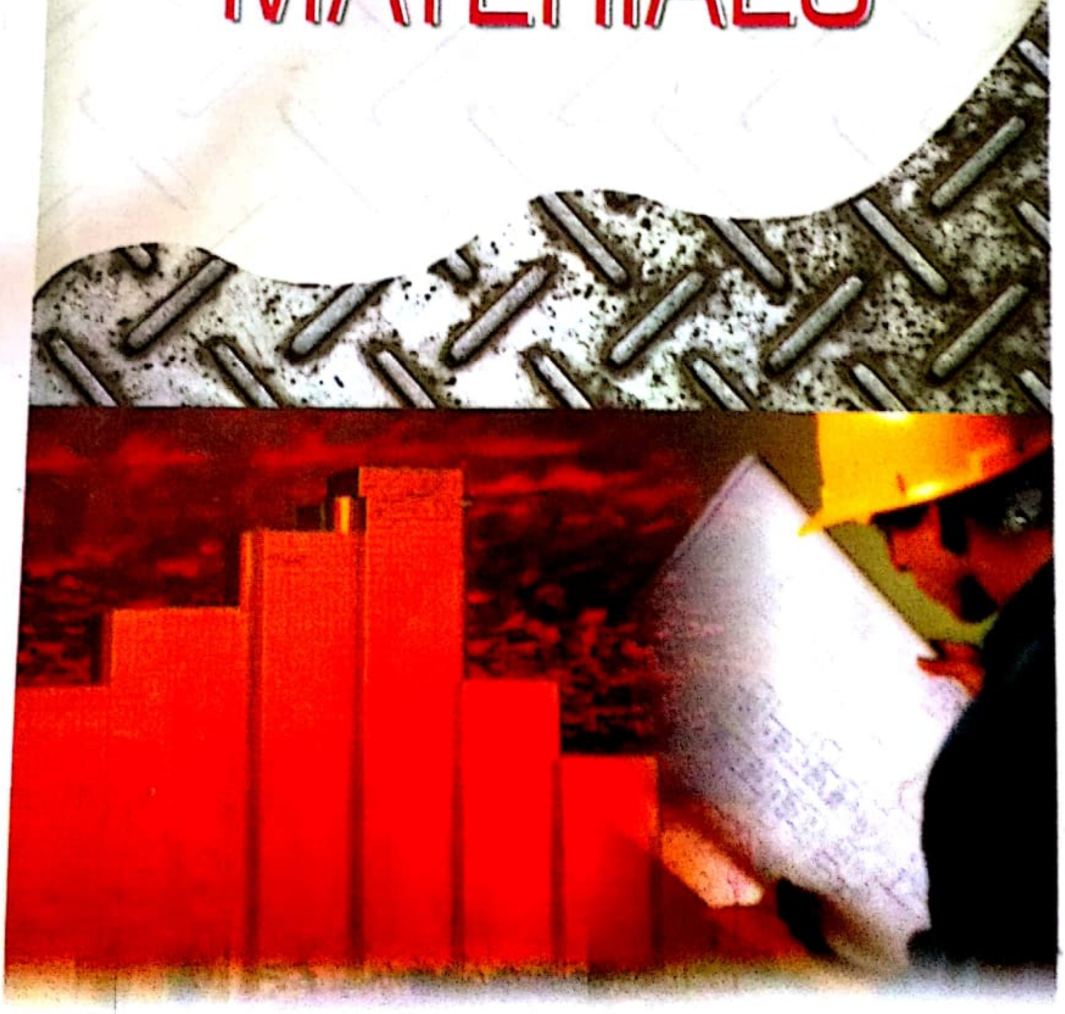
CIVIL ENGINEERING MATERIALS



PARBIN SINGH

KATSON BOOKS

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1

Building Stones

1.1. INTRODUCTION

STONES are naturally occurring compact, solid and massive materials that make the crust of the earth. Technically, the stones are called **rocks.** These rocks occur in a great variety. Those rocks that possess **suitable properties** often find use in building construction. Such rocks are specifically termed as **building stones.** It follows, therefore, that whereas all building stones are essentially rocks in nature, **all rocks may not be useful as building stones.**

Stones have been used in all types of construction since time immemorial. The Pyramids of Egypt, The Eiffel Tower, The Temple of Jagannathpuri, the Taj Mahal, the Red Fort, thousands of grand palaces in different part of the world, the Great China Wall, and hundreds of historical buildings in each big country are made of stones. The greatest thing about stones is that they are **natural** and do not require to be manufactured. Stones, timber and clay had been the most commonly construction materials used by the man right from the beginning of the civilization till the advent of Portland Cement (and hence concrete) in the early nineteenth century.

There are at least two reasons for decreasing use of stones in building construction in the modern times:

First : The stones **are not available** everywhere. In plains, there may not be a rock outcropping for thousands of square kilometer area at a stretch. Transport of ordinary stones from distant places may be a very costly affair compared with bricks, cement or concrete that can be all available or made locally.

Second : Concrete is a **versatile material** that can be prepared with any set of desired properties and that can be used in any conceivable situation in a building: foundations, walls, sills and roofs and up to many stories height. Multistorey and high-rise buildings with stones are simply not thought about these days.

1.2. CLASSIFICATION OF STONES

The building stones are classified in three ways: geologically, chemically and structurally.

A. Geological Classification :

This classification is based on the ***mode of formation*** of the rock from which the building stone is obtained. Three main groups of rocks recognized by the geologists are:

1. Igneous Rocks
2. Sedimentary rocks
3. Metamorphic rocks

1. IGNEOUS ROCKS (Greek: ignis=*fire*). All those rocks of the earth that have been formed by the natural process of cooling and crystallization from originally hot and molten material are grouped together as Igneous Rocks. They are the most abundant rocks in the crust when considered depth wise. The hot molten material is believed to form and occur below the earth due to a number of reasons. It is called **magma.** Although magma has not been seen directly because of the depths at which it is formed, it is known to come out frequently in the form of lava from volcanoes in many parts of the world. **Lava** is, therefore, a form of magma and rocks formed from lava are also, by definition, igneous rocks. In fact, **igneous** rocks are further distinguished by geologists into three sub-classes on the basis of their depth of formation:

(*a*) **The Plutonic Rocks.** These are formed at **great depths** below the surface. They are exposed on the surface by **erosion** of the overlying secondary rocks with passage of time. These are coarsely crystallized, *i.e.* their component crystals can be easily seen without the help of any magnifying glasses. *Granites, syenites and gabbros* are typical igneous plutonic rocks.

(*b*) **The Volcanic Rocks.** These are formed **on the surface of the earth** from lava coming out from numerous volcanoes that erupt from time to time. *Basalts and trap rocks* are very common examples; the constituent minerals of volcanic rocks are *so small* that they can be seen only after magnification under microscopes.

(*c*) **The Hypabyssal Rocks.** These are formed **at shallower depths,** about 2-3 km below the surface from magma that could not come out as lava. They show crystals that are partly coarse and partly fine in size. Rocks known as porphyries belong to this group.

2. SEDIMENTARY ROCKS (sediment= *particle*). **These** are the most **widespread rocks** found covering a great part of the **surface** of the earth. The sedimentary rocks are formed from any type of **preexisting** rocks by a simple process of their breakdown into smaller particles under the influence of natural agencies like wind, water and ice and atmospheric gases. The natural processes of rock disintegration and decay are called **weathering and erosion.** The sediments produced by natural agencies are **transported** by these very natural agencies to riverbeds, lake basins, seas and oceans where their deposition takes places for **millions of years**. Gradually, the particles so deposited are compressed and compacted under their own load into hard massive rocks, called the **secondary rocks.** Since these are formed from sediments it is quite appropriate to call them **sedimentary rocks.**

Just like igneous rocks, sedimentary rocks may also be formed in different manners. Three sub-groups of sedimentary rocks are: Clastic rocks, Chemically formed rocks, and organically formed rocks.

(*a*) **Clastic Rocks.** These are sedimentary rocks formed by deposition and consolidation of disintegrated sediments and fragments from the previous rocks in suitable river basins, lake basins and the sea basins etc. They are **most widespread** and include such types as sandstones, shales, breccias and conglomerates. **Sandstones** are made mostly of silica grains fused together or thoroughly compacted under natural environments. They form very good types of building stones.

(*b*) **Chemically formed Rocks.** Many sedimentary rocks are precipitated from river, lake and especially from seawater by evaporation etc. Some of the components of previous rocks are taken in solution during the processes of weathering and erosion. The waters may get saturated with these compounds with passage of time and precipitate them. The huge accumulations of these precipitates and evaporates ultimately may form rock deposits of considerable importance. **Limestones, gypsum, anhydrite** and **rock salt** are few examples of chemically formed sedimentary rocks. **None of them** is used as a building stone.

(*c*) **Organically formed Sedimentary Rocks.** As we know more than 70 percent of the surface of the earth is covered with water in the form of seas and oceans. Great variety of life exists in these great water bodies. Many sea animals have their hard parts made up of bones, which are a mixture of calcium and magnesium carbonates. These parts accumulate at proper places on the seafloors on the death of these animals. Gradually huge thickness of such deposits gets formed and compacted and consolidated with passage of time. These are the organically formed sedimentary rocks. The best example of organically formed sedimentary rocks is a great variety of **limestones,** which now form greater part of many mountains of the earth, including the Himalayas. Such rocks are known to occur even at Mount Everest indicating the rise of Himalayas from within the sea. Many massive types of limestones form best type of building stones.

3. METAMORPHIC ROCKS (meta= change; morph= form). These are originally either igneous or sedimentary rocks. The process for their change under the influence of increased temperature, pressure and chemical environment is called **metamorphism**. When any existing rock gets subjected to increased temperature or changed stresses and chemically active fluids it undergoes a slow but definite changes in its original structure and chemical constitution. The **new rock** so formed is called a metamorphic rock.

Two well-known examples of metamorphic rocks are **marble** and **slate**. Marble is formed in nature by very gradual (taking million of years) heating of sedimentary rock, limestone ($CaCO_3$), in its natural environment. The heating effect may be caused by rise of magma from below in a limestone area.

Similarly, another sedimentary rock, shale may get so much heated, compressed and chemically affected under the combined action of temperature, pressure and chemically active fluids that it gets changed to a metamorphic rock- slate. Slate develops sheet-like structure (called **rock cleavage**) by virtue of which it can be separated in to thin, hard and strong sheets.

The **nature** of change of an original rock into a metamorphic rock depends on following factors:

(*i*) The **type of agent/s** operating (temperature, pressure, fluids etc.)

(*ii*) The **duration** of operation of the above agents;

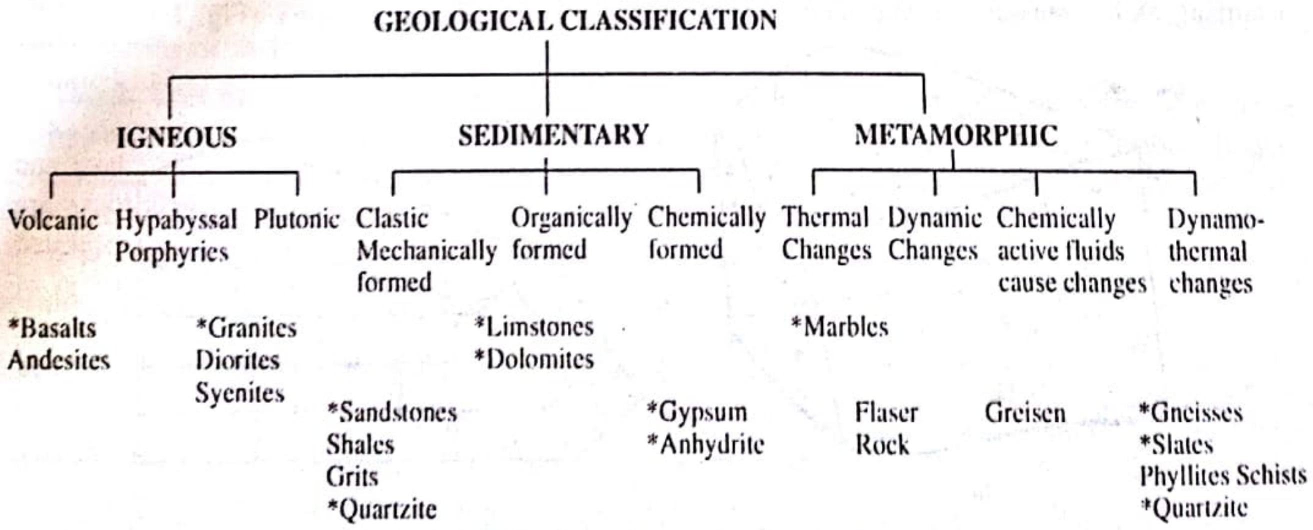
(*iii*) The **nature** and composition of the **original rock**.

The most important fundamental fact about metamorphism is that **all changes in this process take place essentially in solid state**. In other words, the original rock does not actually reach a molten stage.

Some very common metamorphic rocks are Marble, Quartzite, Gneiss, Slate and Schist; the first three rocks form very good building stones in many cases.

The Geological Classification of Building Stones is summarized in Table 1.1.

TABLE 1.1. Geological Classification of Building Stones (abridged).



[* used as building stones where available in abundance]

B. Chemical Classification

On the basis of dominant chemical composition, following three main groups of rocks (stones) are commonly recognized:

1. Siliceous Rocks. These rocks have SILICA (SiO_2) as the predominant component, that is more than 50% of the bulk composition of the rock. **Some sedimentary and metamorphic rocks are**

often entirely made up of silica. These include varieties of quartzites. Naturally, they are classed among the strongest types of building stones. Some other rocks like granites, sandstones and gneisses are also made up predominantly of silica in combined forms. These rocks also form very good building stones.

2. Calcareous Rocks. In these rocks, the dominant component is a carbonate, generally of calcium but often with magnesium. Most commonly they belong to sedimentary and metamorphic groups of rocks. Limestones, dolomites and marbles are entirely carbonate rocks and **all form very good building stones.**

3. Argillaceous Rocks. They are mostly sedimentary and metamorphic rocks having clay (hydrous alumino silicate of K, Na, Ca, Mg, etc.) as the dominant constituent. They are invariably soft and **untrustworthy as building stones.** Shales, Slates and Schists are examples.

TABLE 1.2. Chemical Classifications of Rocks.

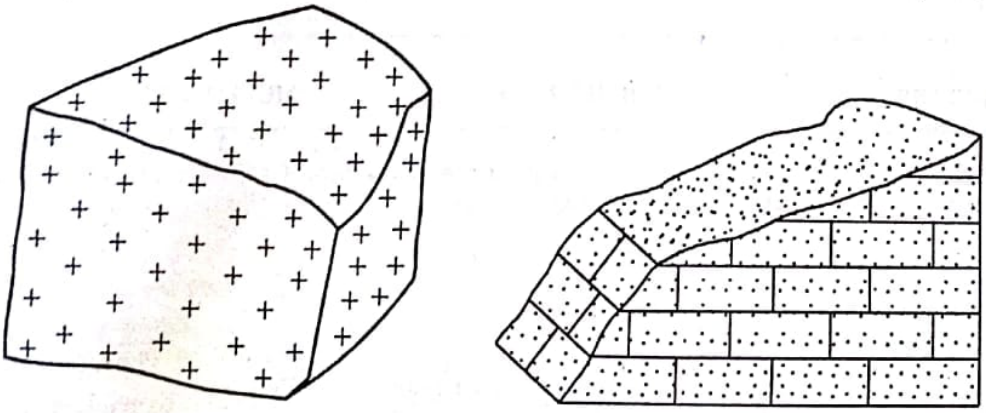
SILICEOUS SiO_2 >50%	*CALCAREOUS* CO_3 > 50%	*ARGILLACEOUS* Clays > 50%
Examples:	*Examples:*	*Examples:*
Granites (Ign.)	Limestones (Sed.)	Clay stones (Sed.)
Quartzites (Sed./meta.)	Dolomites (Sed.)	Siltstones (Sed.)
Gneisses (Meta.)	Marbles (Meta.)	Slates (Meta.)

Ign. = Igneous Sed. = Sedimentary Meta. = Metamorphic

C. Structural (Physical) Classification

Broadly speaking, in apparent structure, the rocks (stones) may either be found in the form of undifferentiated masses or they occur in well defined layers or sheets. A third category is of the foliated rocks.

1. The Massive or Unstratified Rocks. These occur in huge masses without showing any layered structure in them. Igneous and many metamorphic rocks and some sedimentary rocks may be seen occurring as big masses. Granites and quartzites often occur in massive forms. (Fig. 1.1*a*)



(*a*) (*b*)

Fig. 1.1. (*a*) Massive and (*b*) Stratified rocks.

2. The Stratified Rocks. Most sedimentary rocks occur in distinct layers of same or different colour and composition. Their different layers are also called beds and are separated by planes of weakness called bedding planes. As we shall see subsequently, these bedding planes interfere with the engineering properties of stones in a significant manner. (Fig. 1.1*b*)

3. Foliated Rocks. Very often a third group of rocks is distinguished as **foliated rocks** in which there is profuse development **of well defined bands** of different composition. This is seen in schists and gneisses. Sometimes well-defined layers are **induced under pressure,** as in slates. These are also called foliated rocks. The foliated rocks do not commonly yield building stones of any good quality.

A Note On Classification of Stones

It may appear from the above discussion on the classification of the stones that the subject is quite confusing and complex. It is neither. Actually, it is the threefold geological classification that is of fundamental importance and others are of supporting nature. All students who have read science at elementary level know that all the rocks that occur in nature are of three main groups: igneous, sedimentary, and metamorphic. So any building stone must belong to one of these three groups. Once that is known, rest can be established easily whether it is massive or layered and if it is rich in silica or clay or carbonates. Any stone may thus be easily related to the three classification systems. We take following three examples:

(*i*) **Granite.** It is an ***igneous*** rock of ***massive*** (Unstratified) type and ***siliceous*** composition.

(*ii*) **Limestone.** It is a ***sedimentary*** rock, very often ***stratified*** and ***calcareous*** in nature made up mostly of calcium carbonate

(*iii*) **Slate.** It is a ***metamorphic*** rock showing ***foliation*** (sheet structure) and having a ***clayey*** composition.

1.3. SELECTION OF STONES FOR CONSTRUCTION

Three factors are generally considered by an engineer while deciding the use of a stone in the construction jobs :

First. The type of building and the situation where he wants to use the stone such as :

(*i*) a residential building or a public utility building, such as for school, departmental office, community center etc.

(*ii*) commercial building like a cinema hall, shopping complex stadium etc;

(*iii*) a monumental building such as a temple, mosque, church, fort etc.

Second. The precise location in the building where the stone shall give a preferential benefit in terms of cost, appearance, and durability such as in foundations, superstructures, arches, columns, beams, plinths or in flooring, roofing or sills and cantilevers etc.

Third. Cost of construction with stones. This will depend on factors of availability of stone in nearby areas, their extraction, transport and dressing (giving proper shape) before putting them in use. Some times a desired quality of stone may not be available locally. It may have to be imported from other states or even from other countries.

It is only after thorough analysis of factors as mentioned above that the engineer will be in a position to decide about using stone/s in the construction at hand.

1.4. QUALITIES REQUIRED IN STONES

For ensuring a durable, cost-effective and aesthetically appealing construction, the following properties are deemed desirable in the stones available for selection.

1. STRENGTH. For ordinary type of stone-houses, any good rock being traditionally used for the same purpose will normally possess sufficient strength to bear usual loads. But **generalization** for stone mansions, higher and costly buildings are not desirable at all. For such jobs, the engineer must satisfy himself about all the **strength parameters** only after thorough testing in accordance with prescribed codes.

(*i*) **Compressive Strength.** It is the main quality of a building stone and may be defined as ***"the load bearing capacity of a stone expressed as the maximum load per unit area at which the stone starts breaking"***

This property can easily be tested in a civil engineering laboratory on the Universal Testing Machine (U.T.M). Properly selected stone samples (in cube or cylinder shapes) of specified dimensions are loaded in the UTM gradually, one by one, till the rupture point. The compressive strength, **Co,** of the sample is obtained from simple relationship:

$$\boxed{Co = P/A}$$

Where, P is load at breaking point, and A is area of the cross section of sample.

The compressive strength of the most commonly used building stones has been found to range between **280-2800 kg /cm^2**. When these values are compared with those of conventional materials of construction like bricks (A Class; 140 kg/cm^2) and concrete (280 kg/cm^2), **superiority** of stones in this count is established quite easily.

(*ii*) **Transverse Strength.** It is the resistance a stone (or any other material) offers to **bending loads.** In the case of building stones it is to be evaluated only when a stone is required for use as a **beam or a lintel.** This property is commonly determined as Modulus of Rupture "*R*". Method for determination for "*R*" values is described separately in a later section. It has been found that *R*-values for different stones vary between 20-300 kg/cm^2.

(*iii*) **Shear Strength.** Stone of good quality are often used as piers and columns, especially in monumental buildings. In such situations, the stone is to withstand **shearing type** of loads. Hence it must possess sufficient shearing strength. The shearing strength of common building stones lies between 70-160 kg/cm^2.

