localized precipitation of carbides at grain boundaries is prevented.

Copper (CU)

In significant amounts is detrimental to hot-working steels. Copper negatively affects forge welding, but does not seriously affect arc or oxyacetylene welding. Copper can be detrimental to surface quality. Copper is beneficial to atmospheric corrosion resistance when present in amounts exceeding 0.20%. Weathering steels are sold having greater than 0.20% Copper.

Manganese (MN)

A deoxidizer and degasifier and reacts with sulphur to improve forgeability. It increases tensile strength, hardness, hardenability and resistance to wear. It decreases tendency toward scaling and distortion. It increases the rate of carbon-penetration in carburizing.

Molybdenum (MO)

Increases strength, hardness, hardenability, and toughness, as well as creep resistance and strength at elevated temperatures. It improves machinability and resistance to corrosion and it intensifies the effects of other alloying elements. In hot-work steels and high speed steels, it increases red-hardness properties.

Nickel (NI)

Increases strength and hardness without sacrificing ductility and toughness. It also increases resistance to corrosion and scaling at elevated temperatures when introduced in suitable quantities in high-chromium (stainless) steels.

Phosphorus (P)

Increases strength and hardness and improves machinability. However, it adds marked brittleness or cold-shortness to steel.

Silicon (SI)

A deoxidizer and degasified. It increases tensile and yield strength, hardness, forgeability and magnetic permeability.

Sulphur (S)

Improves machinability in free-cutting steels, but without sufficient manganese it produces brittleness at red heat. It decreases weldability, impact toughness and ductility.

Tantalum (TA)

Used as stabilizing elements in stainless steels. Each has a high affinity for carbon and forms carbides, which are uniformly dispersed throughout the steel. Thus, localized precipitation of carbides at grain boundaries is prevented.

Titanium (TI)

Used as stabilizing elements in stainless steels. Each has a high affinity for carbon and forms carbides, which are uniformly dispersed throughout the steel. Thus, localized precipitation of carbides at grain boundaries is prevented.

Tungsten (W)

Increases strength, wear resistance, hardness and toughness. Tungsten steels have superior hot-working and greater cutting efficiency at elevated temperatures.

Vanadium (V)

Increases strength, hardness, wear resistance and resistance to shock impact. It retards grain growth, permitting higher quenching temperatures. It also enhances the red-hardness properties of high-speed metal cutting tools.

Uses of alloy steels :

High Speed Steel

1. Hand tools, such as chisels, punches, hammers etc.
2. Machine tools for cutting metals.
3. Shears for cutting materials.
4. Dies for deep drawing, extrusion, forging etc.
5. For the manufacturing of drills, milling

Stainless Steel:

Stainless steel is ideal for hygienic environments as it's easily sterilized and resistant to corrosion. It is used in the construction of surgical and dental instruments, kidney dishes and operating tables, as well as other medical equipment such as cannulas,steam sterilizers and MRI scanners.

Spring Steel:

Spring steel is a name given to a wide range of steels used in the manufacture of springs, prominently in automotive and industrial suspension applications. These steels are generally low-alloy manganese, medium-carbon steel or high-carbon steel with a very high yield strength. This allows objects made of spring steel to return to their original shape despite significant deflection or twisting.

Silicon Steel:

Silicon steel is a soft magnetic material that is used in electrical power transformers,motors, and generators. It has a high silicon content of about 3.2 mass %, which increases the electrical resistivity of Iron and,therefore, reduces eddy current losses.

Non Ferrous Materials :

When a metal is defined as non-ferrous it means that it does not have a significant amount of iron in its chemical composition.

Non-ferrous materials are also used in the iron and steel industries for eg : For example, bauxite is used as flux for blast furnaces

Properties and uses of light metals and their alloys :

Aluminium and aluminium alloys are non-ferrous metals that are lightweight and characterized by excellent strength, ductility, and corrosion resistance. Aluminium is a good conductor of heat and electricity and is also used as an alloying element in titanium/steel alloys. Aluminium alloys are also resourceful.

Aluminium is lighter than titanium but not as strong. Aluminium alloys have excellent rigidity and flexibility that increase with decreasing temperature.

Below zero temperature, most of the aluminium alloys display a slight change in properties such as impact strength and tensile strengths. Yield may increase and elongation may slightly decrease. Aluminium alloys do not have a ductile-to-brittle transition.

Uses

Methods to join lightweight materials, predominantly metals, are becoming more and more important in the development of hybrid structures for engineering applications. Suitable joining techniques are required to consistently join these materials.

Forming involves a variety of methods that are used to convert a metal into a usable form. Forming processes consist of bending, extrusion bending, brake bending, roll bending, press drawing, etc.

Properties and uses of white metal and their alloys :

Properties of the white-metal bearing alloys, with the exception of wear resistance, was determined at several temperatures ranging from 20° to 200° C. (68° to 390° F.), since it is in reality the properties at the higher temperatures that play the major part in determining the success or failure of a bearing metal under service conditions. The properties studied at these various temperatures included resistance to impact (Izod test) and to pounding (repeated impact), the strength in compression and Brinell hardness. Resistance to wear was determined only at 20° C. In addition to the laboratory
tests, which included those items above described, service tests were run on a series of crank-shaft bearings, prepared of four compositions, and installed in United States Army class B trucks.

E.g.: Rockwell hardness testing machine equipped with a lo-mm ball under
a 60-kg load. A Richie 10, 000-pound capacity tension-compression
machine was employed for the compression bests. A special strain
gage was designed for measuring the deformation of specimens under
compression at elevated temperatures.

Uses

The white metals are any of several light-coloured alloys used as a base for plated silverware, ornaments or novelties, as well as any of several lead-based or tin-based alloys used for things like bearings, jewellery, miniature figures, fusible plugs, some medals and metal type. The term is also used in the antiques trade for an item suspected of being silver, but not hallmarked.

CHAPTER -(Theory Of Heat Treatment)

INTRODUCTION:

Steel and other alloys have a large number of applications in engineering practice under varying conditions, requiring different properties in them. At one place they may be subjected to bending while at the other to twisting. They may be required to withstand various types of stresses and as tool materials to have hardness, specially red hardness, combined with toughness along with anon-brittle cutting edge.

They may be required to bear static or dynamic loads, revolve at extremely high speeds, operate in highly corrosive media, carry an extremely hard skin with a tough core, subjected to fatigue and creep, etc.Such varying condition of their applications require these materials to possess specific properties of the required order to successfully serve under these conditions. But, a material may lack in some or all of these properties either fully or partially. These deficiencies are fulfilled through the process of heat treatment. Generally all steels can be heat treated as per need. Aluminium is the only non-ferrous metal which can be effectively heat treated.

The process of heat treatment involves heating of solid metals to specified (recrystallization) temperatures holding them at that temperature and then cooling them at suitable rates in order to enable the metals to acquire the desired properties to the required extents. All this take place because of the changes in size, form,nature and the distribution of different constituents in the micro-structure of these metals. All heat treatment processes, therefore, comprise the following three stages of components:

1. Heating the metal to a predefined temperature.

2. Holding it at that temperature for sufficient time so that the structure of the metal becomes uniform throughout.

3. Cooling the metal at a predetermined rate in a suitable media so as to force the metal to acquire a desired internal structure and thus, obtain the desired properties to the required extent. All this takes place because of the changes in size,form, nature and the distribution of different constituents in the micro-structure of these metals.

Purpose of Heat Treatment

Metals and alloys are heat treated in order to achieve one or more of the following objectives:

1. To relieve internal stresses set up during other operations like casting, welding, hot and cold working, etc.

2. To improve mechanical properties like hardness,toughness, strength, ductility, etc.

3. To improve machinability

4. To change the internal structure to improve their resistance to heat, wear and corrosion.

5. To effect a change in their grain size.

6. To soften them to make suitable for operations like cold rolling and wire drawing.

7. To improve their electrical and magnetic properties.

8. To make their structure homogenous so as to remove coring and segregation.

9. To drive out trapped gases.

In order to understand the complete mechanism of heat treatment it is essential to know the internal structure, phase transformation, etc. fully. However, a brief review is given:

6.3 Classification of Heat Treatment Processes

Various heat treatment processes can be classified as follows:

1. Annealing.
2. Normalizing.
3. Hardening.
4. Tempering.
5. Case hardening.
6. Surface hardening.
7. Diffusion coating.

6.3.1 Annealing

Annealing is indeed one of the most important heat treatment processes. The internal structure of the metal gets stabilized through this process. This heat treatment is given to the metal so as to achieve one on more of the following objectives:

1. To refine the grains and provide homogenous structure.
2. To relieve internal stresses set up during earlier operations.
3. To soften the metal and, thus, improve its machinability.
4. To effect changes in some mechanical,electrical and magnetic properties.
5. To prepare steel for further treatment or processing.
6. To drive out gases trapped during casting.
7. To produce desired macro structure.

Different type of annealing processes can be classified as follows:

1. Full annealing.
2. Process annealing.
3. Spheroidise annealing.
4. Diffusion annealing.
5. Isothermal annealing.

1. Full annealing

The main objectives of this type of annealing are to soften the metal, relieve its stresses and refine its grain structure. It is also known as high temperature annealing. In this process complete phase recrystallisation takes place and,therefore, all imperfections of the previous structure are wiped out. This involves heating of steel to a temperature about 30^o to 50^oabove the higher critical point for hypoeutectoid steels, and by the same amount above the lower critical point for hyperuectoid steels, holding it at that temperature for sufficient time to allow the internal changes to take place and then cooling slowly. The steel gets softened by this process,together with an appreciable amount of increase in its ductility and toughness.

Annealing temperatures for carbon steels

Cooling is done by allowing approximately 3 to 4 minutes time at elevated temperatures per mm thickness of the largest section. High temperature cooling is usually done in the furnace itself by lowering of temperature at the rate of 10 to 30^o C below the lower critical temperature. The specimen is then air cooled down to the room temperature. This process makes a course pear litic structure which is quite soft and ductile. An alternate method of cooling after soaking is to embed the metal in a non-conducting material like sand, lime, mica, ash, etc.

2. Process annealing

The purpose of process annealing is to remove the ill effects of cold working and often the metal so that its ductility is restored and it can be again plastically deformed or put to service without any danger of its failure due to fracture. It is also known a slow temperature annealing or sub-critical annealing or commercial annealing.The process is extremely useful for mild steels and low carbon steels and is cheaper and quicker than full annealing. Also, less scale is produced during this process. The main out put of this process is increased ductility and plasticity, improved shock resistance, reduced hardness, improved machinability and removal of internal stresses. During cold working operations like cold-rolling, wire drawing, a metal gets severely strain-hardened .

3. Spheroidise annealing

The main purpose of spheroidise annealing is to produce a structure of steel which consists of globules or well dispersed spheroids of cementite in ferrite matrix. Following are the main methods through which the above objective can be obtained:

1. High carbon steels: Heating the steel to a temperature slightly above the lower critical point (say between 730°C to 770°C,depending upon the carbon percentage), holding it at that temperature for sufficient time and than cooling it in the furnace to a temperature 600°Cto 550°C, followed by slowly cooling it down to room temperature instill air.
2. Tool steels and high-alloy steels: Heating to a temperature of 750°C to 800°C, or even higher, holding at that temperature for several hours and then cooling slowly.

4. Diffusion annealing

The purpose of diffusion annealing is to remove the heterogeneity in the chemical composition of steel ingots and heavy castings This process is mainly used before applying full annealing to steel castings. In this process , the metal is heated to a temperature between 1100°C to 1200°C,where diffusion occurs and grains are homogenized. The metal piece being treated is held at the diffusion temperature for a short time to allow complete diffusion and than cooled down to between 800°C to 850°C by keeping it inside the shut off furnace for a period of about 6 to 8 hours. Then it is removed from the furnace and cooled in air down to the room temperature. Then full annealing is performed.

