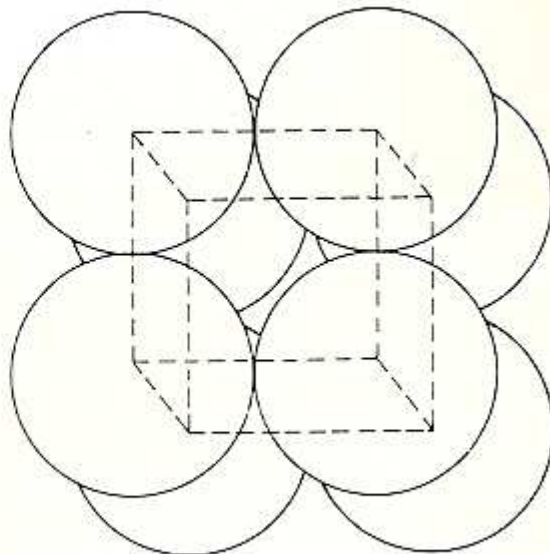
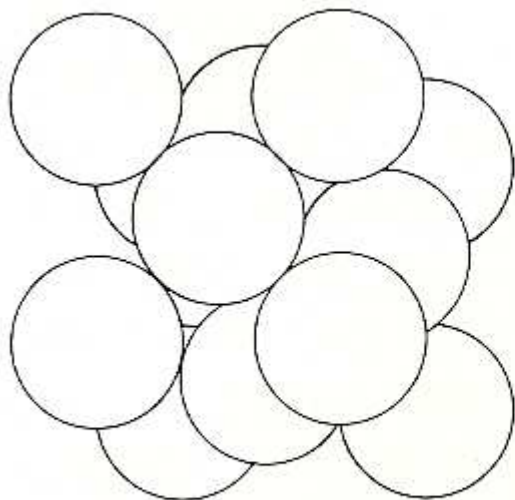




# **NATIONAL DIPLOMA IN MECHANICAL ENGINEERING TECHNOLOGY**



## **PROPERTIES OF MATERIALS**

**COURSE CODE: MEC224**

**YEAR 2- SEMESTER 4**

**THEORY**

# **THEORY**

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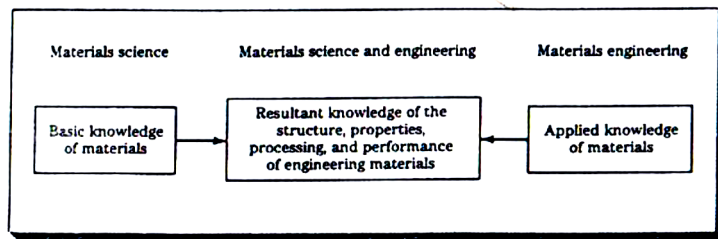
## WEEK 1

## 1.2 REASONS FOR THE STUDY OF PROPERTIES MATERIALS

### 1.1 MATERIALS SCIENCE AND ENGINEERING

Materials science is primarily concerned with the search for basic knowledge about the internal structure, properties, and processing of materials. Materials engineering is mainly concerned with the use of fundamental and applied.

**FIGURE 1.3** Materials knowledge spectrum. Using the combined knowledge of materials from materials science and materials engineering enables engineers to convert materials into the products needed by society.



**FIGURE 1.4** This diagram illustrates how materials science and engineering form a bridge of knowledge from the basic sciences to the engineering disciplines. (Courtesy of the National Academy of Science.)

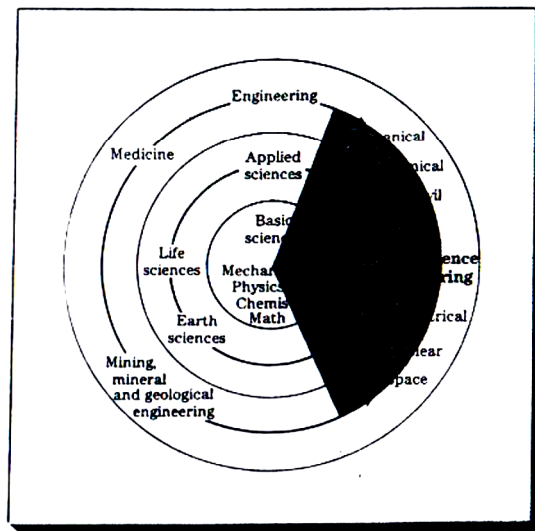


Fig. 1.1 lings between materials science and engineering

Knowledge of material so that the material can be converted into products necessary or desired by society. The name materials science and engineering combines both materials

science and materials engineering and is the subject of this book. Materials science is at the basic knowledge end of the materials knowledge spectrum and materials engineering is at the applied knowledge end, and there is no demarcation line between the two.

Three-ringed diagram which indicates the relationship among the basic sciences (and mathematics), materials science and engineering, and the other engineering disciplines. The basic sciences are located within the first ring or core of the diagram, while the various engineering disciplines (mechanical, electrical, civil, chemical, etc.) are located in the outermost third ring. The applied sciences, metallurgy, ceramics, and polymer science are located in the middle or second ring. Materials science and engineering is shown to form a bridge of materials knowledge from the basic sciences (and mathematics) to the engineering disciplines.

## **1.2 TYPES OF MATERIAL**

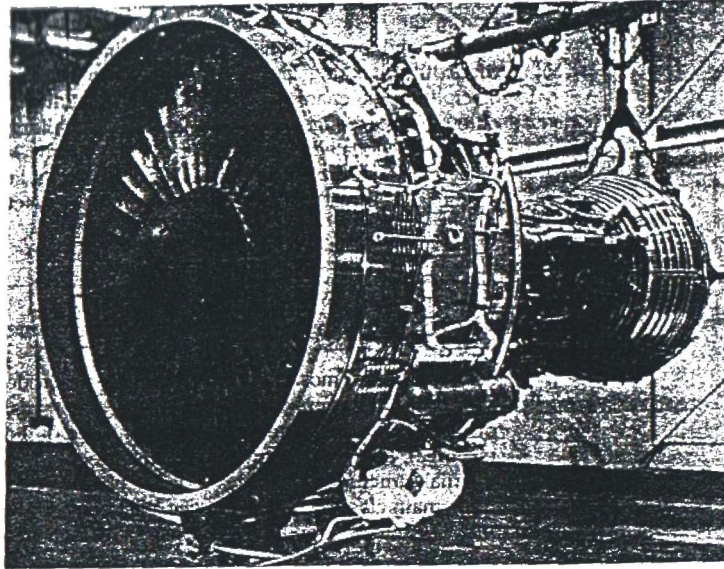
For convenience most engineering materials are divided into three main classes: metallic, polymeric (plastic), and ceramic materials. In this chapter we shall distinguish among them on the basis of some of their important mechanical, electrical, and physical properties. In subsequent chapters we shall study the internal structural differences of these types of materials. In addition to the three main classes of materials, we shall consider two more types, composite materials and electronic materials, because of their great engineering importance.

### **1.2.1 Metallic**

These materials are inorganic substances which are composed of one or more metallic elements and may also contain some nonmetallic elements. Examples of metallic elements are iron, copper, aluminum, nickel, and titanium. Non-metallic elements such as

carbon, nitrogen, and oxygen may also be contained in metallic materials. Metals have a crystalline structure in which the atoms are arranged in an orderly manner. Metals in general are good thermal and electrical conductors. Many metals are relatively strong and ductile at room temperature, and many maintain good strength even at high temperatures. Metals and alloys are commonly divided into two classes: ferrous metals and alloys that contain a large percentage of iron such as the steels and cast irons and nonferrous metals and alloys that do not contain iron or only a relatively small amount of iron. Examples of nonferrous metals are aluminum, copper, zinc, titanium, and nickel.

The picture below is a photograph of a commercial aircraft jet engine which is made in primarily of metal alloys. The metal alloys used inside the engine must be able to withstand the high temperatures and pressures generated during its operation. Many years of research and development work by sciences and engineers were required to perfect this advanced –performance engine.



Materials and materials processes over the past years have been associated with the increase in performance of gas-turbine engines [After Adv. Mat. & Proc., 133(1), 88(1988).]

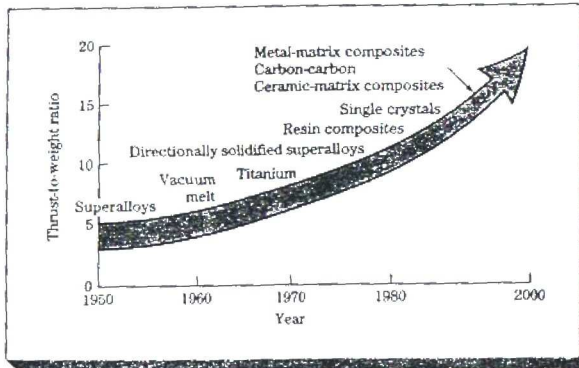


Fig 1.2. air craft turbine engine

Materials and materials processes have been associated with more efficient gas-turbine engine propulsion performance over the past years. Metal-matrix and ceramic-matrix materials may lead to even further increased performance in the future

### 1.2.2 Polymeric (Plastic)

Most polymeric materials consist of organic (carbon-containing) long molecular chains or networks. Structurally, most polymeric materials are non-crystalline but some consist of mixtures of crystalline and non-crystalline regions. The strength and ductility of



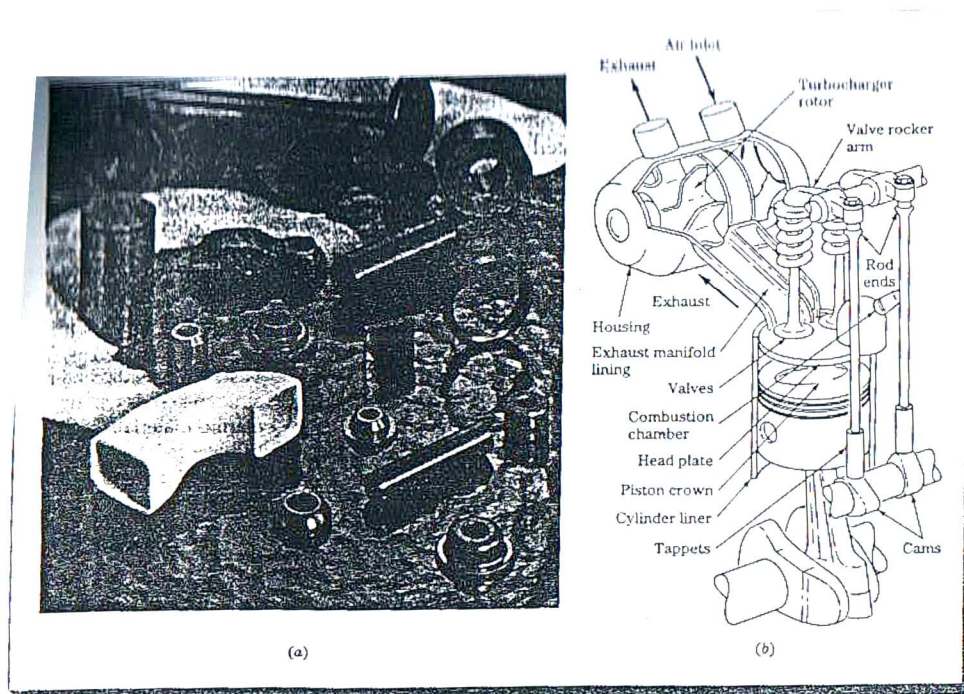
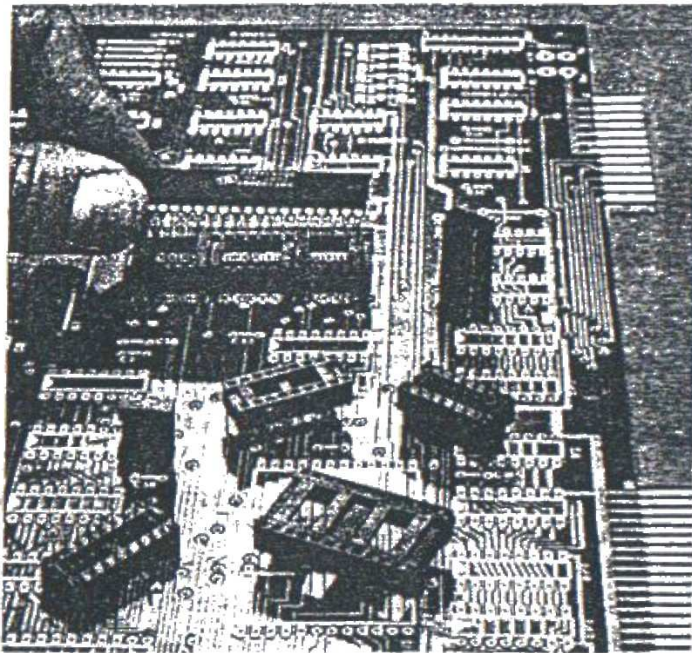
polymeric materials vary greatly. Because of the nature of their internal structure, most polymeric materials are poor conductors of electricity. Some of these materials are good insulators and are used for electrical isolative applications. In general, polymeric materials have low densities and relatively low softening or decomposition temperatures.

### **1.2.3 Ceramic Materials**

Ceramic materials are inorganic materials which consist of metallic and non-metallic elements chemically bonded together. Ceramic materials can be crystalline, noncrystalline, or mixtures of both. Most ceramic materials have high hardness and high-temperature strength but tend to have mechanical brittleness. Lately, new ceramic materials have been developed for engine applications. Advantages of ceramic materials for engine applications are light weight, high strength and hardness, good heat and wear resistance, reduced friction, and insulative properties.

The insulative property along with high heat and wear resistance of many ceramics make them useful for furnace linings for high-temperature liquid

**FIGURE 1.7** The circuit board and connectors shown here utilize the engineering thermoplastic polyetheretherketone to meet stringent high-temperature resistance and dimensional stability requirements and to assure material integrity under soldering conditions. (Courtesy of ICI Americas.)



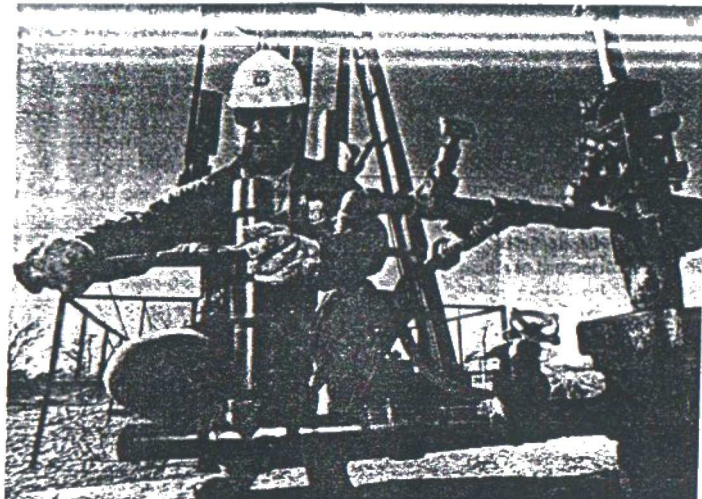
**FIGURE 1.8** (a) Examples of a newly developed generation of engineered ceramic materials for advanced engine applications. The black items include engine valves, valve seat inserts, and piston pins made of silicon nitride. The white item is a port-manifold liner made of an alumina ceramic material. (Courtesy of Norton/TRW Ceramics.) (b) Potential ceramic component applications in a turbocharged diesel engine. (After *Metals and Materials*, December 1988.)

metals such as steel. An important space application for ceramics are the ceramic tiles for the space shuttle. These ceramic materials thermally protect the aluminum internal structure of the space shuttle during ascent out of and reentry into the earth's atmosphere

#### **1.2.4 Composite Materials**

Composite materials are mixtures of two or more materials. Most composite materials consist of a selected filler or reinforcing material and a compatible resin binder to obtain the specific characteristics and properties desired. Usually, the components do not dissolve in each other and can be physically

**FIGURE 1.9** Glass-fiber-reinforced (20 percent chopped-fiber or 40 percent continuous-strand) polyphenylene sulfide (PPS) composites have good resistance to corrosive chemicals encountered in oil-field environments. Shown here are high-strength, thermally stable, compression-molded PPS pipe fittings undergoing field tests. (Courtesy of Phillips 66 Co.)



Identified by an interface between the components. Composites can be of many types. Some of the predominant types are fibrous (composed of fibers in a matrix) and particulate (composed of particles in a matrix). There are many different combinations of reinforcements and matrices used to produce composite materials. Two outstanding types of modern composite materials used for engineering applications are fiberglass-reinforcing material in a polyester or epoxy matrix and carbon fibers in an epoxy matrix. Schematically where carbon-fiber-epoxy composite material will be used for the wings

and engines of the new C-17 transport plane. Another example of the use of composites is glass-reinforced polyphenylene sulfide (PPS) for oilfield fittings. This application utilizes the excellent corrosion resistance of this material.