In Table 1.4. Strength values of some common building stones are shown:

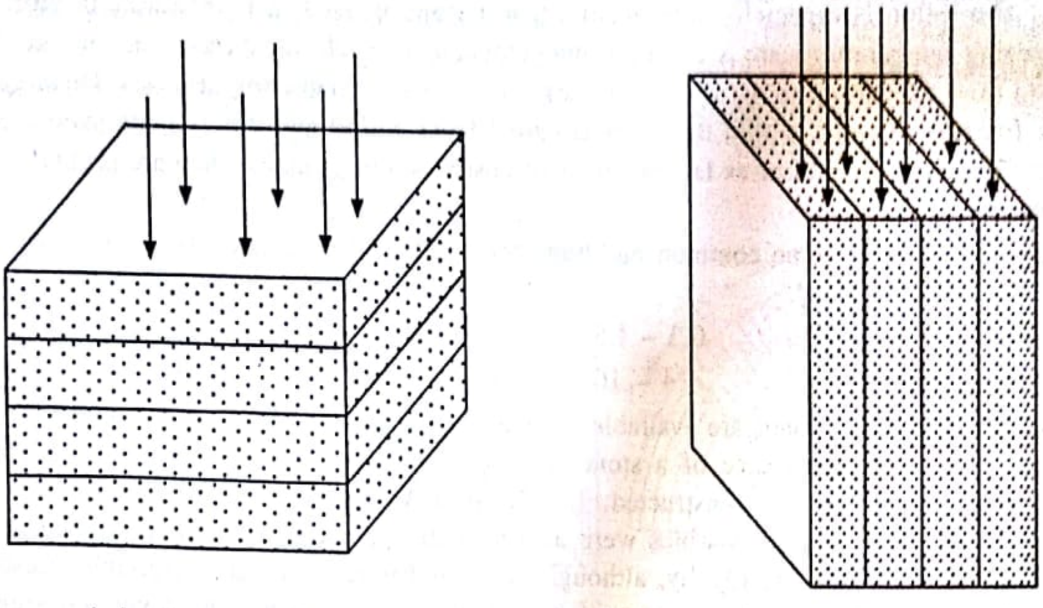
TABLE 1.3. Strength Values of Some Common Building Stones.

S.No.	*Building Stone*	*Rock Class*	*Compressive Strength (kg/cm^2)*	*Transverse Strength (kg/cm^2)*	*Shearing Strength (kg/cm^2)*
1.	GRANITES	Igneous	1400-2100	70-200	80-160
2.	SANDSTONES	Sedimentary	490-1400	35-140	70-120
3.	LIMESTONES	Sedimentary	280-1400	18-175	70-110
4.	MARBLES	Metamorphic	700-1260	50-250	70-130
5.	BASALTS	Igneous	1400-2800	100-300	80-160

From the above table it is quite obvious that the strength values of stones are not precise values; rather they fall in a range, which is quite considerable in all cases. This variation (in strength values) of stones is attributed to at least three factors :

(*a*) **The mineralogical composition of rocks.** The same rock (e.g. granite) may not necessarily have the same composition everywhere. Small variation in the mineral constituents of this rock from one area may be responsible for its different strength from granite of another area.

(*b*) **The structural and textural constitution** of the same rock may also vary from place to place. For example **coarse-grained** compact sand stones may show much different strength values than fine-grained clayey sandstones.



A. Loading perpendicular.

B. Parallel to bedding planes, First case will show higher strength.

Fig. 1.2.

(*c*) **The state of weathering of rocks** has profound influence on its strength qualities. Stones obtained from rock masses exposed on the surface and having suffered considerable weathering **(chemical decomposition and mechanical disintegration)** will have far less strength compared to the same rock buried underneath a thick soil cover and having a fresh appearance.

(*d*) **The direction of loading.** Other things being the same, when a layered rock is loaded **parallel** to the bedding planes, it will show **lower** strength values compared to when it is loaded **perpendicular** to the bedding planes. (Fig. 1.2)

2. HARDNESS. Next to strength, the property of **hardness** of a stone is considered important in its selection. It is quite different from strength. **"Hardness of a stone may be defined as its capacity to resist scratching or abrasion."** Samples of two building stones, say quartzite and limestone, may show the same compressive strength (1000kg/cm^2). Their hardness may be quite different: [7] for quartzite and [3] for limestones. Other things being the same, the limestone will WEAR OUT easily compared to quartzite. Similarly limestones can be scratched easily with a knife whereas it is not possible to make an impression with knife on a granite stone.

The hardness of stones depends on their **mineral composition**. The significance of this property (hardness) lies in its resistance to **wear and tear** during its use in situations where **rubbing action** due to natural agencies (e.g. wind and water) or by artificial causes, such as in flooring slabs etc. is involved. Stones facing the **prevalent sand-laden winds** in an area should be chosen with great care as soft stone may be worn out more easily and quickly than expected.

Toughness is a property related to both hardness and strength. It is defined as the capacity of a stone to withstand the **impact loads.** It is more important a property when the stones are used in industrial buildings where impact loads are a rule than an exception. Thus stones to be used in foundations under heavy machines where vibrations may be a common phenomenon may not be only hard and strong but very tough also.

3. WATER ABSORPTION. Building Stones are liable to come in contact with water when used in foundations and exterior walls. Ideally, they must not absorb moister because water can become cause of many troubles. This quality of absorption of water is tested as water absorption and may be defined as ***'quantity of water absorbed (in percentage terms by weight) by a stone till saturation'***. Thus absorption value of 10% means that a stone on saturation can hold 10% water by weight. A 10 kg block of stone will be having within its body about 1 litre of water.

Water absorption is especially significant when a stone is used in foundations in **cold climates** where freezing temperatures are a common phenomenon. In such situations water within the pores may freeze (and expand up to 10 % by volume) and exert **disintegrating stresses**. Disintegration of stones by freezing of water within the pores is called **frost action** and this process may spoil porous stones used on outer surfaces or as facing stones of costly buildings unless they are properly protected from rains.

Absorption value of some common building stones after 72 immersion in water is of following order:

Granite:	0.3 – 1.5 %	Sandstone:	5 – 8 %
Limestones:	4 – 10 %	Marbles:	0 – 0.5 %

4. APPEARANCE. Stones are available in almost all colours - from milk white to blood red to pitch black. Naturally, appearance of a stone for use in building becomes an important factor for selection. Black houses are not constructed. Taj Mahal at Agra was constructed with **white marble** although red and green or pink marbles were also available. For Red Fort in Delhi, the red colour sandstone was used to indicate royalty, although gray sandstones were also available. Aesthetically **light colours** are preferred in the exterior of buildings. Appearance has, however, no significance when the stone is to be used in obscure positions, such as in **foundations**.

5. WORKABILITY. Stones when obtained from their natural place of occurrence - the outcrops- are quite irregular masses. They require quite a lot of work on them before they can be converted to appropriate shapes for use in construction. Shapes required may vary from ordinary rectangular to square blocks of small sizes, slabs of required dimensions or even as columns of proper roundness and height.

The process of giving a proper shape, dimensions and surface finish to a raw stone before it is fit for use in construction is called DRESSING.

It has been observed that all the stones cannot be dressed or worked easily. The cost involved on dressing per unit block, therefore, also becomes an important factor in selection of stones. Igneous rocks like basalts, traps and granites, for example are very **difficult to dress** and polish. This is because they are very hard and tough. Marbles and limestones, however, are comparatively soft and can be given any size, shape, finish and polish at comparatively lower costs.

✓ **6. DURABILITY.** It denotes the **period in years** for which a stone may stand practically unaltered after being used in construction. A really durable stone must

(*i*) **withstand loads** imposed on it for the entire period of use;

(*ii*) **must keep up original appearance** even when used in exteriors;

(*iii*) **must resist** the effects of heat and cold;

(*iv*) **must not suffer deterioration** and decomposition by gases, effluents and vapours from surrounding industrial towns.

Obviously, durability is a quality of a stone that does not not depend on a single property but rather on a set of properties already discussed. It may be summarized that a stone will be durable when:

(*a*) It has quite high strength values for the designed loads in the buildings;

(*b*) It has a uniform, close packed, dense structure, with very low absorption values;

(*c*) It is made up of very hard and resistant mineral constituents;

(*d*) It is resistant to chemically reactive gases such as sulphour dioxide, carbon dioxide etc.

1.4.1. A Note on Natural Bed of Stone

As already stated stratified or layered rocks show different strength values when loaded perpendicular to bedding and parallel to bedding. The compressive strength of the stone is always greater in the first case where the stone offers maximum resistance. In the latter case, when load is applied parallel to the layers (or beds, as they are called geologically), there is tendency to failure by slipping along the bedding planes. The property of natural bedding has to be kept in mind while placing the stone in a particular location in the building. We take two situations:

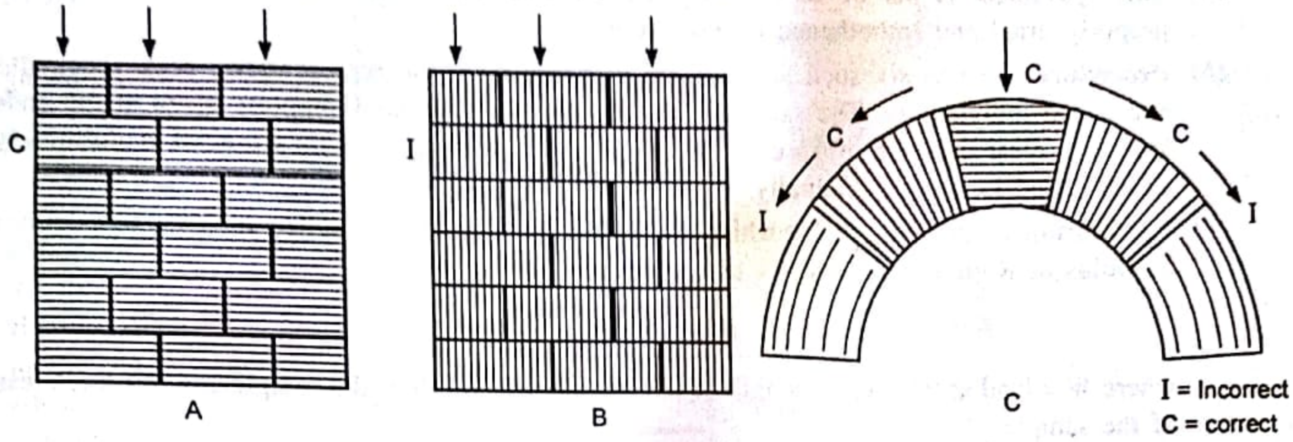


Fig. 1.3(A,B,C). Forces with respect to natural bed.

- In the **walls**, the load acts **vertically** downwards; hence the stone should be placed with the natural bed in a horizontal position (1.3A) and **not** in a parallel position (1.3B).
- In the **arches**, the load acts **transverse** (arch action); hence the stone must be placed with the natural bed vertical or inclined so that it is almost at right angles to direction of resultant forces (1.3C).

1.5. STANDARD TESTS

When stones are proposed to be used in very big and costly structures, some of very important properties need to be tested strictly in accordance with the procedures laid down by the authorized institutions. In our country, Bureau of Indian Standards (BIS) is responsible for issuing such codes on testing methods and values. We give below **outline** of some codes prescribed by the BIS for testing of Building Stones. It is, however, strongly recommended that ***the practising engineer dealing with the actual construction work must always consult and follow the standard relevant codes as in vogue at the time of construction rather than depend on outline of methods and specifications mentioned here.***

1. TESTS FOR COMPRESSIVE STRENGTH (BIS CODE REF. 1121-1974)

(*a*) **Test Samples.** Cubes of 5 cm side or cylinders of 5 cm diameter and of same height. The top and bottom surfaces shall be made ***as smooth as possible*** by polishing.

(*b*) **Test Procedure.** The tests shall be carried out on dry as well as on saturated sample.

For saturating, the samples of proper dimensions shall be immersed in water at 20^{0}-30^{0} C for 72 hours and then tested after removing all moisture by rubbing with dry cloth.

For dry samples, samples of proper shape and size shall be placed in an oven at 105° C for 24 hours and then cooled in a desiccators (and not in open air) to room temperature.

(*c*) **Loading.** Each sample shall be loaded **individually** by placing it over the loading plate of a UTM (Universal Testing Machine). The load will be increased **very gradually**, at a rate of 140 kg/cm^2 per minute or as prescribed in the code. This process (of loading) is continued till the sample breaks, *i.e.* when first crack appears in it and the sample stops taking any further load.

(*d*) **Calculations.** Compressive strength, Co, shall be calculated by using relationship:

$$\boxed{Co = P/A}$$

where P = load at failure point; A = cross sectional area of the sample

The result of each sample is expressed in kg/cm^2. **Six samples** should be tested from each type of rock and the average value is taken as compressive strength.

2. TEST FOR TRANSVERSE STRENGTH

(*a*) **Test Specimen.** A bar of 20 cm length, 5 cm thickness, and 5 cm width which must be properly dried and smoothened by polishing.

(*b*) **Procedure.** Five to six such samples are prepared from the representative rock specimens and tested individually. The sample is placed on two horizontal supports given at the ends leaving a clear distance of 15 cm between the two supports. It is then **loaded transversely** and the load is applied gradually.

(*c*) **Calculations.** The load "*W*" at which the sample starts breaking is noted and used to calculate Modulus of Rupture of the stone using following relationship:

$$\boxed{R = 3Wl/2bd^2}$$

where W = load at failure; l = length of the sample; b = width of the sample and d = thickness of the sample.

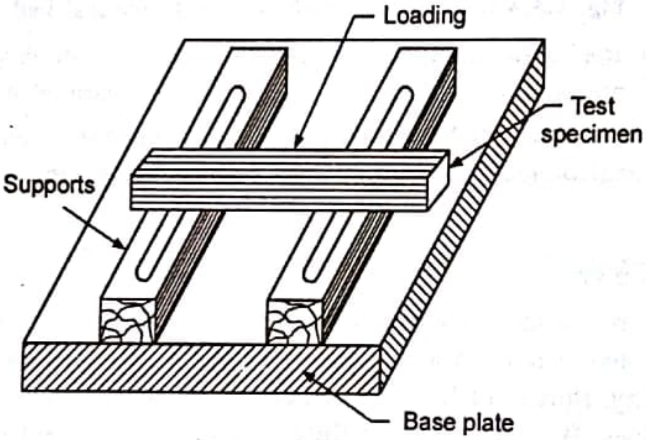


Fig. 1.4. Experimental Set Up for Transverse Strength Test.

3. TEST FOR WATER ABSORPTION : (Refs. IS –1125-1974)

(*a*) **Test Sample.** Take about 1 kg samples from representative stones that have been crushed and made to pass through IS 20 mm sieve.

(*b*) **Procedure.** The selected and weighed sample is placed in **distilled water** in a glass vessel at room temperature (20^0-30^{0}C) for a period of 24 hours.

The sample is then taken out, piece-by-piece, surface dried with a damp cloth and the air-dried by spreading over a damp cloth for ten minutes. The sample is then weighed; let this weight be W_1

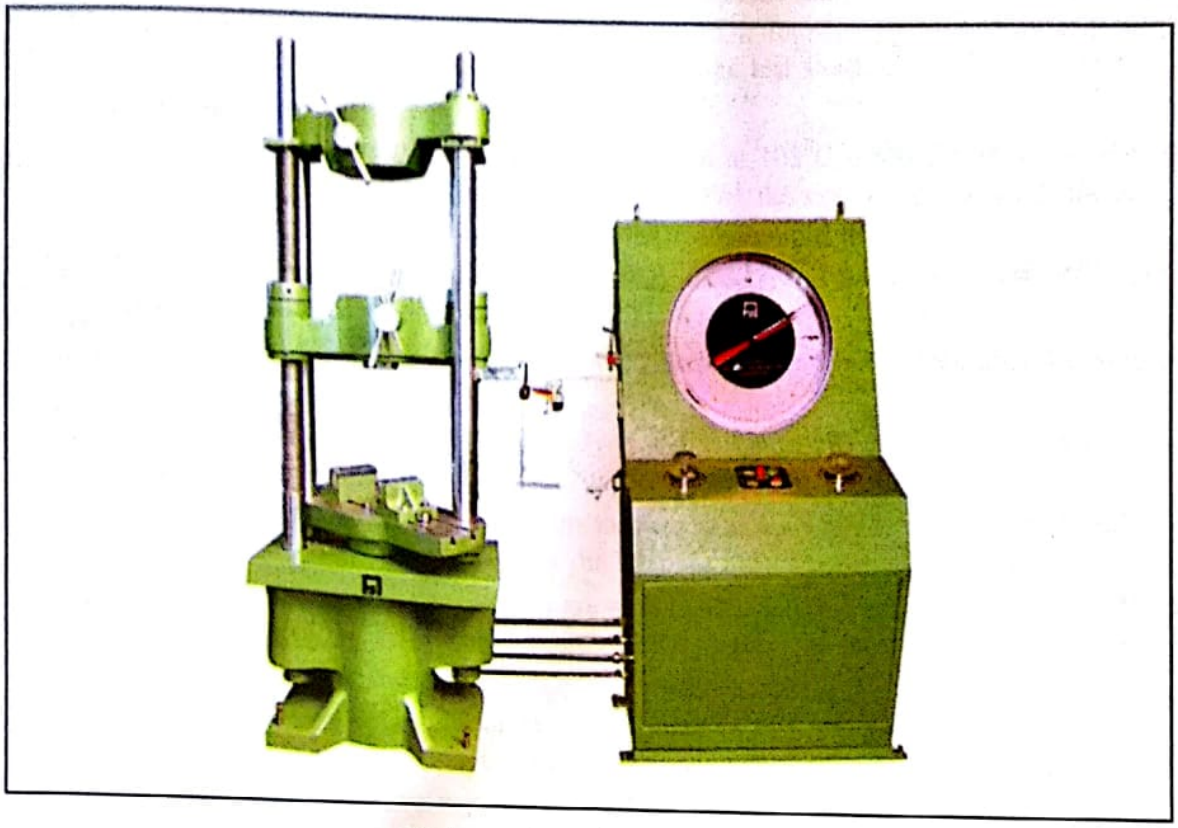
The sample is then dried in an oven at 105^{0}C ± 10^{0}C for at least 24 hours and then cooled by placing in a desiccators. It is weighed again. Let this weight be W_2.

(*c*) **Calculations.** Water Absorption, or **Absorption Value** is calculated by the relationship :

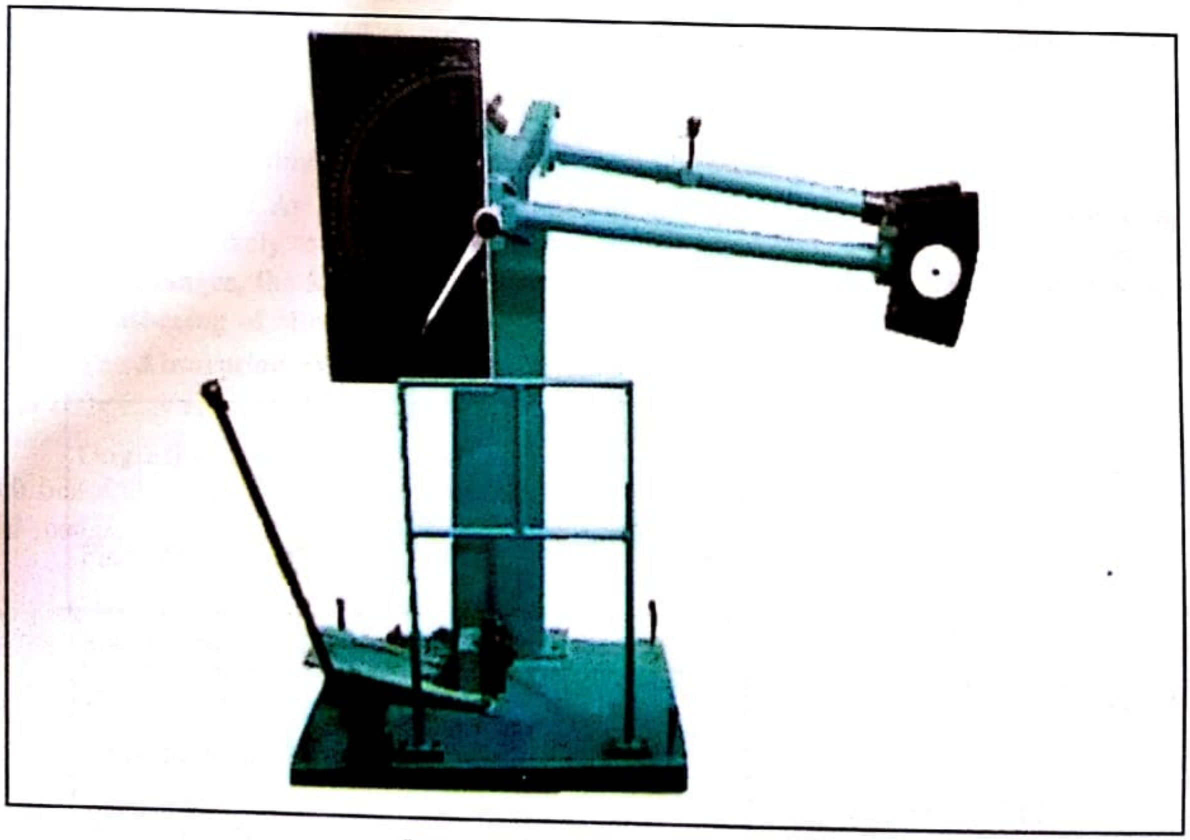
$$\boxed{\frac{W_1 - W_2}{W_2} \times 100}$$

4. TEST FOR WEATHERING RESISTANCE (IS Ref. 1125-1974)

(*a*) **Objective.** This test determines the resistance of stones to deterioration due to exposure to cold humid temperatures favourable for formation of ice and salt crystals within their pores.