5. Isothermal annealing

The isothermal annealing consists of heating steel to austenite state and then cooling it down to a temperature of about 630^{o}C to 680^{o}Cat a relatively faster rate. It is followed by holding it at this constant temperature (i.e isothermal) for some time and then cooling it down to the room temperature at a rapid rate. During the isothermal holding full decomposition to pearlite structure takes place and that is why the process is known as isothermal annealing. Because of the two rapid coolings the total annealing time is considerably reduced.

2 Normalizing

The normalizing process is similar to annealing in sequence but vary in the heating temperature range, holding time and the rate of cooling. Heating temperature of steel is 40^{o}C to 50^{o}Cabove the higher critical point, held at that temperature for a relatively very short period of time (about 15 min.) and then cooled down to room temperature in still air. This heat treatment is commonly used as the final heat treatment for such articles which are supposed to be subjected to higher stress during operation. Due to this treatment internal stress caused during previous operations are removed, internal structure is refined to fine grains and mechanical properties of steel are improved. This process also improves the impact strength, yield point and ultimate tensile strength of steels. As compared to the annealed steels of the same composition the normalized steels will be less ductile but stronger and harder. For improvement of the mechanical properties normalizing process should be preferred and to attain better machinability, softening and greater removal of internal stress annealing process should be employed.

3 Hardening

This process is widely applied to all cutting tools, all machine parts made from alloy steels, dies and some selected machine parts subjected to heavy duty work. In hardening process steel is heated to a temperature within the hardening range, which is 30°C to 50°C above the higher critical point for hypoeutectoid steels and by the same amount above the lower critical point for hypoeutectoid steels, holding it at that temperature for sufficient time to allow it to attain austenitic structure and cooled rapidly by quenching in a suitable medium like water, oil or salt both.

In the process of hardening the steel is developed in such controlled conditions,by rapid quenching, that the transformation is disallowed at the lower critical point and by doing so we force the change to take place at a much lower temperature. By rapid cooling the time allowed to the metal is too short and hence transformation is not able to occur at the lower critical temperature.

4 Tempering

A hardened steel piece, due to martensitic structure, is extremely hard and brittle, due to which it is found unsuitable for most practical purposes. So a subsequent treatment is required to

obtain a desired degree of toughness at the cost of some strength and hardness to make it suitable for use. It is especially true in case of the tools. This is exactly what is mainly aimed at through tempering of steel. This process enables transformation of some martensite into ferrite and cementite. The exact amount of martensite transformed into ferrite plus cementite will depend upon the temperature to which the metal is reheated and the time allowed for the transformation.

The process involves reheating the hardened steel to a temperature below the lower critical temperature, holding it at that temperature for sufficient time and then cooling it slowly down to the room temperature.

IRON-CARBON DIAGRAM

The iron-carbon diagram (also called the iron-carbon phase or equilibrium diagram) is a graphic representation of the respective microstructure states depending on temperature (y axis) and carbon content (x axis)

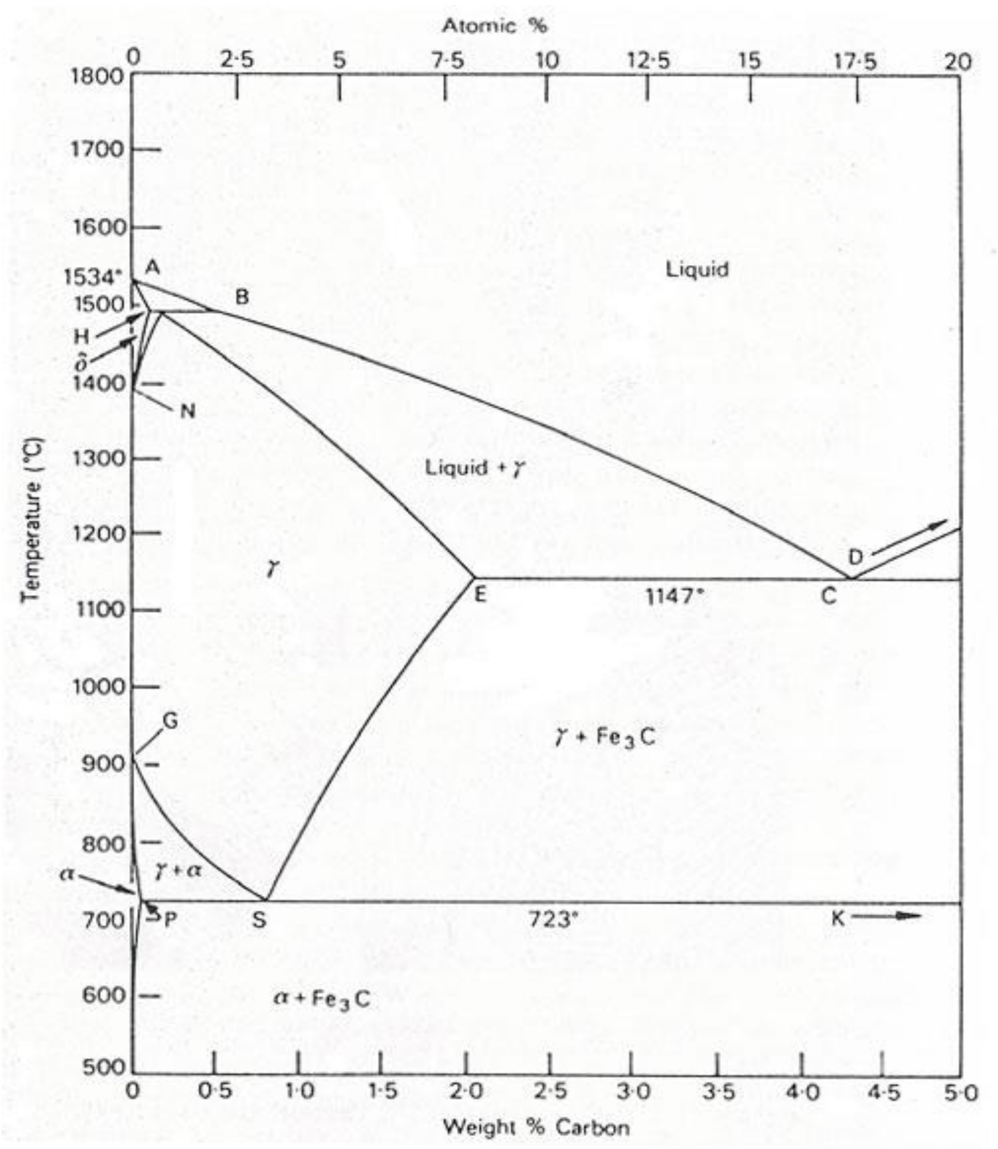


Fig. 1. The iron-carbon diagram.

Carbon is the most important alloying element in iron which significantly affects the allotropy, structure and properties of iron. The study of Fe-C system is thus, important, more so as it

forms the basis of commercial steels and cast irons, and many of the basic features of this system influence the behaviour of even the most complex alloy steels. Steels may have incidental elements, or intentionally added alloying elements, which modify this diagram, but if modifications are interpreted cautiously, then this diagram acts as a guide.

The ability to interpret this diagram is important for proper appreciation of phase changes. Fe-C diagram actually provides a valuable foundation on which to build knowledge of large variety of both plain carbon and alloy steels.

Conventionally, the complete Fe-C diagram should extend from 100% Fe to 100% carbon, but it is normally studied up to around 6.67% carbon as is also illustrated because iron alloys of practical industrial importance contain not more than 5% carbon. Thus, this diagram is only just a part of the complete Fe-C equilibrium diagram.

Ferrite Phase

Ferrite is an interstitial solid solution of carbon in alpha iron and thus, is BCC in structure. It derives its name from Latin word ‘ferrum’ meaning iron. The maximum solubility of carbon in ferrite is 0.02% at 727C (point T in Fig. 1.22), which decreases with the fall of temperature to negligible amount at 0°C (< 0.00005% at 20°C). It is soft and ductile phase.

Austenite:-

It is an interstitial solid solution of carbon in gamma-iron and has FCC structure. It derives its name from ‘Sir Austen’. The maximum solubility of carbon in austenite is 2.11% at 1147°C. which decreases to 0.77% carbon at 727°C. Austenite is soft, ductile tough and malleable (FCC structure) and non-magnetic (paramagnetic). Steels are commonly rolled and forged above about 1100°C when they are in austenitic state due to its high ductility and malleability, which is also due to its FCC structure.

Cementite :-

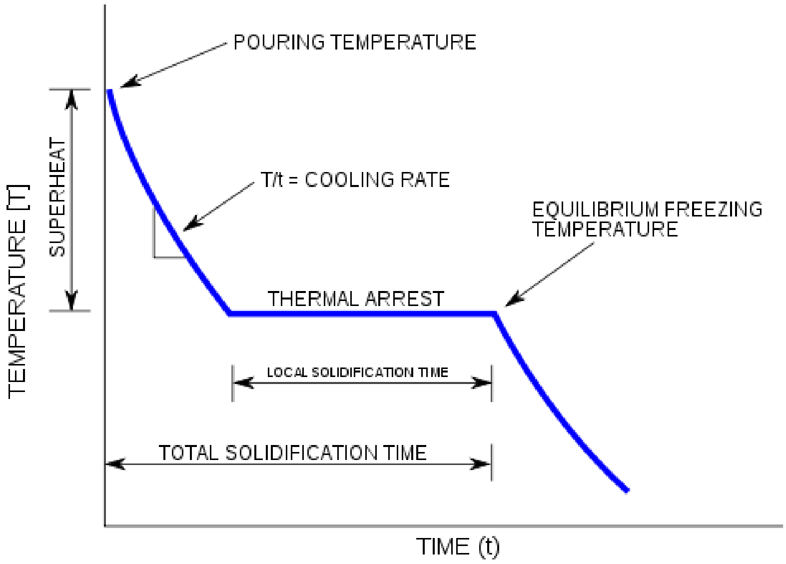
It is an interstitial intermediate compound having a fixed carbon content of 6.67%. It has a complex orthorhombic crystal structure with 12 iron atoms and 4 carbon atoms per unit cell. It is a compound with high hardness (~ 800 VPN), which easily scratches the glass. It is brittle phase with low tensile strength and high compressive strength. °C.

Martensite :-

It is not shown in the equilibrium phase diagram of the iron-carbon system because it is not an equilibrium phase. Equilibrium phases form by slow cooling rates that allow sufficient time for diffusion, whereas martensite is usually formed by very high cooling rates.

COOLING CURVE

A cooling curve is a line graph that represents the change of phase of matter, typically from a gas to a solid or a liquid to a solid. The independent variable (X-axis) is time and the dependent variable (Y-axis) is temperature.[1] Below is an example of a cooling curve used in castings.



The initial point of the graph is the starting temperature of the matter, here noted as the "pouring temperature". When the phase change occurs there is a "thermal arrest", that is the temperature stays constant. This is because the matter has more internal energy as a liquid or gas than in the state that it is cooling to. The amount of energy required for a phase change is known as latent heat. The "cooling rate" is the slope of the cooling curve at any point.

Heat treatment furnace

The most common heat treatments performed in furnaces are annealing, normalizing, hardening, tempering, spheroidizing, carburizing, and stress relieving. Heat treating furnaces seldom are designed for temperatures in excess of 1400 °C (2550 °F) and generally are operated in the 205 to 1095 °C (400 to 2000 °F) range.

FURNACE TYPES

1. Box-Type Batch Furnace:

The simplest of the box-type has an opening (door) at one face just as in a box, and that is why it is named so. The furnace chamber is commonly rectangular in section. It is used for small and medium sized parts. Generally, loading and unloading (after the heat treatment) is done manually through this door. For heavy components, a zig-crane, or an overhead crane may be used.