### **1.3 SUMMARY**

Materials science and materials engineering (collectively, materials science and engineering) form a bridge of materials knowledge between the basic sciences (and mathematics) and the engineering disciplines. Materials science is concerned primarily with the search for basic knowledge about materials, whereas materials engineering is concerned mainly with using applied knowledge about materials.

The three main types of materials are metallic, polymeric, and ceramic materials. Two other types of materials which are very important for modern engineering technology are composite and electronic materials. All these types of materials will be dealt with in this book.

Materials compete with each other for existing and new markets, and so the replacement of one material by another for some application occurs. The availability of raw materials, cost of manufacturing, and the developing new materials and processes for product; are major factors which cause changes in materials usage.

## WEEK 2

### 2.0 ATOMIC STRUCTURE AND BONDING

#### 2.2 STRUCTURE OF ATOMS

Let us now review some of the fundamentals of atomic structure since atoms are the basic structural unit of all engineering materials.

Atoms consist primarily of three basic subatomic particles: protons, neutrons, and electrons. The current simple model of an atom envisions a very small nucleus of about  $10^{-14}$  m in diameter surrounded by a relatively thinly dispersed electron cloud of varying density so that the diameter of the atom is of the order of  $10^{-10}$  m. The nucleus accounts for almost all the mass of the atom and contains the protons and neutrons. A proton has a mass of  $1.673 \times 10^{-24}$  g and a unit charge of  $+1.602 \times 10^{-19}$  coulombs (C). The neutron is slightly heavier than the proton and has a mass of  $1.675 \times 10^{-24}$  kg but no charge. The electron has a relatively small mass of  $9.109 \times 10^{-31}$  kg (that of the proton) and a unit charge of  $-1.602 \times 10^{-19}$  C (equal in charge but opposite in sign from the proton). Table 2.1 summarizes these properties of subatomic particles

The electron charge cloud thus constitutes almost all the volume of the atom but accounts for only a very small part of its mass. The electrons, particularly the outer ones, determine most of the electrical, mechanical, chemical, and thermal properties of the atoms, and thus

	Mass grams (g)	Charge coulombs (C)
Proton	$1.673 \times 10^{-24}$	$+1.602 \times 10^{-19}$

Neutron	$1.675 \times 10^{-24}$	0
Electron	$9.109 \times 10^{-28}$	$-1.602 \times 10^{-19}$

a basic knowledge of atomic structure is important in the study of engineering materials.

## 2.2 ATOMIC NUMBERS AND ATOMIC MASSES

### Atomic Numbers

The atomic number of an atom indicates the number of protons (positively charged particles) which are in its nucleus, and in a neutral atom the atomic number is also equal to the number of electrons in its charge cloud. Each element has its own characteristic atomic number, and thus the atomic number identifies the element. Atomic numbers of the elements from hydrogen, which has an atomic number of 1 to hahnium, which has an atomic number of 105, are located above the atomic symbols of the elements in the periodic table.

### Atomic Numbers

The relative atomic mass of an element is the mass in grams of  $6.023 \times 10^{23}$  atoms (Avogadro's number  $N_A$ ) of that element. The relative atomic masses of the elements from 1 to 105 are located below the atomic symbols in the periodic table of the elements. The carbon atom with 6 protons and 6 neutrons is the carbon 12 atom and is the reference mass for atomic masses. One atomic mass unit (u) is defined as exactly one-twelfth of the mass of a carbon atom which has a mass of 12 u. One molar relative atomic mass of carbon 12 has a mass of 12 g on this scale. One gram-mole or mole (abbreviated mol) of an element is defined as having the mass in grams of the relative molar atomic mass of that element. Thus, for example, 1 gram-mole of aluminum has a mass of 26.98 g and contains  $6.023 \times 10^{23}$  atoms.

## **2.3. ELECTRONIC CONSTRUCTION OF ATOMS**

### **THE ATOM**

For many years scientists have been trying to develop an acceptable model of the micro- and the macro-universe. To this point in man's history, as instruments are refined and additional data are collected, the model of the macro universe is being expanded. Much of this new information is deduced from energy that is continuously bombarding the earth's surface.

If one reflects a moment much of what man suspected about the moon was only a built-up model until it was confirmed by man's landing on its surface. It soon becomes apparent that much of What we actually know is still only a small part of that which actually exists.

In the same manner (but man prefers to be able to assimilate his (milking of the macro-universe into a model so that he may better understand it, so he has attempted to generate a model of the micro-universe.

For purposes of this text the model preferred is the one that views the atom as having almost all its mass concentrated in a positively charged nucleus. In orbit about this nucleus are one or more negatively charged particles called electrons. The net charge of the atom as whole is zero. The nucleus is envisioned to have a positively charged particle called the proton. The number of protons in the nucleus remains unchanged for a particular element. A neutrally charged particle, called the neutron, may also be found in the nucleus. Together, the protons and neutrons are called nucleus. Thus the entire positive charge appears to be concentrated in the protons in the nucleus, which are balanced by the cumulative negative charges of the electrons.



The magnitude of the electron charge (and the proton charge) is  $1.6 \times 10^{-19}$  coulomb (C). Its mass is  $9.108 \times 10^{-31}$  gram (g). The mass of the proton is  $1.673 \times 10^{-24}$ g, and the mass of the neutron is  $1.675 \times 10^{-24}$ g. The mass is concentrated almost entirely in the nucleus.

Elements are designated according to their chemical symbols. Thus iron (Fe) has an *atomic number* of 26 and an *atomic mass number* of 56. It is designated as



This atom would consist of 26 protons and 26 electrons and 30 neutrons. If we let  $A = 56$  and  $Z = 26$ , then the neutron number is

$$N = A - Z = 56 - 26 = 30$$

where  $N$  = neutron number

$A$  = atomic mass number

$Z$  = atomic number

*Isotopes* of any element have the same atomic number but differ in their atomic mass number because, even though they have the same number of electrons and protons (electrically neutral), they differ in the number of neutrons. Thus hydrogen and its isotopes are as follows:

<i>Hydrogen</i> (H)	<i>Deuterium</i> ( ${}^2_1\text{H}$ )	<i>Tritium</i> (H)
1 electron	1 electron	1 electron
1 proton	1 proton	1 proton
0 neutrons	1 neutron	2 neutrons

Opposite charges attract each other, and the centrifugal forces would seem to cause the electrons to want to fly out of orbit. Under normal conditions this centrifugal force would be balanced by the *electrical forces* of attraction. However, a centripetal\* force indicates an acceleration. Such an acceleration dictates that an electrically charged body must



radiate energy. Such energy loss by the orbiting electron would cause it to fall into the nucleus. It is obvious that such a model is not acceptable.

To explain this unacceptable model, discrete energy orbits are assumed. If the electron is found in one of these orbits, it will have a fixed energy value. In these fixed energy levels, the electron does not radiate energy, and the energy level of the electron is balanced by the electrostatic attraction of the nucleus.

\* A centripetal force is the reaction force to the centrifugal force. It is the force which acts toward the center of rotation.

Inside the nucleus the charges are positive. Since positive charges repel, it would seem that the nucleus should fly apart. However, this model of the atom dictates that there be very large forces of attraction at work inside the nucleus. These binding forces are called nuclear forces. Their magnitudes are much greater than the positive charges operating within the nucleus.

As already indicated, this model also envisions the orbital electrons as possessing discrete amounts of energy and therefore as being arranged in definite orbits dictated by the energy required to keep that electron in that particular orbit. These orbits are referred to as shells. The maximum number of electrons permitted in each shell is  $2n^2$ . The symbol  $n$  represents the shell number.

Thus the hydrogen atom has one electron in the first shell and helium has two electrons in the first shell. According to Example 1, this closes the first (K) shell. Lithium has three electrons. The first two will fill the K shell and the one remaining electron will start a new shell L. Sodium, which requires 11 electrons, will have two electrons in the K shell,

eight in the L shell, and one in the M shell. Starting with potassium, this scheme deviates somewhat as one progresses through the list of elements for the transition elements.

The capital letters K, L, M, N, O, P, and Q are used to designate the shells. Each shell is again divided so that no more than two electrons may occupy one subdivision. If two electrons occupy one energy level orbit, their spin must be in opposite directions. This introduces several ideas, which are identified as follows:

The total energy of an electron is designated by a. principal quantum number  $n$ , where « is equal to 1, 2, 3, 4, ...

The angular momentum of the electron is designated by letter and is called the second quantum number. This angular momentum determines the subshell inhabited by the electrons; /has values from 0 to  $(n-1)$  and the subshell is  $2(n+1)$ . The subshells are lettered s,p, d,f, g,h.

Two additional quantum Bombers are used to further define this model.  $m_l$  indicates the magnetic moment of the electron, has values of  $+l$  to 0 to  $-l$  and designates the orbit within a sabshell corresponding to a particular energy level  $L$  Af., which may have values of  $+1$  or  $-1$ , indicates the direction of spin of the electros upon its own axis.

Thus no two elements may have all four quantum numbers alike. The periodic table (Table Z- 1) shows bromine (Br)<sup>35</sup> as  $4d^5 4p^4$ . This is the N shell. A simple model is shown in

The atomic model discussed so far was for electrically neutral atoms only and for atoms in their ground state. It was noted, however, flat each of the  $n$  orbits has its own characteristic energy level. If for some reason (an electric discharge) the electron in its ground state is excited enough so that its energy level is increased, this increase of

strategy may be. Enough to knock it completely out of the atom. On the other hand, it may raise the energy of the atom by some discrete amount and cause the electron to enter orbits. When an atom loses one or more of its electrons, it is said to be ionized. When an electron occupies a higher energy orbit, it is said to be in an excited state. An electron in the excited state will jump back to its ground state with one jump or several jumps. If it returns to its ground state in one jump [Fig. 2-2(a)], it will emit an amount of energy characteristic of that jump. This packet of energy is called a quantum. If it returns to its ground state through several jumps each jump will require a release of a quantum of energy characteristic of that jump.

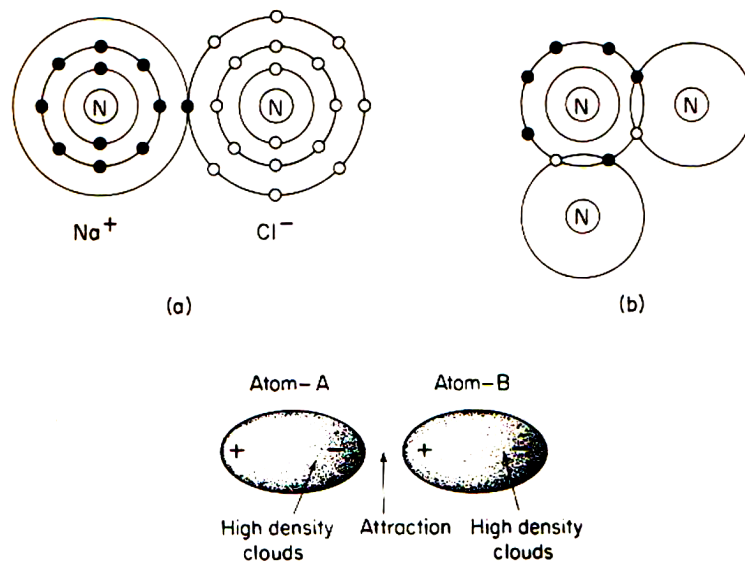


Fig. 2.0. ionic bonding

## WEEK 3

### 3.0 ELECTRONIC STRUCTURE AND CHEMICAL REACTIVITY

#### 3.2 ATOMIC AND MOLECULAR BOND

##### Bonds in Solids

The atoms and molecules in a solid state are more closely packed as compared to gaseous and liquid states and are held together by strong mutual forces of attraction. These interatomic forces are electrostatic in nature and depend upon the electronic structure of matter. When atoms come closer and finally unite to form molecules their electrons rearrange themselves in such a way as to achieve a stable configuration. This arrangement of electrons gives rise to different types of bonds due to which atoms are held together.

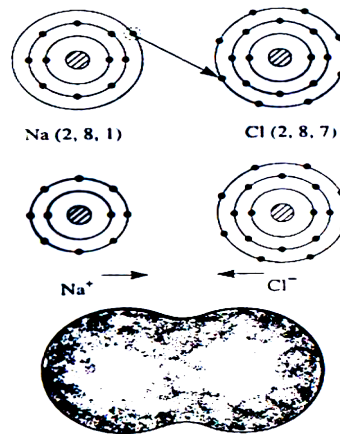


FIG.3.1. BOND IN SOLID

## **IONIC BOND**

Ionic bonds are mainly formed in inorganic compounds like NaCl and KOH etc. and never in pure elements. An ionic bond is really the attractive force between a positive ion and a negative ion when they are brought into close proximity. These ions, of course, are formed when the atoms involved lose or gain electrons in order to stabilize their outer shell electron configuration. Elements are classified as either electropositive or electronegative, depending upon when they tend to lose or gain electrons in order to achieve this stable outer shell electron configuration. Let us consider the combination which takes place between the Sodium (metal) and Chlorine (non-metal) to form Sodium Chloride. The sodium has a single electron in its outer shell and this transfers to join the seven electrons in the outer shell of Chlorine atom. This type of atomic interaction, involving the outright transfer of one electron from another, leads to formation of ions which are held together by electrostatic nature of the binding force, the bond between atoms is said to be ionic or electrovalent.

## **COVALENT BOND**

The covalent bond is formed by sharing of electrons between atoms rather than transfer of electrons. Only a few solids are held together by covalent bonds. Covalent bonding alone is not sufficient to build three dimensional solids. The majority of solids incorporating covalent bonds are bound also either by ionic or van der Waals' bonds.

An excellent example of covalent bonding is found in the Chlorine molecule (Fig. 21.10 a). Here the outer shell of each atom possesses seven electrons. Each chlorine atom would like to gain an electron and thus form a stable octet. This can be done by sharing of two electrons between pairs of chlorine atoms thereby producing stable diatomic

molecules. The nature of covalent bonds in the molecules of hydrogen ( $H_2$ ) and hydrochloric acid ( $HCl$ ) are illustrated in

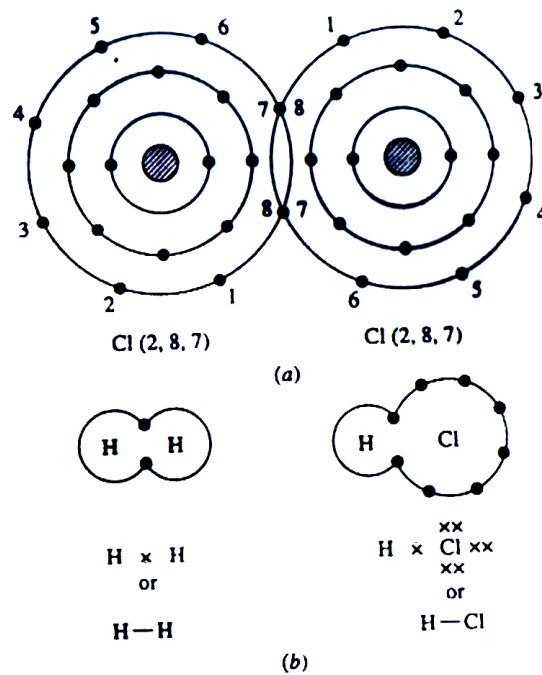


FIG3.2 COVALENT BOND

## METALLIC BOND

A metallic bond results from the sharing of variable number of electrons by a variable number of atoms. The atoms in metal and alloys are held together by such bonds. This type of bond is characteristic of the elements having small number of valence electrons, which are loosely held, so they can be easily released to the common pool. The bonding takes place when each of the

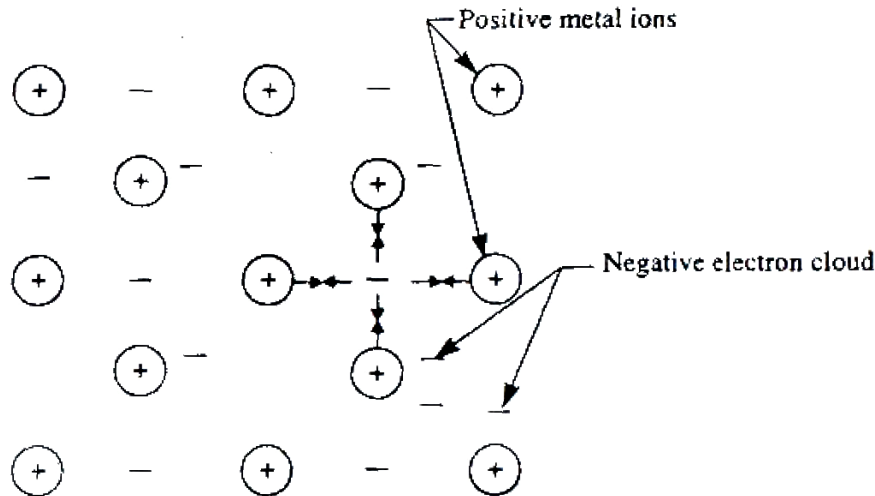


FIG.3.3. METALLIC BOND

of the metal contributes its valence electrons to the formation of an electron cloud that pervades the solid metal. The valence electrons are not bonded directly to an individual atom but they move freely in the sphere of influence of other atoms and are bound to different atoms at different times and that too for a short time.