Universal Testing Machine



Impact Testing Machine

(All Photos in different chapters by : Raja & Sumeet)

(*b*) **Test Samples.** Cubes of 5 cm sides or cylinders of 5 cm diameter prepared from representative rocks and given a fine polish at the ends are used as test samples.

(*c*) **Test Procedure :**

(*i*) Take three samples, previously dried in an oven at 105°C ± 5°C for 24 hours and cooled to room temperature in a desiccator. The sides of the samples are smooth finished. The so dried samples shall be weighed. Let their dry weight be W_1.

(*ii*) Each test sample shall be freely suspended in water for 24 hours at 20°-30°C and then weighed in that condition. Let this weight be W_2.

(*iii*) The test sample shall be taken out of water and surface dried and weighed **in air**; let this weight be W_3.

(*iv*) Now, each sample is placed separately in a dish made of porcelain or glass containing a solution of 2 gm powdered gypsum in 25 ml of water.

(*v*) These three dishes so prepared with the test samples are placed in a ventilated oven at 105 °C ± 2 °C for 5 hours (or till the evaporation of water of solution).

(*vi*) The dishes containing the samples are now removed from the ovens. They are allowed to cool **naturally** to room temperature. This process completes **one cycle of treatment prescribed under the test.**

(*vii*) Again, each sample is placed in a fresh dish in a new solution of 2gm of gypsum in 25 ml of water and the same process of placing in ventilated oven is repeated.

Thirty such cycles are repeated on all the three samples.

(*viii*) Thereafter, each sample is first cleaned by a stiff brush to remove superfluously sticking gypsum and then immersed in clean water for 24 hours.

(*ix*) Each sample is taken out from water; surface dried and weighed fourth time and fifth time:

Fourth time in **air** (W_4)

And fifth time (W_5) in a suspended state **in water**

(*d*) **Calculations:** As a result of **30 cycles of drying in presence of gypsum solution,** each sample is likely to undergo some changes in its absorption and in its volume. **The greater the changes, the lower is their resistance to weathering or, in other words, higher is the weathering of stones.**

The **Absorption Values** are given as described :

Original Absorption $(A_1) = \dfrac{W_3 - W_1}{W_1} \times 100$

Final Absorption $(A_2) = \dfrac{W_4 - W_1}{W_1} \times 100$

The **volumes** of the test specimens :

Original Volume- After 24 hours immersion $(V_1) = \dfrac{W_3 - W_2}{d}$

Final volume after 30 cycles $(V_2) = \dfrac{W_4 - W_5}{d}$

(d = density of water at the time of recording)

5. TESTS FOR DURABILITY OF STONES (Refs: IS 1126-1976)

This is almost like test 4 except that in this case the solution used is that *of sodium sulphate decahydrate*

(*a*) **Test Samples.** Take 3 cubes of 5 cm sides or cylinders of 5cm dia.from the representative rocks. These shall be dried by placing in an oven for 24 hours at $110^0 \pm 10^0$C.

(*b*) **Test Procedure :**

(*i*) The dried test specimens are first weighed in dry condition. Let this weight be W_1.

(*ii*) They are then suspended in a saturated solution of **sodium sulphate decahydrate** at room temperature for a duration of 18 hours.

(*iii*) They are then taken out of the solution, air dried for half an hour and then dried in an oven at $105^0 \pm 5^0$C for 4 hours.

(*iv*) The samples are then cooled to room temperature. This completes one cycle of the test.

(*v*) The above process (*ii-v*) is repeated on the samples as selected at (*i*) for **30 cycles.**

(*vi*) After thirty cycles, each sample is thoroughly washed to remove any sticking sodium sulphate. It is then weighed finally. Let this weight be W_2.

This may be in any case less than W_1. The loss in weight calculated in percentage terms, as follows is a **qualitative measure** of durability of the stone.

(*c*) **Calculations :**

$$\boxed{\frac{W_1 - W_2}{W_1} \times 100}$$

Greater the loss in weight, poorer is **durability.**

1.5. QUARRYING OF STONES

1.5.1. Definition

It is *known that stones occur in nature in the form of natural rock masses forming hills or walls of valleys.* These have to be broken and extracted from those natural **outcrops** for using in the *construction.* **The process of extraction of suitable stones from their natural place of occurrence for use in construction is called quarrying.**

Quarrying is different than **mining** used for extraction of ores for metals in that in mining we go *deep below the surface,* the top surface is left in tact, and the ores are extracted from under the earth. *In quarrying,* however, the process of extraction starts from the surface.

1.5.2. Selection of Quarry Site

Engineers and contractors have to keep following factors into consideration while deciding about the location of a quarry site.

(*i*) **Availability of sound rock.** A quarry can be opened up only where a sound rock that can yield good quality building stones exists in a sufficiently large area. This is essential because quarrying operations require quite heavy initial investment in men and machinery and these have to be economically viable.

(*ii*) **Distance of area of construction.** Quarrying is commonly a commercial operation. The quarry should not be located far away from the construction site because that may involve too heavy cost on transport of stone. At the same time quarry cannot be located within or close to a town.

The quarry site must necessarily be close to a main road so that stones extracted from it can be transported to any outside places at economical rates.

(*iii*) **Availability of water and dumping space.** In quarrying operations, large number of equipment, men and machines are often required. Sufficient open space at safe distance from quarrying must be available. Often lot of water is also required for the workers and even during cutting operations when machines are to be used. This must also be available locally. Dumping space is required for storing the broken stone and also for dumping useless rock fragments obtained during quarrying. Further, adequate drainage outlets for removing any groundwater or surface waters immediately after rains must be provided at the quarry.

1.5.3. Preparatory Steps

Once a site for quarrying of stones has been decided, following preparatory steps become necessary for starting the operations:

(*i*) **Selection of method for quarrying.** Quarrying can be done manually or with the help of machines. Mechanized quarrying is the advanced and preferred method for quarrying. The choice will depend on the size of the quarry, the nature of the rock and the commercial demand of the building stone to be quarried from the site.

(*ii*) **Preparation of a layout.** A scheme for operation process or lay out of the quarry has to be prepared after selecting the method of quarrying. This should include the face of attack, the progression of the attack and various stages in which the blocks of rocks are to be removed.

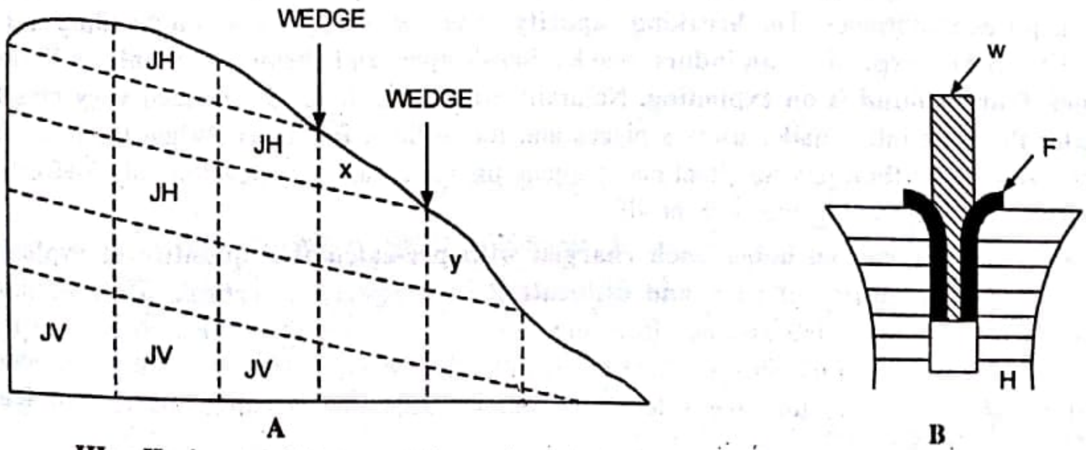
(*iii*) **Removal of the over burden.** The upper surface of natural bedrock is quite often covered with some thickness of soil or **weathered rock called overburden.** Such overburdens as well as loosely held rock pieces have to be removed well before the start of quarrying operations.

1.5.4. Methods of Quarrying

Quarrying methods are classified in two main headings: quarrying without blasting and quarrying by blasting.

A. Quarrying Without Blasting. In these methods, skilled persons remove blocks of rocks from their places of occurrence. They may use **hand tools** or even light channeling machines, called **channellizers.** No explosive material is used for breaking the stones.

The Wedge Method. It consists of digging a few holes at carefully selected places on the rock surface using ***chisels and hammers*** (small scale operations) or ***hammer drills,*** in large operations. Once the holes are ready, a ***steel wedge,*** **w**, is inserted in each hole between two steel strips, ***called feathers*** **(f)** (Fig.1.5). This (wedging) is done in all the holes drilled in a sequence. Such firmly inserted wedges are then struck with hammers ***almost simultaneously.*** As a result of hammer blows through this method, **cracks** may appear along the lines joining the holes in the rock mass. Thereafter long **iron bars** are inserted in the holes and the cracks so caused and the **blocks of the rocks** bound by cracks are **bodily pushed out and forward** from the quarry slope.



JH = Horizontal Jointing; JV = Vertical Jointing; H = Hole W = Wedge; F = Feathers

Fig. 1.5. Quarrying by Wedging.

The channeling method of quarrying involves use of big machines called channellizers. Each channellizer is provided with reciprocating cutting tools. The machines are power driven. When it is desired to obtain large sized **single blocks** of costly stones like marbles and limestones, use of channellizers becomes almost essential. The channellizer can cut a groove of up to 3 m depth, 3 m length and of about 5 cm width or even more. Holes are then drilled horizontally from the free side to meet the groove at the back at its base. (Fig. 1.6.) Using wedges and steel bars, the block, (B), is separated from the rock and hoisted away up to the transporting lorries or wagons.

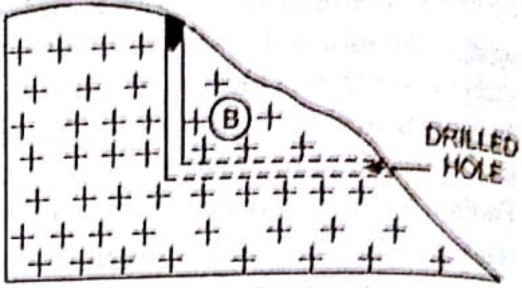


Fig. 1.6. Quarrying by channeling.

Single blocks as big as 30 m long, 3 m thick and 1-3 m wide can be quarried by this method from soft rocks.

B. Quarrying by Blasting. This method involves use of explosives for breaking stones **from very hard rocks like quartzites and sandstones, basalts, traps and non–ornamental granites.** It has been observed that quarrying of these type of hard rock becomes **very laborious and costly** by other methods.

The basic principle employed in this method is to explode a small quantity of an explosive at a calculated depth within the body of the rock. The force generated due to the explosion is sufficient to only create cracks and loosen rock blocks of good size.

Blasting for quarrying for building stones is different in detail from blasting of rocks for road clearance and other purposes. In the latter case the **size of the broken stone** is not of the same consideration as in the case of building stones.

Quarrying by blasting involves a series of systematic operations such as drilling of blast holes, charging of those holes and firing the shots.

(*a*) **Drilling of blast holes.** A blast hole may be defined as a **hole of specified diameter and depth** driven at a **predetermined location** on the body of rock. It may be driven either **manually** or **mechanically** using suitable type of drills.

The type of the explosive selected for use determines the **diameter of the hole.** Many explosives come in standard sized cartridges; hence the diameter of the hole has to be slightly bigger than the outer diameter of the cartridge to allow easy insertion. When blasting powder is used as an explosive, the diameter of hole depends upon the quantity of the explosives that is needed to be accommodated in the shot.

The **depth of the bore hole** depends on the volume of the rock to be broken in one shot. When a large volume of rock is to be loosened in one round, and a number of holes have to be drilled, **their spacing** also acquires importance. The **breaking capacity** or power of explosive is a deciding factor. **A given quantity of any explosive can induce cracks, break open and throw away only a limited volume of rock from around it on exploding.** Naturally when blast holes are located **very closely,** they will shatter the rock into smaller useless pieces and throw them **far away.** When the holes are spaced **too far from each other,** reverse effect may happen: the rock mass may develop only **ineffective cracking** not helpful in loosening the rock at all.

Hence, **only properly spaced holes, each charged with pre-calculated quantity of explosive will loosen the desired quantity of rock and dislocate it in a desired direction.** While deciding about the spacing of shot holes, the distance from the free side(s) of the quarry has to be kept into consideration. When a fully charged shot is made to explode, the **thrust of the shot** is directed along **the line of shortest distance** to the free side of the quarry. This line is called the **line of least resistance.** (Fig. 1.7, HA)

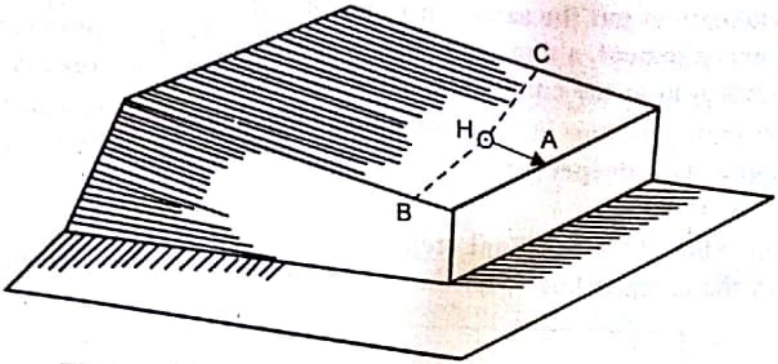


Fig. 1.7. Spacing of holes and line of least resistance.

If this line happens to be **very long,** it may prove **ineffective** in displacing the broken stones towards the free side of he quarry; if this line is **too short**, the broken rocks may be thrown **farther away** than desired. This shows its importance in planning the total blasting programme.

(*b*) **Charging of Blast holes.** The loading (also called charging) of the blast holes with pre-determined quantities of selected type of explosive is to be done **with great care and caution.** A slight negligence in this operation may lead to fatal accidents.

Following are important steps for charging :

(*i*) Each drilled hole is **cleared of all the obstructions**, projections and any broken material with the help of wooden rods.

(*ii*) **Measured quantity of the explosive cartridge or powder is then inserted** in small quantity at a time. Before adding the next batch of explosive, the previously placed quantity is packed firmly by using **wooden tamping rods** (*remember: metallic rods are never used).*

(*iii*) When **blasting powder** is used as the explosive, a **fuse** is also inserted at this stage. In the case of a **cartridge explosive**, the **primer** (a small cartridge containing high explosive to initiate the charge) is introduced and connected to a safety fuse. The hole is generally filled **up to 1/3 or 1/2 of its total length with the explosive.**

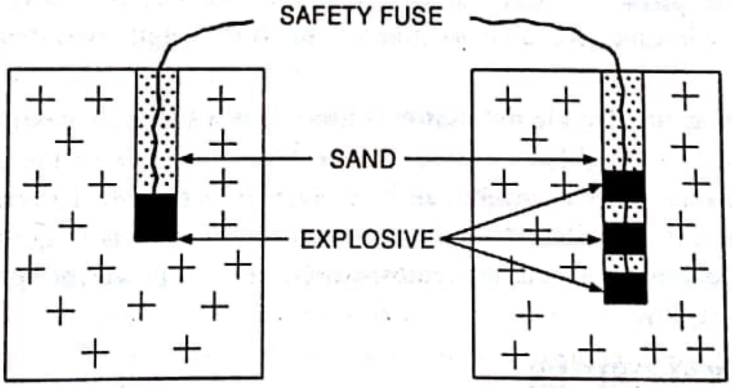


Fig. 1.8. Stemming of Blast Holes.

(*iv*) The hole is then **properly stemmed.** By **stemming** is understood filling and packing the remaining length of the blast hole with **an inert and non-combustible material like powdered rock, sand and /or clay.** This is also done in **installments.** Each installment of the stemming material placed in the hole is first thoroughly compacted with the help of wooden tamping rods and spatula before placing the next installment. The **main object of the stemming process is to prevent the escape of the gases produced on ignition through the hole without doing any breaking job.**

(*v*) It is also customary to **put the safety fuse** (for firing) in the beginning of stemming operation. **In another arrangement,** a thin rod is kept inserted in the hole during the stemming process. This rod is removed at the completion of stemming and safety fuse is inserted in its place.

(*vi*) Sometimes stemming is done in **repeated layers** alternating with explosive layers. This becomes almost essential with **deeper holes** where large quantities of explosives are required to be used. (Fig. 1.8 A&B).

(*c*) **Firing of the Shot.** It is **the final step** in the process of blasting. It involves igniting the explosive filled up in the charged hole with the help of a **safety fuse** or by **electric detonators.**

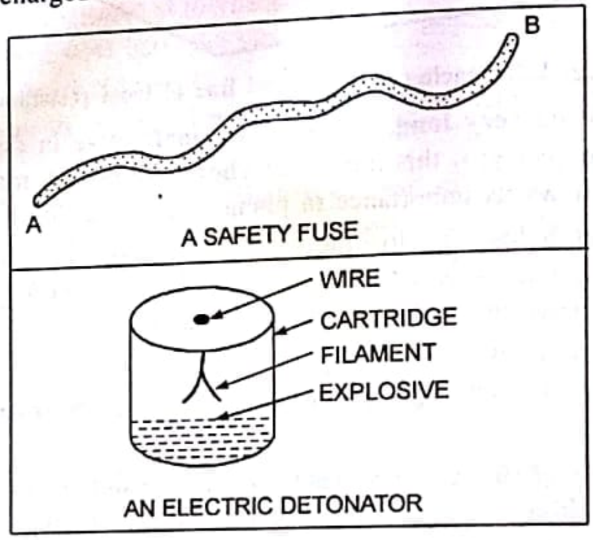


Fig. 1.9. (A) A Safety Fuse (B) An Electric Detonator.

A safety fuse is essentially a **thin strain** of gunpowder properly wrapped in a **cotton thread.** When ignited, it burns from one end to the other end of the thread **at a fixed speed,** generally taking **100 to 130 seconds** per meter. One end of such a fuse length is connected to the blasting cap of the **primer cartridge** (already placed in the blast hole along with the charge). The other **free end** of the fuse trails behind at the surface outside the shot. It is this free end that is ignited by the firing man who has only that much time available to him as the fuse length will take the fire to the shot. (Fig. 1.9A)

In electric detonation, an **electric detonator** is used. It is a specially designed metallic cap, which contains a small quantity of **highly sensitive charge** filled in it. Over the charge hangs a **copper filament** through which an electric current can be conveyed. When all the arrangements are declared **final and safe,** the current is **switched on** from a control panel located quite away from the shots. This ignites the small explosive in the detonator, which gives a powerful spark thereby igniting the main charge in the blast hole.

1.6. BLASTING EXPLOSIVES

1.6.1. Definition

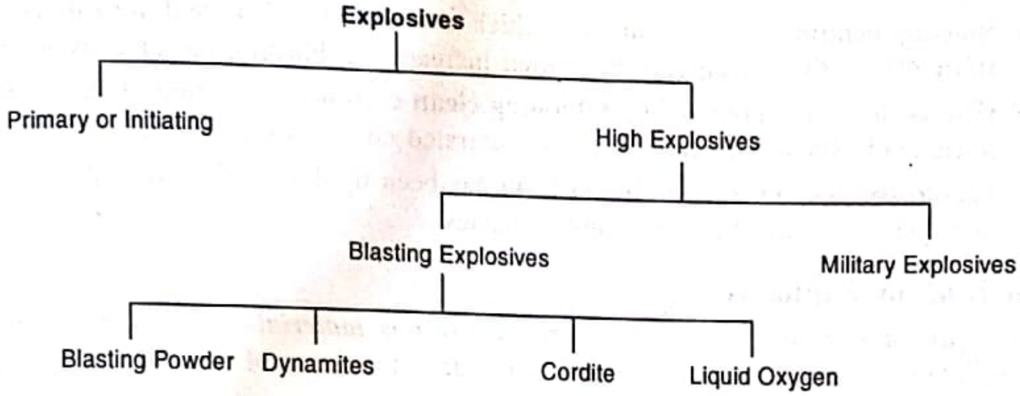
An explosive is **essentially a chemical compound** in solid or semi-solid (jelly like) state that upon igniting changes **instantaneously** to a gaseous state. This change involves tremendous increase in its volume accompanied with **generation of lot of energy and heat.** When an explosive is burst within the body of a rock, large volumes of forceful gases are produced **that travel in all directions with great pressure.** They escape to the atmosphere after creating cracks and fractures and even blowing away the rocks along their passage.