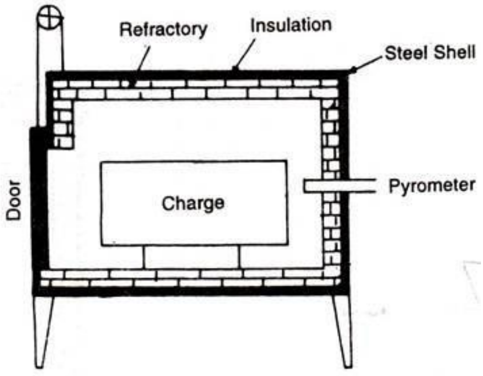


Fig. 10.1. Box-type furnace.

Box-type furnaces are quite flexible, and can be used for annealing, pack-carburising, and hardening of low alloy steels. The furnace should be used to its full capacity to drive the maximum advantages.

Though such furnaces can be heated by a fuel, but commonly electric resistance heating is done. The resistance wire in the form of coil is placed inside the refractory (high alumina) grooves. A thermocouple fitted through the rear wall of the chamber is connected to a pyrometer to automatically control the temperature.

2. Bogie-Hearth Furnace:

It is a modified version of box-type batch furnace having a movable hearth mounted on wheels. This car-type hearth is moved out to load and unload (after the heat treatment) the charge. The car hearth with the loaded charge is put inside the furnace and then sealed with granular sand sealing troughs, or solid seals. Such furnaces are normally non-atmospheric controlled. The heating may be done by a fuel, or by electric resistance heating elements. It is also possible to use a programmed cycle here.

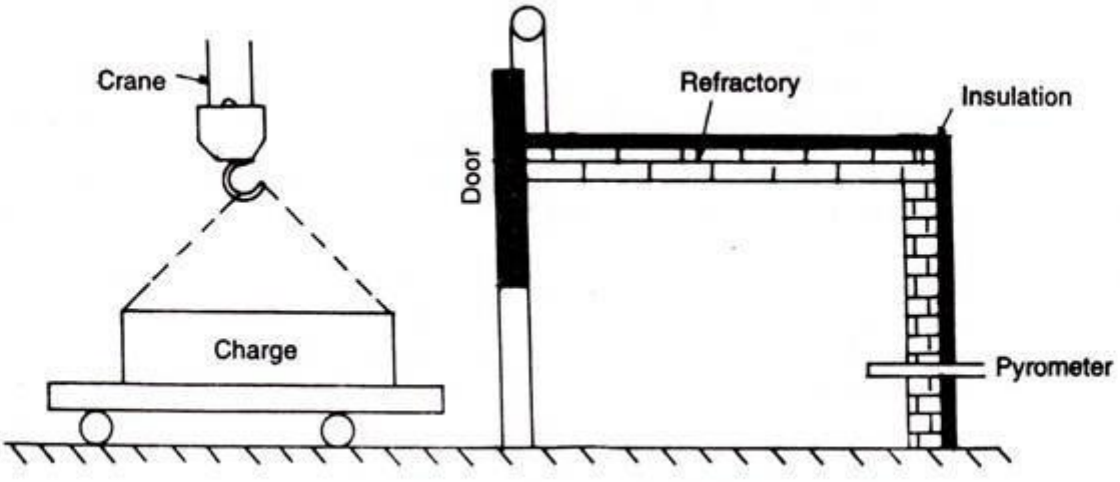


Fig. 10.2. Bogie-hearth (car bottom) furnace.

Normally bogie-hearth furnaces are used in temperature range of 540°C to 1100°C such as for stress- relieving, annealing, hardening of components. It is commonly used for heat treating bulky and heavy components although it can also be used for small components.

3. Muffle Furnace:

A muffle is a hollow cuboid or cylindrical retort made of special refractory material, or non-scaling steel. A furnace, in which the heat source does not directly make contact with the material being heat-treated, is described as a muffle furnace. The components are charged in a muffle, and gas firing, or electrical energy can be used to heat the muffle from outside.

The gas is burnt outside the muffle, and the heating is effected by the hot gases which are made to circulate through the ring like space between the interior-wall and the exterior-muffle wall.

The products of combustion of the gas do not enter the heating chamber (the muffle), and thus, the atmosphere of the furnace can be controlled, and thus, scaling of the components can be prevented. Also, such a furnace gives reasonable uniformity of temperature distribution. Fig. 10.2 illustrates such a furnace schematically. Gas carburising of small parts such as parts of

cycle-chain is carried out in a non-scaling steel retort (muffle) revolving around the horizontal axis.

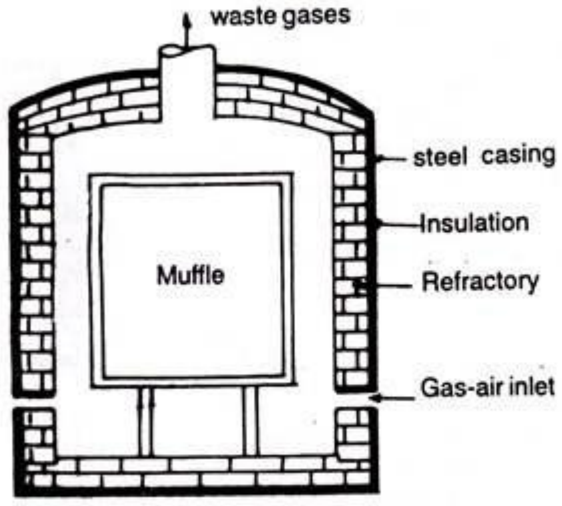


Fig. 10.2. Gas-fired muffle furnace.

Commonly, electrically heated muffle furnaces are extensively used for the heat treatment of small sized components. Fig. 10.3 illustrates heating element like nichrome or kanthal wire wound around the muffle, or are placed in the ring-like space to heat the muffle with its contents. For high temperatures, electric muffle is heated by glow bars, or radiant elements, where the steel gets heated by direct radiations. Muffle furnaces are used for bright annealing, nitriding, carburising, bright hardening

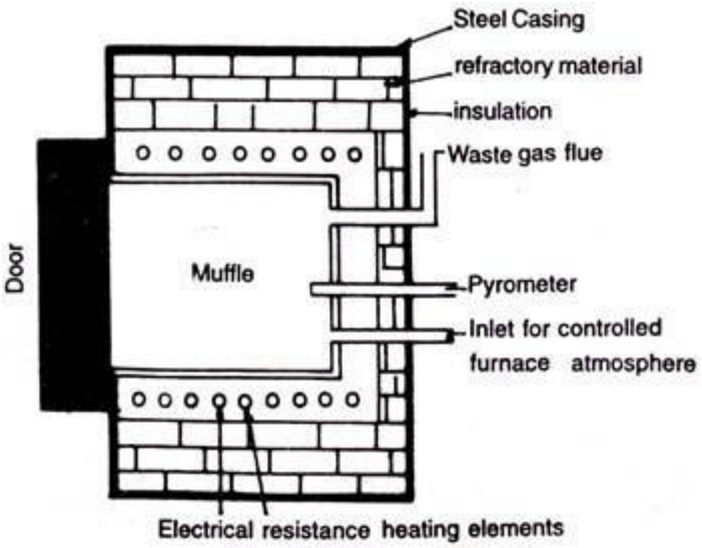


Fig. 10.3. Electric muffle furnace.

There are two main types of muffle batch-type furnaces, depending on the design. A horizontal type is illustrated in figures 10.2 and 10.3. The second type is a vertical muffle pit furnace.

4. Pit Furnace (Vertical Furnace):

A pit furnace consists of the furnace placed in a pit. The furnace extends to the shop-floor level or slightly above it. It has a cover or lid put on top of the furnace. The long and slender parts such as tubes, spindles, shafts, rods, etc. are suspended from suitable fixtures from top, or may be supported from the lower end to remain in vertical position. Heating in such a manner reduces distortion and warpage.

The components can be put on the bottom hearth of the furnaces for heating or held in a basket inside the furnace (Fig. 10.4). The non-scaling steel retort can help high degree of control of atmosphere. Fans promote both uniformity of temperature as well as gas composition. Fig. 10.4 furnace is used for gas carburising or other case-hardening treatments.

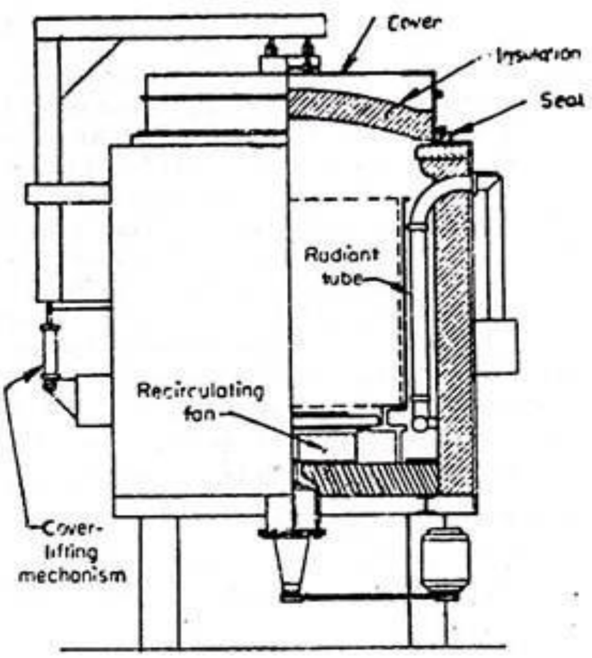


Fig. Muffle pit furnace

A Pit furnace may not have a muffle. Pit furnaces are particularly suited for parts to be cooled in the furnace. Direct quenching particularly with large charge and in a large furnace is not feasible. Not only that the temperature may fall during opening of lid, the brief exposure to atmosphere results in the formation of adhering black scale.

5. Bell Furnaces:

Bell furnaces have removable covers, called ‘bells’. The charge is put on a hearth, and on top of it is put a retort (Fig.), which is sealed at the bottom with sand, etc.

The supply of the protective gas is constantly given to inside of this scaled retort for continuous protection.

An outer ‘bell’-shaped container having the heating elements fitted on inner wall is lowered to cover such an assembly as being done in Fig. and finally looks like as in Fig. The heating of the charge is done in controlled protective gas atmosphere for the required length of the time.

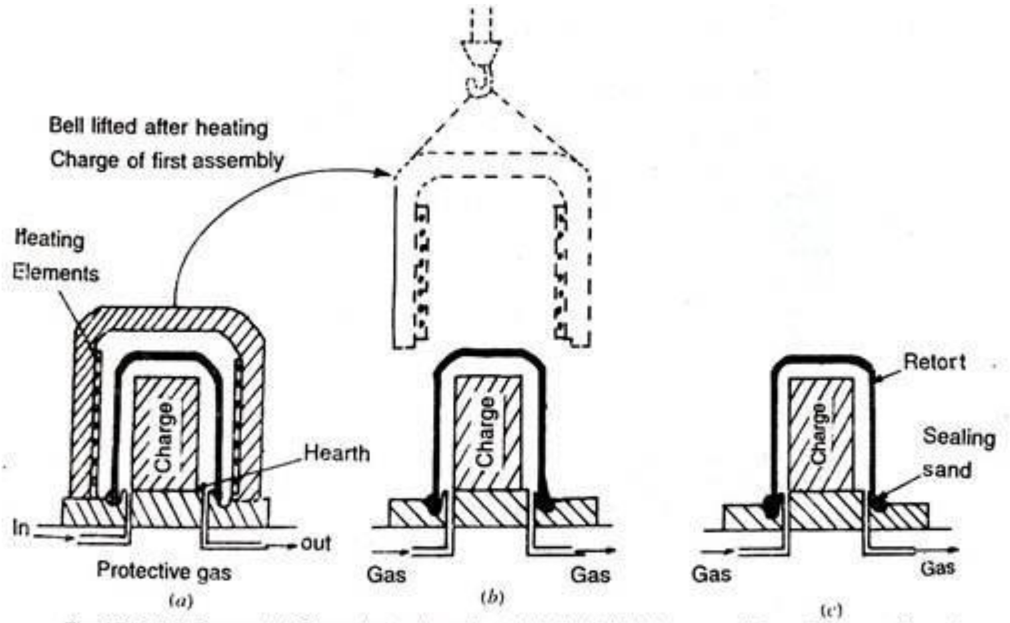


Fig. 10.5. Bell Furnace (a) Charge being heated by the bell. (b) Bell in removed from first assembly and being put on second assembly. (c) Third assembly ready.