Schematic picture of the metal ions (positive) and that a', electron cloud (negative). The cohesion of a metallic crystal is due to the attraction of the positive nuclei and the valence electrons passing between them. A metallic bond thus conceived can exist only between a large aggregate of metallic atoms and must therefore be non-directional. The high electrical conductivity to metals is given by the free electrons moving freely in an electric field.

### 3.2. TYPES OF CRYSTALS

#### BODY CENTRED CUBIC (BCC) STRUCTURES

In this type of structure, the unit cell (in the shape of a cube) contains one atom at each of its 8 corners and another atom at the body centre. It is thus obvious, that each unit cell shares 8 atoms one on each of its corners in addition to one atom at the body centre.

The common examples of this type of structure are  $\alpha$ -iron (below  $910^{\circ}\text{C}$ ),  $\gamma$ -iron ( $1400^{\circ}\text{C}$  to  $1539^{\circ}\text{C}$ ), tungsten, vanadium, molybdenum, chromium and alkali metals (i.e. sodium and caesium etc).

### **FACE CENTRED CUBIC (FCC) STRUCTURES**

In this type of structure, the unit cell (in the shape of a cube) contains one atom at the centre of its each face, in addition to one atom at each of its 8 corners as shown in Fig. 3.15. It may be noted that this type of structure does not contain any atom at the centre of the unit cell. It is thus obvious that each unit cell shares 14 atoms.

The common examples of this type of structure are  $\gamma$ -iron ( $910^{\circ}\text{C}$  to  $1400^{\circ}\text{C}$ ), copper, silver, gold, aluminum, nickel, lead and platinum etc. The face centred cubic structures are also found in ceramic crystals.

### **HEXAGONAL CLOSE PACKED (HCP) STRUCTURES**

In this type of structure, the unit cell contains one atom at each corner of the hexagonal prism, one atom each at the centre of the hexagonal faces and three more atoms within the body of the cell. It is thus obvious that each unit cell shares 14 atoms, and contains 3 atoms.

The common examples of this type of structure are magnesium, zinc, titanium, zirconium, beryllium, and cadmium etc.





## 4.0 PHASE TRANSFORMATIONS

### 4.2 EQUILIBRIUM DIAGRAM COOLING CURVES

A cooling curve is a graph of the structure of a pure metal or a combination of that metal with another metal. The latter is called an alloy. Thus studying a particular cooling curve yields data related to a particular combination of two or more metals of the entire temperature range through which an alloy cools. If the characteristics of another alloy of the same two metals are desired, the cooling curve for the never combination is needed. An equilibrium diagram is a composite of all cooling curves of all the possible combinations of two or more metals. It should be stressed that equilibrium diagrams are related to the conditions of cooling that occur slowly enough to be considered stable — hence the term equilibrium.

Assume a closed system. If the ice at  $-10^{\circ}\text{F}$  is heated, it absorbs heat until the ice reaches  $32^{\circ}\text{F}$ , at which point it will begin to melt. The mixture of ice and water will remain at  $32^{\circ}\text{F}$ , because all the heat is being used to melt whatever ice is being transformed to water at  $32^{\circ}\text{F}$ . Once all the ice has been transformed to water at  $32^{\circ}\text{F}$ , the heat added to the system will be used to raise the temperature of the water to  $212^{\circ}\text{F}$ . At this point the heat will all go toward transforming the water into steam at  $212^{\circ}\text{F}$ . The mixture of water and steam remains at  $212^{\circ}\text{F}$  until all the water converts to steam, at which time the heat input raises the temperature of the steam. The plot of this heating system.

The reverse mechanism takes place if the steam is in a closed system and if it is allowed to cool to  $212^{\circ}\text{F}$ . The plateaus at  $32^{\circ}\text{F}$

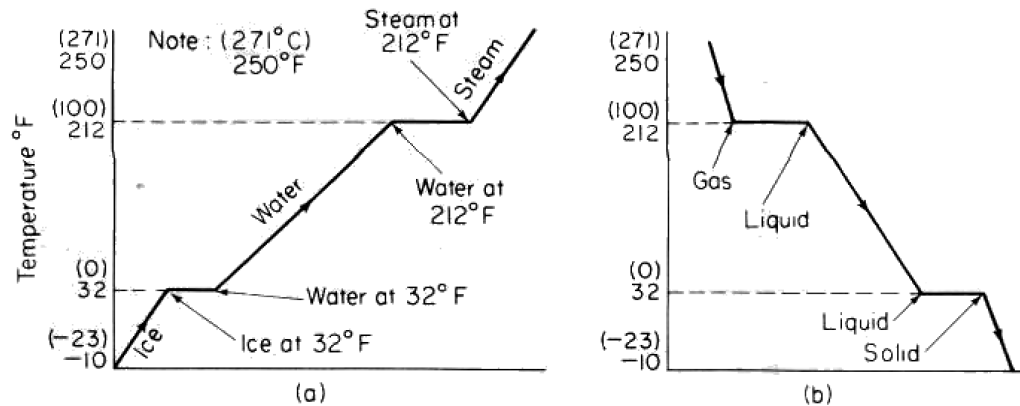


Fig. 4.1. phase changes in metals

and 212°F are the temperatures on the curve at which phase changes occur.

Several definitions are in order at this time: (1) The elements that make up an alloy or the chemical compounds that may be formed from these elements are called components. They are considered components if chemical means are needed to separate them. (2) A phase is a part of an alloy that does not require chemical methods to make that part distinguishable from other parts. That is, physical means can be used to distinguish the parts of the alloy.

If a pure metal is heated and then cooled very slowly, its cooling curve may be plotted. The curve *ab* represents the cooling of the melt. At temperature *T* and at point *b*, the pure metal starts to precipitate out of solution. At point *c* the entire melt has transformed to the solid pure metal. Note that curve *bc* is level and (hat the phase change occurs at one temperature *T*. From *c* to The solid metal undergoes cooling.

Two metals have been heated to point *a*, where both are liquid and are dissolved in each other. On slow cooling they remain liquid until they reach *T<sub>1</sub>* at which temperature solidification starts. At *I<sub>2</sub>* the solidification has been completed, and the entire mixture is

a solid solution. The cooling of the solid continues to d. Point b is the point where crystallization begins and is referred to as the liquidus point. Point c is the point on the curve where final solidification takes place. It is referred to as the solidus point.

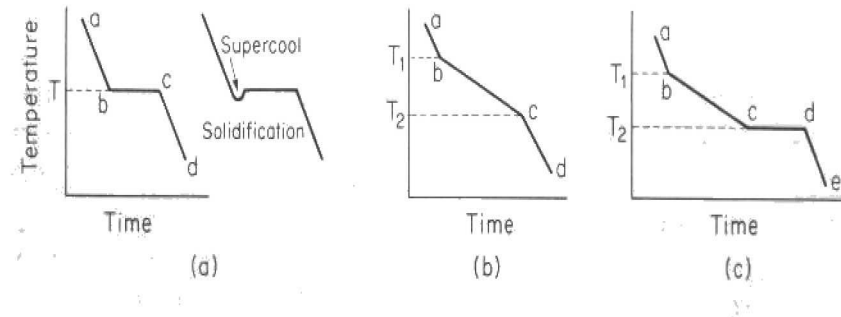


Fig. 4.2. cooling curves pure metals

where crystallization begins and is referred to as the liquidus point. Point c is the point on the curve where final solidification takes place. It is referred to as the solidus point.

Another type of cooling curve is one that exhibits characteristics. This occurs when two metals A and B are soluble in the liquid state but insoluble in the solid state.

In this mechanism the liquid solution starts to cool at a. At b, pure metal A starts to form and precipitate out of the liquid phase. As the temperature drops from  $T_1$  to  $T_2$ , pure metal A continues to precipitate. As metal A precipitates out, the ratio of B to A increases, and we say that the liquid remaining becomes richer in B. This mechanism of freezing results in the slope of the curve becoming steeper.

At c the freezing is that of the remaining metals of A and B. The temperature remains constant until all solidification is complete at d. Line de represents the normal cooling of the solid phases.

Several cooling curves of combinations of metals A and B. These curves have been rotated through 90 degrees, and the points a and b have been projected to the back plane as shown. That is, all points a are on the liquid line and all points b are on the solidus

'fine. When all the liquidus points are connected by a smooth line, and all the solidus points are connected by another smooth line, the equilibrium diagram results.

## **4.2. THE ONE-TWO-ONE AND INVERSE LEVER RULES**

The one-two-one rule provides a simple method for determining the

Phases that exist in a particular region. The procedure is to draw a horizontal line  $xy$  that starts at the solid boundary  $x$  and terminates at the liquid boundary  $y$ . The  $xy$  line itself lies in a two-phase region. The two phases are solid and liquid.

It should also be noted that in our example the overall composition of the alloy  $P$  is always 75 per cent metal  $A$  and 25 per cent metal  $B$ . Since there is only one phase (liquid) for temperatures above  $T_V$  the composition of the alloy is always liquid. The same is true for the single-phase solid that exists below the temperature  $T_3$  for alloy  $P$ .

However, at the intersection  $z$  of the temperature line  $it$  and the composition line  $P$ , two phases exist, namely liquid and solid. The composition of the liquid phase and the solid phase varies as the alloy cools along line  $P$ .

The line  $jcv$ , through point  $z$ , intersects the solidus line at  $x$ . If a perpendicular is dropped from point  $x$  to the abscissa of the graph, it will be seen that the line shows the composition of the solid phase as being



calculated by taking the length of the line zy and dividing this by xy. To get the percentage the values are multiplied by 100, Thus

### **4.3. TYPES OF EQUILIBRIUM DIAGRAMS**

There are several combinations of liquid solubility and solid solubility states that yield characteristic equilibrium diagrams. Equilibrium diagrams reflect combinations of these characteristic diagrams and may be classified with reference to their solid-liquid state combinations. That is, the components that enter into an alloy may be insoluble, partially soluble, or completely soluble in each other in the liquid or solid state. Several of these combinations are discussed with the use of hypothetical diagrams.

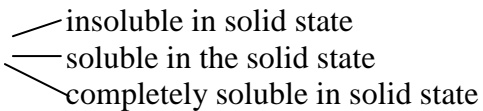
Certain elements may exist as two separate phases in the liquid state and two distinct phases in the solid state. This indicates a system completely insoluble in the liquid state and completely insoluble in the solid state. The idealized equilibrium diagram, characteristic of such a system. The liquid solubility of element A in element B is practically zero. As the system cools below  $T_1$ , solid A forms and precipitates out, and two phases exist. At  $T_2$ , solid B forms and exists as a separate phase with A.

Left portion of such a system. At the top of the diagram two liquids are shown existing as separate phases. The non-vertical boundary lines would indicate a very slight solubility.

Parallel boundaries (idealized) would indicate no solubility of the two liquids.

Systems that show this type of solubility combinations in the liquid and solid states are iron-oxygen, silver-iron, silver-tungsten, and copper-tungsten.

Another system is that in which the components are partially soluble in the liquid state. They may be partially soluble in the solid state, or they may be completely "soluble or insoluble in the solid state.

Partially soluble in liquid state partially 

- insoluble in solid state
- soluble in the solid state
- completely soluble in solid state

Figure 4-5 shows a diagram in which the elements are partially soluble in the liquid state and insoluble in the solid state. For alloy X the single-phase liquid state exists above  $T_1$ . Below the upper transformation line there exist two distinct liquid phases: one rich in element A and the other rich in element B. The partial solubility in the liquid phases exists in this region of the diagram. Below  $T_1$ , the A-rich phase solidifies, and a liquid-solid combination exists. As the temperature drops below  $T_2$ , B solidifies independently of A, so that B coexists with the A phase.

Partially soluble ( $L_1 + L_2$ ) and the solid phases are partially soluble ( $\alpha + \beta$ ). Thus, as the two partially soluble liquids cool, A and B exist as partially soluble in each other as an alpha ( $\alpha$ ) phase. The remaining liquid Z, solidifies as a partially soluble beta ( $\beta$ ) phase. Systems that show partial liquid solubility and partial solid solubility are zinc-bismuth, aluminum-lead, copper-iron, and zinc-lead.

Diagram in which the two components are partially soluble in the liquid state and completely soluble in the solid state. That is, elements A and B combine to form a single phase on cooling.

Another series of equilibrium diagrams is that in which the constituents are completely soluble in the liquid state in combination with varying degrees of solubility in the solid state such as these are nickel-copper, antimony-bismuth, chromium-molybdenum, gold-silver, and tungsten-molybdenum.

In some instances components may be completely soluble in the liquid state and completely insoluble in the solid state. One such equilibrium diagram. Bismuth-cadmium

forms such a diagram. In this example, the metals A and B in the alloy X are completely soluble above the liquidus line. As the temperature drops below the liquidus line, A precipitates out as heat is removed. At T the two metals A and B are evidently completely insoluble in each other, since the cooling curves exhibit a flat, or hold. Below T, the metals A and B are insoluble in each other.

A special invariant combination of A and B exists in this diagram. Whenever a combination of 60 per cent A with 40 per cent B exists, the two solidify as a eutectic. However, the eutectic also exhibits the fact that A and B are completely insoluble in the solid state.

The most common solubility combination of components is the case where the components are completely soluble in the liquid state and partially soluble in the solid state. Such systems are formed by combining copper-silver, copper-zinc<sup>^</sup> copper-beryllium, copper-tin, copper-aluminum, magnesium-aluminum, lead-antimony, lead-tin, and aluminum-silicon. The metals A and B are completely soluble in the liquid state and that in no case is pure A or pure B formed, except at the terminal sides of the diagram.

## **INTER METALLIC COMPOUNDS**

The addition of alloys to pure metals may alter the dimensions or the configuration of their lattice structures. The addition of alloying elements (solute) to a pure metal (solvent) may be accomplished in several ways.

In some instances, solute atoms may displace solvent atoms in a solid lattice. When this occurs, it is called a substitution solid solution. Since it is rare that the solute atoms are the same size as the solvent atoms that they displace, the result is a distortion of the lattice.



If elements are to be completely soluble in one another, they must have the same type of lattice structure. The greater the size difference between the atoms of the two elements, the less their solid solubility in substitutional solutions. That is, if atom A is larger than atom B, it will be less likely to substitute for a B atom in the lattice than would an atom C whose size is more nearly the size of B. It is also true that the tendency toward the formation of intermetallic compounds takes precedent generally over the formation of a substitutional solid solution. As the concentration of the solute increases, so does the probability of formation of a substitutional solid solution increase.

When the solute atoms lodge in the space between the solvent atoms the system is called an interstitial solid solution. This happens when the solute atoms are small, about half the diameter of the solvent atoms, and are able to fit in between the larger atoms in a lattice. Obviously, the size of the space between the solvent atoms, as well the size of the solute atoms, is important to the formation of an interstitial solid solution. Iron, nickel, chromium, manganese, molybdenum, tungsten, and vanadium are elements that lend themselves to being the solvent in the formation of interstitial solid solutions. Carbon, hydrogen, boron, nitrogen, and oxygen are atoms that have diameters small enough to act as the solute atoms in interstitial solid solutions. Iron, at room temperature, dissolves very small amounts of carbon interstitially. Above 1333°F the lattice structure changes from body-centered cubic lattice to face-centered cubic lattice, and the interatomic spacing increases, which makes it possible for carbon to form interstitial solid solutions.

If the atoms are insoluble in each other, a mechanical mixture results. The intermetallic compound results when the two, solute and solvent, atoms join each other. These space lattices are very complex. They transform from the liquid phase to the solid compound

phase at a fixed temperature and at a fixed composition. They differ from chemical compounds in that the rules of valence bonding, described earlier, do not apply. The mechanical properties associated with intermetallic compounds are high strength and hardness, low ductility, and low conductivity. As stated, intermetallic compounds form at one temperature. the alloy of A and B that has a composition of 55 percent and 45 percent B freezes from the liquid directly to our intermetallic compound. The region characteristic of such a compound is a straight line that divides the diagram into two distinct sections.

## **INVARIANT SYSTEMS**

Several additional combinations of a two-component system form when two elements are in the required fixed percentages for a particular change in phase to take place. In the binary system there are five such important reversible and invariant transformations. They are as follows (the diagrams are hypothetical):

These are invariant systems because they occur whenever an alloy has a fixed composition. For example, at a temperature  $T_B$ , anytime the composition of the liquid phase is 40 per cent A and 60 per cent B, that liquid will transform directly into a two-phase  $\alpha + \beta$ . It will behave as though it is a pure metal. As indicated, such a transformation is called a eutectic transformation.