1.6.2. Classification

Explosives are broadly classified into **two main groups:** Primary Explosives and High Explosives. The high explosives are further divided into Blasting Explosives and Military Explosives as shown in Table 1.4.

1. **Primary Explosives.** These include a number of such explosives which have **very high sensitivity** so that they explode very quickly even from a very feeble spark. Hence they can be used only for igniting the main charge. Examples are *lead azide, mercuric fluminate and diazodinitrophenol.*

TABLE 1.4. Classification of Explosives.



2. **High Explosives.** These form a group of explosives that require a **definite amount of heat (temperature)** or shock for exploding. This heat or shock is generally provided by exploding a primary explosive placed in close contact with the high explosive. Two types of high explosives are: Military Explosives and Blasting Explosives:

(*a*) **Military Explosives.** These are very powerful explosives comprising mostly mixtures of nitrated compounds. A few well-known examples often used in military operations are: **T.N.T.** (Trinitrotoluene), **PETN** (Penta-erthrio-tetra-trinitrotoluene) and **CYCLONITE** (Cyclo-trimethylene-trinitramine).

(*b*) **Blasting Explosives.** These are **group** of explosives which are **specifically used for blasting of rocks in quarrying and road making operations.** They range in composition from simple mixtures of nitrates to complex compounds. They come in **solid,** semi-solid and **even liquid** (oxygen) state. At present there is a wide range of blasting explosives available with varying degrees of blasting power and which can be used with ease in both **dry** as well as **wet environments.** Following is only brief mention of **important characteristics** of some most commonly used blasting explosives.

(*i*) **Blasting powder.** It is usually a **mechanical mixture** of sodium nitrate or **potassium nitrate** with large proportions of **sulphur** and **charcoal**. It has been the **most commonly used** blasting explosives for many centuries. It is well suited for soft rocks and especially in small scale quarrying operations. The usual composition of blasting powder is: **nitrate : 70-75%; sulphur: 10-15% and charcoal: 10-15%.**

In quarrying, **[1 kg]** of blasting powder of above composition can loosen and displace about **[4 cubic meters]** of rocks from a soft rock.

(*ii*) **Dynamite. Alfred Nobel** of Sweden invented dynamite in 1860. (It is the same Alfred Nobel ***who instituted the so famous and prestigious Nobel Prize***). Straight dynamite is a patented mixture of **nitroglycerine** (75%) and **non-explosive material like sandy earth, charcoal or calcium carbonate.** The whole material makes a **jelly-like** paste and is supplied in the form of **cartridges of different strength.**

Since the invention of dynamite, this explosive has been **improved** in many ways. Some types of different strengths are :

(*a*) *Straight Dynamite.* These have, besides nitroglycerine, non-explosive materials to the extent of 25-40 per cent. Similarly, 60% dynamite signifies a type having 60% nitroglycerine and 40% inert material.

(*b*) *Gelatin Dynamite.* These contain ammonium nitrate as an additional essential component besides nitroglycerine and the inert materials.

(*iii*) **Cordite.** It is a patented name for a combination of nitroglycerine and nitro cellulose. The explosive **bursts with smokeless gases** and is **especially useful for underwater blasting.**

(*iv*) **Blasting gelatin.** It is a dynamite in which **nitro cellulose is added in proportion greater than 8% to the nitroglycerine,** which increases its blasting power considerably.

(*v*) **Gun cotton.** It is prepared by saturating **clean cotton** in a mixture of sulphuric acid and nitric acid. Sticks are made from the saturated cotton while in wet condition.

(*vi*) **Liquid oxygen.** Oxygen in liquid form has been used as a blasting explosive in mining and quarrying operations in many countries.

1.6.3. Handling of Explosive

Explosives are always to be treated as very dangerous materials. They need great care and caution during their **storage, transport** to place of use and at the time of **use** in quarrying operations.

(*a*) **Transportation of Explosive.** Before transportation of explosive from the place of manufacture to another place, it must be ensured that:

- (*i*) explosives are **properly packed** in suitable and safe **containers;**
- (*ii*) they have been thoroughly **tested** for their stability and **sensitivity;**
- (*iii*) **no other inflammable material** has been placed in the same wagon or lorry in which explosives are placed;
- (*iv*) **no blasting caps or detonators** are placed in the same wagon.

(*b*) **Storage :**

- (*i*) the storage place must be **away from the populated area;**
- (*ii*) they must be stored in **specially constructed** explosive chambers;
- (*iii*) blasting caps, detonators, and main explosives must be stored in **separate** and different **compartments.**
- (*iv*) **entry** to the explosive stores **must be totally restricted** and regulated to avoid accidental blasts.

(*c*) **Use (Charging and Firing) :**

- (*i*) explosives should be always used under the strict supervision of an **expert in handling the explosive;**
- (*ii*) **no attempt should be made** to charge the blast holes with chilled, damaged or frozen explosives;
- (*iii*) **no attempt** should be made **to force a cartridge into the hole;** rather the hole should be made wide enough to allow easy insertion of a cartridge being used;
- (*iv*) the charged holes **should never be tapped** with any **metallic bars or rods;** only wooden rods should be used for such jobs, if needed at all;
- (*v*) no attempt should be made **to fasten the safety fuse** to the blasting cap **using teeth;** only fingers must be used;
- (*vi*) the **length of the safety fuse** should be **more than** actually required by the firing man to escape to a safe distance after igniting it;

(*vii*) the safety fuse should be ignited only after getting a clear signal from the blasting supervisor.

(*d*) **After Firing.** Many a times a charge may **fail to explode.** It is called a **misfire. Misfires often become the cause of fatal accidents.** Following precautions are necessary in this case:

(*i*) **No hasty attempts** should be made to find the **cause** of a misfire. Let a **good deal of time pass** before actually approaching the missed shot to investigate the cause. It may actually not be a missed shot; it may be a **delayed** shot.

(*ii*) The misfired charge **must never be drilled again** for charging afresh. In fact a second blast hole should be made at a safe distance (at least 1 m) from the missed shot.

1.7. DRESSING OF STONES

1.7.1. Definition

By dressing of stones is meant the process of ***giving a proper size, shape and finish to the roughly broken stone as obtained from the quarry.*** This is done either manually or mechanically or in some cases using both the methods.

1.7.2. Objects

Stones as obtained from the quarries are very **rough and irregular** in shape. Besides, they may be **too bulky to be used in construction.** Hence various objectives of dressing are:

(*a*) **To reduce the size of blocks to easily portable units.** This is often done **at the quarry itself** because transport of big blocks may become a costly affair.

(*b*) **To give a proper shape to the stone.** We can use stones in foundations as **blocks**, in walls as **small units**, in floors as **slabs** and in columns as rounded or square **pillars. Each situation requires a proper shape** that has to be given under the process of dressing.

(*c*) **To obtain an appealing finish.** Stones always come in rough and rugged forms. For use in building construction in **walls and exteriors**, they have to be given an **aesthetically appealing finish. A stone house** has its own distinction, beauty **and individuality in a concrete jungle.**

1.7.3. Methods of Stone Dressing

As said earlier, dressing of stones can be done both manually or mechanically.

Manually, skilled workmen **can work wonders** on suitable type of stones with chisels, hammers and abrasives. Not only they can give excellent finish and polish but also may do **carving and engraving** that can withstand for centuries.

Mechanically, special saw-fitted machines can cut slabs, blocks and any other shape from rough rocks. These are called **rock cutters.** The grinding and **polishing machines** are fitted with wheels or discs with abrasives capable enough to give **polish and fine finish** to any desired degree even on the hardest of stones.

The Traditional Dressing Methods applied in manual dressing are described in outline as below :

(*a*) **Pitched Dressing. In** this method, only the **edges of a block of stone** are made **level** with the skilful use of **hammers.** The surface is left in original cut. (Fig. 1.10 A)

(*b*) **Hammer Dressing.** It is that of dressing in which **edges as well as faces** are reduce to an even regular surfaces. **It has a pitted appearance on the surface.** (Fig. 1.10 B)

(*c*) **Chisel Drafting.** In this method straight grooves are made with the help of a chisel at all the four edges. The superfluous stone from the center is removed by chisels. Chisel drafted stones are specially used in plinths and corners of the building. (Fig. 1.10 C)

(*d*) **Rough Tooling.** The edges are first made square by using chisel and hammer. Then a series of grooves of variable width are developed over the surface of the stone.

(*e*) **Punched Dressing.** It is done on the stones that have already been **rough-tooled.** A series of parallel ridges are made on the stone surface using hammer and chisel. It is also called **furrowed finish.**

(*f*) **Close Picked Fine Tooling.** This is an extreme type of dressing in which almost every type of projecting irregularity is removed from all the four sides of a stone. Its surface is given fine finish and an appealing look. (Fig 1.10 D)

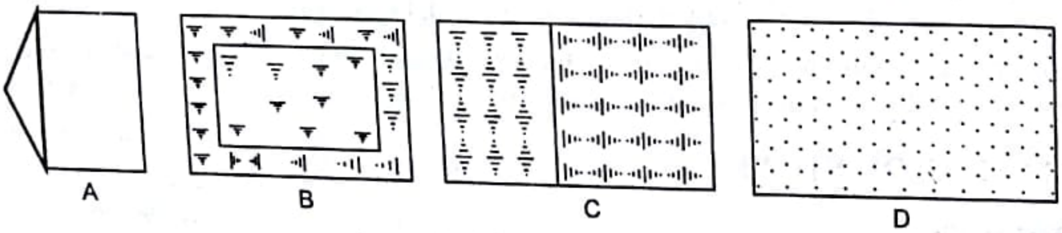


Fig. 1.10. Types of Dressing.
A = Pitched Dressing; B = Hammer Dressing; C = Chisel Dressing; D = Fine Tooling

(*g*) **Boasted Finish.** It is a very common type of finish in which the surface of the stone is covered with parallel marks that may run in a particular direction on a particular face. A boaster, which is actually a wide-edged chisel is used for this purpose and hence the name.

Numerous other types of finishes are given to stone in the dressing process depending upon the skill of the worker and fancy of the owner.

1.7.4. Tools Used in the Dressing of Stones

In manual dressing, a variety of stones are used to obtain a desired finish. Among them **hammers and chisels** deserve special mention. Some of the common hammers and chisels are shown in the Fig. 1.11.

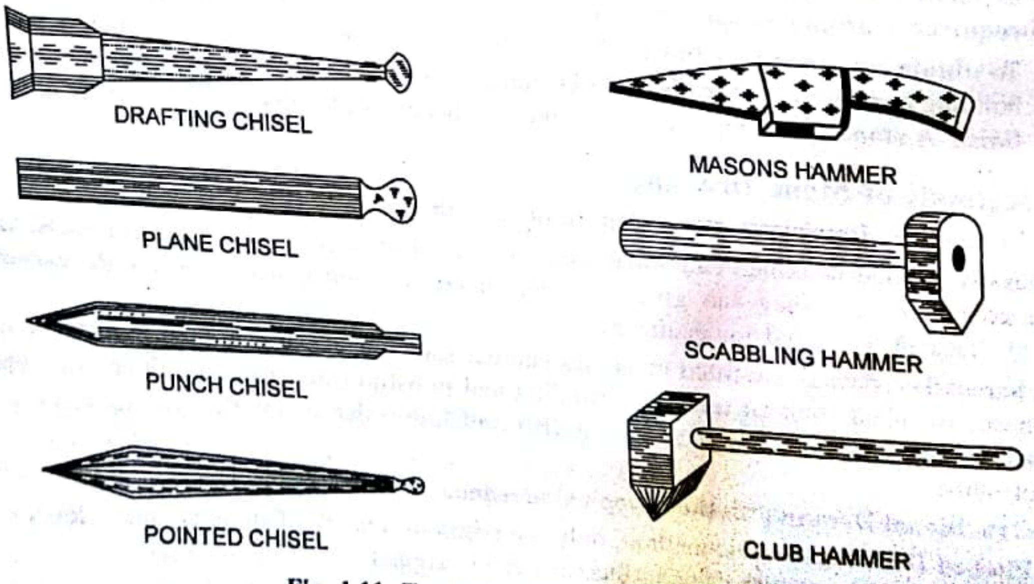


Fig. 1.11. Types of Hammers and Chisels.

1.8. SOME COMMON BUILDING STONES

1.8.1. GRANITE

It is a coarse to medium grained Igneous Rock made up **essentially of felspar orthoclase and quartz minerals.** It may also contain some accessory minerals like **mica, hornblende and tourmaline.**

Granites are generally light coloured and often spotted. **Most** granites possess excellent building properties such as: high strength values and very high hardness, excellent durability and very low absorption value. **Granites occur in appealing** colours and have a capacity to take very fine, glassy, mirror-like finish on polishing. These have, however, poor fire resistance and should be avoided around stoves in cold countries.

Occurrence: India has got almost inexhaustible deposits of granites confined mostly in Peninsular India in states like Andhra, Karnataka and Kerala. In the Himalayan regions, granites are found locally in some places in Kashmir and Himachal Pradesh.

1.8.2. Basalt

It is a volcanic type of Igneous Rock that is formed from cooling of lava coming out of volcanoes.

The basalts, also called Traps, show great variation in their mineral composition. Their essential minerals are the felspars and ferromagnesian components like hornblende and augite.

Basalts are dark coloured, fine-textured crystalline rocks. They sometimes show cavities and pores developed during cooling process because of escape of gases.

Basalts, like granites, possess very high strength values. They are quite resistant to weathering. However, their high hardness makes them difficult stones to dress.

In occurrence, basalts and traps are perhaps the most common rocks of India. The so called Deccan Traps covering more than four hundred thousand square km area of southern India including Maharashtra and Gujarat are made of lava flows of basaltic composition.

1.8.3. LIMESTONES

Limestones are fine textured sedimentary rocks of **calcareous composition** and of organic origin. They occur in **stratified formations** and also as masses. They are made up of calcium carbonate, although some varieties may contain good proportion of magnesium carbonate. Another rock, **Dolomite,** which is predominantly made up of **magnesium carbonate** has same properties as limestones. Both of these rock often occur close by in nature. Limestone is however, more common and important.

Limestones occur in great variety of colours: from pure white chalk, through grey to grayish black massive limestones. The colour of limestone depends on its composition, especially the type of impurities that are present finely dispersed throughout the carbonate matrix.

All limestones are NOT useful as building stones. Some varieties, for instance, the argillaceous limestones are practically unfit because of their poor strength values. The dense, compact and massive varieties, however, **make excellent building stones** and many buildings made of them have withstood the test of time.

The use of limestones should be avoided as facing stone in industrial towns where emanations from industries are likely to interact chemically with the limestone and destroy its look and durability.

India has huge deposits of limestones of building grade in Andhra Pradesh, Delhi State, Madhya Pradesh, Uttaranchal, Uttar Pradesh, Rajasthan, Himachal Pradesh and Jammu and Kashmir. In many states, limestones are also extracted for use in manufacture of Portland cement.

1.8.4. Marble

Marble is a metamorphic rock of granular texture and calcareous composition. It is formed in nature from limestone through the process of metamorphism. The essential mineral in marble is recrystallised calcite (calcium carbonate: $CaCO_3$).

In texture, marble is a fine-grained rock with a uniform granular (sugar-like) texture. These textures are developed due to heat acting on limestone in nature at the time of its conversion to marble.

Marble occurs in a variety of colours from pure white, red, pink, green to dense black. The colour of marble depends on the type of impurities finely dispersed through the rock during the formation stage.

A good quality marble generally satisfies all the requisite properties of a good building stone. They are quite strong, uniform in texture, least porous and take **excellent polish**. They are suitable both as ornamental stones and for general construction.

Occurrence. India has got fairly widespread deposits of marbles of good quality. Presently, they are exploited at different places in the state of Rajasthan at Jodhpur, Jaipur and Ajmer. Marbles from Makrana in Jodhpur are of pink and white colour while those of Ajmer are of green and yellow shades. Marbles of quite good quality are also available in Baramulla district of Jammu and Kashmir.

1.8.5. Sandstones

Definition. Sandstones are sedimentary rocks, siliceous in composition, mostly stratified in structure and showing texture variable from coarse to medium to fine grained.

Composition. The essential mineral of all the sandstones is Quartz (SiO_2). Among the accessory minerals, mica, felspars and some dark minerals are sometimes present. In cemented varieties of sandstones, the cementing material may be siliceous, ferruginous, calcareous or clayey in nature. And, this property of (cementing material) is most important in defining the suitability or otherwise of a sandstone in building construction.

Texture. Sandstones show a variety of texture ranging from coarse-grained, medium grained to fine grained.

Colour. Sandstones occur in many colours: white, grey, pink, red, maroon and dark.

Building Properties. Many sandstones, especially those with siliceous cementing material, light in colour and fine-grained in texture are excellent building materials.

Occurrence. India is bestowed with huge reserves of really good quality sandstones spread in the states of Madhya Pradesh, Uttar Pradesh, Orissa, Bihar and Jammu and Kashmir. The Vindhyan Sandstones of Madhya Pradesh that are spread over five lakh square kilometers have been often described as most eminently suitable for building and architectural work.

1.8.6. Gneisses

Definition. A Geniss (pronounced as nees) is geologically a metamorphic rock. It is generally siliceous in composition and foliated or banded in structure. In most cases, gneisses resemble closely to granites from which they are commonly derived by the process of metamorphism

Composition. Gneisses show wide variation in mineral composition depending upon the composition of the original rock from which they have been formed by metamorphism. Gneisses formed from granites have, more or less, the same mineral composition, as the parent rock. Felspar, quartz and ferromagnesian minerals are rearranged due to heat and pressure in bands or folia.

Textures and Structures. In texture, gneisses are coarsely crystalline rocks. They often show banded or foliated structures in which case micaceous minerals are segregated in distinct bands, which are separated from bands of granular minerals like felspars and quarts. Foliation when developed prominently makes the gneiss useless as a building stone.

Building Properties. When coarsely crystalline and uniformly textured, gneisses are as good building stones as granites. These are varieties that are light in appearance, free from mica and black minerals that are often used in construction in areas of their occurrence. Dark coloured and foliated varieties are better avoided.

Indian Occurrence. In India, gneisses of excellent building qualities are found in most of the southern states like Andhra Pradesh, Karnataka, Tamil Nadu and Orissa. They also occur in Bengal and Bihar.

1.8.7. Laterite

Definition. It is a sedimentary rock composed mostly of oxides of aluminium with varying amounts of oxides of iron.

Texture and Structure. The rock is formed from chemical decomposition of alkaline igneous rocks by leaching of some components. This results in spongy structure and porous texture.

Building Properties. The laterites are light to dark red in colour depending upon the quantity of iron oxide in their composition. They are poor in compressive strength, which varies from 20-30 kg/cm^2. Laterites are used only in ordinary construction and mostly as road metals rather that building stone.

Indian Occurrence. Laterites are found in Maharashtra, Madhya Pradesh, Bihar, Orissa, and also in some southern states like Andhra Pradesh, Madras and Kerala.

1.8.8. Slate

Definition. It is a metamorphic rock with a distinct foliated (Cleavage) structure. It is commonly siliceous in composition.

Texture and Structure. Slate is a very fine textured rock, so much so that its constituents cannot be identified clearly even under microscope.

The most typical property of slate is its **cleavage structure** by virtue of which it can be split into thin and smooth surfaced layers. This **slaty cleavage** makes it a cheap roofing material in ordinary construction.

Building Properties. Slate shows great variation in its building properties, which depend on the thickness of individual layers from slate mass and the colour of the rock. The rock is practically impervious and hence very suitable as roofing stone. Thick-layered slates have good compressive strength and find use as sills and for pavements inside and outside palatial buildings.

1.9. DETERIORATION AND PRESERVATION OF STONES

1.9.1. Definition

خراب ہونا/بگڑنا — [illegible]

Stones, like all other materials used in construction, deteriorate with time. Some undesirable changes are likely to develop in them after years of their exposure to natural agencies like wind, water and temperature. Appearance gets definitely affected. Strength qualities may not be easily affected with time, but when they do, the durability and safety of the building get endangered.

1.9.2. Causes of Deterioration

These may be either physical or chemical or both in nature.

Physical Causes. Among these, the frost action, the temperature effects and the rubbing action of winds may be quite significant.

(*i*) **Frost Action.** In cold humid climates, porous stones may absorb moisture from the atmosphere quite easily. When this happens in winters, water within the pores freezes and expands exerting tensile stresses from within. This natural slow and steady process, called **frost action** is repeated winter after winter. Frost action is capable of causing **splitting and spalling** on the surface of a stone. The stone may start disintegrating chip by chip and year after year, from surface inwards.

(*ii*) **Temperature Changes.** Stones like all other materials expand on heating and contract on cooling. Their co-efficient of expansion, is of course negligible when considered on short-term basis. But when considered for many scores of years and especially when stones are made of different minerals having different expansion and contraction coefficients some minor stresses do develop within the stone exposed to heating action of the sun. The surface of stone starts getting affected, apparently insignificantly in the beginning. The effect deserves due consideration when stones are used in arid regions on the exterior portions.