After heating the first charge, the bell is taken off and is put on another assembly and the heating is then done of the second assembly for the required time. Meanwhile, the first assembly and its charge cools under the protective atmosphere as the gas is constantly being fed in and out of the sealed retort.

The hearth could be rectangular, or circular. One bell can take care of several retort assemblies. Fans may be provided inside the hearth assembly for rapid heating and uniformity of temperature.

Temperature could be controlled by having thermocouples, automatic temperature controllers. As the heating bell shifts after completion of heating of one assembly to another, it leads to economic heating procedure as the heating bell is not continuously cooled and reheated. This procedure needs more floor space and overhead cranes, etc.

Bell furnace is used for bright annealing, nitriding, bright normalising, ion-nitriding stress relieving, etc

6. Salt Bath Furnaces:

Molten salt bath furnace essentially consists of an oval or rectangular container made of steel, cast iron, or a refractory pot which holds the molten salts. The pol is heated to and maintained at the required heat treating temperature either by the combustion of a fuel (fuel oil, or gas), or by electrical resistors.

Electrically heated salt bath furnaces are much more common in use, now-a-days. Refractory pots are preferred for use with the neutral salts (free from cyanides or carbonates). Steel or cast ire ns are suitable for other salts used for cyaniding, or liquid carburising, etc.

The mode of heat transfer to the charge is mainly by convection through the liquid bath. As the molten salt bath comes in best intimate contact with the charge, the heat transfer to the charge is very quick. Moreover, the molten salts possess high heat capacity resulting further in very fast heating up of the charge as compared to air furnaces (around five times). Thus, the heat treatment time is drastically reduced resulting in good economy.

Advantages of Salt Bath Furnaces:

Some of the advantages of salt bath furnaces are:

1. Because of better temperature control, all the components at a time are healed to the same uniform heat treatment temperature, resulting in highly reproducible properties.

2. There is no danger of oxidation and decarburization.

3. As the heating rate is high, heat treatment time is reduced.

4. Selective heat treatment can be done by immersing only the desired section of the components in the molten salt bath.

5. Different shapes, sizes of variable section thicknesses of light and heavy parts can be given heat treatment simultaneously with different heal treatment times at the same heat treatment temperature.

6. Desired furnace atmosphere can be obtained by properly selecting the salt mixture.

7. Initial cost of installation of such a furnace is very low.

Disadvantages of Salt Bath Furnaces:

1. High cost of pots which are to be replaced periodically.

2. Replacement of pots is quite time and labour oriented problem.

3. Pollution problems about fumes, but more critical the disposal of spent salts.

4. A large number of salt mixtures have cyanide as an important gradient. All necessary precautions have to be taken while using such salts. Proper ventilation, fume hoods, separates gloves, tongs etc. are required. Even otherwise too these salts are hazardous lo labour working there.

5. A steel hardened in cyanide bath should not be tempered in a salt bath without completely removing any sticking salt otherwise violent explosion can occur

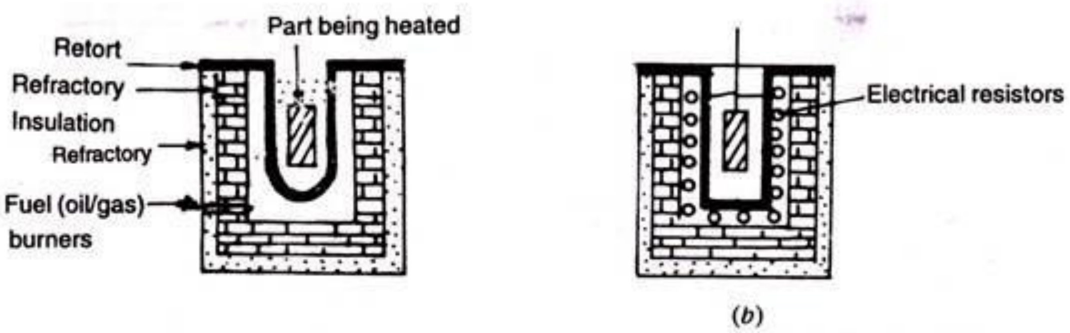


Fig. 10.6. Externally heated Salt bath furnaces. (a) Fuel-fired furnace. (b) Electrical resistance furnace

In the immersion heating element type salt bath furnaces, the heating element is immersed in the salt and remains there for heating, maintaining the temperature and even after shut down of the furnaces.

Immersed Electrode Type Salt Bath Furnace:

The most commonly used industrial salt bath furnace is the immersed electrode type furnace. It has molten salt bath with immersed electrodes to supply the power. The electrodes normally are of mild steels, or of steel having 28% chromium and 2% nickel. Electrodes are flats with square or rectangular cross section as the opposing surfaces of such electrodes cause better concentration of magnetic flux than a round surface.

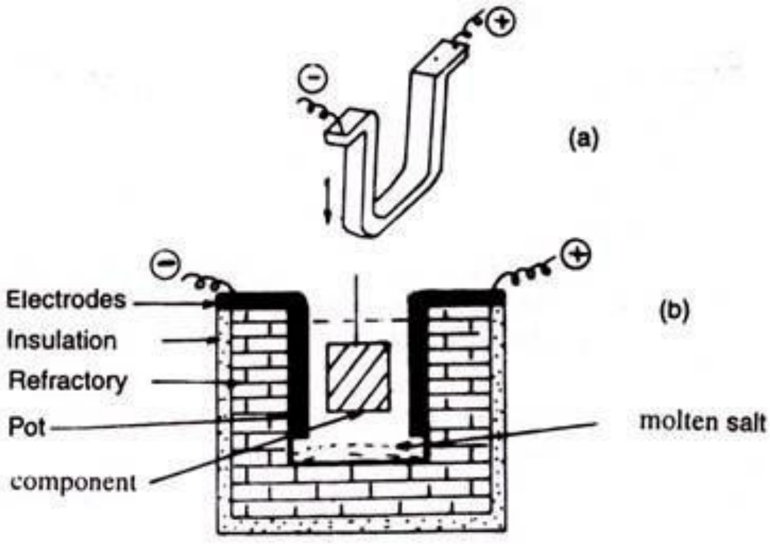


Fig. 10.7. Immersed electrode salt bath furnace

The electrodes are connected to the secondary of the transformer to power the furnace. As the molten salts have electrical resistance, the heat is generated within the salt bath when the current is passed through the electrodes.

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E-NOTES, SUBJECT: MATERIALS AND METALLURGY, COURSE: DIPLOMA
MECHANICAL ENGINEERING, SEM- 4TH
(PREPARED BY: MR. GOVIND, ASSISTANT PROFESSOR .MED)

CHAPTER -(Plastic)

Introduction

The word, plastic, was derived from the word *'Plastikos'* meaning *'to mould'* in Greek. Fossil fuels have compounds containing hydrogen and carbon (hydrocarbon) which act as building blocks for long polymer molecules. These building blocks are known as monomers, they link together to form long carbon chains called polymers.

Plastic is defined as a material that contains as an essential ingredient an organic substance of large molecular weight. It is also defined as polymers of long carbon chains.

Plastic is material consisting of any of a wide range of synthetic or semi-synthetic organic compounds that are malleable and so can be molded into solid objects.

Plasticity is the general property of all materials which can deform irreversibly without breaking but, in the class of moldable polymers, this occurs to such a degree that their actual name derives from this specific ability.

Plastics are typically organic polymers of high molecular mass and often contain other substances. They are usually synthetic, most commonly derived from petrochemicals, however, an array of variants are made from renewable materials such as polylactic acid from corn or cellulosics from cotton linters.[1]

Due to their low cost, ease of manufacture, versatility, and imperviousness to water, plastics are used in a multitude of products of different scale, including paper clips and spacecraft. They have prevailed over traditional materials, such as wood, stone, horn and bone, leather, metal, glass, and ceramic, in some products previously left to natural materials.

Various Sources of Plastics

- The main source of synthetic plastics is crude oil.
- Coal and natural gas are also used to produce plastics.
- Petrol, paraffin, lubricating oils and high petroleum gases are bi-products, produced during the refining of crude oil.

- These gases are broken down into monomers. Monomers are chemical substances consisting of a single molecule.
- A process called Polymerisation occurs when thousands of monomers are linked together. The compounds formed as called polymers.
- Combining the element carbon with one or more other elements such as oxygen, hydrogen, chlorine, fluorine and nitrogen makes most polymers.

Types of Plastics :-

Depending on physical properties, plastics are divided into two types: Thermoplastic and thermosetting.

1. Thermoplastic: Plastics that can be deformed easily upon heating and can be bent easily. Linear polymers and a combination of linear and cross-linked polymers come under thermoplastics. Example: PVC, nylon, polythene, etc.

   Examples of thermoplastic materials are polyethylene, polypropylene, polyvinyl chloride, polystyrene, polyamides, polyesters, and polyurethanes. High-temperature thermoplastics include polyetherether ketones, liquid crystalline polymers, polysulfones, and polyphenylene sulfide.

2. Thermosetting: Plastics that cannot be softened again by heating once they are molded. Heavily cross-linked polymers come under the category of thermosetting plastics. Example: Bakelite, melamine, etc. Bakelite is used for making electrical switches whereas melamine is used for floor tiles.

The main thermosetting plastics are epoxy resin, melamine formaldehyde, polyester resin and urea formaldehyde. Good electrical insulator, hard, brittle unless reinforced, resists chemicals well. Used for casting and encapsulation, adhesives, bonding of other materials.

Recycling of Plastic

- Recycling of plastic is very important. If they are not recycled at the proper time, then they get mixed with other chemicals or materials and hence become more difficult to recycle and become a source of pollution.
- They are non-biodegradable and they do not get decomposed by the microbial action.
- To avoid this, it is important to use biopolymers or biodegradable polymers.

Properties of Plastic

- Strong and ductile
- Poor conductors of heat and electricity
- Easily molded into different shape and size
- Resist corrosion and are resistant to many chemicals.

Representative polymers

Molded plastic food replicas on display outside a restaurant in Japan.

Plastic piping and firestops being installed in Ontario. Certain plastic pipes can be used in some non-combustible buildings, provided they are firestopped properly and that the flame spread ratings comply with the local building code.

Bakelite

The first plastic based on a synthetic polymer was made from phenol and formaldehyde, with the first viable and cheap synthesis methods invented in 1907, by Leo Hendrik Baekeland, a Belgian-born American living in New York state. Baekeland was looking for an insulating shellac to coat wires in electric motors and generators. He found that combining phenol (C_6H_5OH) and formaldehyde ($HCOH$) formed a sticky mass and later found that the material could be mixed with wood flour, asbestos, or slate dust to create strong and fire resistant "composite" materials. Bakelite was originally used for electrical and mechanical parts, coming into widespread use in consumer goods and jewelry in the 1920s. Bakelite was a purely synthetic material, not derived from living matter. It was also an early thermosetting plastic.

Polystyrene and PVC

Styrene polymerization

Plasticised polystyrene is a rigid, brittle, inexpensive plastic that has been used to make plastic model kits and similar knick-knacks. It also is the basis for some of the most popular "foamed" plastics, under the name *styrene foam* or *Styrofoam*. Like most other foam plastics, foamed polystyrene can be manufactured in an "open cell" form, in which the foam bubbles are interconnected, as in an absorbent sponge, and "closed cell", in which all the bubbles are distinct, like tiny balloons, as in gas-filled foam insulation and flotation devices. In the late 1950s, *high impact* styrene was introduced, which was not brittle. It finds much current use as the substance of toy figurines and novelties.