The inverse lever rule was discussed in Sec. 4-2. If this rule is applied to alloy R, it will be seen that the liquid phase at e has the necessary 40 per cent A, 60 per cent B composition to be classified as a eutectic. At  $t_i$  and q, solidification starts in a manner such that its composition is z. As the alloy cools further to  $7a$ , the composition of the solid phase changes from z to x, and the liquid phase changes from q to y. It should be

remembered that the composition of each phase is determined by dropping a perpendicular to the abscissa and reading the percentages of A and B. Thus the percentage of B in the solid will increase from about  $z \sim 4$  per cent to  $x = 6$  per cent, while the percentage of B in the liquid will be enriched from about  $q = 20$  per cent to  $y = 30$  per cent. The percentages of A in the solid and liquid will decrease accordingly. The a-region represents a solid solution in which metal A is the solvent.

At  $T_f$ , the composition of the solid has moved from  $j_c = 6$  per cent B to  $w = 10$  per cent B, while the composition of the liquid has moved from  $y = 30$  per cent B to  $e = 60$  per cent B. Thus the liquid has a eutectic composition at  $e$  of 40 per cent A and 60 per cent B. As alloy R cools below TK, this eutectic liquid solidifies as if it were a pure metal [see Fig. 4-2(a)]. The result is solid A and B in the form of an alpha ( $\alpha$ ) phase, and A and B in the form of an eutectic phase.

Also, any alpha that solidifies above TK, between compositions A = 90 per cent and A  $\sim$  40 per cent, is called primary alpha. If beta solidifies above TE, between compositions A  $\sim$  40 per cent and X = 10 per cent, it is called primary beta ( $\beta$ ).

There is still another movement that takes place. Below TV the  $\alpha$ -phase is rich in component B. It cannot hold all the A component as it cools and forces it out of the lattice structure. In a like manner, some of the B component is forced out of the  $\beta$ -phase, which is A rich,

The composite analysis just discussed is shown in Table 4-2. The same analysis can be made for alloy 5,

It should be emphasized that a eutectic alloy has a fixed percentage of A to B, Since the eutectic liquid horizontal line, there can be only eutectic composition between  $A = 90$  per cent and  $A = 10$  per cent.

It should also be noted that only at composition E does the eutectic, and only the eutectic, form. To the left of E,  $A = 90$  per cent to  $A = 40$  per cent, the eutectic and a crystals form. This is called a hypoeutectic structure. To the right of E,  $A = 40$  per cent to  $A = 10$  per cent, the eutectic and  $\beta$  crystals form. This is called a hypereutectic structure.

## WEEK 5

### 5.1 INGOT CASTING

When a metal is to be produced in a wrought form it is first cast as an ingot of a shape and size suitable for processing in the plant available. Whilst steel is normally cast into ingots of approximately square section, non-ferrous alloys are frequently cast as flat slabs for rolling to strip or sheet; bars for the production of wire; and cylindrical billets for the extrusion of sections.

Metallurgical, as well as economic, considerations demand that molten metal shall solidify rapidly as soon as it is poured into the mould. Ingot moulds are therefore made from metal, and are either massive and of cast iron or of thin-walled copper which is water-cooled. In either case the molten metal will chill rapidly on making contact with the mould surface.

When the charge in the steel-making furnace is ready it is poured into a teeming ladle which has been conveyed to the teeming platform by means of a travelling electric crane. The ladle is a refractory-lined steel vessel equipped with a trunnion on each side, by means of which it is lifted. In order that the slag which floats on the top of the molten steel shall not enter the ingots the charge is poured from the bottom of the ladle (Fig. 5.1). Hence the steel outer shell has a hole in the bottom near to the rim, in which is fitted a refractory nozzle, together with a stopper of similar material which fits into the nozzle. The stopper is carried on the end of a steel rod, protected by refractory sleeving, which extends vertically through the molten bath. The stopper rod is connected to a lever mechanism by means of which an operator controls the raising and lowering of the stopper, and consequently the rate of pouring. The ladle is generally heated by gas before the charge is tapped into it.

When the molten steel has been poured into the ladle it may be deoxidised with ferro-manganese, ferro-silicon or aluminium. It is then allowed to stand for some time, whilst slag and other non-metallic materials float to the surface, after which it is teemed into the ingot moulds.

2.201 The ingot moulds are made from cast iron. A typical composition for the purpose is as follows: carbon, 3.5%; silicon, 1.0%; manganese, 0.8%; phosphorous, 0.15%; sulphur, 0.07%. These moulds are of various shapes and sizes. In cross-section they may be square or rectangular with rounded

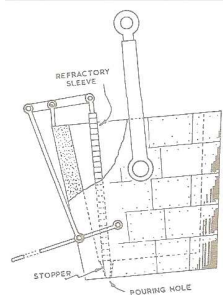


Fig. 5.1: The principles of the Bottom pouring ladle

edges, eight-sided, fluted, twelve-sided or circular with walls corrugated. The purpose of these corrugations is partly to accelerate solidification and thus produce a fine grain in the ingot and partly to minimize the formation of cracks in the ingot surface during the first rolling operation. Some typical ingot mould sections, in order to facilitate 'stripping' the ingot from the mould it is necessary to taper the mould cavity to the extent of about 20 mm per metre on diameter.

One end of the ingot is thus slightly larger than the other end, and moulds are commonly referred to as 'big-end-up' or 'big-end-down', according to whether they taper downwards or upwards. The big-end-down type of

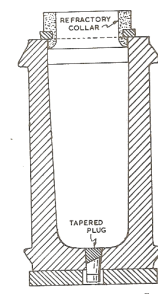
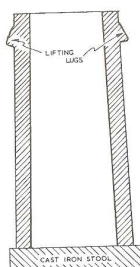


Fig. 5.2: Big-end-down ingot mould

Fig. 5.3 Big-end-up ingot mould with 'Hot Top'

mould (Fig. 5.2) is the older. It is open at both ends, and when ready for use stands on a thick cast-iron 'stool' which forms the bottom of the mould. Stripping of the ingot is thus relatively easy, since it is only necessary to lift the mould from off the solid ingot, which is left standing on the stool. 2.202 The newer big-end-up type of mould (Fig. 5.3) is usually closed at the bottom except for a round hole which is fitted with a tapered plug which facilitates the stripping of the solid ingot. This type of mould is generally fitted with a

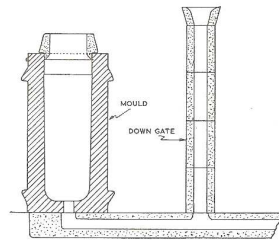


Fig. 5.4: Assembly for the bottom pouring of steel ingot

removable refractory collar or 'hot-top' which is placed on top of the mould. The function of this refractory collar is to slow down the rate of cooling at the top of the ingot and thus provide a reservoir of molten metal which can 'feed' into the main body of the ingot as it solidifies and hence contracts. The hot-top thus minimizes piping

Some high-grade steel ingots are bottom-poured into big-end-up moulds. The main reason for this procedure is to prevent splashing of the metal on to the sides of the mould, as is possible with the top-pouring method. These splashing freeze on to the mould walls and cause discontinuities in the surface of the solid ingot, with consequent imperfections on the surface of the rolled products. By using the more expensive bottom-pouring method, however, the mould is filled without agitation or splashing of the metal. In addition, the degree of oxidation of the metal during teeming is much less than it is with the top-pouring method.

The principles of continuous casting of aluminium alloys and other metals are mentioned later in this chapter). Similar processes have also been adapted to the casting of round, square and rectangular sections in steel; and slabs of 0.1 m<sup>2</sup> or more in cross-section are currently in production.

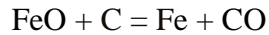
Illustrates one development of this type of process for the manufacture of steel strip between 2.5 mm and 25 mm thick. After the metal has cooled sufficiently in the water-cooled mould to form a solid shell on the outside, it is passed through a pair of squeeze rolls, the distance between the axes of which exceeds the centre width of the interior of the mould exit. The degree of reduction in centre thickness is of the order of 2:1. A number of pairs of rolls in succession may be employed beneath the mould.

## 5.2 Types of Steel Ingot

It was shown that pipe formation is likely to be more extensive in an ingot cast in a big-end-down mould than in one cast in a big-end-up mould. In fact, in the former type of ingot the formation of a secondary pipe is a probability which will be further increased if any gas is liberated during solidification of the steel. In either type of mould the extent of the pipe can be limited by the use of a hot-top as indicated.

It should not be assumed that all grades of steel are completely deoxidised before casting, for, whilst high-carbon steels are invariably completely killed, much semi-killed steel is produced, together with large quantities of low carbon 'rimming' steel, which receives little or no deoxidation.

Most of the excess oxygen (present as the oxide FeO) in molten steel at the end of the refining process is removed by the carbon which is added, according to the following reaction:



Some oxygen, however, can remain in the melt in equilibrium with carbon and the relationship between the amounts of oxygen and carbon which can exist together in the melt in this way is shown.

If the carbon content of the molten steel is known, therefore, the exact amount of deoxidant necessary completely to deoxidise the steel can be calculated, and if only partial deoxidation is required, then the amount of deoxidant added will be correspondingly less than this amount.

**High-carbon steels, medium-carbon steels for forging and steels for sand castings are completely killed, since a structure free from blow-holes is essential, but for many applications, particularly in soft steels, where the quality of the surface of the product is more important than that of the interior, the process called 'rimming' is used. In this process little or no deoxidant is used, and when the melt begins to solidify a layer of almost pure metal first forms at the surface of the mould. This causes the concentration of oxygen in the remaining liquid to increase so that the above reaction (1) begins again, with the consequent evolution of carbon monoxide, which tends to sweep away accumulated impurities from the face of the growing crystals. Thus a shell of very 'clean' metal is produced, and its thickness will depend largely upon the degree of initial deoxidation. When the metal has cooled to the point where solidification begins throughout the remaining liquid much of the evolved gas will be trapped (Fig. 5.5), and porosity in the interior of the ingot will result. Provided that these blow-holes are far enough below the surface, they will weld up effectively when the ingot is heavily worked in a rolling mill. If, however, they are too close to the skin of the ingot they may break through the surface so that they become oxidised, with the result that they do not weld up on rolling. Sometimes the rimming action, that is the reaction between the oxygen and the carbon with the resultant evolution of carbon monoxide, is stopped after the primary stage is over. This is done by deoxidizing the partly solid steel in the ingot mould by adding a calculated amount of aluminium.**

The main characteristics of rimmed steel is a surface skin which is relatively 'clean' and pure, and this gives a good surface to the finished product. Such

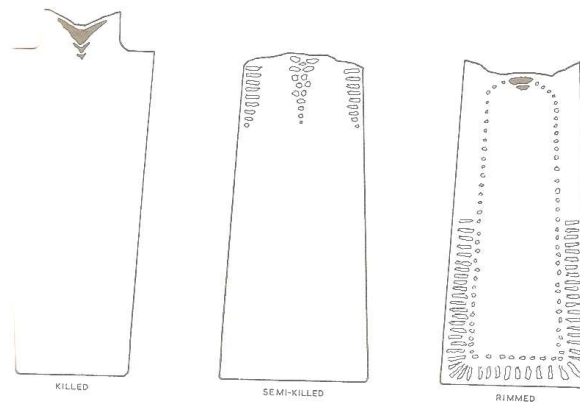


Fig. 5.5: Types of steel ingot

Steel is used for deep-drawing processes, tin-plate manufacture, and the production of galvanized sheeting.

In a semi-killed ingot the oxygen content after partial deoxidation is lower than in a rimming steel, so that the evolution of carbon monoxide tends to take place at a later stage in the solidification process. The porosity produced ; largely instrumental in eliminating the pipe.

Moreover, impurities tend to be 'pushed' nearer to the top of the ingot by the evolved gas, so that much of this impure material is cropped off. Thus some of the useful features of both completely killed and rimming ingots are combined in a semi-killed ingot.

Some alloy steels and special forging steels are now vacuum de-gassed in order further to improve their soundness, one method of de-gassing. Here a stream of molten steel is drawn into a vacuum chamber which contains the ingot mould. Reduction of the internal pressure within the stream leads to its de-gasification. In this way the whole charge is treated successively. Dissolved gases such as hydrogen and nitrogen boil off. This upsets chemical equilibrium within the molten steel so that reactions occur between oxides and silicates and dissolved carbon:

$\text{Silicates} + \text{C} \rightarrow \text{Si} + \text{CO}$  (Boils off).

Silicon thus liberated dissolves in the steel



## WEEK 6

### 6.1 EQUILIBRIUM OR CONSTITUTIONAL DIAGRAMS

The solidification of an alloy generally occurs as a continuous process over a range of falling temperature and even after becoming solid, constitutional changes of far reaching importance may continue to take place. In a series of alloys such as the cupro-nickels or the carbon steels, it is possible by plotting temperature against composition to represent graphically the changes which take place during and subsequent to solidification. Such graphs, suitably annotated, are known as equilibrium diagrams, and a knowledge of them is useful in the control of casting operations and heat treatment processes. An objection to these diagrams, which is sometimes raised, is that they deal with alloys in a stable or equilibrium condition, only realised by either extremely slow cooling or very prolonged annealing, a condition rarely obtained in practice. *Nevertheless they do show the direction in which changes are likely to occur.*

While often appearing complicated, the sections covering industrial alloys can be interpreted on the basis of three simple types-eutectic, solid solution and peritectic, each characterised by a definite arrangement of lines. They do not indicate the structural arrangement of the phases, i.e. laminate, globules, films; nor do they indicate the velocity of reactions.

### 6.2 EUTECTIC

For the present purpose the lead-antimony system may be considered a simple eutectic, in which the metals are completely soluble in the liquid and entirely insoluble in the solid state. The equilibrium diagram is shown in Fig. 36. Alloys within the temperature-composition limits above AEC are liquid and the boundary lines AE and EC, obtained from cooling curves, are known as the *liquidus*. A characteristic of this diagram is that the liquidus consists of two branches falling in temperature from the freezing point of the two metals to a minimum intersection point, known as the eutectic point (E).

All the alloys become completely solid at the same temperature, corresponding to the temperature at E, and the boundary ADEBC is known as the *solidus*. The areas ADE and CBE represent alloys in a pasty condition -solid dendrites and liquid.

Consider the *solidification of an alloy* of composition  $x$  (40 % lead). At temperature  $t_b$  seed crystals of antimony are formed. The melt is consequently enriched in lead and is represented by a point, such as  $Y_1$  (55 % lead). Its temperature must therefore fall to  $t_2$  if the dendrites are to continue to grow by further deposition of antimony and consequent enrichment of the liquid in lead. This process is repeated continuously until the composition and temperature are given by point E. Further separation of antimony proceeds along an extension of CE (shown dotted), reaching a point  $E_1$  which is supercooled sufficiently below curve AE\* to cause solidification of lead with heat burst and cessation of growth of antimony. Lead crystals can continue to grow for a very short time only since its separation along line AE soon enriches the alloy in antimony to a point at which antimony must again separate. This process of alternate solidification of minute quantities of lead and antimony maintains the alloy at an almost constant temperature, until it is completely solid, then normal cooling IS resumed as indicated by the cooling curves in Fig. 36.

Similarly, any alloy between E and A (13 to 0 % antimony) commences to solidify on reaching line AE by forming lead dendrites and the residual melt is gradually enriched in antimony until point E is reached, when it

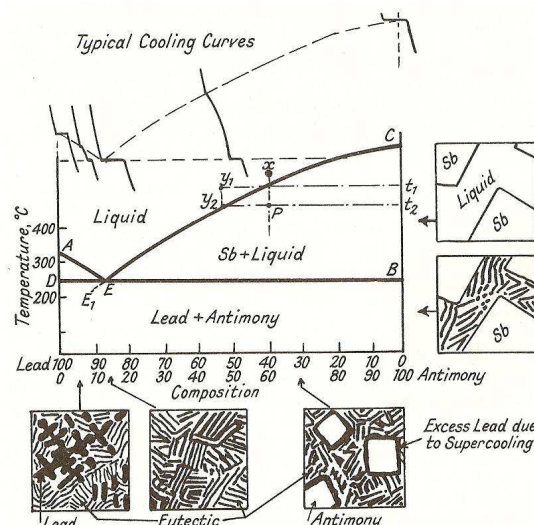


Fig. 6.1 Eutectic diagram structures and cooling curves. A similar structure is observed in all the other alloy of lead and antimony has the same structure. As a rule, one constituent forms a continuous matrix and the other is dispersed. The dispersed constituent may consist of small globules or all tend to be fine in the centre of the grain, thus showing a copper-silver eutectic of the same type.

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$\text{CuAl}_2$  embedded in  $\text{CuAl}_2$ -Al eutectic. Other eutectic structures are shown

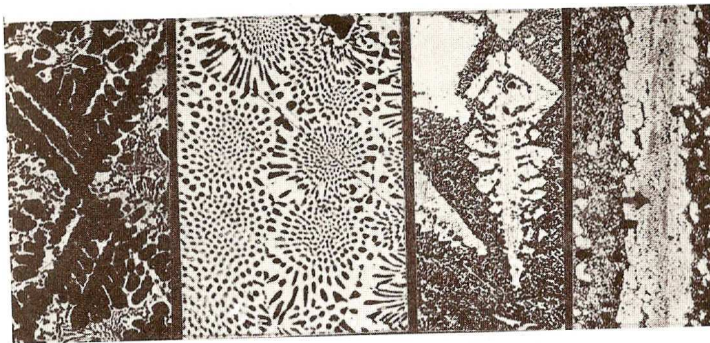
A *eutectoid*, as its name implies, is closely related to a eutectic and the eutectoid diagram, so important in the case of steels and aluminium bronze can be interpreted in a manner similar to the eutectic diagram just discuss (I. Just as the liquid may be considered to break up into two kinds of crystal on solidification, so the eutectoid is formed from the breaking up of a *solid solution* into two different, but intimately mixed, constituents.