(*iii*) **Wind Action.** Strong winds rich in sand and dust particles act as virtual **sand papers**. These are capable of **polishing the stones** when they have a uniform texture and composition. But when the stones are made up of mineral constituents of different hardness, the soft minerals get polished more and may be gradually removed causing **pitting**. The adjoining hard minerals may also fall apart on losing the grip. Hence a process of slow physical disintegration starts on the surface of the stone exposed to wind action.

Wind action is a powerful scrubbing process in areas of strong winds lying on the borders of deserts.

Chemical Causes. The atmospheric moisture and some of the atmospheric gases and vapours emanating from industries are quite harmful for many types of stones exposed to their direct attack. A few examples may illustrate this type of slow deterioration of stones:

(*i*) **Water Vapours.** Water on chemical combination with atmospheric carbon dioxide makes **carbonic acid**. This acid has **mild corrosive action** on some stones. Thus it can slowly attack and eat up the strongest rock granite by its action on the felspar mineral of the stone according to following reaction :

$$\boxed{\underset{\text{Orthoclase}}{2KAlSi_3O_8} + \underset{\text{Carbon dioxide}}{CO_2} + \underset{\text{Water}}{2H_2O} = \underset{\text{Clay}}{Al_2Si_2O_5} + \underset{\text{K. carbon}}{K_2CO_3} + \underset{\text{Silica}}{4SiO_2}}$$

The clay formed in this reaction from orthoclase is a very **soft mineral** and gets easily removed from the rock with passage of time leaving behind **pits** on the surface.

(*ii*) **Limestone and marble** are both composed of calcium carbonate ($CaCO_3$). In industrial towns where SO_3 vapours are emanated from many industrial chimneys, they mix with atmospheric moisture and make an injurious sulphurous acid. This acid reacts with carbonates of the stone converting that into a **sulphate** and in the process tarnishing the surface of the stone.

The so hotly debated controversy of threat of deterioration to the marbles used in Taj Mahal from the sulphurous emanations from Mathura Refinery are based on this basic fact. It is asserted that to act on the stone surface, there has to be some minimum proportion of sulphourous vapour in the atmosphere, which will not be there because of one refinery.

1.9.3. Preservation

It is quite possible to protect the stone from quick deterioration by adopting one or more of the following three methods:

(*i*) **Careful Selection.** While selecting stones in a given area, a general assessment about the weathering resistance of the stone can be formed from quarries, old exposures or from the stones used in old buildings. If a stone has shown too much deterioration at those places, it is likely to deteriorate in a similar manner when used in building construction again in new buildings. Hence it may not be selected for use in similar situations exposed to weather.

Similarly, if a stone is to be used in an already established or proposed industrial town, its composition must be given due consideration. Limestones, marbles and dolomites, all carbonate rocks, are likely to deteriorate fast, especially on exposed parts. We should prefer use of siliceous stones like sandstones and quartzites instead.

If the area is of strong winds and located close to deserts, we should select only **fine textured stones** having uniform composition and good hardness, e.g. quartzites instead of granites.

(*ii*) **Careful Construction.** While constructing a stone house, in part or complete, a set of precautions can increase the life and beauty of the building to a considerable extent. Such as:

(*a*) **Stones of proper size** and shape should only be used with a mortar of matching quality so that no open spaces are left for moisture and gases to seep or get in.

(*b*) **No ledge of stone** should be left projecting out as it may act as a gathering place for water during rains.

(*c*) Use of **different stones** in alternate layers or even in the same layer should be avoided. Homogeneity in the stone construction is considered a better policy.

(*d*) **Only well seasoned stones** be used in constructions. When stratified, their bedding planes should be given proper consideration while piacing them in load bearing positions.

(*iii*) **Application of Preservatives.** When a stone has already been used and there is a risk of its deterioration because of the environmental conditions, a preventive measure may be taken by applying some well known preservative on it.

A preservative is an **emulsion of an oil or a paint or a solution** which when applied on a stone (or any other such material) protects it from the direct attack of some deteriorating agency.

A really effective preservative must be

- easily applicable,
- easily penetrating,
- unleachable and above all,
- economical.

Further, the preservative **must not** change the natural appearance of the stone (unless it is desired to be changed) and produce odd smell.

A large number or preservatives are available for preventing the deterioration of stones. The following are mentioned for reference only.

(*i*) **Linseed Oil.** It is used both in cold and boiled form. Boiled linseed oil will change the appearance of a stone to a darker shade.

(*ii*) **Paraffin.** It is commonly used in the dissolved form in naptha. It also interferes with the original colour of the stone.

(*iii*) **Coal Tar.** It is a cheap and effective preservative except that it changes the look of the stone.

(*iv*) **Baryta Solution.** It is simply a solution of barium hydroxide and has been found resistant against sulphate salt attacks on the stone surface. It reacts with calcium sulphate forming barium sulphate, which is more stable and protects the surface of the stone from further deterioration.

(*v*) **Paints.** When stone deterioration has spoiled the appearance of a stone to a considerable extent, best course would be to cover it with a paint. It will stop further deterioration and also improve the look.

1.10. ARTIFICIAL STONE

Definition. It is a **stone-like mass** made by mixing together **crushed stone pieces with cement and water** in the presence of colouring pigments.

Types. Artificial stone, in the broadest sense of the term, may be best called **a type of cement concrete.** This can be made in various shapes and in different composition. The **components** of artificial stones are decided by the engineer and **pre-mixed in fixed proportions with cement and water.** After thorough mixing, the paste is filled in **proper moulds** and allowed to set in. Thereafter they are removed and placed on plain protected surface for **curing and hardening.**

Grooves, cavities and hollows can be provided in the stone as desired at the moulding stage.

Terrazzo and Mosaic Tiles are simple and common varieties of artificial stones. **In Terrazzo,** it is **marble** in the form of chips that is the main material used with the cement mix for making the stone.

In the case of Tiles, it is the **top surface of the normal cement concrete** in which marble chips are spread uniformly during the casting process.

Uses. Artificial stones have the general properties and appearance of natural stones to some extent. These have the **advantage** that these can be **cast and cured at the place of their use** and in any desired shape. Moreover, these stones often can be given **any desired polish.** For these reasons artificial stones are used in buildings to gives decorative looks.

TYPICAL QUESTIONS

(A) ESSAY TYPES

1. (*a*) What are building stones ?
   (*b*) How are they classified ?
   (*c*) Describe briefly geological classification of building stone (rocks). Give examples of two building stones falling in each geological group of rocks.
2. (*a*) Are all rocks suitable for use in building construction ?
   (*b*) Discuss in some detail some major properties that will have to be tested in a rock before it can be selected for use in building construction.
   (*c*) Give examples from rocks with respect to the properties discussed in (*b*).
3. Give the geological and structural classification of the following stones in a tabular form : Marble, sandstone, granite, slate, gneiss, dolomite, quartzite, limestone.
4. (*a*) Explain the following tests as performed on a building stone. Why and when these tests become absolutely necessary :
   1. Transverse strength test;
   2. Resistance to weathering;
   3. Durability test.

   (*b*) What are the relevant IS codes for each of the above tests:
5. (*a*) Give a comparative amount of the various methods used for "QUARRYING OF BUILDING STONES".
   (*b*) Why the same method is not suitable for quarrying of all the types of stones ?
6. What do you understand by DRESSING OF STONES? What are the main objects in dressing of stones and how they are achieved ? Explain, with suitable sketches, important methods of dressing of stones.
7. (*a*) How do stones suffer deterioration ? Give examples to support your answer.
   (*b*) What are the functions of a preservative on a stone? Discuss briefly role played by a few of common preservatives used in protection of stones.
   (*c*) "There is a risk of rapid deterioration of marble of Taj Mahal due to the Mathura Refinery". Is this statement correct ? If so, how ? If not, why ?

(B) OBJECTIVE TYPE

Tick the right answer :

1. Stones are not as commonly used in building construction in townships as bricks because:
   (*i*) They are common (*ii*) They are costly
   (*iii*) They do not have good properties (*iv*) None of the above.

2. Stones behave best to the compressive load when they are placed with their natural bedding:
   - (*i*) Parallel to the load.
   - (*ii*) Perpendicular to the load.
   - (*iii*) Oblique to the load.
   - (*iv*) None of the above.

3. Quarrying of stones is the process of :
   - (*i*) Giving a suitable shape to the stone.
   - (*ii*) Applying a coat of a chemical to save it from deterioration.
   - (*iii*) Breaking it from its natural outcrop.
   - (*iv*) None of the above.

4. The strength of a stone depends on
   - (*i*) Chemical composition.
   - (*ii*) Degree of packing of constituents.
   - (*iii*) Structure of the rock.
   - (*iv*) All of the above.
   - (*v*) None of the above.

5. The strength of a type of rock (e.g. Granite)
   - (*i*) Is the same for all the samples obtained from anywhere in the world.
   - (*ii*) Varies from place to p[lace, even if two samples have same composition, texture and structure.
   - (*iii*) Lies within a range.
   - (*iv*) None of the above.

6. Place the stones given on the left side to their classes given on the right:

(*i*) Granite	A. IGNEOUS
(*ii*) Diorite	
(*iii*) Marble	B. SEDIMENTARY
(*iv*) Quartzite	
(*v*) Sandstone	C. METAMORPHIC
(*vi*) Limestone	
(*vii*) Porphry	
(*viii*) Laterite	
(*ix*) Slate	
(*x*) Dolomite	

7. Formation of Igneous Rocks pre-supposes existence of;
   - (*i*) Molten material below the surface of the earth.
   - (*ii*) A river/lake/sea basin.
   - (*iii*) Pre-existing rocks and conditions of heat pressure and chemically active fluids.
   - (*iv*) None of the above.

ANSWERS: 1. (*ii*); 2. (*ii*); 3. (*iii*); 4. (*iv*); 5. (*iii*); 7. (*i*)
6. A = [(*i*), (*ii*), (*vii*)]; B = [(*iv*), (*v*), (*vi*), (*viii*)]; C = [(*iii*), (*iv*), (*ix*)]

RELEVANT IS CODES ON BUILDING STONES*

A. METHODS OF TESTS FOR

(*i*) Compressive strength	IS: 1121 (Part I) 1974
(*ii*) Transverse Strength	IS: 1121 (Part II) 1974
(*iii*) Tensile Strength	IS: 1121 (Part III) 1974
(*iv*) Shear Strength	IS: 1121 (Part IV) 1974

(*v*)	True Specific Gravity	IS: 1122-1974
(*vi*)	Apparent Specific Gravity, Water absorption and porosity	IS: 1124-1974
(*vii*)	Weathering Resistance	IS: 1125-1974
(*viii*)	Durability	IS: 1126-1974
(*ix*)	Resistance to wear by abrasion	IS: 1706-1972
(*x*)	Permeability	IS: 4348-1973
(*xi*)	Toughness	IS: 5218-1969

B. RECOMMENDATIONS FOR

(*i*)	Dimensions and workability of natural Building Stones	IS: 1127-1970
(*ii*)	Dressing of natural Building Stones	IS: 1129-1972
(*iii*)	Physical properties of MARBLE	IS: 1130-1969
(*iv*)	Limestone Slabs and Tiles	IS: 1128-1974
(*v*)	Packing and stacking of slabs	IS: 8348-1977
(*vi*)	Quarrying of stones for construction purposes	IS: 8381-1977
(*vii*)	Maintenance and preservation of stones in Buildings	IS: 8759-1977

[**Note:** Most of these codes stand reaffirmed in 1993 and 1998]

❑❑❑

2

Clay Products

2.1. CLAYS

Clay is a naturally occurring material that is found almost everywhere on the surface of the earth making the soil cover or the soft ground. It is so widespread in its occurrence that in common language it is often referred to as **earth.**

In its origin, clay is a secondary material formed in nature by chemical decomposition, mechanical disintegration and reconstitution of rock particles by natural agencies such as wind, water, ice and atmosphere.

Mineralogically, pure clay may be composed of one or more minerals of Clay Group such as *Kaolinite, Montmorillonite, Illite, Vermiculite and Allophane etc.* **Kaolinite** is the **most important** mineral component of common **clays.** It is formed from all rocks containing felspar mineral as per following reaction:

$$2KAlSi_3O_8 + 2H_2O + CO_2 = Al_2Si_2O_5(OH)_4 + K_2CO_3 + 4SiO_2$$

(Felspar Orthoclase + Carbonic acid = Kaolinite + Pot.Carbonate + Silica Colloids)

Clays occur universally. Man has used them since ancient times for making earthenware of great variety.

2.2. CLASSIFICATION OF CLAYS

Clays are classified in two ways: **genesis** or their mode of formation and their dominant **characteristics.**

2.2.1. Genetically Speaking

All clays fall in two groups:

- The Residual Clays and
- The Transported Clays.

The Residual Clays. The Residual Group of Clays includes all varieties of clays that are found **covering the rocks** from which they are formed by natural processes. Such clays are pure in their chemical **composition** that is related broadly to the **parent rock. China Clay** is the best example of **residual** clays.

The Transported Clays. These are the **most common clays** spread on the earth. They are formed by the disintegration and decomposition of the **pre-existing rocks by the natural agencies** followed by the removal and transport of broken pieces to far off places where they are **finally deposited.** Hence any such deposit of transported clay will have all the particles transported from many different places and different source materials. The transported clays are, therefore, quite **heterogeneous** in mineralogical and chemical composition.

The transported clays are sometimes further distinguished into **glacial** clays, **marine** clays, **alluvial** clays and **lacustarine** clays when glaciers, seas, rivers and lakes respectively have played dominant roles in their formation.

2.2.2. On the basis of their **dominant characteristics,** clays are grouped into four groups: **China** Clay, **Fire** Clay, **Vitrifying** Clays and **Brick** Clays.

(*i*) **China Clay.** It is the purest type of clay containing very high percentage of mineral Kaolinite or kaolin- $Al_2Si_2O_5(OH)_4$. It is considered high-grade clay and is used for the manufacture of crockery and other porcelain ware.

(*ii*) **Fire Clays.** They are also called **refractory clays** and contain, besides Kaolinite, **silica and alumina** in very high proportions. These clays have the characteristic of **withstanding** very high temperatures **without suffering any deformation of shape given to them** at the time of moulding. They are mainly used in the manufacture of refractory **bricks** that are of great importance in many metallurgical, mechanical and chemical operations.

(*iii*) **Vitrifying Clays.** These clays are rich in fluxing compounds like iron oxides and carbonates of calcium and magnesium. They are easily fusible, *i.e.* **cannot withstand high temperatures.** On heating to high temperatures, (above 1100°C) the fluxes get softened and form glass-like material that acts as a strong bonding agent between the other clay particles. This results in the formation of a smooth surfaced hard-burnt clay product.

The vitrifying clays, called hard-burning clays, are specially used for the manufacture of facing bricks, flooring tiles, sewer pipes, and other similar ornamental and dense clay products.

(*iv*) **The Brick Clays.** These are **low-grade clays** used most for the manufacture of **building bricks** and similar clay products. Brick clays are rich in **silica, alumina, oxides of iron, calcium, magnesium** and organic matter. It is the mutual **proportion of these components that defines their suitability or otherwise for making good quality bricks for building construction.** As mentioned earlier, the oxides of iron, calcium and magnesium act as fluxes that fuse easily at brick-making temperatures and bind the alumina and silica particles thoroughly giving the brick desired properties **of cohesion and strength.**

PART A : BRICKS

2.3. INTRODUCTION

Building Bricks may be defined as "Structural units of **rectangular** shape and **convenient** size that are made from **suitable types of clays** by different processes involving ***moulding, drying*** and ***burning.***"

It is now established that even in remote ancient civilizations bricks were the common material of construction. It is believed that it was in Egypt that sun dried bricks were used some 6000 years ago. Excavation of prehistoric sites in our country has revealed that bricks were used abundantly in the Indus Valley Civilization at Mohen-jo-daro and Harrapa.

Even at present, brick is the most basic and favoured material for common construction throughout the world. This may be attributed to a number of factors:

1. Availability of Clays. Clays suitable for making bricks are available **almost universally.** Hence brick making can be adopted anywhere in the world. This is **not true** either for **stones** or for **concrete** that are the materials which compete with clays.

2. Construction Methods. Brick making and brick masonry have become **traditional human activities** almost in all parts of the world right from village level to towns and cities. This is not the case with **stones** where experienced hands **are less easily available.** With **concrete,** only experienced and **qualified persons** can handle the construction work.

3. Size, Shape and Handling. Bricks are made in **ready- to-use** sizes and shapes. This affords very convenient handling and use. For **stones,** however, some **minimum dressing** is absolutely essential. In the case of **concrete,** an elaborate **formwork and shuttering** are basic requirements. Moreover, transporting and lying of **concrete** also requires great care, caution and expertise.

4. Cost. Bricks as also brickwork **are cheaper** compared to **stone masonry** and construction with **concrete** in most cases. This is because of the factors mentioned under availability, size and shape and construction methods.

2.4. MANUFACTURE OF BRICKS

The process of manufacture of bricks is carried out in a number of stages. It is essentially a **sequential process**, that is, next stage is reached only when the previous stage has been completed in all respects. No jumping over or omission of a particular stage is possible. Each stage has its own significance in the process. These stages are listed below.

1. **Selection** of suitable type of clay (brick earth);
2. **Preparation** and Tempering of Mud;
3. **Moulding** of brick units;
4. **Drying** of moulded bricks;
5. **Loading** of the dried bricks in kilns;
6. **Firing** or Burning of dried bricks;
7. **Cooling** of the Units;
8. **Unloading** of the kiln.

STAGE 1 : SELECTION OF SUITABLE BRICK EARTH

Good type of bricks cannot be made from every type of clay. A suitable brick earth should have the following composition in the desired proportions:

1. Alumina (20-30%). All clays are chemically hydrous aluminium silicates. The alumina content is responsible for giving the **plastic character** to the clays in wet conditions. When alumina is higher than 30%, or so, the brick will become more plastic and also shrink more on drying. This may develop cracks in the moulded bricks on drying. But if the alumina is present in lesser than 20%, the clay may be difficult to mould to proper shapes. Hence by experience it has been found that the above percentage of alumina (20-30%) gives it desired qualities of plasticity and resistance against shrinkage on drying.

2. Silica (50-60%). Silica is present in many clays in two forms: as a constituent of clay minerals and also as free silica in the form of sand or quartz. When present in ideal proportions, *i.e.* 50-60 %, silica imparts the qualities of hardness and strength to the brick. It is also responsible for resistance against shrinkage and durability of the brick to weather. However, when the proportions of silica are exceptionally high in the clays, they will not be mouldable easily. Such bricks, when burnt would be quite brittle and porous. Moreover, they may not burn easily.

3. Iron Oxides (4-6%). This oxide acts as a **flux**, *i.e.* it lowers down the softening temperature of silica and other clay components during firing. Further, the iron oxide imparts the very characteristic **red colour** to the burnt bricks.

The excess of the iron oxide makes the bricks **too soft** during the burning stage; they suffer deformation in shape and size. Further, the burnt brick may acquire a darker shade that may not be appealing at all. A **deficiency** of iron oxide in the clays may make their **burning difficult** and also give them a yellowish appearance.

4. Lime (4-6%). This component makes, like iron oxides, burning and hardening of the bricks quicker with following two riders:

(*a*) It should **not be more than 4%,** because in that case may result in excessive softening of the clays on heating;

(*b*) It must be present only in finely powdered and thoroughly dispersed form. Otherwise when lime is present as nodules it may give rise to slaking when the brick comes in contact with moisture after its use. **Slaking** is a harmful reaction and may cause slow disintegration of the bricks.

Magnesia, which is invariably associated with lime, **has similar effects.** Hence it is their total percentage proportion that should be considered while deciding about the quality of the clay.

The Undesired Components: Brick clays should be ideally free from following harmful components: Lime Nodules, Organic Matter, Sulphides and Sulphates.

(*i*) **The Lime Nodules.** These hinder in the proper burning of the bricks when placed in the kilns. Moreover, when present in the burnt bricks these are likely to cause disintegration of the bricks by their slaking action.

(*ii*) **The Organic Matter.** Roots of grasses, leaves and other vegetable matter will produce carbon on burning within the body of the brick. It may make the brick darker in appearance and too porous in nature. Both are harmful effects. Hence any vegetable matter present in abundance in the brick earth should be removed at the preparation stage.

(*iii*) **Sulphides and Sulphates.** Iron sulphide in the form of pyrite and alkalkies in the form of potash and soda are often present in some clays. The effect of iron sulphide is that it causes disintegration of the brick during burning stage itself.

(*iv*) **The alkali salts** act as fluxes during burning and creating additional softening. Some of them may be present in the burnt bricks. When such bricks are used, the alkalies absorb moisture from the atmosphere and form solutions within the body of such a brick. On evaporation these solutions form **white patches or encrustation** which disfigure the brick surface. This effect is called **efflorescence** and is quite unpleasant to see in a brick building.

Summarizing, the ideal composition of a good clay for making bricks should be within these limits:

Clay	: 20-30%	Silica	: 50-60%
CaO + Mgo	: 4-5%	Iron Oxides	: 4-6%

The Clays should be free from alkalies, organic matter and lime nodules.