Polyvinyl chloride

Vinylchloride polymerization

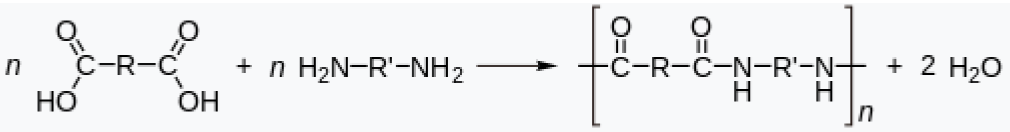
Polyvinyl chloride (PVC, commonly called "vinyl") incorporates chlorine atoms. The C-Cl bonds in the backbone are hydrophobic and resist oxidation (and burning). PVC is stiff, strong, heat and weather resistant, properties that recommend its use in devices for plumbing, gutters, house siding, enclosures for computers and other electronics gear. PVC can also be softened with chemical processing, and in this form it is now used for shrink-wrap, food packaging, and rain gear.

All PVC polymers are degraded by heat and light. When this happens, hydrogen chloride is released into the atmosphere and oxidation of the compound occurs. Because hydrogen chloride readily combines with water vapor in the air to form hydrochloric acid, polyvinyl chloride is not recommended for long-term archival storage of silver, photographic film or paper (mylar is preferable).

Nylon

The plastics industry was revolutionized in the 1930s with the announcement of polyamide (PA), far better known by its trade name nylon. Nylon was the first purely synthetic fiber, introduced by DuPont Corporation at the 1939 World's Fair in New York City.

His work led to the discovery of synthetic nylon fiber, which was very strong but also very flexible. The first application was for bristles for toothbrushes. However, Du Pont's real target was silk, particularly silk stockings. Carothers and his team synthesized a number of different polyamides including polyamide 6.6 and 4.6, as well as polyesters.



General condensation polymerization reaction for nylon

Nylon mania came to an abrupt stop at the end of 1941 when the US entered World War II. The production capacity that had been built up to produce nylon stockings, or just *nylons*, for American women was taken over to manufacture vast numbers of parachutes for fliers and paratroopers. After the war ended, DuPont went back to selling nylon to the public, engaging in another promotional campaign in 1946 that resulted in an even bigger craze, triggering the so-called nylon riots.

Nylons still remain important plastics, and not just for use in fabrics. In its bulk form it is very wear resistant, particularly if oil-impregnated, and so is used to build gears, plain bearings, valve seats, seals and because of good heat-resistance, increasingly for under-the-hood applications in cars, and other mechanical parts.

Poly(methyl methacrylate)

Poly(methyl methacrylate) (PMMA), also known as acrylic or acrylic glass as well as by the trade names Plexiglas, Acrylite, Lucite, and Perspex among several others (see below), is a transparent thermoplastic often used in sheet form as a lightweight or shatter-resistant alternative to glass. The same material can be utilised as a casting resin, in inks and coatings, and has many other uses.

Rubber

Natural rubber

Natural rubber is an elastomer (an elastic hydrocarbon polymer) that originally was derived from *latex*, a milky colloidal suspension found in specialised vessels in some plants. It is useful directly in this form (indeed, the first appearance of rubber in Europe was cloth waterproofed with unvulcanized latex from Brazil).

However, in 1839, Charles Goodyear invented vulcanized rubber; a form of natural rubber heated with sulfur (and a few other chemicals), forming cross-links between polymer chains (vulcanization), improving elasticity and durability.

Synthetic rubber

The first fully synthetic rubber was synthesized by Sergei Lebedev in 1910. In World War II, supply blockades of natural rubber from South East Asia caused a boom in development of synthetic rubber, notably styrene-butadiene rubber. In 1941, annual production of synthetic rubber in the U.S. was only 231 tonnes which increased to 840,000 tonnes in 1945. In the space race and nuclear arms race, Caltech researchers experimented with using synthetic rubbers for solid fuel for rockets. Ultimately, all large military rockets and missiles would use synthetic rubber based solid fuels, and they would also play a significant part in the civilian space effort.

Plastic coating

A plastic coating gives metals a thick, wear resistant finish that excludes water and air from the surface of the metal and so prevents corrosion. Plastic coating is applied mainly by: hot dip coating in a fluidised bed of polymer powder. hot dip coating a product in a vinyl Plastisol.

Three are following method of plastic coating:-

1.Dipping coating:- Plastic Dip Coating is a process that involves immersing a preheated part into liquid Plastisol to form a plastic coating that can add protection and aesthetics to most metal parts. The procedure can enhance the appearance of the part, provide a soft grip, or protect the part from chemicals and abrasion. The coating is available in many colors and textures, and special purpose additives can be used to provide specific characteristics like fungus resistance, dielectric strength, and flame retardancy.

2.Electrostatic coating :- It is a manufacturing process that employs charged particles to more efficiently paint a workpiece. Paint, in the form of either powdered particles or atomized liquid, is initially projected towards a conductive workpiece using normal spraying methods, and is then accelerated toward the work piece by a powerful electrostatic charge.

An addition to the electrostatic coating (or e-coating) process is dipping electrically conductive parts into a tank of paint that is then electrostatically charged. The ionic bond of the paint to the metal creates the paint coating, in which its thickness is directly proportional to the length of time the parts are left in the tank and the time the charge remains active. Once the parts are removed from the paint tank, they are rinsed off to remove any residual paint that is not ionically bonded, leaving a thin film of electrostatically bonded paint on the surface of the part.

3.Vacuum Coating:- Vacuum coating processes use vacuum technology to create a sub-atmospheric pressure environment and an atomic or molecular condensable vapor source to deposit thin films and coatings.

Various Sources of Plastics

- The main source of synthetic plastics is crude oil.
- Coal and natural gas are also used to produce plastics.
- Petrol, paraffin, lubricating oils and high petroleum gases are bi-products, produced during the refining of crude oil.
- These gases are broken down into monomers. Monomers are chemical substances consisting of a single molecule.
- A process called Polymerisation occurs when thousands of monomers are linked together. The compounds formed as called polymers.
- Combining the element carbon with one or more other elements such as oxygen, hydrogen, chlorine, fluorine and nitrogen makes most polymers.

Various Trade Name of Plastics

1. Polyethylene terephthalate (PETE or PET):

PET is the most widely produced plastic in the world. It is used predominantly as a fiber (known by the trade name “polyester”) and for bottling or packaging. For example, PET is the plastic used for bottled water and is highly recyclable

Three words or short phrases to describe the major benefits of Polyethylene relative to other plastics and materials would be:

- Wide applications as a fiber (“polyester”)

- Extremely effective moisture barrier
- Shatterproof

2. Polyethylene (PE):

There are a number of different variants of polyethylene. Low and high density polyethylene (LDPE and HDPE respectively) are the two most common and the material properties vary across the different variants.

HDPE plastic container

1. LDPE: LDPE is the plastic used for plastic bags in grocery stores. It has high ductility but low tensile strength.

1. HDPE: A stiff plastic used for more robust plastic packaging like laundry detergent containers as well as for construction applications or trash bins.

1. UHMW: Extremely strong plastic that can rival or even exceed steel in strength and is used is for applications like medical devices (e.g. artificial hips).

3. Polyvinyl Chloride (PVC):

Polyvinyl Chloride is perhaps most well known for its use in residential and commercial property construction applications. Different types of PVC are used for plumbing, insulation of electrical wires, and “vinyl” siding. In the construction business PVC pipe is often referred to by the term “schedule 40” which indicates the thickness of the pipe relative to its length.

Three words or short phrases to describe the major benefits of PVC relative to other plastics and materials would be:

- Brittle
- Rigid (although different PVC variants are actually designed to be very flexible)
- Strong

4. Polypropylene (PP):

Polypropylene is used in a variety of applications to include packaging for consumer products, plastic parts for the automotive industry, special devices like living hinges, and textiles. It is semi-transparent, has a low-friction surface, doesn’t react well with liquids, is easily repaired from damage and has good electrical resistance (i.e. it is a good electrical insulator). Perhaps most importantly, polypropylene is adaptable to a variety of manufacturing techniques which makes it one of the most commonly produced and highly demanded plastics on the market.

Two short phrases to describe the major benefits of Polypropylene relative to other plastics and materials would be:

- Unique Use For Living Hinges
- Simple To Manufacture

5. Polystyrene (PS):

Polystyrene is used widely in packaging under the trade name “styrofoam.” It is also available as a naturally transparent solid commonly used for consumer products like soft drink lids or medical devices like test tubes or petri dishes.

One short phrase to describe the major benefits of Polystyrene relative to other plastics and materials would be:

6. Polylactic Acid (PLA):

Polylactic Acid is unique in relation to the other plastics on this list in that it is derived from biomass rather than petroleum. Accordingly it biodegrades much quicker than traditional plastic materials.

Two words or short phrases to describe the major benefits of Polylactic Acid relative to other plastics and materials would be:

- Biodegradable
- DIY 3D Printing (compare PLA to ABS)

7. Polycarbonate (PC):

Polycarbonate is a transparent material known for its particularly high impact strength relative to other plastics. It is used in greenhouses where high transmissivity

and high strength are both required or in riot gear for police.

Two words or short phrases to describe the major benefits of Polycarbonate relative to other plastics and materials would be:

- Transparent
- High Strength

8. Acrylic (PMMA):

Acrylic is best known for its use in optical devices. It is extremely transparent, scratch resistant, and much less susceptible to damaging human skin or eye tissue if it fails (e.g. shatters) in close proximity to sensitive tissue.

Two words or short phrases to describe the major benefits of Acrylic relative to other plastic.

CHAPTER -(Advanced Material)

INTRODUCTION

A composite material (also called a composition material or shortened to composite, which is the common name) is a material made from two or more constituent materials with significantly different physical or chemical properties that, when combined, produce a material with characteristics different from the individual components. The individual components remain separate and distinct within the finished structure, differentiating composites from mixtures and solid solutions.

The new material may be preferred for many reasons. Common exam include materials which are stronger, lighter, or less expensive when compared to traditional materials.

More recently, researchers have also begun to actively include sensing, actuation, computation and communication into composites,[3] which are known as Robotic Materials.

Typical engineered composite materials include:

- Reinforced concrete and masonry
- Composite wood such as plywood
- Reinforced plastics, such as fibre-reinforced polymer or fiberglass
- Ceramic matrix composites (composite ceramic and metal matrices)
- Metal matrix composites
- and other Advanced composite materials

Composite materials are generally used for buildings, bridges, and structures such as boat hulls, swimming pool panels, racing car bodies, shower stalls, bathtubs, storage tanks, imitation granite and cultured marble sinks and countertops.

Classification of composites

Composite material is a material composed of two or more distinct phases (matrix phase and dispersed phase) and having bulk properties significantly different form those of any of the constituents.

- Matrix phase

The primary phase, having a continuous character, is called matrix. Matrix is usually more ductile and less hard phase. It holds the dispersed phase and shares a load with it.

- Dispersed (reinforcing) phase

The second phase (or phases) is embedded in the matrix in a discontinuous form. This secondary phase is called dispersed phase. Dispersed phase is usually stronger than the matrix, therefore it is sometimes called reinforcing phase.

Many of common materials (metal alloys, doped Ceramics and Polymers mixed with additives) also have a small amount of dispersed phases in their structures, however they are not considered as composite materials since their properties are similar to those of their base constituents (physical properties of steel are similar to those of pure iron).

There are two classification systems of composite materials. One of them is based on the matrix material (metal, ceramic, polymer) and the second is based on the material structure:

Classification of composites I

Metal Matrix Composites (MMC)

Metal Matrix Composites are composed of a metallic matrix (aluminum, magnesium, iron, cobalt, copper) and a dispersed ceramic (oxides, carbides) or metallic (lead, tungsten, molybdenum) phase.

Ceramic Matrix Composites (CMC)

Ceramic Matrix Composites are composed of a ceramic matrix and embedded fibers of other ceramic material (dispersed phase).