### 6.2.1 Interpretation of equilibrium diagrams

At this stage it is convenient to summarise a few rules which help in interpreting equilibrium diagrams for two elements.

- (1) The diagram consists of solubility lines which divide it into areas, known as *phase fields*, representing either single or double constituents, such as ADE in Fig. 36. Single phase fields are always separated from one another by a two-phase region, and three phases can only exist at a single temperature (e.g. E).
- (2) If a vertical line, drawn to represent the composition of an alloy, crosses a line in the diagram, it denotes that some change occurs in the alloy.
- (3) At any point in a two-phase field the
  - (a) *Composition* of the constituents, in equilibrium with each other, is given by the intersection of the boundaries by the horizontal line drawn through the point. For example, at point P in Fig. 36 the intersections  $t_2$  and Y2 represent solid antimony and liquid containing Y2 per cent of lead;
  - (b) *Relative weights* are given by the relative lengths of the lines,  $Pt_2$  and  $Ph$

$$\frac{\text{weight of liquid}}{\text{weight of solid antimony}} = \frac{Pt_2}{PY_2'}$$



- 37 Copper dendrites in copper – silver eutectic 35% copper
- 38 Copper-silver eutectic. Note colonies (x 80)
- 39  $\text{CuAl}_2$  dendrites in eutectic; 45 % copper ( x 1.00)
- 40 30% copper-tin alloy showing effect of peritectic reaction (x 80)

### 6.2.2 Solid solution diagram

A typical diagram for two metals completely soluble in both the liquid and solid states is shown in Fig. 6.2 for copper and nickel. Again there is a range of solidification, but in this case not pure metals, but solid solution always solidifies and in certain cases the temperature of solidification may be higher or lower than that of the pure metals.

Consider the solidification of an alloy of any composition, say  $x$  (50% copper). When it reaches a temperature  $t$ , freezing starts as shown by the liquidus curve, the solid formed, however, is not of the same composition  $a$ ;  $x$  but of composition  $Y$  (35 % copper), on the solidus at temperature, which of course shows the temperature at which solid alloy of composition  $Y$  would commence to melt on heating, forming a liquid of composition  $e$  the first dendrites are richer in nickel the remaining melt will have a composition such as  $X_1$  richer in copper than the original composition  $x$ . At temperature  $t_1$  the composition of the solid in equilibrium with the liquid is  $y$  and fresh deposition of solid will adjust this composition: At the same time original dendrites should absorb copper from the liquid to change their composition from  $y$  to  $Y$ . Finally, the liquid  $X_2$  vanishes at temperature  $t_2$  and the solid has the uniform composition of  $x$ . This state of affairs rarely occurs in commercial alloys owing to the rapid cooling which prevents the attainment of equilibrium.

The effect of rapid cooling is to prevent the first dendrite  $Y$  from absorbing the proper amount of copper as the temperature falls to  $t_1$ . Hence the average composition of the solid is not  $Y$ , but one between  $Y$  and  $Y_1$ . As a result the liquid contains more copper than that indicated by  $X_1$ : Each layer of solid which is deposited on the dendrite skeleton differs in composition from the preceding layer and when temperature  $t_2$  is reached there still remains some liquid richer in copper than  $X_2$  which solidifies at some temperature  $t_3$ . The alloy consists of a number of cored crystals whose average composition is  $X$ , but in each the primary skeleton is rich in nickel and the interdendrite spaces are rich in copper. Many commercial alloys have this type of structure in the cast form and a typical photograph is shown in Fig. 65. Suitable annealing eliminates the cored structure by allowing diffusion of the atoms to occur (Fig. 67).

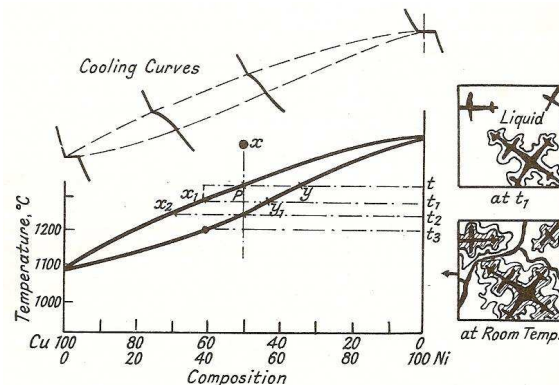
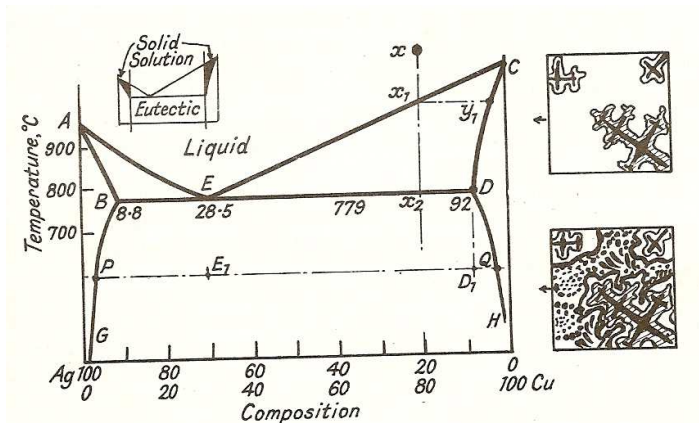


Fig. 6.2: Equilibrium diagram for two metals completely soluble in the liquid and solid states

Zone refining is a process used for purifying metals, particularly silicon and germanium for transistors. It uses the fact revealed in Fig. 41, namely that the first crystals deposited are much purer in one component than the liquid at the same temperature. A narrow zone in a bar of the impure metal is melted at one end and caused to move along the bar so that metal is melting into the zone on one side and freezing out at the other. The first solid frozen out is purer than the average composition while the liquid becomes enriched in solute which is deposited at the other end of the bar. Repeated cycling in one direction can reduce the impurity to below 1 part in  $10^8$ .

### 6.2.3 COMBINATION TYPES

Where, among other factors, the two kinds of atoms are very different in size, each metal may be capable of dissolving only a limited percentage of the other. Then the equilibrium diagram formed may be classed as intermediate between the two types just discussed, and consists of two parts, one resembling a simple eutectic and the other which may be regarded as a part of a complete solid solution curve.



### 6.3 EUTECTIC AND SOLID SOLUTIONS

A typical diagram is shown in Fig. 6.3 of the copper-silver system. The small inset drawing shows the components. The liquidus AEC is precisely similar to that shown in the simple eutectic. The solidus ABEDC, however, has two sections, AB and CD, *resembling parts* of the solidus in Fig. 6.2. In fact, alloys containing less than 8.8 % or more than 92 % copper will solidify forming cored solid solutions in a manner exactly as has been already described in the case of a simple solid solution series. \*

The point B denotes the maximum amount of copper which can dissolve in silver when the alloy is just solid, while the point D gives the corresponding information regarding silver soluble in copper. All alloys between B and D solidify as described for the simple eutectic, except that, *instead of pure metals separating from the melt we can only have solid solutions Band D, which will be cored unless the cooling is exceptionally slow.*

#### Changes in the solid state

The solubility of the metals in each other after solidification will undergo changes upon further cooling, as shown by the curves BG, DH.

Consider the changes occurring during the solidification of an alloy of composition  $x$  (80 % copper).

- (1) Solidification will commence at a temperature represented by point  $X_1$  on liquidus, and solid of composition  $Y_1$  will separate out.
- (2) The temperature will fall to that of the eutectic E. Ignoring the effect of coring, the alloy will now consist of a solid solution whose composition is denoted by D and liquid of composition E (28.5 % silver), the relative proportions of liquid to solid being in proportion to the lengths of  $X_2D$  to  $x_2E$ .
- (3) The liquid will solidify completely at this temperature into a eutectic composed of two solid solutions, Band D, in the proportions of ED to EE.
- (4) Upon further cooling the solid solutions Band D in the eutectic will become respectively poorer in copper and silver. Their compositions at any temperature, say 600°C, are P and Q and the relative proportions are given by the lengths of EIQ and EIP.
- (5) Similarly, the primary dendrites of composition D will split up into two solid solutions of Q and P in the proportion of  $PD_1$  to  $QD_1$ . These changes in the solid state take considerable time to complete themselves and may be partially if not completely prevented by quenching. Herein lies a fact of which advantage is repeatedly taken in heat-treatment processes.

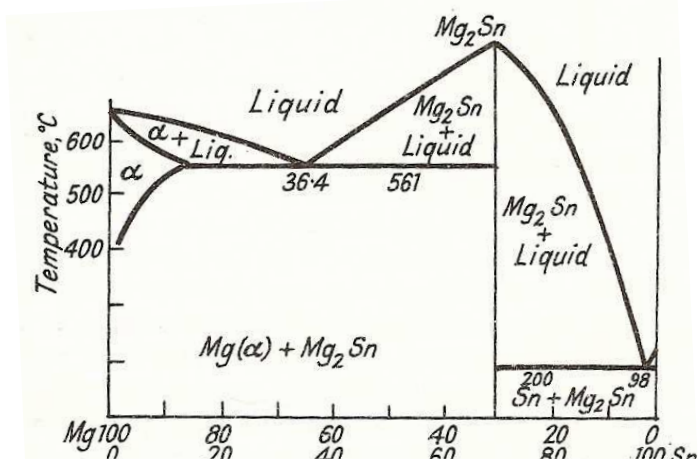




Fig. 6.4: Equilibrium diagram showing presence of intermetallic compound

## 6.4 INTERMEDIATE PHASES

In many binary alloy systems mutual solubility of the metals is limited and intermediate phases (called  $\beta$ ,  $\gamma$ ,  $\delta$ ) are formed, which may be classed as two types.

- (1) *Intermetallic compounds of fixed composition* which obey the usual valency laws, like ordinary chemical compounds (e.g. NaCl). A typical example is  $\text{Mg}_2\text{Sn}$  containing 29.08 % magnesium. The constitutional diagram is shown in Fig. 6.4. The compound has a definite melting-point which is lowered by addition of excess magnesium, or of tin. The diagram consists in fact, of two eutectic diagrams placed together, each resembling and not therefore calling for further observation.
- (2) *Intermetallic compounds of variable composition* which do not obey the valency law; known as *electron compounds*. Many of these fall into three classes according to the ratio of valency electrons to the number of atoms:
  - (a) Ratio  $\frac{e}{a}$ -beta ( $\beta$ ), e.g. CuZn,  $\text{Cu}_3\text{Al}$ .
  - (b) Ratio  $\frac{e}{a}$ -gamma ( $\gamma$ ), e.g.  $\text{Cu}_5\text{Zn}_{18}$ ,  $\text{Cu}_8\text{Al}_{14}$ .
  - (c) Ratio  $\frac{e}{a}$ -epsilon ( $\epsilon$ ), e.g.  $\text{CuZn}_3$ ,  $\text{Cu}_3\text{Sn}$ .

### Peritectic diagram

In many systems of alloys a reaction takes place, at a definite temperature, between the definite proportion of the solid already deposited and the residual melt (BP: BA in Fig. 44) to form another solid solution or compound of a composition intermediate between that of the first solid and the liquid. This is known as a peritectic reaction and it gives rise to a diagram such as is shown below.

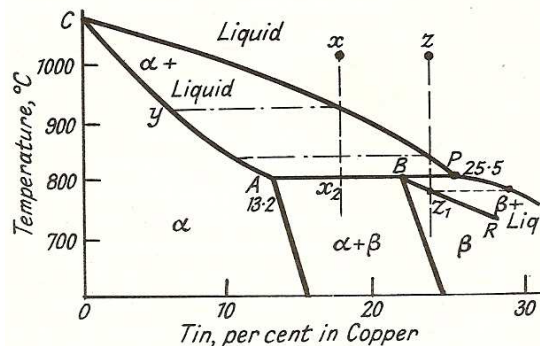


Fig. 6.5: equilibrium diagram showing peritectic reaction (Cu-Sn)

If the effect of coring is ignored any alloy up to 13.2 % tin (A) will solidify as described for a solid solution, as will also alloys with more than 25.5 % tin. Consider alloy  $x$ ; primary crystals  $y$  form and as the liquid cools the solid ( $\alpha$ ) changes to A, while

the liquid changes its composition along the liquidus CP to P. The liquid which remains ( $Ax_2$  to  $Px_2$ ) reacts with the solid crystals A to form a new intermediate phase (B). Since  $X_2$  lies between A and B, all the liquid P will be used up before the crystals A, and the alloy will then consist of

solid  $x$  and  $\sim$  crystals of composition A and B respectively. An alloy of composition Z again commences to solidify by depositing  $\alpha$  (solid solution which changes in composition to A at 798°C. Theoretically, these  $\alpha$  crystals are then completely converted to  $\sim$  crystals of composition B, since Z lies between B and P, and the excess liquid P, solidifies by depositing  $\beta$ , which changes in composition along solidus BR to ZI.

In practice these peritectic reactions rarely go to completion owing to the fact that primary  $\theta$  crystals become coated with a skin of  $\gamma$  which prevents the diffusion of the tin rich material to the central regions. Even in alloys of composition Z, a core of  $\theta$  remains. A typical example of this effect for an alloy of 30 % copper in tin. The  $\text{Cu}_3\text{Sn}$  ( $\theta$ ) is coated with  $\text{Cu}_3\text{Sn}_3$  ( $\gamma$ ) and the background is eutectic of  $\gamma + \text{Sn}$ .

## WEEK 7

### 7.1 EXTRACTION OF METALS FROM ORES

Iron Ore is an unimpressive looking rock that may contain only 30% iron. The source of all ferrous material is iron ore, a chemical compound of iron and oxygen in the earth crust. The production of iron involves the separation of iron from its oxide, known chemically as a reducing process carried in blast furnace Iron Ore as a sort of earth or rock containing iron. This Ore is found intermixed in rock, gravel, clay, sand or even mud Getting pure iron out of this form is very costly, but necessary. The following are some of the classes of iron ore.

**MAGNETITE-** ( $\text{Fe}_3\text{O}_4$ ) (Ferrous ferric oxide) color (Green, blue). This contains about 72.4% Iron when pure. It is magnetic and this feature makes it easy for its exploration.

**HAEMATITE** – ( $\text{Fe}_2\text{O}_3$ ) (Ferric Oxide) colour (Red, black and green) this contains about 70% Iron.

**LIMONITE** – ( $2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$ ) Ferric Oxide colour (yellow, red, brown and black) this is another type of Ore which is among the hydroxides Ores and has a composition ranging from about 60% Iron.

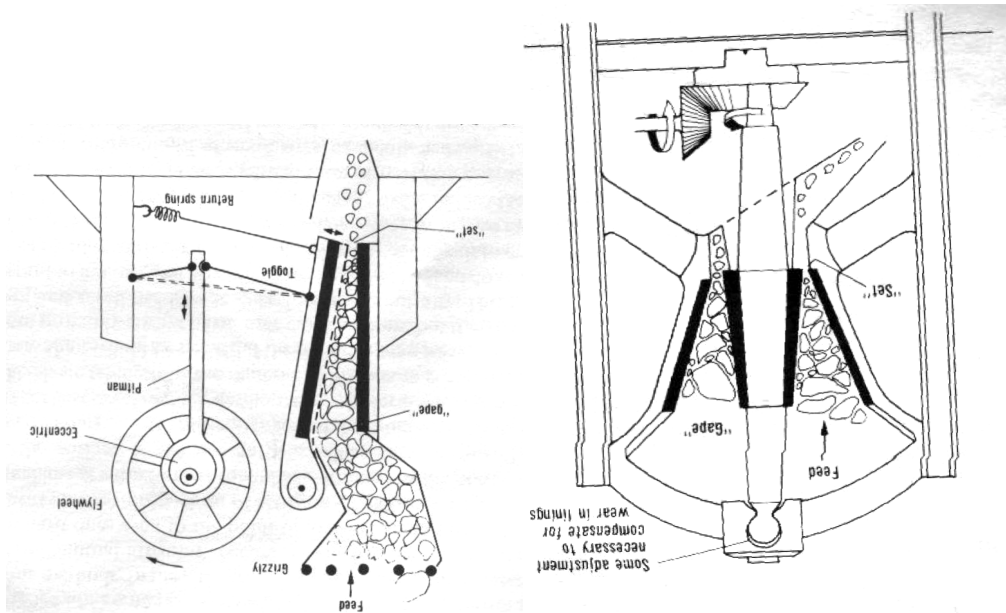
**SIDERITE** – ( $\text{FeCO}_3$ ) Iron Carbonate colour (Green, brown and yellow) this contains about 48% Iron and is in the family of Carbonate Ore.