2.4.1. Field Tests For Brick Earth

When the manufacture of bricks is to be taken on a large and continuous scale, it is always advisable to go for thorough **survey of deposits of clays.** Such a survey should include **mapping** the area where these deposits are available for considerable depth, **analysis** of their chemical composition and **testing** the engineering properties of the test specimens made from such earth. Such a survey will assure the **total quantity** of the brick earth and also **the quality** of the clay vis-à-vis bricks.

In India brick making is as yet mostly a **small-scale** industry. Elaborate chemical analysis, laboratory testing of engineering properties and quantity surveys may be both costly and time consuming beyond the reach of small-scale manufacturer. Hence, for most small brick making units, following four **simple field tests** are often considered enough for determination of **suitability or otherwise** of clay deposits for brick making.

(*i*) **Test for the Consistency of Soil.** Small sized balls are made from the soils by mixing it with **appropriate quantities** of sand and water. These balls are allowed to **air-dry under a shaded place.** When they are completely dry, each ball is observed minutely for its **shape, size,** and appearance of **any cracks.**

Obviously, when the **soil is of a suitable type,** the balls made out of it will **not** show any deformation or cracks in them. If some shrinkage effects are observed, we may vary the mutual proportions of soil, sand and water and make new balls and check them for cracks. These may not show the defects observed in earlier balls. Thus, by varying these proportions, **a right proportion** is found for making good quality bricks. However, **if negative results are obtained in all the trials,** it simply means the brick clay is **not suitable** for making bricks.

(*ii*) **Test for Moulding Properties.** This test is usually performed on the soils that have passed the consistency test. The soil is first **thoroughly kneaded** after adding some more water for preparing a homogeneous mud. Thin threads, **about 3-4 mm thick**, are made by rolling between the palms of two hands from small amount of the mud paste. The **length of such threads** will be indicative of the good **plastic nature** of the soil. The longer and thinner the threads, the soil is of good plasticity. In non-plastic type of clays, threads break quickly on rolling.

Test bricks are made from such a paste and allowed to dry. The Clay is described as **satisfactory** if the corners, edges and surface shape **remain intact** even after drying.

(*iii*) **Test to determine Deformation on Burning.** This test helps in finding out **approximate ratio of fluxes in the clays.** Test bricks are made from the mud prepared as in the first two cases. The test bricks are **air-dried.** These are burnt in a **potter's kiln** for three to five days and then cooled in air.

The clays are of **satisfactory quality** when such bricks show

(*i*) typical red colour,

(*ii*) have **maintained their dimensions** at corners and edges and

(*iii*) have burnt uniformly.

On the other hand, if the burnt bricks show defects like **warping** of the surfaces, **twisting** at edges or corners and **swelling** at places, the **brick clay is considered defective** and unsuitable for making good bricks.

(*iv*) **Strength Tests.** These tests are made on the brick samples made from the clays that have already passed the first three tests. The field test involves **dropping** the properly burnt bricks, **one by one,** from a height of **2-3 meters** on hard dry ground below. Good quality bricks should easily withstand this shock without breaking. Poor quality bricks break easily on falling from such heights. When more reliable information about the strength qualities is required, samples of properly made and burnt bricks are tested for strength values **in a civil engineering laboratory.**

2.5. STAGE 2: PREPARATION OF MUD

2.5.1. Winning

The process of obtaining brick earth from its natural deposit is often called **winning.** The brick earth deposit is first **cleared off** from vegetation, pebbles and other organic matter. **Manual digging** or mechanical excavation methods are used to obtain dry soil or brick earth. Such clay is **spread on even ground for seasoning** *i.e.* exposed to atmosphere for good time. It is at this stage that the earth is further cleaned off **any pebbles, stones, lime nodules and visible organic matter.** If needed, any additional quantity of sand and lime are also thoroughly mixed with the soil.

The seasoned clay is then ready for making mud by mixing with adequate quantities of water as described below.

2.5.2. Tempering

It is the process of **converting the brick earth to mud of proper consistency by thoroughly mixing with desired quantities of water.** It is done either by manual labour or with the help of a mechanical device called **pug mill.**

In **manual tempering,** the clay is spread on a platform and thoroughly kneaded under feet of either men or cattle. Water is added gradually in small quantities till desired homogeneity and plasticity are obtained.

Pug Mill Tempering. The process is sometimes called **pugging** and is achieved by a mechanical device called **Pug Mill.** A simple pug mill consists of a steel cylinder covered at the top and having a hole at or near the bottom. It is 2-3 m in height, a part being below the ground. The top diameter of the pug mill is slightly bigger (1m) than the diameter at the base (0.7 m).

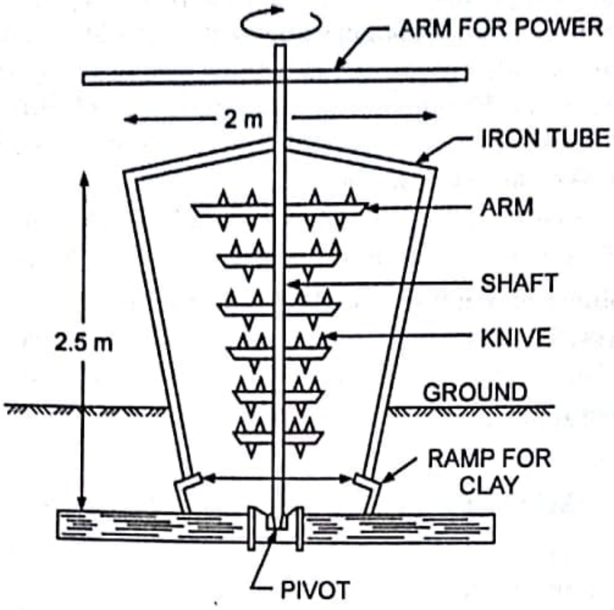


Fig. 2.1. The Pug Mill.

The most important part of a pug mill is a central vertical shaft pivoted at the base, which can be rotated with the help of a long arm through animal or motor power. The central shaft is attached with horizontal blades each carrying some knives (Fig. 2.1).

Seasoned clay and water are added from an opening provided at the top. Once the required quantity of clay and water are fed into the pug mill, the shaft is made to rotate. This action provides the churning effect to the clay-water mixture that is converted after some time into **mud** of desired plasticity and consistency. The **mud** is then taken out from the hole at the base and new charge is filled.

2.6. STAGE 3: MOULDING OF BRICKS.

Moulding is the process of making green bricks of proper shape and size from thoroughly tempered clay. There are two main methods of moulding: Hand moulding and machine moulding.

2.6.1. Hand Moulding

This is the process of moulding of bricks from the tempered mud using **skilled manpower.** In India, even today, the most common method for brick manufacture is hand moulding. In hand moulding, the quality of tempered clay is invariably kept soft, so that it can be given the desired shapes quite easily. The mud contains more water (18-25% by weight) than what is used when machine moulding process is used. It is for this reason that this method is sometimes referred as Soft Mud Process. Bricks are shaped from such a soft mud by hand either on a specially prepared ground (called **ground moulding**) or on specially designed tables (called **table moulding**).

Tools. The essential tools used in the hand moulding process are: a brick mould; cutting wire or edge, wooden plates and a stock board.

The Mould is made of wood or steel. Its inside dimensions are kept slightly bigger than the desired dimensions of the finished brick. This is done because the bricks on drying are liable to shrink in size. The mould may be a **single unit** or a **multiple unit** type.

The Stock Board, also called moulding block, is a small wooden board with a raised central **projection** carrying the identification marks (frog) of the manufacturer.

The Pallets are thin wooden plates used for handling the green bricks from the moulding boards to the drying field.

The Strike, made of wood or metal, has its one edge quite thin to slash surplus mud from the top of the moulded brick while it is in the mould. Sometimes a thin wire strung in a wooden block for holding is used for the same purpose, it is called **cutting wire.**

2.6.2. Ground Moulding

This is the most common method of moulding bricks in our country. In this process a stretch of land is first flattened, levelled and cleaned. It is often made smooth by mud plastering. Some sand is sprinkled uniformly over it to make it non-sticky.

There are two variations of ground moulding:

(*a*) **For making ordinary bricks.** The mould is either first dipped in water or some sand is sprinkled on its inside surface. The first method is often called **slop moulding** and the second as the **sand moulding**. This step is necessary to avoid sticking of the green mud to the inner sides of the mould. Then the mould is placed on the ground at desired spot. A lump of mud is dashed into the mould by hand. Care is taken to see that the mud reaches to the sides and corners of the mould. This is where the skill of the workman is involved. Any surplus mud is then removed by using the strike or the cutting wire. The **mould** is then lifted up with a jerk, leaving behind the moulded **brick** on the ground below.

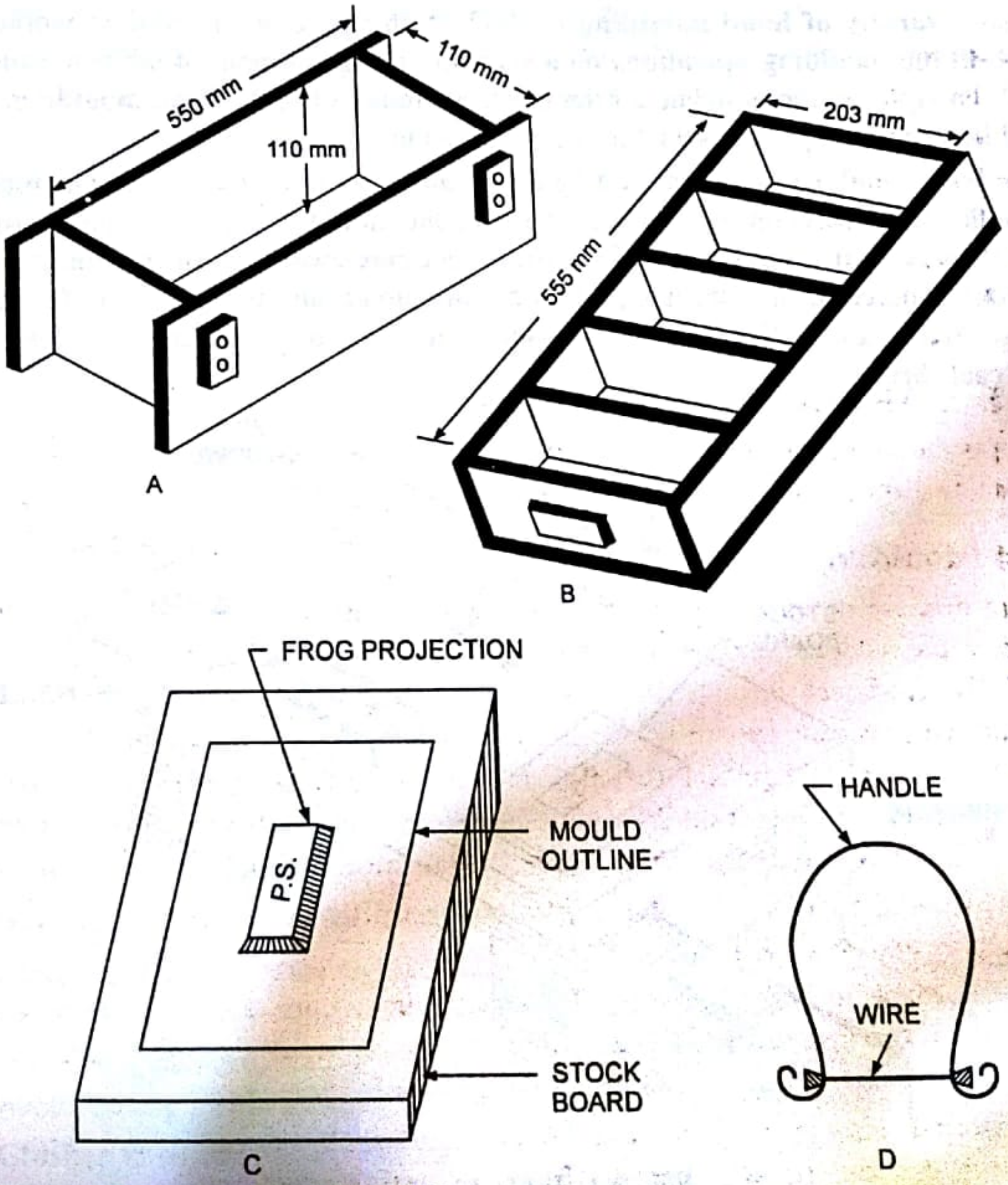


Fig. 2.2 A. Single Brick Mould; B. Multiple Brick Mould; C. Stock Board with Frog; D. Cutting W

The moulder then keeps the mould at the next place and repeats the above process again and again shifting the moulding process after moulding two-three bricks at a place. The face of the brick that rests on the surface is naturally rough and without any identification mark.

(*b*) **Moulding bricks with frog.** This is achieved by using a stock board and pallets. The stock board is provided with a raised projection carrying the trade mark (identification mark) of the brick manufacturer. Here the mould is placed on the stock board (instead of ground) and a brick is moulded as usual. The brick is then taken away using two pallets to the drying field. This process where pallets and stock board are used is called **pallet moulding.**

2.6.3. Frog

A frog is an **identification mark** (e.g. PQR-ABC, XYZ, made on a brick) during the moulding stage with the help of a stock board. This mark is left in a depressed area of 10-20cm created by corresponding projection on the stock board on one side of the brick. It serves two useful purposes:

(*a*) The name of the manufacturer of the brick is easily found and he can be known for the quality of the brick.

(*b*) During use, the frog-faced side is placed upwards. It accommodates some extra mortar. Hence a key action results forming a bond of greater strength between the upper and the lower brick in the construction work.

2.6.4. Table Moulding

It is also a **variety of hand moulding** method. In this process, the skilled worker - the moulder carries out all the moulding operations on a specially designed table of suitable dimensions. Such a table is large enough to accommodate all the materials required in the hand moulding, namely: a stock board, moulds, cutting edge, buckets for water and sand and tempered mud.

The process is similar to pallet moulding on ground. The moulder places the stock board in front of him, sprinkles some sand on the inside surfaces of the mould, places it on the board, dashes a lump of mud into it, presses it thoroughly and skillfully and cuts away any surplus mud with the strike or the cutting edge. Thereafter he places a pallet over the mould and turns it over. The moulded brick is thereby transferred to the pallet, which is carried away by a helper standing nearby. The process is repeated for each brick.

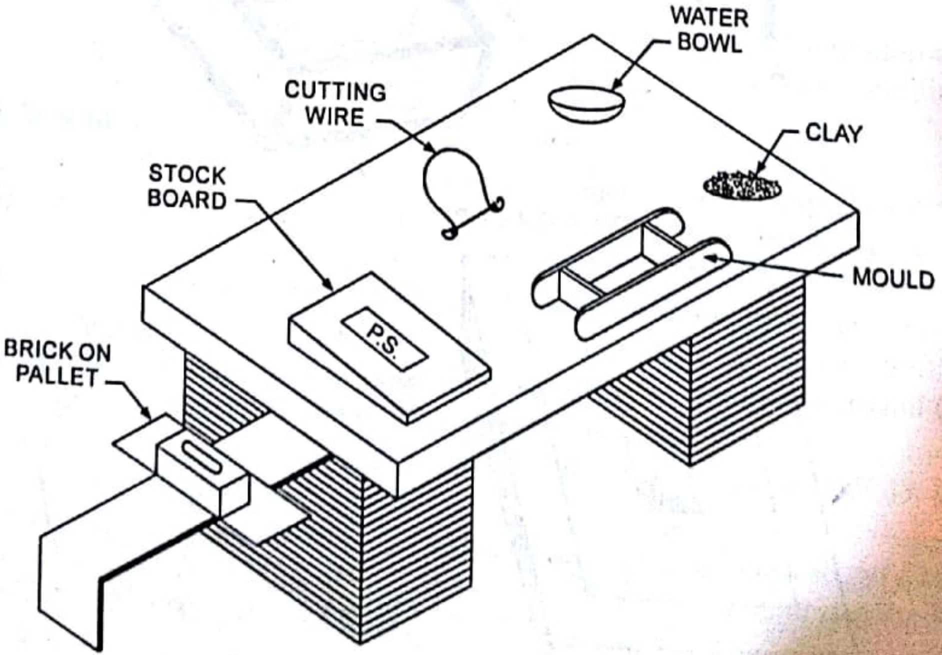


Fig. 2.3. Table Moulding.

Although initial cost is slightly higher in table moulding compared to ground moulding, it is often considered more efficient and economical in the long run as production is better in quality and quantity.

2.6.5. Machine Moulding

Machine moulding is the essential process in all Mechanized Brick Making Plants. It is both cheaper in the longer run and gives bricks of uniform quality. There are two chief methods of machine moulding: first, Stiff Mud Method and second, Dry Press method.

(*a*) **Stiff Mud Process.** In this method, the thoroughly cleaned brick clay is mixed with only a small quantity of water (8-12% by vol.) during tempering in pug mills so that it is **quite stiff** in consistency. This stiff mix is then made to pass out under pressure from a moulding machine.

Two versions of machines used in Stiff Mud process are shown in Fig 2.4 and 2.5

The First Type, called the **worm gear moulding machine** consists of

(*i*) a feeding chamber provided with a worm gear to apply pressure;

(*ii*) a hopper at the top to receive the clay mix from the pug mill;

(*iii*) a fixed die provided at the front narrow end;

(*iv*) a conveyor belt on a set of rollers;

(*v*) cutting wire device adjusted in front of the die.

The operation steps on the machine consist of

(*a*) feeding the properly mixed stiff mud into the chamber through the hopper;

(*b*) forcing forward the mud charge using the worm gear.

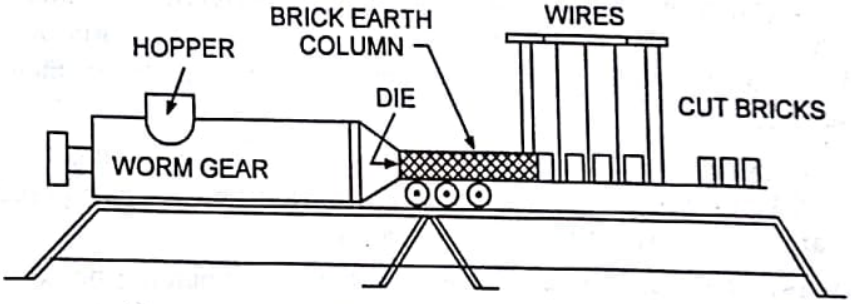


Fig. 2.4. Worm Gear Type Moulding Machine.

The pressed mud comes out through the die in the form of a **continuous rectangular ribbon** having the height and width of the bricks. This ribbon gets cut into brick-lengths by pressing down the cutting wire device when the conveyor belt is under the device. The cut out bricks are then carried forward on the conveyor belt and taken away for drying. The lengths can be cut edge-wise or side-wise depending on the die.

This machine can mould 1000-2000 units per hour or even more depending upon the designed capacity of machine.

The second type of machine is a **Vacuum Press.** Its salient features are:

(*i*) A cylindrical Shell or body (B);

(*ii*) A Screw Device (to push the mud) (BS);

(*iii*) A partition P, which is thoroughly perforated for breaking the mix into minute grains while passing through it under pressure from behind;

(*iv*) The Vacuum Chamber, VC, in which vacuum of desired order (say 60-70 cm of Hg) is obtainable through exhaustion pipe, EP, (for de -airing the mix);

(*v*) The Crusher C in the vacuum chamber;

(*vi*) The Chamber Screws, Cs, to push the clay down;

(*vii*) A die, D, for giving the required shape to the clay;

A sealing head, SH, for stopping any air from entering the chamber.

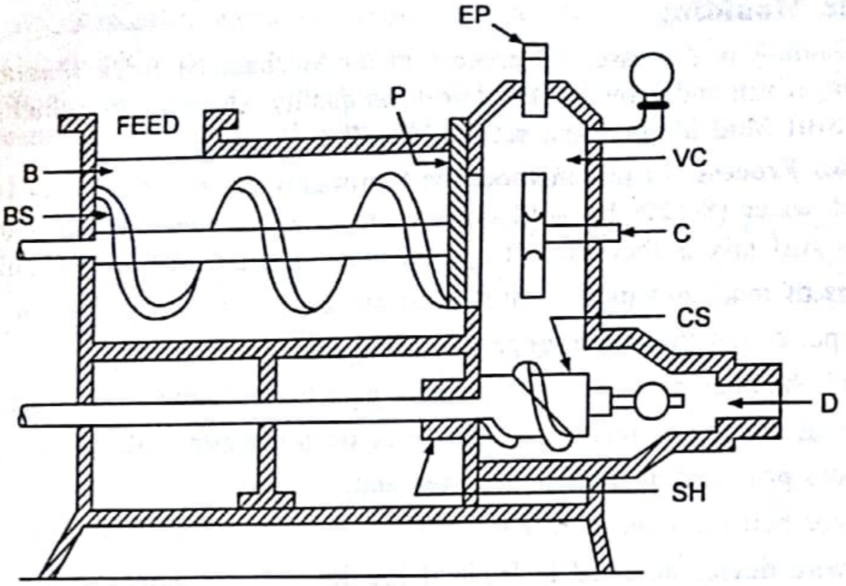


Fig. 2.5. A Vacuum Press for brick moulding (see text).