Polymer Matrix Composites (PMC)

Polymer Matrix Composites are composed of a matrix from thermoset (Unsaturated Polyester (UP), Epoxiy (EP)) or thermoplastic (Polycarbonate (PC), Polyvinylchloride, Nylon, Polysterene) and embedded glass, carbon, steel or Kevlar fibers (dispersed phase).

Classification of composite materials II

(based on reinforcing material structure)

Particulate Composites

Particulate Composites consist of a matrix reinforced by a dispersed phase in form of particles.

1. Composites with random orientation of particles.

2. Composites with preferred orientation of particles. Dispersed phase of these materials consists of two-dimensional flat platelets (flakes), laid parallel to each other.

Fibrous Composites

1. Short-fiber reinforced composites. Short-fiber reinforced composites consist of a matrix reinforced by a dispersed phase in form of discontinuous fibers (length < 100*diameter).
   I. Composites with random orientation of fibers.
   II. Composites with preferred orientation of fibers.
2. Long-fiber reinforced composites. Long-fiber reinforced composites consist of a matrix reinforced by a dispersed phase in form of continuous fibers.
   I. Unidirectional orientation of fibers.
   II. Bidirectional orientation of fibers (woven).

Laminate Composites

When a fiber reinforced composite consists of several layers with different fiber orientations, it is called multilayer (angle-ply) composite.

Related internal links

- Structure of composites
- Estimations of composite materials properties
- Metal Matrix Composites
- Ceramic Matrix Composites
- Polymer Matrix Composites

PROPERTIES OF COMPOSITES

HIGH STRENGTH TO WEIGHT RATIO

Fibre composites are extremely strong for their weight. By refining the laminate many characteristics can be enhanced. A common laminate of say 3mm Chopped strand mat, is quite flexible compared to say a 3 mm ply. However it will bend a long way more than the ply before yielding. Stiffness should not be confused with Strength. A carbon fibre laminate on the other hand, will have a stiffness of many times that of mild steel of the same thickness, increased ultimate strength, yet only be less than 1/4 of it's weight.

LIGHTWEIGHT

A standard Fibreglass laminate has a specific gravity in the region of 1.5, compared to Alloy of 2.7 or steel of 7.8. When you then start looking at Carbon laminates, strengths can be many times that of steel, but only a fraction of the weight.

A DVD case lid was produced using carbon fibre to reduce the case's overall weight so that it could be carried as cabin baggage whilst traveling, and for improved security. It was used by support crew for the All Blacks during their 1999 Rugby World Cup campaign.

FIRE RESISTANCE

The ability for composites to withstand fire has been steadily improving over the years. There is two types of systems to be considered:

Fire Retardant - Are self-extinguishing laminates, usually made with chlorinated resins and additives such as Antimony trioxide. These release CO2 when burning so when the flame source is removed, the self-extinguish.

Fire Resistant - More difficult and made with the likes of Phenolic Resins. These are difficult to use, are cured with formaldehyde, and require a hi degree of post curing to achieve true fire resistance.

Other materials are also becoming more readily available to be used as in tumescent layers, which expand and blanket the surface, preventing spread of flame. There is a paint on coating usually applied to the back of the product laminate, plus a thin fibre film to go under the Gelcoat giving the outer surface a blanketing coat as well.

Fibreglass Developments Ltd produces a Fire Door as part of our Steridor TM range. Use of special Phenolic resin has allowed us to create the *only* fully tested Composite door in Australasia. Fire rated by BRANZ to 4 hours, this door is also approved by MAF as meeting all their Hygiene requirements.

ELECTRICAL PROPERTIES

Fibreglass Developments Ltd produced the Insulator Support straps for the Tranz Rail main trunk electrification. The straps, although only 4mm thick, meet the required loads of 22kN, as well as easily meeting insulation requirements.

CHEMICAL & WEATHERING RESISTANCE

Composite products have good weathering properties and resist the attack of a wide range of chemicals. This depends almost entirely on the resin used in manufacture, but by careful selection resistance to all but the most extreme conditions can be achieved. Because of this, composites are used in the manufacture of chemical storage tanks, pipes, chimneys and ducts, boat hulls and vehiclebodies.

FDL manufactured architectural panels for the construction of the Auckland Marine Rescue Centre. Composite panels were chosen because of their ability to withstand salty sea side conditions without corrosion.

COLOUR

Almost any shade of any colour can be incorporated into the product during manufacture by pigmenting the gelcoat used. Costs are therefore reduced by no further finishing or painting. Soluble dyes can be used if a translucent product is desired. We do not however, recommend dark colours. These produce excessive heat on the surface which can lead to the surface deteriorating and showing print through, where the Resin matrix cures more and shrinks, bringing the fibres to the surface. In extreme cases delamination can occur.

TRANSLUCENCY

Polyester resins are widely used to manufacture translucent mouldings and sheets. Light transmission of up to 85% can be achieved.

DESIGN FLEXIBILITY

Because of the versatility of composites, product design is only limited by your imagination.

LOW THERMAL CONDUCTIVITY

Fibreglass Developments has been involved in the development and production of specialized meat containers which maintain prime cuts of chilled meat at the correct temperature for Export markets. They are manufactured using the RTM process, with special reinforcing and foam inserts.

MANUFACTURING ECONOMY

Fibreglass Developments produces several models of fuel pump covers for Fuel quip. Fibreglass is an ideal material for producing items of this type for many reasons, including being very economical.
Because of its versatile properties, fibreglass can be used in many varied applications.

APPLICATION

The most important reason why we need composite materials is the versatality in their properties which enables them to be applied in large number of fields. Other reasons are their light weight, corrosion resistance and durability.

Advantages of Composite Materials

- As molded dimensional accuracy. Tight tolerance, repeatable moldings. ...
- Chemical Resistance.
- Consolidated Parts and Function.
- Corrosion Resistance.
- Design Flexibility.
- Durable.
- High Flexural Modulus to Carry Demanding Loads. High Impact Strength.
- High Performance at Elevated Temperatures.

A ceramic is a solid material comprising an inorganic compound of metal or metalloid and non-metal with ionic or covalent bonds. Common examples are earthenware, porcelain, and brick.

The crystallinity of ceramic materials ranges from highly oriented to semi-crystalline, vitrified, and often completely amorphous (e.g., glasses). Most often, fired ceramics are either vitrified or semi-vitrified as is the case with earthenware, stoneware, and porcelain. Varying crystallinity and electron composition in the ionic and covalent bonds cause most ceramic materials to be good thermal and electrical insulators (extensively researched in ceramic engineering). With such a large range of possible options for the composition/structure of a ceramic (e.g. nearly all of the elements, nearly all types of bonding, and all levels of crystallinity), the breadth of the subject is vast, and identifiable attributes (e.g. hardness, toughness, electrical conductivity, etc.) are difficult to specify for the group as a whole. General properties such as high melting temperature, high hardness, poor conductivity, high moduli of elasticity, chemical resistance and low ductility are the norm,[1] with known exceptions to each of these rules (e.g. piezoelectric ceramics, glass transition temperature, superconductive ceramics, etc.). Many composites, such as fiberglass and carbon fiber, while containing ceramic materials, are not considered to be part of the ceramic family.[2]

Materials

A ceramic material is an inorganic, non-metallic, often crystalline oxide, nitride or carbide material. Some elements, such as carbon or silicon, may be considered ceramics. Ceramic materials are brittle, hard, strong in compression, and weak in shearing and tension. They withstand chemical erosion that occurs in other materials subjected to acidic or caustic environments. Ceramics generally can withstand very high temperatures, ranging from 1,000 °C to 1,600 °C (1,800 °F to 3,000 °F). Glass is often not considered a ceramic because of its amorphous (noncrystalline) character. However, glassmaking involves several steps of the ceramic process, and its mechanical properties are similar to ceramic materials.

Traditional ceramic raw materials include clay minerals such as kaolinite, whereas more recent materials include aluminium oxide, more commonly known as alumina. The modern ceramic materials, which are classified as advanced ceramics, include silicon carbide and tungsten carbide. Both are valued for their abrasion resistance and hence find use in applications such as the wear plates of crushing equipment in mining operations. Advanced ceramics are also used in the medicine, electrical, electronics industries and body armor.

Crystalline ceramics

Crystalline ceramic materials are not amenable to a great range of processing. Methods for dealing with them tend to fall into one of two categories – either make the ceramic in the desired shape, by reaction in situ, or by "forming" powders into the desired shape, and then sintering to form a solid body. Ceramic forming techniques include shaping by hand (sometimes including a rotation process called "throwing"), slip casting, tape casting (used for making very thin ceramic capacitors), injection molding, dry pressing, and other variations.

Noncrystalline ceramics

crystalline ceramics, being glass, tend to be formed from melts. The glass is shaped when either fully molten, by casting, or when in a state of toffee-like viscosity, by methods such as blowing into a mold. If later heat treatments cause this glass to become partly crystalline, the resulting material is known as a glass-ceramic, widely used as cook-tops and also as a glass composite material for nuclear waste disposal.

History

Human beings appear to have been making their own ceramics for at least 26,000 years, subjecting clay and silica to intense heat to fuse and form ceramic materials. The earliest found so far were in southern central Europe, and were sculpted figures, not dishes.

The earliest known pottery was made by mixing animal products with clay, and baked in kilns at up to 800° centigrade. While actual pottery fragments have been found up to 19,000 years old, it wasn't until about ten thousand years later that regular pottery became common.

An early people that spread across much of Europe is named after its use of pottery, the Corded Ware culture.

Properties

The physical properties of any ceramic substance are a direct result of its crystalline structure and chemical composition. Solid-state chemistry reveals the fundamental connection between microstructure and properties such as localized density variations, grain size distribution, type of porosity and second-phase content, which can all be correlated with ceramic properties such as mechanical strength σ by the Hall-Petch equation, hardness, toughness, dielectric constant, and the optical properties exhibited by transparent materials.

Ceramography is the art and science of preparation, examination and evaluation of ceramic microstructures. Evaluation and characterization of ceramic microstructures is often implemented on similar spatial scales to that used commonly in the emerging field of nanotechnology: from tens of angstroms (A) to tens of micrometers (µm). This is typically somewhere between the minimum wavelength of visible light and the resolution limit of the naked eye.

The microstructure includes most grains, secondary phases, grain boundaries, pores, micro-cracks, structural defects and hardness microindentions. Most bulk mechanical, optical, thermal, electrical and magnetic properties are significantly affected by the observed microstructure. The fabrication method and process conditions are generally indicated by the microstructure. The root cause of many ceramic failures is evident in the cleaved and polished microstructure. Physical properties which constitute the field of materials science and engineering include the following:

Mechanical properties

Cutting disks made of silicon carbide

Mechanical properties are important in structural and building materials as well as textile fabrics. In modern materials science, fracture mechanics is an important tool in improving the mechanical performance of materials and components. It applies the physics of stress and strain, in particular the theories of elasticity and plasticity, to the microscopic crystallographic defects found in real materials in order to predict the macroscopic mechanical failure of bodies. Fractography is widely used with fracture mechanics to understand the causes of failures and also verify the theoretical failure predictions with real life failures.

Ceramic materials are usually ionic or covalent bonded materials, and can be crystalline or amorphous. A material held together by either type of bond will tend to fracture before any plastic deformation takes place, which results in poor toughness in these materials. Additionally, because these materials tend to be porous, the pores and other microscopic imperfections act as stress concentrators, decreasing the toughness further, and reducing the tensile strength. These combine to give catastrophic failures, as opposed to the more ductile failure modes of metals.

These materials do show plastic deformation. However, because of the rigid structure of the crystalline materials, there are very few available slip systems for dislocations to move, and so they deform very slowly. With the non-crystalline (glassy) materials, viscous flow is the dominant source of plastic deformation, and is also very slow. It is therefore neglected in many applications of ceramic materials.