### 7.2. BENEFICIATION OR PRELIMINARY, TREATMENT OF IRON ORE FOR SMELTING.

The term Beneficiation with regard to iron ore refers to all methods used to improve its chemical and physical properties in ways that will make it a more desirable feed for the blast furnace or increase the efficiency of the smelting process.

Since iron ores are mined from earth crust it is considerably rich in earthly materials. This material and other compounds which are combined in nature with iron ores are usually reduced before smelting in blast furnace the manufacture of Pig Iron. Some of the methods used are as follows.

1. **CUTTING** – Is accomplished by crushers such as gyrators and jaw crusher. The iron ore is broken into smaller suitable pieces by large crushers. The purpose is to avoid handling of problems due to oversize.



**2. GRINDING** – Is the process whereby coarse material are reduced to fine powders. For grinding we have ball mills, steel rod mills e.t.c

Grinding is mainly carried out in ball mills or in similar equipment (tube, peddle, and rod mill).the typical ball shape is a barrel shaped vessel rotating on it's horizontal axis. It has special replaceable cylindrical liners, lifters, and end plates and is loaded to just under half full with balls of steel or cast iron.

The linings and end walls have traditionally been made of high alloyed steels including 13% Mn “Hadfield” steel or special iron. The section being design of replacement in so far as is possible.

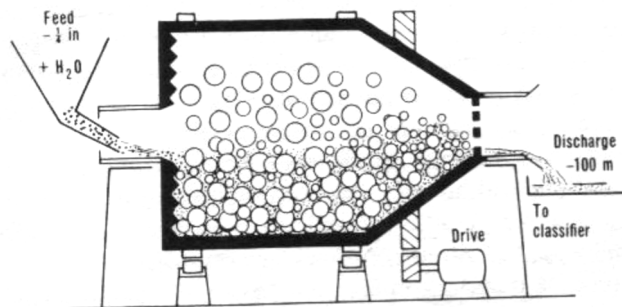


FIG 7.1. GRINDING



## WEEK 8

### 8.0 CONCENTRATION OF ORES

#### 8.1. CONCENTRATION –

This is the removal as much as possible, the earthly waste or gangue which would otherwise take up useful space in the blast furnace and thus reducing output one of the processes for concentration of ores are:-

##### (iii) Heavy media separation process –

This is based on the sink and float process. When a mixture of particles of two minerals are placed in a liquid having an intermediate Specific gravity between the two minerals. The mineral with high specific gravity will sink while the lower one will float.

##### (iv) Magnetic Separation Process –

After grinding the ore and the waste is passed over a rotating drum, whereby the ore is magnetized to the drum and the waste will flow away. In the case of magnetic the unwanted materials are removed by magnetic separation.

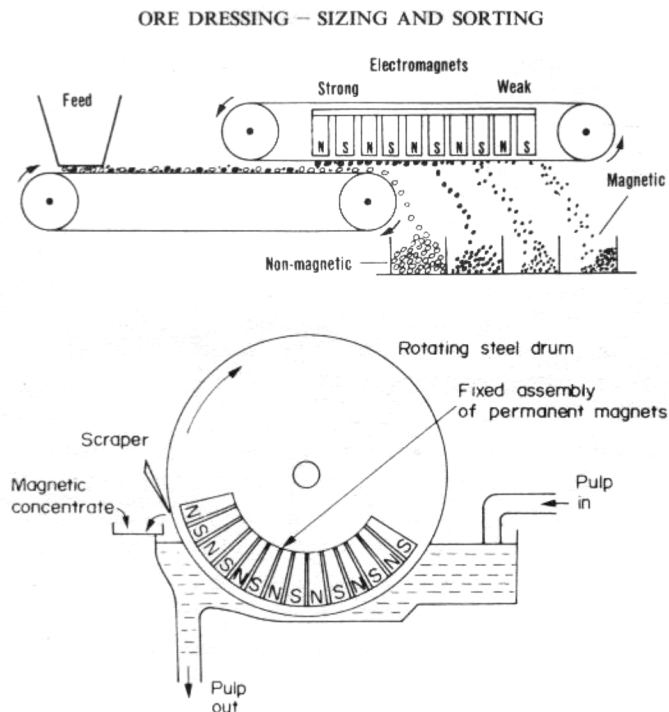


FIG. 8.1. CONCENTRATION

**(iii) Washing with water to separate the ore from the waste.**

**(iv) CALCINATION –**

This involve roasting in an excess air. This operation is effected in a kiln and is usually applied to ores which contain a large amount of moisture or carbon dioxide. Calcinations of the hydrated ores drive off moisture and combined water and leaves the ore more porous.

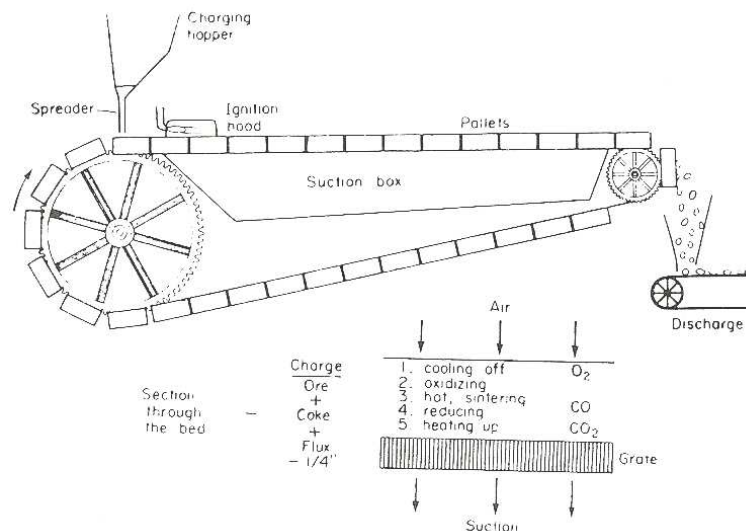
These substances may cause irregular working in the blast furnace and are best removed before the ore is smelted. This operation also helps to remove sulphur by oxidizing it to sulphur dioxide. This converts ferrous carbonate to ferrous oxide.

**(v) AGGLOMERATION –**

During the processes mentioned above, a large amount of iron may be found in the resulting dust. This dust rich in iron can be reclaimed but cannot be charged into the blast furnace in dust form. This is because the dust will fill up the spaces between the winps of the charge thus impeding the upward flow of gases or may be blown out of the furnace.

Agglomeration may be defined as method of coalescing small iron particles lost driving concentration under the influence of heat to form large particles or masses. The dust can be conditioned as follows to enable it be charged into the furnace.

**(i) Sintering –**



Schematic Dwight Lloyd sintering machine

The dust is mixed with small amount of coke or breeze and fed to a Duight – Liog machine. Ignition of the coke, assisted by air drawn through the pellets generates sufficient heat to frit together the particles of ore producing a porous and easily reducible sinter.

**(ii) Palletizing –**

Dust is mixed with a little starch and water and rolled in a drowm so that small balls are formed. Coal dust is then added and the small balls rolled on to a grate of a sintering machine where they are first dried and then baked at  $1000^{\circ}\text{c}$  to harden them.

It can be defined as a method of agglomeration in which balls or pellets which are subsequently harden by heat treatment.

**(iii) Nodulizing –**

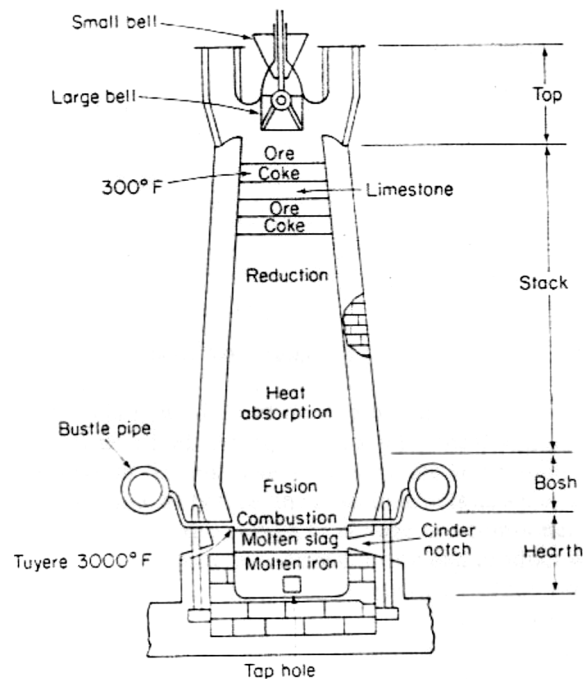
This is a process of forming an aggreme ration of fine materials by rolling at high temperature in a rotating kiln.

## 9.1. MANUFACTURE OF PIG IRON

The principal raw material for all ferrous metals (cast iron, wrought iron and steel) is Pig Iron. Pig Iron is extracted from Iron Ore. The first stage in the production of pig iron is to reduce iron ore to iron. This operation is termed smelting which is carried out in a container called blast furnace. Blast furnace is a retical steel shell that is roughly cylindrical in shape and is lined with a refractory material. Modern blast furnaces are about 30 meters tall (taller than a 12 storey building) and 9 meters in diameter.

The materials (iron ore, coke and limestone) are fed into the furnace, and are often called the charge. The solid raw materials are charged in alternate layers from the top surface.

Iron ore – This forms about 1/20 of the earth crust and is sort of rock containing iron.



Coke – Is a form of carbon. It serves as a fuel to generate heat. Heat is provided by burning the coke with hot air.

The hot air is introduced at the bottom of the furnace through large dusts called TUYERES to burn with the coke, producing intense heat (raising the temperature to about 1150° C). The purpose of coke is to produce heat and carbon monoxide (a reducing gas meaning that it removes oxygen) which in turn reacts with iron ore to produce iron and carbon dioxide. The coke burns first, it in turn, melts the iron ore and limestone, and a chemical reaction takes place that produces free iron. The purpose of hot air is to aid combustion.

The use of hot air instead of cold air reduces the amount of coke consumption needed by more than 70%. The air is heated in air pre-heaters or stoves. The hot gases work their way to the top of the furnace and are collected, after being filtered by dust catchers. These hot gases are then routed through the stove. At the same-time the limestone melts and removes

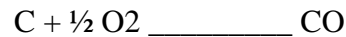
impurities or wastes (gangue) from the iron ore to form a fluid called slag. As the smelting continues the molten iron is the heaviest it sinks to the base of the furnace and the slag floats on top of molten iron. As shown in the diagram below the furnace is provided with two tapping holes. The slag is first drawn from the upper hole and the molten iron is allowed to run from the lower hole into moulds. The blocks (moulds) of iron so formed are termed 'Pigs' and are referred to collectively as 'Pig iron' iron are produced and tapped from the furnace every three to four hours. The pig iron is tapped at a temperature of about 1427° C. the slag is used in brick making, as an asphalt filler, and as a spread on ice to prevent falling.

Chemical reactions taking place are as follows:-

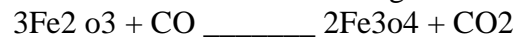
The removal of oxygen from the iron oxide is brought about by the chemical reaction known as reduction or reducing process. The reducing agent in this case bring carbon monoxide gas (co) which readily combines with oxygen and becomes carbon dioxide gas (CO<sub>2</sub>), leaving iron. Coke in the region of tuyeres burns completely.



Carbon dioxide is reduced by coke to carbon monoxide



Carbon monoxide reduces iron ore in three stages



The operation of blast furnace is a continuous process and they are normally shut down only for re-lining and over heavy. They are operated in groups so that shut downs, taken in rotation, do not stop production.

The five major elements present in pig iron are carbon, silicon, manganese, phosphorus and sulphur.

## 9.2. COMPOSITION OF PIG IRON

Pig iron contains 3-4% carbon with silicon, phosphorus manganese and sulphurous varying amounts and larger dependent on the type of ore smelted. A high phosphorous ore will give a high phosphorous iron, known as BASIC IRON whilst the haematite ores give low phosphorous iron, known as ACID IRON.

### DIFFERENCES IN THE COMPOSITION OF ACID AND BASIC IRONS

ELEMENT	PERCENTAGE IN BASIC IRON	PERCENTAGE IN HAEMATITE IRON
CARBON (C)	3.50	3.75
SILICON (S)	0.85	2.00
SULPHUR (S)	0.08	0.04
PHOSPHORUS (P)	1.60	0.045
MANGANESE (MN)	1.00	0.50

**CARBON** – Is the most important. It is found in iron in two forms

- (1) Combined with elemental iron, forming iron carbide (cementite)
- (2) As free carbon (Graphite) in flake form.

**SILICON** – A high silicon content is associated with a high carbon content and it influences the form which the carbon takes in iron. It makes steel fevid. It tends to produce giaphilisation (the brake down of cementite to produce (graphite) causing the steel to become weak.

**MANGANESE** – It tends to make the harmful effect of surphur is also useful as it to form manganese sulphide which has a high melting point and is only sparingly soluble in the metal carbon steel contain up to 1% manganese.

**SILICON** – Is a very good deoxidizer. It removes the gases and an oxide prevents blow holes and thereby makes the steel together and harder.

**MANGANESE** – Also serves as a good deoxidizing and purifying agent. It also combines with sulphur to form manganese sulphur and thereby reduces the harful effects of sulphur remaining in the steel. When used in ordinary low carbon steel, it makes the metal luctile and sulphur – this may come from the coke or it may be present in the ore. It forms ferros sulphide which has a comparatively low melting point and is very brittle. It is a very undersirable impority as it makes both iron and steel brittle and weak and for this reason as always kept as low as possible about 0.05%. The ferrous sulphide or iron sulphide collects at the grain boundaries making steel cold – shot (unsuitable for cold working) because of it brittleness, it also makes steel hot – short (unsuitable for hot working) because it melts a hot working temperatures and of so cause the steel to crumble.

**PHOSPHORUS** – Almost all of the phosphorous I the ore is absorbed by the iron during smelting. Because it imparts a hardness and brittleness to the metal at normal temperatures, it is always kept to minimum. It does, however, give flirty to melten iron and this is useful when casting intricate shape involving thin component parts. The proportion of phosphorus present in Pig iron will determine whether the acid or the basic process should be used in steel making. Iron Ores are graded according to their phosphorus content.

There are two major steel making processes, although they offer widely in method of operation they are identical in principle. In both cases, the excess carbon and other unwanted impurities are oxidized out. The steel melted.

## **10.0 STEEL MAKING PROCESSES**

### **10.1. BESSEMER PROCESS**

This method of steel making was invented by Sir Henry Bessemer and does not use a furnace but a converter. The Bessemer converter is a pear – shaped steel vessel that is open method, refractory – lined, and upon a trunnion, so that it can be swing into a horizontal position for charging and pouring and into a vertical position for blowing.

The converter is tilted to the horizontal position to receive the charge of molten Pig Iron because it does not melt metal and operates only on molten charges and when about half filled, it is turned up.

Air is blown into the converter. The oxygen in the air oxidizes (combine) the carbon together with the impurities present. As the impurities are oxidized and the metal becomes purer, its melting point uses considerably but this presents no problem because the action is highly exothermic, i.e. much heat is generated during the oxidation. The temperature is entirely dependent on the impurities in the metal and a shortage of these materials would result in a smaller temperature rise which might not keep the metal fully molten.

The blow with a converter is a spectacular performance beginning with a great agitation of the metal and an increasingly large agitation of the metal and an increasingly large flame from the mouth. Silicon is oxidized first, followed by manganese and finally carbon, the elimination of which causes the boil with a violent reaction as carbon monoxide is which dies away as the carbon is exhausted. The metal still contains dissolved oxides and will need the addition of carbon to bring it to the required level.

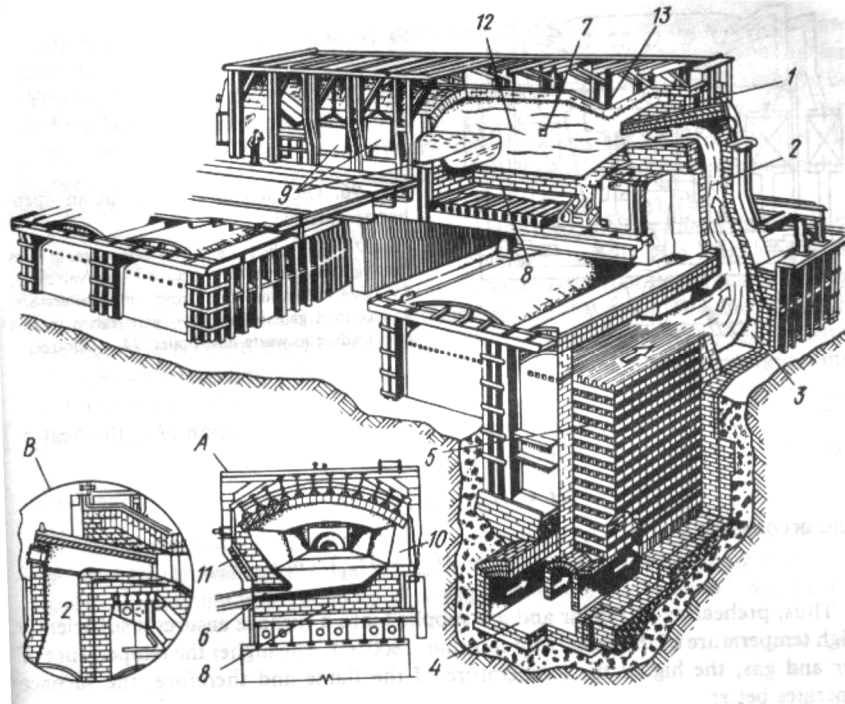
At the end of the blow the Bessemer is tilted back to the horizontal. Both de-oxidation and recarbonizing are achieved with the addition of ferro-manganese, an alloy of iron, manganese and carbon to give the required carbon content the open hearth charge consist of molten. Pig Iron, steel scrap which limestone is added to form slag which floats on the surface of the metal and absorbs impurities. Excess silicon, manganese and carbon are moved from the metal by the oxidizing action of the flames in much the same manner as in the Bessemer converter.