Operation. The feed of properly mixed clay is supplied to the chamber from the pug mill. It is then pushed into the vacuum chamber with the help of body screws through the perforated screen. This mass is de-aired and crushed by operating crusher C. Thereafter it is made to pass through the die by operating the crushing screws. It comes out from the die in the form of a **continuous ribbon** that has the width and thickness dimensions of a brick. The brick lengths are then cut from this ribbon by using knives or wires.

The main advantage of this type of vacuum-machine is that de-airing of clay before pressing through the die results in bricks that are denser and hence stronger. Their porosity is very low and hence such bricks are quite resistant to water absorption.

Dry Press process. It is yet another common method for moulding bricks in mechanized brick making plants. In this method only a very small quantity of water is added to finely crushed and thoroughly cleaned batch of clay so that the resulting mix is almost dry, at best **damp**. Such damp clay is fed through hoppers to special brick moulds. Each mould is placed under a plunger and pressure applied to the tune of **50-150kg/cm^2** through hydraulic presses. Such a pressure is sufficient enough to convert the loose damp clay mass into a dense, very compact brick unit, which is then removed from the mould. Such bricks are aptly called **PRESSED BRICKS** rather than moulded bricks. Moreover, they have **perfect shapes** on all the sides, edges and corners.

2.7. STAGE IV. DRYING OF BRICKS

After moulding (or pressing), the green bricks have to be **dried** before burning. This is essential for at least **three** reasons:

Firstly, to make the green bricks strong enough to bear **rough handling** during stacking etc. in the kilns for burning. **Secondly,** to allow loss of moisture from the bricks **at a slow rate.** If the green bricks are straightway brought to the kiln for burning, the loss of moisture will be fast enough to cause their **disintegration. Thirdly,** to save fuel during burning stage. This is simple to explain; a brick containing 10 percent moisture will require more fuel to burn completely than a brick containing only 4-5% moisture.

Drying of green moulded bricks is achieved either by natural methods or by artificial methods. In **the natural methods**, there are two distinct stages involved in the drying process :

Pre Stacking Stage. The moulded bricks are laid **sidewise** and flat wise for 2-3 days in turn in the drying fields so that they become hard enough to handle for stacking in heaps (Fig. 2.6).

Stacking Stage. In this stage, the hardened bricks are arranged in well-made layers, **one layer above another,** in a cautious manner by the skilled workers. Stacking is done in specially prepared **drying grounds.** Each stack may be about **100 cm wide, 10 brick layers high and as long as the ground allows.** Enough space is left between the individual bricks in a stack and also between layers **for free circulation of air around each brick.** This is a very essential aspect of stacking for ensuring proper drying. Further, the stacks are properly protected from direct sun, rain and strong winds.

Air-drying by stacking method may take 4-10 days depending upon the season and place of drying. Air-dried bricks still retain **2-4%** moisture in them.

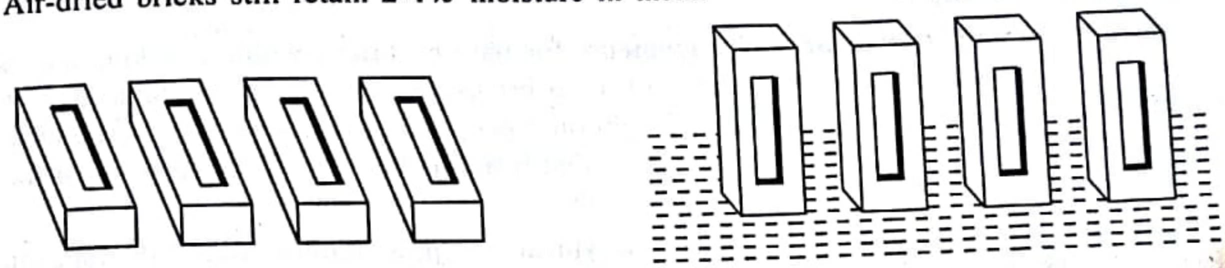


Fig. 2.6. Drying in air.

Sun Dried Bricks : Adobe

The Sun-dried bricks are also called adobe. At many places in the world, these are the poor man's construction material even during the present times. It is established that these bricks can sustain enough load in small construction provided they are sheltered properly from continuous rains.

The Artificial Drying. This method becomes essential in mechanized brick making units. It is only by this method that the drying of bricks can be ensured throughout the year **independent of weather conditions.** Artificial Drying may be achieved either in specially designed chambers or tunnels.

In the Chamber Drying, bricks are arranged in stacks **within specially designed drying chambers** keeping sufficient spaces for free circulation of hot air around them. Hot air under controlled conditions of **temperature and humidity** is made to circulate through these stacks for 2-4 days or more. Th dried bricks are then taken out and next batch of green bricks is stacked in layers within the chambe

In the Tunnel Drying, bricks are stacked on mobile cars that are made to travel on rails withi a specially designed **drying tunnel.** The tunnel is divided into **compartments** and each car loade with green bricks is made to stay in a particular compartment for **pre-fixed duration.** The cars co out from the **other end** of the tunnel one by one. This process may take 2-3 days for a car load bricks to dry to desired extent.

2.8. STAGE V. BURNING OF BRICKS

2.8.1. Need

Burning of dried bricks is **absolutely essential** to develop in them the desired building propert such as sufficient strength, hardness, durability and resistance to decay and disintegration. At l three chemical changes are known to take place in the brick- earth during the burning proc dehydration, oxidation and vitrification.

Dehydration. It means complete removal of water from the pores of the bricks. It is compl at the temperature range of 425-765^{0}C. Bricks heated at this temperature lose all the free water also to a good extent the water of crystallization from its components.

Oxidation. It starts taking place during heating of the bricks at the above temperature range and gets completed at about 900°C. All the organic matter in the brick earth gets oxidized: carbon and sulphur are eliminated as oxides. The fluxes (lime, magnesia and iron) also become reactive at these temperatures. The brick acquires the red colour due to the oxidation of iron in the clays.

Vitrification. It is the last reaction that takes place at temperatures ranging from 900°C to 1100°C or so and is required to take place in tiles. In this process, the constituents of clay, that is, alumina and silica, start softening in the presence of the fluxing compounds. The constituent grains get bound firmly.

2.8.2. Methods of burning

Bricks are burnt in two ways: Clamp Burning and Kiln Burning.

A. *Clamps or Pazwas*

Actually Pazwas are **working arrangements** for burning bricks without making any permanent structures. In this process, **alternate** layers of dried bricks and any locally available fuel of ordinary type are **stacked together** up to a desired height on a **properly prepared ground**. The heap so made is then plastered from outside with mud. It is ignited from the base and **allowed to burn** for a **month** or so and then allowed to cool for another month.

There are many variations of clamps. In a typical clamp, a sloping ground of trapezoidal shape and slope angle of about 15° is prepared. The narrow end is dug below the ground level and filling raises the wider end. Over this ground, the first layer of locally available fuel such as grass, wood, leaves branches etc. is laid up to a **height of about 1 m.** Three to five layers of **sun dried bricks** are properly stacked over such a fuel layer keeping **sufficient open spaces** between the bricks and the layers. After this, **another layer of fuel,** of slightly smaller height is laid. This **process is repeated** till the desired height is achieved. **Mud plastering** is done from outside and the kiln is ignited from the narrow end at the base. It is allowed to burn for a month. Another month is allowed to let it cool naturally. After 8 weeks or so, the lot of brick is ready for use. (Fig. 2.7)

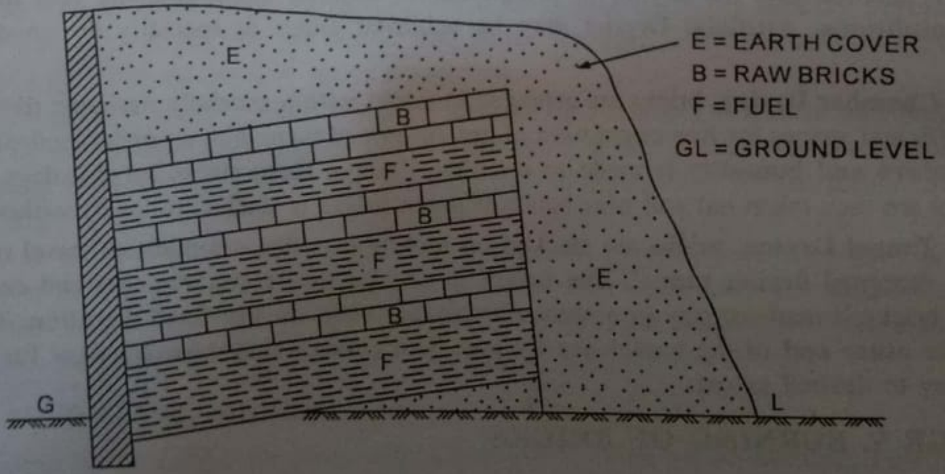


Fig. 2.7. Section of A Clamp.

In a clamp of 10 m × 7.5 m sides, about **one-lakh** bricks can be burnt in two months.

Advantages. The Clamp Burning has following advantages :

(*i*) It is **easy** to erect and operate;

(*ii*) **Any type of fuel** can be used in clamp burning;

(*iii*) It requires **least supervision** after burning;

(*iv*) It is comparatively **very economical.**

For these reasons, Clamp Burning remains even now a common method of obtaining ordinary type of bricks in many parts of the country.

Disadvantages :

(*i*) Burning of bricks is **not uniform;** some bricks, especially from the lower regions, **get over burnt** whereas bricks from middle and upper regions of the clamp may remain **under burnt.**

(*ii*) There is **no possibility to regulate heat** in the clamp once it starts burning;

(*iii*) Quite a considerable quantity of bricks get damaged due to crumbling and falling when the intervening layers of fuel get burnt.

(*iv*) Time required for burning is too long.

B. *Brick Kilns*

Many types of permanent structures are used for burning bricks. They are termed as kilns. Kilns may be divided into two broad groups depending upon their principle of construction: The intermittent kilns and the continuous kilns.

(*a*) **The Intermittent Kilns** are those types from which the burnt bricks can be made available **only after a definite interval of time** after these are put on fire. That is, the brick supply from such kilns is intermittent and not continuous.

(*b*) **The Continuous Kilns.** These are brick kilns from which it is possible to get the supply of bricks **almost continuously**. This is because they consist of **a number of chambers.** Operations in these chambers are **so controlled** that at any given time, when one chamber is in the **loading** process, another chamber may be in the **burning stage**, a third chamber in the **preheating** stage, a fourth chamber in the **cooling stage** and a fifth chamber in the **unloading** or supply stage. The operations are shifted from chamber to chamber in such a way that at any time one chamber is available for unloading. The continuous kilns are becoming more popular although majority of kilns in the countryside are still of intermittent type. We shall describe one type of intermittent and three types of continuous kilns.

1. *THE ALLAHABAD KILN*

It is a common type of ***intermittent kiln.*** In construction, it is generally ***rectangular*** in shape and has four permanent walls. It may be constructed totally underground or partly underground and partly over ground.

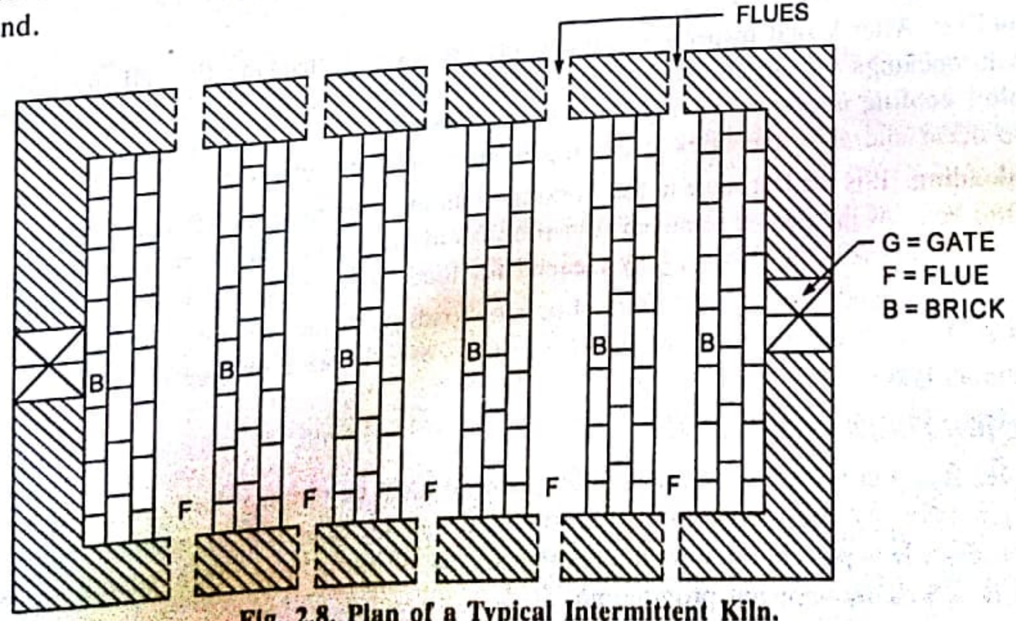


Fig. 2.8. Plan of a Typical Intermittent Kiln.

The top of the loaded section is thoroughly covered with 20-30 cm deep layer of ash and dust taking care that none of openings from the kilns get blocked in the process. Metal plates may be placed over them during the operation to cover the top.

Preheating. After the particular section is loaded properly, it may be put to preheating stage. During this stage, hot and waste gases from a preceding burning chamber are made to pass to the loaded chamber by raising the dampers between the two chambers. These gases, though not very hot to ensure complete burning, may be hot enough to make the bricks completely dry and make them ready for final burning. This is a very important aspect of continuous kiln ensuring good economy.

Burning. The bricks are set to the burning stage after they have been preheated. During burning, required volume of air is supplied by regulating the opening and raising of the gates or the dampers provided in the outer walls. Additional quantities of fuel may be added from the flues provided at the top. It generally takes 24-30 hours for perfect burning of a preheated lot in a section of the kiln.

Cooling. The brick section in which burning process is already over, is made to pass through a **cooling stage**. In this stage all the outer gates are closed by lowering the dampers. The interdepartmental gates are opened up for leading the hot gases to the preheating sections. It may take a section 3-4 days to cool down completely before unloading can be started from it.

Unloading. The top layer of dust and ash are first removed from the top of the section put to unloading. Bricks are removed from top to bottom, one by one, exercising all the care that they are not broken during the handling process.

Setting For Continuous Operation. As already said, in continuous kilns of Bull's Trench type, a scheme of operations has to be chalked out in such a manner that at any given time, all the major operations of brick making are taking place almost simultaneously. The exact scheme will depend on the size of the kiln and number of chambers in it. Given below is only a hypothetical scheme for a six-chambered kiln meant to illustrate the process.

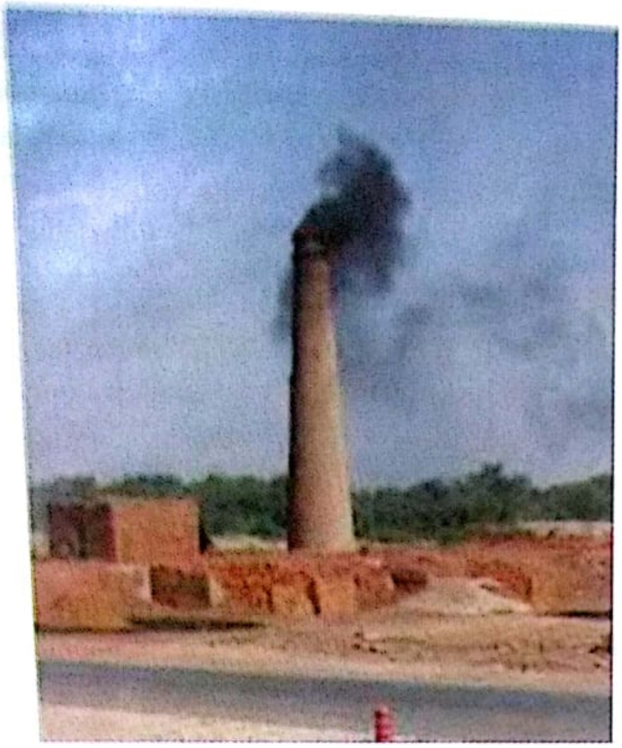
STAGE 1	1	2	3	4	5	6
	Burning ⟶	Preheating 00	Loading	Cleaning	Unloading	Cooling
STAGE 2	1 Cooling	2 Burning ⟶	3 Preheating 00	4 Loading	5 Cleaning	6 Unloading
STAGE 3	1 Unloading	2 Cooling	3 Burning ⟶	4 Preheating 00	5 Loading	6 Cleaning

⟶ Arrow indicates direction of progress of firing;
00 Double Circles indicate chamber with chimneys
01 The above process can be completed for all the six stages to make a cycle.

3. *THE HOFFMAN'S CONTINUOUS KILN*

Principle. It is a modern and more refined type of brick kiln used fro burning a large number of bricks and other clay products under controlled conditions of temperature.

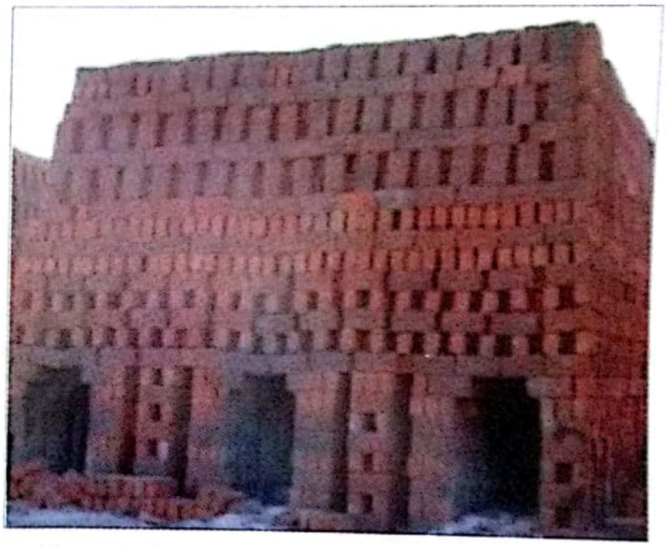
Construction. In construction, Hoffman's kiln consists of circular walled structure generally made over the ground. The circular space enclosed in this way is commonly divided into 12 chambers by suitable partition walls. The adjacent chambers are interconnected by communicating doors, which can be opened or closed by raising or lowering dampers. A Hoffman's kiln is also provided with a central chimney which is connected to all the twelve chambers through flues. The flues can be closed or opened by dampers provided at the back of each chamber. Each chamber is also provided with a



Kiln from a distance

Kiln Floor Ready for Loading. Partition doors are also seen.

Dampers for control of flame circulation



Stacking of Bricks-Note spacing for heat circulation

Burnt bricks unloaded from the Kiln

Top of Loaded Kiln showing location of small fuel holes separate gate in the outer wall through which it can be loaded, unloaded and fired (Fig. 2.10). The kiln has a permanent roof so that it can be worked throughout the year. The central chimney, the permanent roof and over-ground construction are three main characters in which it differs from the Bull's trench kiln.

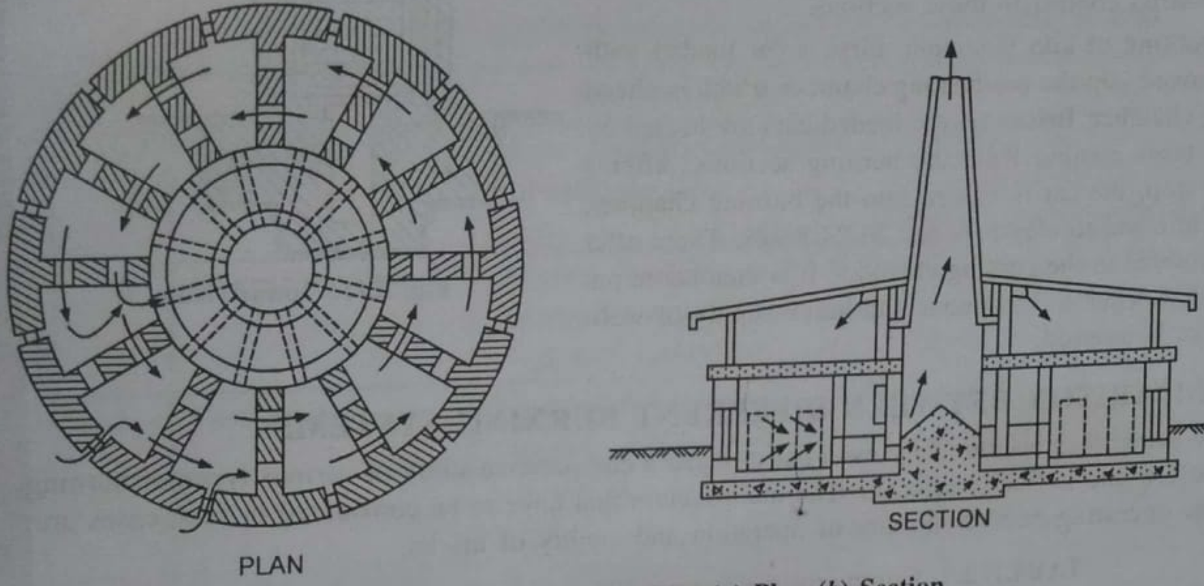


Fig. 2.10. Hoffman's kiln (*a*) Plan (*b*) Section.