To overcome the brittle behaviour, ceramic material development has introduced the class of ceramic matrix composite materials, in which ceramic fibers are embedded and with specific coatings are forming fiber bridges across any crack. This mechanism substantially increases the fracture toughness of such ceramics. Ceramic disc brakes are an example of using a ceramic matrix composite material manufactured with a specific process.

Ice-templating for enhanced mechanical properties

If a ceramic will be subjected to substantial mechanical loading it can undergo a process called ice-templating, which allows some control of the microstructure of the ceramic product and therefore some control of the mechanical properties. Ceramic engineers use this technique to tune the mechanical properties to their desired application. Specifically, strength is increased when this technique is employed. Ice templating allows the creation of macroscopic pores in a unidirectional arrangement. The applications of this oxide strengthening technique are important for solid oxide fuel cells and water filtration devices.

To process a sample through ice templating, an aqueous colloidal suspension is prepared containing the dissolved ceramic powder evenly dispersed throughout the colloid. The solution is then cooled from the bottom to the top on a platform that allows for unidirectional cooling. This forces ice crystals to grow in compliance to the unidirectional cooling, and these ice crystals force the dissolved YSZ particles to the solidification front of the solid-liquid interphase boundary, resulting in pure ice crystals lined up unidirectionally alongside concentrated pockets of colloidal particles. The sample is then simultaneously heated and the pressure is reduced enough to force the ice crystals to sublimate and the YSZ pockets begin to anneal together to form macroscopically aligned ceramic microstructures. The sample is then further sintered to complete the evaporation of the residual water and the final consolidation of the ceramic microstructure.

During ice-templating a few variables can be controlled to influence the pore size and morphology of the microstructure. These important variables are the initial solids loading of the colloid, the cooling rate, the sintering temperature and duration, and the use of certain additives which can influence the micro-structural morphology during the process. A good understanding of these parameters is essential to understanding the relationships between processing, microstructure, and mechanical properties of anisotropically porous materials.

Electrical properties

Semiconductors

Some ceramics are semiconductors. Most of these are transition metal oxides that are II-VI semiconductors, such as zinc oxide.

While there are prospects of mass-producing blue LEDs from zinc oxide, ceramicists are most interested in the electrical properties that show grain boundary effects.

One of the most widely used of these is the varistor. These are devices that exhibit the property that resistance drops sharply at a certain threshold voltage. Once the voltage across the device reaches the threshold, there is a breakdown of the electrical structure in the vicinity of the grain boundaries, which results in its electrical resistance dropping from several megohms down to a few hundred ohms. The major advantage of these is that they can dissipate a lot of energy, and they self-reset – after the voltage across the device drops below the threshold, its resistance returns to being high.

This makes them ideal for surge-protection applications; as there is control over the threshold voltage and energy tolerance, they find use in all sorts of applications. The best demonstration of their ability can be found in electrical substations, where they are employed to protect the infrastructure from lightning strikes. They have rapid response, are low maintenance, and do not appreciably degrade from use, making them virtually ideal devices for this application.

Ferroelectricity and supersets

Piezoelectricity, a link between electrical and mechanical response, is exhibited by a large number of ceramic materials, including the quartz used to measure time in watches and other electronics. Such devices use both properties of piezoelectrics, using electricity to produce a mechanical motion (powering the device) and then using this mechanical motion to produce electricity (generating a signal). The unit of time measured is the natural interval required for electricity to be converted into mechanical energy and back again.

The piezoelectric effect is generally stronger in materials that also exhibit pyroelectricity, and all pyroelectric materials are also piezoelectric. These materials can be used to inter-convert between thermal, mechanical, or electrical energy; for instance, after synthesis in a furnace, a pyroelectric crystal allowed to cool under no applied stress generally builds up a static charge of thousands of volts. Such materials are used in motion sensors, where the tiny rise in temperature from a warm body entering the room is enough to produce a measurable voltage in the crystal.

In turn, pyroelectricity is seen most strongly in materials which also display the ferroelectric effect, in which a stable electric dipole can be oriented or reversed by applying an electrostatic field. Pyroelectricity is also a necessary consequence of ferroelectricity. This can be used to store information in ferroelectric capacitors, elements of ferroelectric RAM.

At the transition temperature, the material's dielectric response becomes theoretically infinite. While a lack of temperature control would rule out any practical use of the material near its critical temperature, the dielectric effect remains exceptionally strong even at much higher temperatures. Titanates with critical temperatures far below room temperature have become synonymous with "ceramic" in the context of ceramic capacitors for just this reason.

Optical properties

Cermax xenon arc lamp with synthetic sapphire output window

Optically transparent materials focus on the response of a material to incoming lightwaves of a range of wavelengths. Frequency selective optical filters can be utilized to alter or enhance the brightness and contrast of a digital image. Guided lightwave transmission via frequency selective waveguides involves the emerging field of fiber optics and the ability of certain glassy compositions as a transmission medium for a range of frequencies simultaneously (multi-mode optical fiber) with little or no interference between competing wavelengths or frequencies. This resonant mode of energy and data transmission via electromagnetic (light) wave propagation, though low powered, is virtually lossless. Optical waveguides are used as components in Integrated optical circuits (e.g. light-emitting diodes, LEDs) or as the transmission medium in local and long haul optical communication systems. Also of value to the emerging materials scientist is the sensitivity of materials to radiation in the thermal infrared (IR) portion of the electromagnetic spectrum. This heat-seeking ability is responsible for such diverse optical phenomena as Night-vision and IR luminescence.

Thus, there is an increasing need in the military sector for high-strength, robust materials which have the capability to transmit light (electromagnetic waves) in the visible (0.4 – 0.7 micrometers) and mid-infrared (1 – 5 micrometers) regions of the spectrum. These materials are needed for applications requiring transparent armor, including next-generation high-speed missiles and pods, as well as protection against improvised explosive devices (IED).

In the formation of polycrystalline materials (metals and ceramics) the size of the crystalline grains is determined largely by the size of the crystalline particles present in the raw material during formation (or pressing) of the object. Moreover, the size of the grain boundaries scales directly with particle size. Thus a reduction of the original particle size below the wavelength of visible light (~ 0.5 micrometers for shortwave violet) eliminates any light scattering, resulting in a transparent material.

Recently, Japanese scientists have developed techniques to produce ceramic parts that rival the transparency of traditional crystals (grown from a single seed) and exceed the fracture toughness of a single crystal.[citation needed] In particular, scientists at the Japanese firm Konoshima Ltd., a producer of ceramic construction materials and industrial chemicals, have been looking for markets for their transparent ceramics.

VERY SHORT ANSWER TYPE QUESTIONS

Q.1. Define composites.

Ans. Composites are the combination of two or more materials to form a new material with enhanced material properties .

Q. 2. Name various types of composite material.

Ans. (i) particle reinforced composite.
(ii) Fibre reinforced composite.
(iii) structural composite.

Q.3. Define ceramics .

Ans . ceramics are inorganic and non metallic materials that are used at high temperature.

Q. 4. Name any four ceramices.

Ans. (i) Glass (ii) Refractory
(iii) clay products (iv) Abrasive

Q.5. Define heat insulating materials.

Ans. Heat insulating materials are those who resist the flow of heat to and from a body.

Q.6. How are refractory materials classified ?

Ans. (1) Acid refactory
(2) Base refactory
(3) Neutral refactory

Q.7. What is asbestos?

Ans. It is a fibrous mineral substance which is used as heat insulating material.

Q.8. what is glass wool?

Ans. Glass wool is a heat insulating material which is used as insulation against heat and cold.

Q.9. what is thermocol?

Ans. It is a heat insulating material which is used as heat insulation in t.v. , air heaters and other electrical equipments.

Q.10. what is mica?

Ans. Mica is a naturally mineral which is used as heat insulating material.

Q.11. Name various tool and die materials.

Ans . (a) carbon steel (b) high speed steel
(c) cemented carbide (d) diamond.

Q. 12. Name any four heat insulating material.

Ans. (a) asbestos (b) glass wool
(c) thermocol (d) cork

Q.13. Name various material for nuclear energy.

Ans. (a) uranium (b) thorium
(c) zirconium (d) niobium

Q.14. name various refractory materials.

Ans. (a) silica (b) aluminium silica
(c) bauxile (d) graphite

SHORT ANSWER TYPE QUESTIONS

Q.1. Discuss composite material.

Ans. Composite materials are produced by combining to dissimilar materials into a new material that may be better suited for a particular application than either of the original materials. Many composite materials are composed of just to phases one is termed the matrix which is continuous and surrounds the other phase often cold dispersed phase.

Q.2. How composites materials classified .

Ans. Composite materials are classified as:

(i) Particle reinforced
  (a) Large particle (b) Dispersion strengthened

(ii) Fiber reinforced
  (a) continuous (b) Discontinuous

(iii) structural
  (a) Laminates (b) Sandwich panels.

Q.3. Describe the properties of composite materials.

Ans. (i) High strength
(ii) Fire resistance and chemical resistance
(iii) Light in weight
(iv) Good thermal shock resistance
(v) Dimensional stability
(vi) High fracture toughness.

Q.4. Write the properties of ceramics.

Ans. (i) High strength.
(ii) Excellent wear resistance.
(iii) Non-Magnetic.
(iv) Low thermal coefficient.
(v) Excellent surface finish.

Q.5. Write general characteristics and uses of ceramics.

Ans. Ceramics are usually a hard brittle nature , inorganic , non-metallic materials. They are abrasive –resistant , heat-resistant and can sustain large compressive load even at high temperatures. The nature of the chemical bond in ceramics is generally ionic in character. Ceramic include a wide range of silicate , metallic oxides and combinations of silicates and metal oxides. The main used is as insulators , thermal and electrical . it also used in glass products.

Q.6. Write the properties and uses of heat insulating materials.

Ans . The heat insulating materials are that material which reduced the rate of flow of heat. The insulating material is placed between a warm region to reduce the rate of heat flow to the cooler region . The heat insulation is useful not only because it help to provide has comfortable living condition but also it helped to conserve fuel or electrical power. In industries, heat insulation is used for purposes such as enclosing heating equipment, Example of heat insulator are asbestos, cork, fiber boards which helps to maintain a uniform temperature in an enclosure.

Q.7. Write the application of composites.

Ans. The main application of composites are:

(1) Building construction
(2) Satellite
(3) Electronics and computer components
(4) Automobiles
(5) It is used in pressure vessel and heat exchanger

Q.8. what is use of glass wool.

Ans. The glass wool is used as insulation against heat and cool. The glass wool form is used in space

Losses of heat form pipe, boilers, tanks,ducts etc.

Q.9. write the use of thermocole.

Ans. The thermocol is used as heat insulation as moulded packing for T.V., air heater and other electrical and electronic items to protect these items from shock.

Q.10. write requisite qualities of bearing metals.

Ans. (1) The bearing metal should with stand deformation and extrusion under severe loadiy.

(2) It should be able to resist the temperature.

(3) It should be able to resist the corrosion.

(4) It should have anti- seizne, anti frictional properties.

Q.11. How are bearing alloys classified?

Ans. (1) copper base bearing alloy.

(2) white metal bearing alloy

(3) Bimetallic and trimettalic bearing alloy

(4) Tin base bearing alloy

Q. 12. Write the properties of asbestos.

Ans. The main properties of asbestos are:

(1) It has high co- efficient of friction.
(2) It is acid prrof.
(3) It has high resistant to heat and fire.
(4) It is good insulator.

Q. 13. What is Domomite refactory. Give its properties& uses.

Ans. It is double carbide of calcium and magnesium. Its chemical formula is $CaMg(Co_3)_2$. It is used for maintenance of open hearth furnace.

Properties-

1. It has less strength & contraction.
2. It is good insulated.

Uses-

It is used i open hearth furnance to making bottom and side parts.

Q.14. what are joining material.

Ans. The materials which is used for joining the materials are known as joining materials.they are also known as adhesive. These are of two types one is natural adhesive and second is synthetic adhesive.