### **10.2. OPEN HEARTH PROCESS**

The making of steel in an open hearth furnace take many hours as against approximately forty five minutes in a Bessemer converter. The Open hearth can be roughly divided into two.

- (1) The hearth is a rectangular steel chamber lined with a suitable fire resisting material and shaped at the bases to form a shallow depression to hold metal.
- (2) Four pre-heating chambers, brickwork built below the hearth and arranged in pairs, each consisting of a chamber for air and a chamber for gas. The hearth is heated by a mixture of gas and air is made to pass through one pair of chambers previously heated by the hot waste gases from the hearth whilst the other pair of chambers is being heated in the same manner ready to receive in its turn the incoming gas and air. At suitable interval the

direction of flow is reversed and in this manner. The temperature of the gas and air are raised to the degree necessary to maintain the intense heat at the hearth.



hFig. 10.1. open hearth

NOTE : Both the Bessemer and open hearth processes in either case can be said to be “acid” or “basic” the acid process were so called because the utilized low phosphorus pig iron and therefore did not require the addition of lime to the charge. The slag formed was acid since it contained an excess of silica bricks.

Those pig iron rich in phosphorus require the charge to be treated with lime and this produces a basic slag. This basic slag would quickly attack ordinary acid silica brick furnace used in basic steel making had to be lined with a basic refractory such as burnt magnesite ( $\text{MgO}$ ) or burnt dolomite ( $\text{MgO} \cdot \text{CaO}$ )



## WEEK 11

### 11.1. CAST IRON

Is alloy of iron and carbon containing between 2- 6.67% carbon. Cast iron is widely used for the manufacture of numerous components in automobile engines. Other elements like manganese, sulphur, silicon and phosphorus may be found in traceable amount. The manganese and silicon inclusion in cast iron is beneficial while effort is usually made to get rid of the phosphorus and sulphur in view of their adverse effect on the final structure of this material is manufactured from the copola furnace.

It has relatively low melting point ranging from 1130 – 1250 C. this is advantageous because it can be easily melted, requires less-fuel and more easily operated in furnaces. This makes it economically a cheap material on account of its cheap refining process. The fluidity property of this material increase its ability to easily fills intricate moulds completely. This property gives cast iron good casting impression more than can be obtained from molten steel. While shrinkage in the mould is much less, thus permitting the production in thin section and intricate casting.

Cast iron is a brittle material, therefore it cannot be used in those part which are subjected to shocks. The properties of cast iron which makes it a valuable material for engineering purposes are its low cost, good casting characteristics, high compressive strength, wear resistance, and excellent machinability. Has a reasonable degree of corrosion resistance at low and elevated temperatures. It is a rigid material with partially self lubrication properties on account of the presence of graphite. The compressive strength of cast iron is much greater than its tensile strength compressive = 400 to 1000 MPa

Tensile = 100 to 200 MPa

It has ability to absorb and dampenvibration modification of cast iron structure can be made by varying the cooling rate, in the mould, by varying the composition at a suitable stage in its molten state or by heat treatment. As a result of these modification processes, cast iron is now available in the following grades.

Grey cast iron-contains about 3-3.5% carbon. The grey colour is due to the fact that the carbon is present in the form of free graphite. Here carbon exists in free form called graphite as resort of rate. The existence of graphite in the microstructure is in flake form on a matrix of ferrite or pearlite or a combination of these two background.

Properties

High compressive strength and no ductility low tensile strength. Machinability – it is easily machined. A very good property of grey cast iron is that the free graphite in its structure acts as a lubricant. Due to this reason, it is very suitable for those parts where sliding to make good casting.

Good resistance to corrosion. It is hard and brittle because of the graphite flakes in its structure. The brittleness of grey cast iron stops this material being use where shock loads are likely to be encountered.

Es – Natural for machine beds and frame, machine tool bodies, automobile cylinder blocks, crank case, brake drum, pipes and pipe fitting and agricultural implements.

### **11.2. CHEMICAL COMPOSITION** – high silicon, low sulphur

White Cast Iron – contains 2-2.3% carbon nonragca. The carbon combine with iron in the form of hard iron carbide known as cementile, which is the hardest consititivent of iron. The cementite is caused bu rapid or quick cooling of molten iron when fracture, the broken surface appears whites hence the name white cast iron. The carbon is completely dissolved in iron forming a solid solution of martensitic. This however to some extentent depends on the carbon content.

Properties – High tensile strength

Low compressive strength

Hard and brittle and machininable since it is hard, it is difficult to by grinding.

Resistance to abrasion and wear.

#### **Uses**

It is used for inferior casting and in place of car wheels. Is also used as raw material in the production malleable cast iron and wrought iron. Crushing machine parts as rolls for crushing grains grinding mill plate, furnace components.

FIG.11.1. CRUSHING AND GRINDING

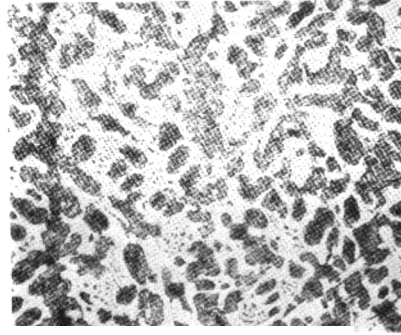
### **11.3. CHEMICAL COMPOSITION** – Low silicon, High sulphur.

#### **Malleable Cast Iron.**

The malleable cast iron is obtained from white cast iron by a suitable heat treatment process (the annealing). The annealing process separates the combined carbon of the white cast iron into noduces of free graphite.



White cast iron



hypoeutectic



hypereutectic

FIG.11.2. structure of malleable cast iron

## Properties

Ductile – may be bent without breaking or fracture. Its tensile strength is usually higher than that of grey cast iron.

## Uses

Are used for making thin or (small) castings particularly where shock loads are likely e.g pipe fittings, door hinges, locks, brake supports, parts agricultural machinery, hubs of wagon wheels, small fittings for railway rolling stock e.t.c.

The malleable cast iron is available in three forms through heat treatment of white cast iron because of its extreme hardness which renders the iron much softer. White hearth, Black hearth and Pearlitic, the names being descriptive of the microstructure.

### White hearth Malleable Cast Iron

If the white iron has a high carbon content, the process used is the 'whiteheart' process in which some of the carbon is removed. The cast iron is closely packed with hematite ore in a box or sealed containers and is heated to 900-1000°C for two to three

Surface carbon is oxidized (decarburized) by contact with the ore, combining with oxygen and escaping as carbon dioxide gas. Much of the combined carbon at the center diffuses outwards and is also oxidized, and in heavy sections or core, any remaining carbon will form

a combination of ferrite evenly or nodules. The iron is very white after this process – hence the name ‘White heart’.

### **Properties**

High tensile strength

Good ductility

Good machinability

### **Uses**

Wheel hub, steering column housing for agric machines, brakes and thread grides for textile machines. Black heart malleable cast iron if the white iron has a low carbon content, the process used is called ‘Black heart’ process to which no attempt is made to remove the carbon. The cast iron are closely packed to container with non – reactive (inert) materials such as crushed slag or gravel to prevent decarburization of the surface and annealing takes place at 850-940C, with a soaking period of between 3 to 4 days. The cementite decomposed into iron and fine graphite, which is precipitated in the form of nodules within the iron. The dull black appearance of the metal gives it the name ‘Black heart’.

## **BLACK HEART**

### **Properties**

High tensile strength

Good ductility

### **Uses**

Automobile industries, axle boxes, brake parts, coupling for rail way rolling stocks and pedals, rear axle housings, wheel hubs, differential carries pearlitic malleable cast iron – is made by heat treating white.

**Properties** – high tensile strength, good ductility, good machineability

**Uses** – axles and differential housings, camshafts and gears

## **Nodular or spheroidal graphite cast iron**

Is also known as ductile or high strength cast iron. The nodular cast iron is produced by adding magnesium to the molten cast iron. The magnesium converts the graphite of cast iron from flake form to spheroidal or nodular form. This way, the mechanical properties are considerably improved. The nodular cast iron behaves like steel.

### **Properties**

High tensile strength is greater than any other found of cast iron.

Ductile

Readily machineable.

## Uses

Pipes, fittings for gas, oil, water, sewage and chemicals. Automobile parts cylinder blocks, crankshafts, connecting rods, exhaust manifolds, water pumps, timing gears, gearbox casings, steering boxes etc

### 11.4. ALLOY CAST IRON

The micro-structural effects which alloying elements have on a cast iron are, in most cases, similar to the effects these elements have on the structure of steel. Alloying elements can therefore be used to improve mechanical properties (strength, wear resist are to refer again, to increase hardness by stabilizing cementite and forming hardcarbides and

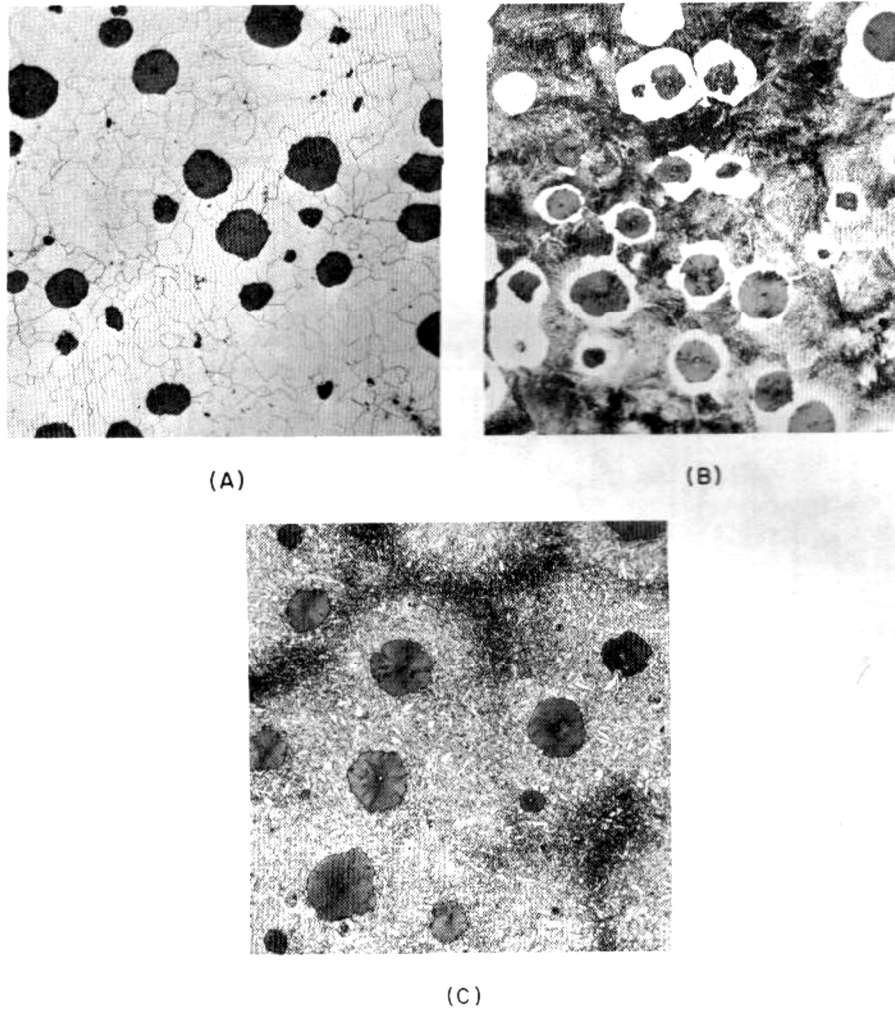


FIG 11.3. ALLOY CAST IRON

Desirable, martensitic and austenitic structures at ambient temperatures. Improvements in resistance to atmospheric corrosion and also deterioration at high temperatures are also attainable. Some of the alloying elements are Nickel chrominion, molybolenun, vanadium, coppet etc.

## WEEK 12

### 12.0 PROPERTIES AND APPLICATION OF NON FERROUS METAL

#### 12.1. NON –FERROUS METALS

Non ferrous metal are metals that contain little or no iron the certain a metal other than iron as their main constituent the non ferrous metals are usually employed in industry due to the following characteristic.

Easy to fabricate (casting, rolling, forging and machining.)

Resistance to corrosion

Very good

Electrical and thermal conductivity

Low weight

Attractive appearance

**1. ALUMINIUM**– is grayish white produced by electrical process from the oxide (alumina), which is prepared from a clay mineral called bauxite ( $\text{Al}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$ )

#### PROPERTIES

Pure aluminum (melting point  $660^\circ\text{C}$ ) is light weak, soft. It is malleable and ductile and can easily be machined, forged, rolled and extruded. It is a good conductor of electrical and heat next to copper.

Aluminum is not generally used in a pure state, since it is too soft and weak it is alloyed with other metals to form alloys are used extensively in industry.

#### USES

It is extensively used in aircraft and automobile components (Crankcases & pistons for internal combustion engine where saving of weight is an advantage. Its specific gravity is about 2.68 compared with 7.8 for steel.

High resistance to corrosion and its non-toxicity makes it a useful metal for cooking utensils under ordinary conditions.

Aluminum foil for food wrappers and bottle caps. In super-pure form it is used as a decorative medium e.g in wheel and other car trims used for overhead cables because of its good electrical conductivity. Ladder, T.V. aerial.

#### 2. COPPER

Is reddish brown coloured metal refined from copper ore (copper sulphide).

#### PROPERTIES

Melting point is  $1083^\circ\text{C}$ . its specific gravity is 8.9

It has high electrical and thermal conductivity

It is malleable and ductile and is easily change into wire and tubing. It can be casted, rolled, forged.etc.

Good resistance to corrosion.

## **USES**

It is largely used in making electrical cables and wires. Electroplating in making coins and household utensils. Used for making communications soldering in water pipe, castings, forgings, sheets. Used for making useful alloys with tin, zinc, nickel and aluminum. Alloyed with zinc to form brass or with tin to form bronze. Electric motor. wi

## **3. ZINC**

Us bluish -white (lustrous) metals Zinc ore are widely distributed throughout the world and much of the extraction is from the sulphide ores Zinc often associated with lead, silver and sometimes gold.

### **PROPERTIES**

Melting point  $420^{\circ}\text{C}$

It shows extremely good resistance to atmospheric corrosion.

It is brittle coarse and crystalline, easiest corrosion

### **USES**

It is used for covering steel sheets to form galvanizes in due to its high resistance to atmospheric corrosion. The covering is done by dipping the sheets, wire, nails and piping into a molten zinc bath after initial fluxing

When rolled into sheets, zinc is used for roof covering and for providing a damp proof non-corrosive lining to container. Use in the manufacture of brasses. And in due field to produce automotive parts (carburetors), soldering flux, battery cans washing machine parts, padlocks and model toys.

## **4. TIN**

Is silvery white, produced from tinstone ( $\text{SnO}_2$ ). When bar of tin is bent, a sound called 'cry' of tin is heard.

### **PROPERTIES**

Melting point  $232^{\circ}\text{C}$

It is soft, malleable and ductile. It can be rolled into very thin sheet (foil). Good corrosion resistance in moist atmospheric condition. When polished has a high light reflectivity. It has a crystalline structure.

### **USES**

It is used as a protective coating on other metals, such as iron and steel sheets to form tin plate, mainly in the canning industry. Is used for food stuff containers because the tin resists attack by fruit juices.

It is used in making soft solders.

It is used for making tin foil used as moisture proof packing.

## **5. LEAD**

Produced from galena (Lead Sulphide  $\text{PbS}$ ). Has a bright silvery grey (lustrous, shining) colour. When cut, the surface soon tarnishes (oxidize) to dull grey when exposed to air.

### **PROPERTIES**

Is one of the heaviest common metals with specific gravity of 11.36. It has a low melting point of  $327^{\circ}\text{C}$ . low strength and low electrical conductivity. It is very soft and malleable and is easily cut with a knife high corrosion resistance. Lead is resistant to many acids, but oddly enough, is attacked by pure water.

## **USES**

Used for making solders e.g. plumber and tin man's solder. As lining for acid tanks sheaths (cover) for power and telephone cables. In manufacture of connectors and grids in and acid batteries. It is used in chemical and plumbing industries. Is a good insulator against nuclear radiation.

## **6. NICKEL**

Silvery white metal capable of taking a high polish. Its specific gravity is 8.85 and melting point 1425°C

### **PROPERTIES**

Resistance to corrosion and oxidation. It resists the attacks of most of the acids. But it dissolves readily in nitric acid. Strong and harder than iron.

### **USES**

It is used extensively for electroplating. It's most important application is in the manufacture of stainless and alloy steels for b decorative and corrosion protection.

## **7. PURPOSES**

Is the lightest metal used as an engineering material with specific gravity of 1.74 while is about two-thirds that of aluminum. Its melting (650°C) point is slightly lower than that of aluminum and readily combines with oxygen.

### **PROPERTIES**

It is harder than aluminum. It soft, Low tensile strength. It is preferable when it is light in weight is important, because of its low density of 1.74

### **USES**

In aircraft and missile industries for the production of rockets, signals and flares. It is employed in photographic flash bulbs and thermite bulbs.

## **8. MAGNESIUM**

Magnesium plates are used to prevent corrosion by saltwater in underwater fittings on ship hulls. Magnesium rods, when inserted in galvanized domestic water tanks, will prolong the life of the tank.

Most important non-ferrous alloy

## **9. ALLOY**

Is a mixture of two or more metals.

## **10. COPPER ALLOYS**

Brass—colour (yellow)

Is an alloy of 60% copper and 40% zinc. There are many different grades employed for special purpose the properties and colour depend upon the protections of the two elements. Example the 60% copper and 40% zinc is called yellow brass

### **PROPERTIES**

Cast well, corrosion resistance

### **USES**

Water pipe fittings, electrical (plug pins) fittings, screws, nuts, bolts hinges, door handles, keys

Bronze – colour (dark yellow)

Is an alloy of 90% copper and 10% tin called phosphor bronze.



## **PROPERTIES**

Cast well, good resist surface wear bearing material, bronzes are superior to brasses in corrosion resistance. Bronzes are more costly than the brasses and hence are used only when cheaper alloys do not prove to be satisfactory.

## **USES**

Bearing sleeves and bushes, water pump castings, warm

### **11. TIN ALLOY**

Tin man's solder:

Is an alloy of 62% tin and 38% lead soft, little strength

## **USES**

For making solder

### **12. ALUMINIUM ALLOY**

Duralumin –colour (grayish white)

Is an alloy of 96% Aluminum and 4% copper.

## **PROPERTIES**

Light, cast well, medium strength.

## **USES**

Aircraft parts, Engine cylinder head, Crank cases, pistons, window frames.

### **13. ZINC ALLOY**

Die – cast metal – colour (grey)

Is an alloy of 4% Aluminum and 96%.

## **PROPERTIES**

Weak, cast well, brittle

## **USES**

Petrol pumps, car door handles, carbureting wing mirrors, low cost cast parts.

## **14. NON METALLIC MATERIALS**

Are classified as organic if they contain animal or vegetable cells (dead or alive) or carbon. Leather and wood are examples, materials are classified as inorganic if they are other than animal, vegetables or carbon bearing.

There are fundamental differences between organic and inorganic materials. Organic materials will usually dissolve in organic liquids, such as alcohol or carbon tetrachloride, but will not dissolve in water. In general, inorganic materials resist heat more effectively than organic substances examples of inorganic materials are minerals, cement, ceramic, Glass, Graphite examples of organic materials are plastics, petroleum products, wood, paper rubber, leather liquid, solid, gaseous- the form of existence of matter.

Liquid- The state of substance which can permit easy deformation or flow and take shape containing vessel.

Solid- The feature which show geometrical pattern in terms of shape.

Gaseous- The form of a substance which has higher tendency for expansion if not limited by boundary.

Melting point- The temperature at which a material is change from solid to liquid state.

Lustre property- Which give a material a shining and reflective surface.

## **13.0 HOT WORKING AND COLD WORKING PROCESSES**

### **13.1. MECHANICAL SHAPING OF METALS**

Working involves the manipulation of material when in the solid state it usually produces mechanical properties that are better than those of a cast material. Working metal must be ductile or malleable, or be made so as a result of heating or heat treatment. They are often of a simple micro structure. Shaping of metal can be divided into two.

Hot working operations and cold working operations

Hot working can be carried out more rapidly, since less power is required. While cold working process, in the other hand are used in the final stages of shaping of materials, so that a high quality surface finish can be obtained or suitable strength and hardness developed in the material.

The grain structure produced by working is different from that of casting. The figure below illustrates the grain structure a casting. The grain at the outside are small due the rapid cooling and those just below the surface are columnar because the grow towards the core, which is the last to solidify, the grain at the core are coarse and equiaxed because the core will cool very slowly. (Worked) wrought parts usually display grain flow or grain fibre, when taset along the grain they show a greater strength than across the grain and by arranging the grain fibre, the required directional strength can be obtained.

Hot working processes

Hot working is a deformation process which is carried out at a temperature above that of re crystallization for the material. It produce large deformation without causing residual stresses consequently, deformation and re crystallization take place at the same time the material remains malleable during the working process. Intermediate annealing processes are therefore not required, so working takes place very rapidly.

#### **Advantages**

Less amount of energy is needed for hot working of metal.

The coarse grain structure is refined

Materials are left in the fully annealed condition and are suitable for cold working there by making deformation easy.

Scales are formed on the surface which gives some protection against corrosion during storage

Porosity in metal is eliminated.

### **Disadvantages**

Poor surface finish rough and scaly

Dimensional accuracy is due to shrinkage on cooling

Due to distortion on cooling, hot working leads to geometrical inaccuracy.

Damage to tools from abrasive scale on metal surface

Low strength and rigidity for metal considered

Fully annealed condition of the material coupled with a relatively coarse grain leads to a poor finishes

Hot working equipment and maintenance cost are high

## **13.2. HOT ROLLING**

This is chiefly applied for the braking down of large steel ingots to sections, strip sheet and rod of various sizes. This operation involves subjecting the ingot at high temperature to train of rolls either of two-high reversing mill or three high mills. The rollers could be plain or grooved according to the section or type of product being manufactured.

Hot rolling is also applied to most non-ferrous alloys in the initial stages of braking down, but finishing is more likely to be a cold rolling operation.

## **13.3. HOT EXTRUSION**

A wide variety of sections can be produced by the process including round rods, hexagonal brass sections, tube. The hot extrusion process consist of taking a round cylindrical cast billet of metal which has been heater to above the critical temperature, planning it in a cylindrical container of slightly large diameter, close at one end by a ram or piston and all the other end by a die. The die has an opening or openings out in it having cross-section of the required product. On moving the piston along the cylinder against the billet, the billet is forced against the die under the influence of the enormors pressure generated in thr billet, the metal is force to extrude the orifice cut in die. Sometimes the cylinder is heated prior to extrusion to avoid excessive cooling of the billet. The use of lubricant is employed during extrusion to reduce friction between the billet and the cylinder.

### **TYPES OF EXTRUSION**

Direct extrusion – In this process the hot billet is placed into the container and the ram or piston moved forward which now force the billet to move relative to the container wall. There is frictional force between the billet and the container

wall. The billet pass under pressure through the die to produce the section replicate of the opening on the die

Indirect extrusion – Is similar to direct extrusion except that the extruded part is forced through the ram. Less force required by this method, since there is no frictional force between the billet and the container. The weakening of the ram when it is made hollow and the impossibility of providing adequate support for the extruded part constitute limitations of this process.

**IMPACT EXTRUSION** – Is a method used for producing such items as tooth-past tubes and other collapsible tubes in lead or aluminum, cigar tubes in aluminum and dry battery cases in zinc.

A small slug or blank of the metal to be formed is placed in a die and punch delivers a very high impact force to the blank. The metal of the blank is forced through the small clearance between punch and die and travels up the sides of the punch forming a thin walled tube.

**HAND FORGING** – This involves the application of successive hammer blows on hot metal ingot and represents the most ancient method of shaping metal by blacksmiths. Various ferrous and non-ferrous metals can be shaped by this means and a relatively fine grain structure is obtained after forging, finer than the coarse as cast structure obtained in casting.

**DROP FORGING** (Drop stamping) – If a large number of identical forged components are required, then it is convenient to make them by drop forging process. In this process a shaped die is used, one half being attached to the hammer and the other to the anvil. The hammer working between two vertical guides is mechanically lifted some distance above the anvil and allowed to fall under its own weight onto the metal being forged, which must be hot and force it into the cavity.

**HEADING OR UPSETTING** – Is employed for the manufacture of bolts, rivets etc. the stock bar is heated for a portion of its length and then forged. In general the operation involves increase in diameter at the expense of the length.

**HOT PRESSING** – Is a development of drop forging process. The hammer of drop forging is replaced by hydraulically driven ram so that instead of receiving rapid successive hammer blows, the metal is gradually squeezed into the cavity by the pressure of the ram.

## **14.0 COLD WORKING PROCESSES**

**14.1. Cold working** – Is a plastic deformation performed at the metal. Do not permit large deformation without frequent heat treatment to soften the metal. Cold working causes residual stresses and so increases the hardness and strength of the metal. During cold working the crystal structure becomes broken up and distorted and the material becomes strained or work hardened.

### **Advantages of cold working**

1. it improves mechanical strength and hardness with corresponding loss in ductility.
2. high dimensional accuracy (tolerance)
3. good surface finish is obtained no scale oxidation
4. uniform structure or relatively high geometrical accuracy.
5. working hardnesses improves the machining characteristic of the metal.

### **Disadvantages of cold working**

1. high cost than hot worked materials. It is only a finishing process for material previously hot-worked therefore the processing cost is added to the hot worked cost.
2. material loss ductility due to work hardening and are less suitable for bending etc.
3. clean surface is easily corrected
4. availability limited to rods and bars also sheets and strip, solid drawn tubes.

## **14.2. TYPES OF COLD WORKING PROCESS**

1. **COLD ROLLING** – This is a deformation process for finishing operation to obtain a standard size roll material using rolls. This is used for the production of sheet and strip materials. The majority of cold rolling operation are carried out on 4-high mills. In the 4-high mill, the two small diameter work rolls are power driven and the large backup rolls are for transmitting pressure to the work rolls thus preventing excessive deflection under load of work rolls. Component or section to be cold rolled is first broken down near to the finishing size by hot working and then pickled (immersed in hot dilute sulphuric acid) to remove surface scales or oxides caused by hot rolling before cold rolling. For the production of minor finish, metal foils, the rolling is carried out with well polished rolls in a controlled atmosphere. Cold rolling is usually carried out with inter-stage – annealing

process under controlled atmosphere to avoid scaling. Bright – mild steel is one of the typical products of cold rolling.

2. **DRAWING** – This is used for the production of wire, rods and tubing. This is a process of reduction of diameter of rod or wires by passing it through an orifice in a die. Is exclusively a cold working process, because it relies on the ductility of the annealed material being pulled or drawn through a die with a reducing diameter. In the manufacture of wire, the material is pulled through the die by winding it on to a rotating drum. While In the production of tube the bore is maintained by the use of a mandrel. The material is lubricated with or soap before it enters the die aperture. Drawing die are made from high carbon steel, tungsten, carbide and diamond.

### **14.3. COLD PRESSING AND DEEP DRAWING**

These processes are closely related to each other the operations range from making suitable pressing in one stage to cupping followed by a number of redrawings. In each case the components are produced from sheet stock, and range from mild-steel motor car bodies to carriage very high ductility in the sheet stock, and only a limited range of alloys are, therefore available for the process. Example brass, copper, pure aluminum. Very ductile metals in sheet form, can be drawn and stretched into a cup like shape using punch and die, this is shown in figure below.

Cold pressing is very widely used and alloys which are not quite sufficiently ductile for deep drawing are generally suitable for shaping by simple press work. Sheet metal can be pressed into shape between formers as shown in figure below. Motor car bodies are produced in this way.

### **14.4. COINING AND EMBOSSING**

**COINING** – Is a cold forging process in which deformation takes place entirely by compression. It is confined mainly to the manufacture of coins, medals, keys and small plaques. Coining operation is carried out in a closed die. It is a method of impressing an image or engraving in a die on a metal. Coining causes thin metal being coined to flow and fills the cavity on the dies during compression or by local indentation and extrusion process as shown in figure below.

**EMBOSSING** – Differs from coining in that virtually no change in thickness takes place during pressing. This process can be regarded as local bending and forming consequently, the force necessary to emboss metal is much less than in

coining. The material used for embossing the process is effected by using male and female dies. Typical embossed products include badges, military buttons, nameplates and identification tags.

**SPINNING** – Is the operation of shaping thin sheet metal (blank) that is sufficiently soft and ductile by pressing or forcing it against a rotating formed to produce a hollow solid of revolution. The original process is a hand process that employs a simple lathe, a modern development of this process is power spinning which is basically the same as hand spinning but the metal is worked by a roller.

Is a relatively simple process in which a circular blank of metal is fixed to the spinning chuck of a lathe? As the blank rotates it is forced up into shape by means of hand operated tools of blunt steel or hardwood, supported on a hand rest.

The function of the hand tool is to press the metal into contact with a form of the desired shape. This form is also fixed to the rotating chuck. The operation is in some respects similar to that of a potter's wheel in which the lump of clay is replaced by a flat disc of metal. Large reflectors aluminium teapots and hot water bottles and other domestic hollow ware are frequently produced by spinning.

#### **14.5. FLOW FORMING**

Is a similar process to spinning, but the displacement of the metal is parallel to the axis of rotation, the diameter of the blank is almost the same as that of the finished component, but its thickness is greater. Flow forming is done using a machine that is heavier than that used for power spinning, and has been used to advantage for parts such as turbine shafts and diaphragms that are previously turned from necessary heavy forgings.

## **15.0 PROPERTIES AND APPLICATION OF NON METALLIC MATERIALS**

### **15.1 GLASS**

Glass may be defined as a hard, brittle, transparent material chiefly composed of silica, combined with varying proportion of oxides of sodium, potassium calcium, magnesium, iron and other. Material

#### **15.1.1 CONSTITUENTS OF GLASS AND THEIR FUNCTIONS**

1. Silica – Is the principal constituent of glass if silica alone is used in the manufacture of glass, it could be fused only at a very high temperature but it would give a good glass on cooling. However, it is imperative to add some alkaline materials (sodium or potassium carbonate) and lime in suitable proportions to make the molten silica glass sufficiently viscous to make it amply workable and resistant against weathering agencies.
2. Sodium – Is an alkaline material, added in suitable proportion to reduce the melting point of silica and to impart viscosity to the molten glass.
3. lime- Is added in the form of chalk its imparts durability to the glass in place of lime, sometimes, lead oxide is also added it makes the glass bright and shining.
4. Manganese Dioxide – Is added in suitable proportion to correct the colour of glass due to the presence of iron in raw materials of glass.
5. Cullet – Is old broken glass of the same type as that which is intended to be prepared. It is added in small quantity to provide body to the glass.
6. Colouring Substance- While manufacturing a coloured glass, a suitable colouring substance is added at fusion stage to provide the desired colour to the glass.

### **WOOD/TIMBER**

Withstands shocks and bumps.

#### **PROPERTIES**

Good material for compression member, non conductor of heat and electricity, light weight, easy to shape, suitable for sound proof.

**APPLICATIONS-** Tool handles, foundry patterns, packaging, furnitures, rafters, ladders, doors, windows.

### **CERAMIC**

High compressive strength

#### **PROPERTIES**

High strength at high temperature, hard, brittle, high resistance to wear, good electrical insulation properties, high melting point, good chemical stability, good thermal stability.

High corrosion resistance.



**APPLICATIONS-** Extrusion dies, cutting tools, refractory materials, sanitary wares, abrasives, insulators and semi-conductors.

## **GLASS**

### **PROPERTIES**

Hard, brittle, transparency, crystalline, resistance to corrosion, poor resistance to thermal shock.

**APPLICATIONS-** Laboratory wares, bottles, mirrors, lenses, windows, thousands of items in the body of a guided missile are made of glass. Glass linings are applied on equipments likely to be affected by chemical corrosion such as valves.

## **ASBESTOS**

### **PROPERTIES**

Brittle, fire resistant, heat resistant does not break down under heat.

**APPLICATIONS-** Roofing sheets, ceiling, fire proof pants, building sheets, break linings, tiles.

## **RUBBER**

Plasticity of rubber makes it amenable to all manufacturing process.

### **PROPERTIES**

Elastic, electrical insulator, strong and tough, highly impermeable to both water and air, great resistance to acids, petroleum products etc.

**Applications-** Transmission belt, seals, packings, tyres and tubes, hose pipes, thermal insulation

Damping pad for engine mounting.

Thermal insulation.