Q. 15. How you classify joining materii.

Joining material (Adhesive)- Natural, synthetic,
Natural adhesive- starch, animal, plants
Synthetic adhesive- polyvinyal alcohol, sodium siicate glue, polyvinyal estate.

Q. 16. Write the uses of asbestors.

Ans: (1) it is used in cement as a fibre material.
(2) it js used as a covering material of magnetic oil.
(3) it is used in fuse box and switch box as a lining.
(4) it is used for making fire proof clothes.

LONG ANSWER TYPE QUESTIONS

Q.1. what is composite material? Explain Various types of composite material.

Ans. Composite materials are produced by combining two dissimilar materials into a new material taht may be letter suited for a particular application that euther of the original material alone.

The composite materials can be divided as:

(1) Particle Reinforced Composite: The dispered phase for particle- reinforced composites in equiaxed i.e particle dimensions are approximately the same in all directions. In large-particle composites, the large is used to indicate that particle matrix interaction cannot be treated on the atomic or molecular level,rather continuous mechanics are used. For most of these compositions, the perticulate phase is harder and stiffer than matrix.

(2) Fibre Reinforced Composite: The most important composites are those in which the dispered phase is in the form of fibre. In this type of composite, the matrix phase binds the fibre together and acts as the medium by which as externally applied stress is transmitted and distributed to the fibres; only s very small proportion of an applied load is sustained by the matrix phase.

(3) Structural composite: A structural composite is normally composed of both homogeneous and composite matei, the properties of which depends,not only on the properties of the constituent materials but also on the geometrical design of the various structural elements. The common structural composites are , laminar composites and sandwich panels. A laminar composite is composed at two- dimensional sheets or panels that have a preferred high- strength direction. Sandwhich panels consists of two strong outer sheets seprated by a layer of less dense material which has lower stiffness and low strength.

Q.2. Explain cork and fibre boards and write their applications.

Ans. Cork: Cork is the outer bark of oak tree. The cork is used in composition from. It is ground up and then moulded into blocks under heat and pressure.

Depending on the end uses, the particles may be bkund together by Cork's own natural resins or with other binders to provides additional qualities.

Cork is generally used in composition form. It is baked into block wuth its own natural resins or with other bender. The blocks can be used as sliced into thin sheets. It is generally used as a low temperature insulation for cold storage rooms, refrigerator car, freezer cabinets,roof insulations and duct insulations. It is also used as gaskets and friction materials.

Fire Board: the fire boards are made from fibrous materials such as wood, vegetable,fibre etc.

The wood pulp, textile fibres or other vegetable fibres with a saturated solution of zinc chloride is mixed and then dried. These boards are generally 3 mm to 18 mm thick.

These boards are used as sound insulation in theatres,halls and buildings. These are also used as heat insulation, internal finishing of rooms, making table tops and flush door etc.

Q.3 Explain various types of ceramics.

Ans. The various typed of ceramics are:

(1) Clay Product: Clay is one of the most widely used ceramic material. The formed piece is dried to remove moisture,after which it is fired at an elevated temperature. The clay based proi are white ware, structural etc.
(2) Abrasive: An abrasive is commonly made of ceramic material. It is hard mechanicly resistant material used for grinding or cutting. It can wear away a softer material. An abrasive may be natural e.g. diamond, garnet etc. Or synthetic e.g. silicon carbide and aluminium oxide.
(3) Cement: It is a ceramic material for bonding solids together. This is set very quickly when water is added to it. Ut is used for making floors, roofs, beams, bridges, water tank etc.
(4) Glass: It is transparent silica product which may be amorphous or crystalline depending upon heat treatment. It is inorganic product of fusion of one or more oxides of silicon, boron, calcium etc. Cooled to a rigid material without crystallization.

(5) Refractories: Refractories are ceramics materials that can with stand usually high heat as well as abrosion and the corrosive effects of acids and alkalis. They sre used in furnaces, stills for the cracking of petroleum, ceramickilns and electrolytic cell for aluminium products.

Q.4. Explain various tool and die materials.

Tool materials: The tool materials are

(1) Carbon steel:Carbon steel containing 0.9 to 1.5% carbon. It is fairly resistant to abrasion. It is easy to machine. It has high surface hardness with a fairly tough core.

(2) H.S.S. : As named H.S.S.- high speed are removed metal as cutting tool snd operated at much higher cutting speeds. High speed steels are characterized by being heat- treatable to very high hardness and of retaining their hardness and cutting ability at temperatures as high 540° C H.S.S. has excellent red hardness, good wear resistance, good shock resistance, fair machinability, good non- deforming property but poor resistance to decarbrization.

These are four general thpes as

(1) 18-4-1 High speed- 18% W, 4%Cr, 1% V
(2) Cobalt high speed steel-5-8% Co, 20% W, 4% Cr, 2% V
(3) Vandium high speed steel- 0.7% C and more than 1% V
(4) Molybdeum high speed steel- 6% W, 4% Cr and 2% V.

(3) Diamond: Diamond is the hardest material which is used for tools and can with stand a temperature upto 1650°C. It has low thermal expansion,hogh heat conductivity,very low coefficient of friction against metals and poor electrical conductor.

Die materials: The die materials are:

(1) High carbon, high chrome steel:They are used for cutting hard materials and where production rates are high.

(2) Tungsten carbide: It js used for high production rates and where die wear resistance is to be maintained at elevated temperature.

(3) Water hardening steels : They are used where material cost lf the die must be kow and the die shape is simple.

Q.5 Explain various materials for nuclear energy.

Ans. The materials for nuclear energyare:

(1) **Uranium**: It is used as a nuclear fuel . It is very reactive, easily oxidised and exists in yhree allotropic form. Uranium oxide is highly refractory.

(2) **Plutonium**: It is a concentrated nuclear fuel. It is very reactive, easily oxidised and highly toxic. It has poor corrosion resistance and is used for making atomic bombs.

(3) **Thorium**: It is FCC metal. It is radio active material. Thorium is soft and weak in pure form. Uranium when added to thorium increases the strength.

(4) **Berylium**: It has a HCP crystal structure. It is used as a moderated, reflector. It is very reactive metal. It is corroded by traves of water in carbon- di- oxide.

(5) **Niobium**: It has a B.C.C structure. It has excellent compatibility with uranium. Impurities such as oxygen, carbon, hydrogen and nitroyhave a detrimental effect on the workability of niobium.

CHAPTER - (Metallurgy)

VERY SHORT ANSWER TYPE QUESTIONS

Q.1. Define solid solution.

Ans. When elements combine to form alloy by completely dissolving in each other is called solid solution.

Q.2. Name various types of solid solution.

Ans. (i) Substitutional solid solution.

(ii) Interstitial solid solution.

Q.3. Define cooling curves.

Ans. It is a method to determine the temperature at which phase changes occur in an alloy system.

Q.4. Define substitutional solid solution.

Ans. A solid solution in which a solute atom occupy two alternative position in the lattice of solvent metal is called substitutional solid solution.

Q.5. Define interstitial solid solution.

Ans. A solution in which the atoms of the solute metal occupy the vacant positions or interstices between the atoms of the solvent.

Q.6. What is binary alloy.

Ans. It is a homogeneous mixture of two metal or non metal which increase the properties of a alloy is known as binary alloy.

Q.7. What is a lever Rule.

Ans. The tool is used to find the composition of solid phase and liquid phase in homogeneous solid solution.

SECTION-B

SHORT ANSWER TYPE QUESTIONS

Q.1. Explain solid solution and its type.

Ans. Solid solution: A solid solution is simply a solution in the solid state and consists of two kinds of atoms combined in the types of space lattice. Brass is a solid solution of copper and zinc. Solid solution are two types.

(1) Substitutional solid solution: In substitutional solid solution, the atoms of the solute substitute for atoms of the solvent in the lattice structure of the solvent. The solid solution of two types.
   (a) Random or disordered substitutional solid solution: In the formation of substitutional solid solution the solute atoms do not occupy any specific position but are distributed at random in the lattice structure of the solvent. This alloy is said to be a disordered substitutional solid solution.
   (b) Ordered substitutional solid solution: In the formation of substitutional solid solution,if the atoms of the solute material occupy similar lattice points with in the crystal of the solvent material. The alloy is said to be a ordered substitutional solid solution.

(2) Interstitial solid solution: Interstitial solid solution forms when solute atoms are very small as compared to the solvent atoms, they are unable to substitute solvent atomd and can not fit into the interstices or spaces in the crystal lattice of solvent atoms.

Q.2. what is the effect of grain size on properties of metal.

Ans. The grain size of metal can effect physical and mechanical properties of metal. If we can change the grain size of metal we can achieve lot of new properties in metal. If the grain size of metal is fine it will be strong and tough but. If the grain size of metal is large it should be less strong and having less weight.

Q.3. what is dendritic solidification. Dendritic

Ans. The crystal structure of any material is depends upon the mixture of component, cooling rate, impurities on the material. A perfect crystal is achieved when metal is pure and cooling rate is less. When we get tree type crystal structure then it is known as dendritic solidification.

Q.4. what is thermal equilibrium diagram.

Ans. The diagram which can show the phenomenon in which temperature a alloy can change their phase from solid to liquid is known as thermal equilibrium diagram.

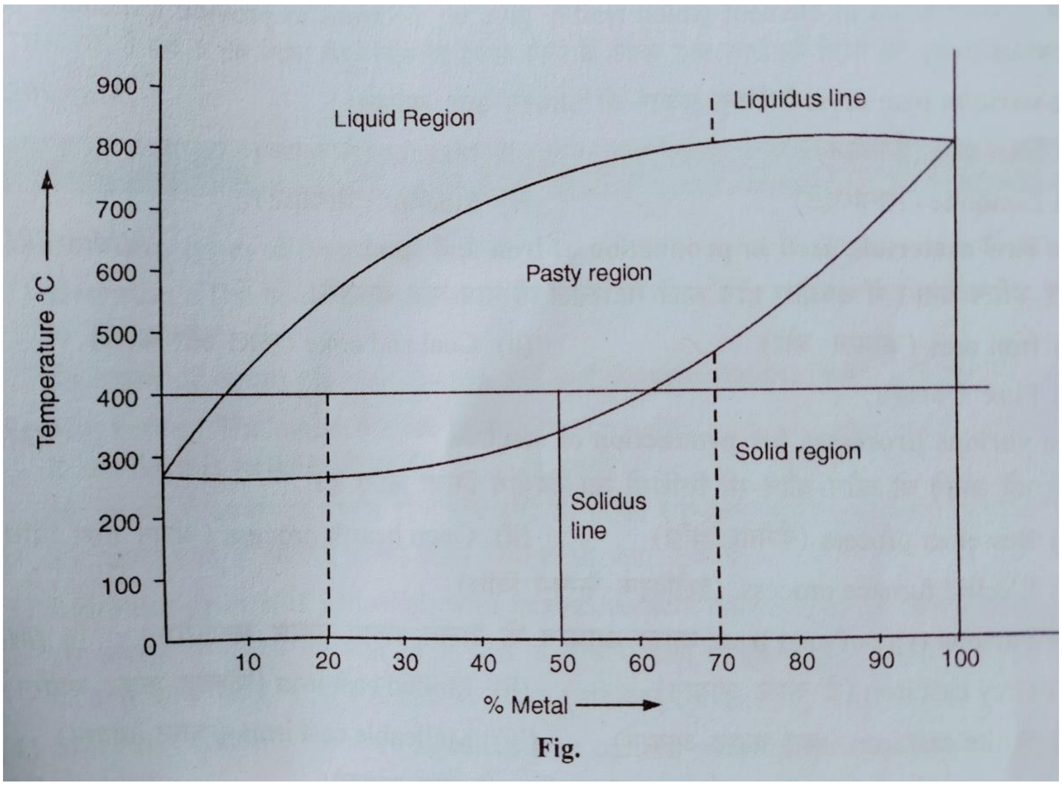


Fig.