Working. The kiln works on the principle of continuous kilns. At any given time, some chambers can be in the burning, others in the pre-heating, still others in cooling and some in the unloading stages.

The most important condition for the working of this kiln is the establishment of an upward draught or current of air within the kiln. This is done by closing all the outer gates except of the chamber, which is being unloaded. Natural air enters the kiln through this gate. It is made to pass through different chambers by opening their inter-connecting doors. The flue at the back of each chamber is kept closed. The air is thus made to do the job of cooling, burning and pre-heating. It (air) is then made to enter the chimney by opening the back flue of that chamber which is in pre-heating stage.

Scheme of operation. like the Bull's trench kiln, the Hoffman's kiln is also operated to give a continuous supply of bricks. A scheme of cyclic operation is prepared in advance and adhered to during the working. There are many possibilities. One such scheme is illustrated below. The scheme may be modified on the basis of time required for each operation but the sequence of operations remains generally the same.

Operation	*I stage*	*II stage*	*III stage*	*IV stage*	*V stage*
Burning	1-2	3-4	5-6	7-8	9-10
Preheating	3-4	5-6	7-8	9-10	11-12
Loading	5-6	7-8	9-10	11-12	1-2
Cleaning	7-8	9-10	11-12	1-2	3-4
Unloading	9-10	11-12	1-2	3-4	5-6
Cooling	11-12	1-2	3-4	5-6	7-8

4. *THE TUNNEL KILN*

It is a continuous type of kiln and is considered highly efficient. It consists of a channel or tunnel 60 to 150 m long and 3-5 m wide. The tunnel is provided with rail tracks for cars. Such a tunnel is commonly divided into three sections for working, namely pre-heating section, the burning section & the cooling section (Fig. 2.11).

The flow & temperature of gases as also humidity is kept under strict control in these sections.

The working of kiln is simple. First, a car loaded with bricks is moved into the pre-heating chamber which is ahead of burning chamber. Bricks on the loaded cars are heated by the waste gases coming from the burning sections. After a few hours stop, the car is moved into the burning chamber. It may be allowed to stay here for 20-24 hours. There after the car is moved to the cooling chamber. It is then taken out and unloaded. Thus a continuous and quick supply of well-burnt bricks is assured.

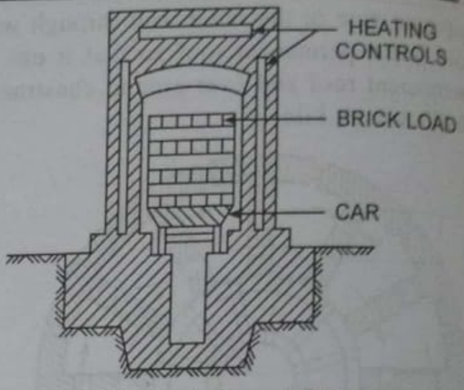


Fig. 2.11. Tunnel Kiln.

2.9. COMPARISON BETWEEN DIFFERENT BURNING SYSTEMS

It may sometimes become very essential to make a comparative study of various types of burning systems before one is finally selected. The main factors that have to be considered in such cases are: initial cost, operating cost, continuity of operation and quality of bricks.

TABLE 2.1. Comparison Between Clamp And Kiln Burning.

S.No	*Factor*	*Clamp Burning*	*Kiln Burning*
1.	**Initial Cost**	Very low as no pucca construction is required	Very high as permanent construction is involved
2.	**Operating Cost** **Fuel** **Labour** **Use of Waste Hot Gases**	Overall operating cost is low **Low**, as ordinary type locally available fuel can be used. Easily available at lower wages as not much skill is required. Not possible, the waste hot gases are allowed to pass into the atmosphere without any use.	Overall operating cost is high **High**, as only a **better** type of coal which may have to be transported from outside is required. Only qualified and trained supervisors and skilled labour can be used. Hot waste gases are invariably used for preheating the dried bricks before burning. Hence **maximum conservation** of heat is possible.
3.	**Continuity of operation**	It is essentially a discontinuous operation. A minimum of one to two months are required for heating and cooling of kiln.	Kilns of both continuous and intermittent types can be designed. Bricks can be obtained regularly or after an interval of a fortnight respectively.
4.	**Quality of bricks**	**Ordinary**; because there is no control on rate and degree of burning.	Very good because heat can be regulated by controlling air flows and quantity of fuel.
5.	**Suitability**	Suitable for obtaining limited number of **ordinary types** of bricks; not suitable for large-scale quality bricks.	Not suitable for small quantity, suitable for large-scale business type manufacture of good quality bricks.

From the above, it is obvious that when bricks have to be manufactured in a limited number without much consideration of quality, clamp burning has its own advantages. But when bricks have to be manufactured on a commercial scale, kiln- burning has to be adopted. While comparing the different types of kilns, it is found that above factors still hold good.

TABLE 2.2. Comparison Between Bulls Trench and Hoffmans Kiln.

S.No	*Factor*	*Bull's Trench kiln*	*Hoffman's kiln*
1.	**Initial Cost**	Low, because construction is of ordinary type.	High, because construction requires perfect designing and high quality material.
2.	**Operating Cost**	Higher, because quantity of fuel consumed is more and conservation of heat is less.	Lower, because maximum conservation of heat is possible in this type of kiln.
3.	**Continuity**	Semi-continuous in strict sense because it has no roof and cannot burn bricks during monsoons.	Perfect, because it has a permanent roof and burning operations can be carried out throughout the year.
4.	**Quality of bricks**	Ratio of best quality to total bricks is less.	Ratio of best quality bricks to total bricks is quite high.
5.	**Suitability**	Quite suitable for low-investment production of bricks..	Best suited for semi-mechanized and mechanized production.

2.10. PROPERTIES OF BRICKS

The essential properties of bricks may be conveniently discussed under four headings:

1. Physical properties,
2. Mechanical characteristics,
3. Thermal characteristics and
4. Durability.

2.10.1. Physical Properties

These include shape, size, colour and density of a brick.

(*i*) **Shape.** The standard shape of an ideal brick is truly rectangular. It has well defined and sharp edges and corners. The surface of the bricks is regular and even.

Special purpose bricks may, however, be either cut or manufactured in various other shapes. These are generally modifications of rectangular shapes.

(*ii*) **Size.** The size of a brick used in construction varies from country to country and from place to place in the same country. In India, the recommended **standard size of an ideal brick is 19 × 9 × 9 cm,** which with mortar joint gives net dimensions of 20 × 10 × 10 cm. These dimensions have been found very convenient in handling the bricks during construction and also making quantity estimates. **Five hundred such bricks will be required for completing one cubic meter of brick masonry.**

Besides the recommended size as above, the most commonly adopted size in our country as also in Pakistan and Bangladesh is 22 × 10.5 × 7 cm (8.75 × 4.25 × 2.87 inches approximately) It may be interesting to note that in U.K, U.S.A, U.S.S.R., the commonly used bricks have following dimensions

Country	*Length (cm)*	*Thickness (cm)*	*Height (cm)*
United Kingdom (U.K)	20	9.5	5.5
United States of America	20	10	10
	30	10	10
U.S.S.R	25	12	6.5

(*iii*) **Colour.** The most common colour of building bricks fall under the class RED. It may vary from deep red to light red to buff and purple. Very dark shades of red indicate **over burning** whereas yellow colour is often indicative of **under burning**.

(*iv*) **Density**. The density of bricks or weight per unit volume depends mostly on the type of clay used and the method of brick moulding (soft-mud, stiff-mud, hard pressed etc). In the case of standard bricks, density varies from 1600kg/cubic meter to 1900 kg/cubic meter. A single bricks (19 × 9 × 9 cm) will weigh between 3.2 to 3.5 kg.

2.10.2. Mechanical Properties

Under this heading, compressive strength and flexure strength are included.

(*i*) **Compressive Strength.** It is the most important property of bricks especially because they are to be used in load bearing walls. The compressive strength of a brick depends on the composition of the clay and degree of burning. It may vary from 35 kg/cm^2 to more than 200 kg/cm^2.

(*ii*) **Flexure Strength.** Bricks are often used in situations where bending loads are likely to develop in a building. As such, bricks used in such places should possess sufficient strength against transverse loads. It is specified that the flexural strength of a common building brick shall not be less than 10 kg/cm^2. Best grade bricks often possess flexural strength over 20 kg/cm^2.

Similarly, it is required that a good building brick shall possess a shearing strength of 50-70 kg/cm^2.

2.10.3. Insulation

Besides being hard and strong, an ideal brick should also provide adequate insulation against heat, cold and noise.

The **heat and sound conductivity of bricks** varies greatly with their density and porosity. Very dense and heavy bricks conduct heat and sound at a greater rate. They have, therefore, **poor** thermal and acoustic (sound) insulation qualities. For this reason, bricks should be so designed that they are light, strong and give adequate insulation.

2.10.4. Durability

By durability of bricks is understood the length of time for which they remain unaltered and strong when used in construction.

Experience has shown that properly manufactured bricks are among the most durable of man made materials of construction. Their life can be counted in hundreds of years.

The durability of bricks depends on a number of factors such as: absorption value, frost resistance and efflorescence.

(*i*) **Absorption value.** This property is related to the **porosity** of the brick.

True porosity is defined as the ratio of volume of pores to the **gross** volume of sample of the substance.

Apparent porosity, more often called absorption value or simply absorption , is the quantity of water absorbed by the (brick) sample. This is expressed in percentage terms of the dry weight of the sample:

$$\boxed{\text{Absorption} = \frac{W_2 - W_1}{W_1} \times 100}$$

where W_2 is weight after 24 hours immersion in water and W_1 is the oven dry weight of the same sample.

The absorption value of bricks varies greatly. It is however, recommended that in *AA* grade bricks, the absorption value shall not be greater than 20 percent and for ordinary building bricks, not greater than 25 percent.

The absorption characteristics of bricks effects their quality in many ways :

Firstly – higher porosity means less solid materials, hence, strength is reduced.

Secondly – higher absorption will lead to other water–related defects such as frost–action and efflorescence.

Thirdly – higher absorption results in deeper penetration of water which becomes a source of dampness.

(*ii*) **Frost resistance.** Water on freezing expands by about 10% in volume and exerts a pressure of the order of 140 kg/cm^2. When bricks are used in cold climates, their decay due to this phenomenon of frost action may be a common process. This is especially so because bricks are quite porous materials (apparent porosity =20-25%). It is, therefore, essential that bricks in these areas should be properly protected from rain to minimize absorption.

(*iii*) **Efflorescence.** It is a common **disfiguring and deteriorating process** of bricks in hot and humid climates. In efflorescence, brick surface gets covered with white or grey coloured patches of salts. These salts are present in the original brick clay. When rainwater penetrates into the bricks, the salts get dissolved easily. After the rains, evaporation starts. The salts move out along with the water and form thin encrustations on the surface of the bricks. Salts which are commonly precipitated during efflorescence are: sulphates of calcium, magnesium, sodium and potassium. It is why great emphasis should be laid while testing the chemical composition of the clay for the brick manufacture.

2.11. SUMMARY (QUALITIES OF A GOOD BRICK)

1. It should have a rectangular shape, regular surface and red coloured appearance.
2. It should confirm in size to the specified dimensions (19 × 9 × 9 cm)
3. It should be properly burnt. This can be ascertained by holding two bricks freely, one in each hand, and striking them. A **sharp metallic sound** indicates good burning whereas a dull thud would indicate incomplete burning.
4. A good building brick should not absorb water more than 20% of its dry weight. Absorption should not exceed 25% in any case.
5. A good building brick should possess requisite compressive strength, which in no case should be less than 35 kg/cm^2. A rough test for the strength of the brick is to let it fall freely from a height of about one meter on to a hard floor. **It should not break.**
6. Brick should be hard enough so that it is not scratched by fingernail.
7. A good brick has a uniform colour and structure throughout its body. This can be checked by taking a brick from the lot and breaking it into two parts. The broken surface in both the halves should have same appearances and structure (Fig. 2.12).

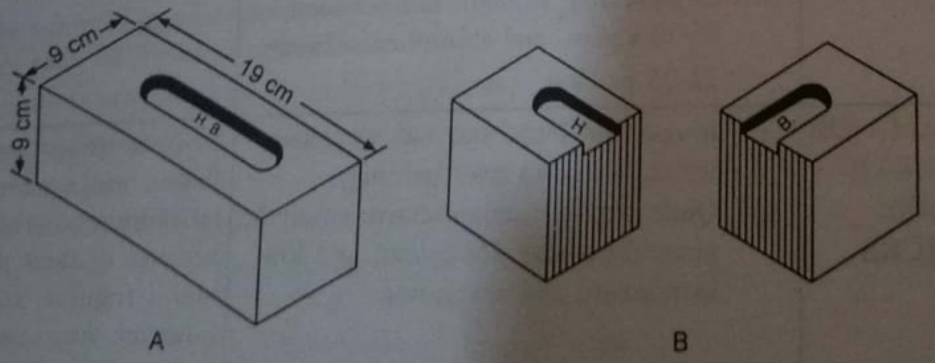


Fig. 2.12. Qualities of a good brick. (A) Whole Brick (B) Two parts of a broken brick.

2.12. CLASSIFICATION OF BRICKS

In every country, bricks have been divided into different classes on the basis of their properties. In India also, the Bureau of Indian Standards have classified burnt bricks into following four mai classes referred to as 1st class, 2nd class etc. For details, ISS 1077-1971 may be referred. Mai requirements of the four groups of bricks are given below :

TABLE 2.3. Classification of Bricks.

S.No.	*Class*	*Characteristics*	*Use*
1	**FIRST CLASS BRICKS**	(*i*) Well burnt having even surface and perfectly rectangular shape. (*ii*) When two bricks are struck against each other a ringing-sound is produced. (*iii*) Its compressive strength shall not be less than 140 kg/cm^2 and its absorption after 24 hours, immersion shall not exceed 20 percent. (*iv*) It should show a uniform appearance, texture and structure when seen on fracturing.	Excellent for all types of construction in the exterior walls when the plastering is not required. Also suitable for flooring.
2.	**SECOND CLASS BRICKS**	(*i*) Well burnt, even slight over burning is accepted. (*ii*) Metallic-ringing sound is also a must in this case as well. (*iii*) In shape, rectangular, but slight irregularity is permitted. Surface may be slightly uneven. (*iv*) Compressive strength shall not be less than 70 kg/cm^2 and absorption value between 20-22 percent. (*v*) Slight difference in structure on fractured surface is admissible.	(*i*) For exterior work when plastering is to be done. (*ii*) For interior walls. These bricks may not be used for flooring.
3.	**THIRD CLASS BRICKS**	(*i*) Poorly and unevenly burnt, that is, may be over burnt or under burnt. (*ii*) On striking a dull thud (rather than metallic sound) is produced. (*iii*) Appearance, shape and size are also non-uniform and irregular. (*iv*) Compressive strength lies between 35-70 kg/cm^2 and absorption between 22-25 percent.	Used mostly in ordinary type of construction and in dry situations.
4.	**JHAMA OR FOURTH CLASS BRICKS**	(*i*) Irregular in shape and dark in colour, which is due to over burning. (*ii*) Quite strong in compressive strength, generally above 150kg/cm^2 and low in porosity and absorption.	Despite their good strength, Jhama bricks are unfit for use in building construction. This is because of their distorted shape and irregular size. They are, however, very commonly used in broken form, in road construction, foundations and floors as a coarse aggregate material.

HEAVY DUTY BRICKS

Exceptionally dense, perfectly burnt and very strong bricks are sometimes classified as heavy-duty bricks. They have ideally rectangular shapes and smooth surfaces, giving typical metallic sounds.

These heavy-duty bricks may have compressive strength as high as 440 kg/cm^2 absorption as low as 5 % with least efflorescence.

The heavy-duty bricks are specially useful in situations where high loads are involved and where a construction has to remain in contact with water.

2.13. STANDARD TEST FOR BRICKS

Various properties of bricks in the preceding pages are tested and evaluated according to a set practice. These tests have been described in detail in relevant codes prepared and published by Bureau of Indian Standards. In the following pages, we give only an outline of most important of these tests.

2.13.1. Compressive Strength (ISS: 1077-1970)

(*i*) Take five whole bricks at random from the lot of brick samples and immerse them in water for 24 hours at room temperature.

(*ii*) After 24 hours, take them out, allow them to drain and then clean the surplus water.

(*iii*) Now, fill their frogs (any other voids) by a layer of standard 1:1 mortar (1part cement and 1 part sand). Store these bricks under damp sacks for 24 hours (to allow setting of mortar).

(*iv*) Place the bricks in water for seven days (this is to allow the mortar to harden).

(*v*) Take the bricks out of the water to drain and remove the surplus water. When surface dry, each brick is tested individually.

(*vi*) Place the brick flat wise, with frog end facing upward, between two plywood sheets.

(*vii*) Bricks so adjusted between the plywood sheets is placed on the bed of testing machine and load applied axially and at a uniform rate of 140 kg/cm^2 per minute.

(*viii*) Note the load at which the brick fails (gets broken). This load, P, divided by cross-section area (A) of the brick gives the compressive strength, Co.

$$\boxed{\text{Co} = P/A}$$

(*ix*) The arithmetic mean of the compressive strength values of all the five bricks shall be taken as the compressive strength of that lot of bricks represented by the test sample (and not all the bricks of a kiln)

(*x*) The brick shall be classified accordingly on the basis of the Compressive strength obtained as above.

2.13.2. Water Absorption Test (ISS 1077-1970)

(*i*) Take five whole bricks at random from the lot of bricks.

(*ii*) Dry these samples to a constant weight by placing them in a ventilated oven at 110^0 C + 5^0 C. This may take 48 hours or more time.

(*iii*) The specimens are weighed individually after cooling.

(*iv*) The dry, weighed samples are then immersed in water, at room temperature, for 24 hours.

(*v*) After 24 hours, the samples are taken out. Each sample is wiped dry and weighed individually within three minutes after it is taken out from water.

(*vi*) Absorption value is calculated by the simple relationship :

$$\boxed{\text{Absorption\%} = \frac{W_2 - W_1}{W_1} \times 100}$$

where W_1 is dry weight and W_2 is weight after immersion for 24 hours.

(*vii*) The average of **five values** for the five samples shall be taken as the water absorption of the brick lot represented by the five bricks.

(*viii*) It shall be within the specified limits for the classification of the bricks.

Efflorescence Test (IS 1077 –1970)

(*i*) Take five bricks at random from the lot to be tested.

(*ii*) Place each brick on end in a separate shallow flat bottom dish containing distilled water. Note that depth of immersion of bricks should not be less than 2.5 cm in each case.

(*iii*) Keep the above dishes (containing water and bricks) in a warm (18^{0}-30^{0} C) room, which has adequate ventilation. (The water from the dishes will be lost due to absorption by bricks and subsequent evaporation)

(*iv*) Add fresh quantity of distilled water when the bricks appear having dried.

(*v*) At the end of second drying, each brick is observed for efflorescence, that is appearance of any white patch of salt on the surface of the brick.

The efflorescence is reported only by qualitive words as follows:

- **Serious.** Salt deposition is all around and quite heavy and increases with repeated wetting and drying. Powdering of salt is prominent.
- **Heavy.** Salt deposits cover more than 50 percent surface area. Tendency to powder is absent
- **Moderate.** Salt deposits cover 10-50 percent surface area. The salts forms thin layers without showing any tendency to peal off in flakes or become powdery.
- **Slight.** Salt covers surface area of less than 10 percent and forms only a very thin sticky layer.
- **Nil.** There is seen no deposits of any salt even after repeated wetting.

It is required that efflorescence should not exceed than the specified degree in various classes of bricks. For example, in heavy-duty bricks, it is required to be nil, and for first class bricks, it shall be only slight.

2.13.3. Dimensions Tolerance Test (IS 1077-1970)

Objective. The test is performed to check whether the bricks are of required dimensions or not. It is completed in the following manner :

(*i*) Take twenty bricks at random out of the test lot.

(*ii*) Remove any loose particles of clay and projecting blisters etc. from the bricks.

(*iii*) Arrange the bricks on a smooth level surface in a straight series in such a way that the adjoining surfaces are in contact with each other. The arrangement will be done in accordance with the dimensions that are being checked. Thus,

- For length, bricks will be laid length wise
- For width, bricks are laid so that width faces the observer
- For height, bricks are laid on the side, so that height faces the observer.

(*iv*) The overall length of the brick rows is then measured in each case. These shall be within the specified limits for different classes of bricks. Thus, when the bricks are of standard size (19 × 9 × 9 cm), following limits are specified.

Class of bricks	*Length (in cms)*	*Width (in cms)*	*Height (in cms)*
A – Class	368 – 392	174 – 186	174 – 186
B – Class	350 – 410	165 – 195	165 – 195

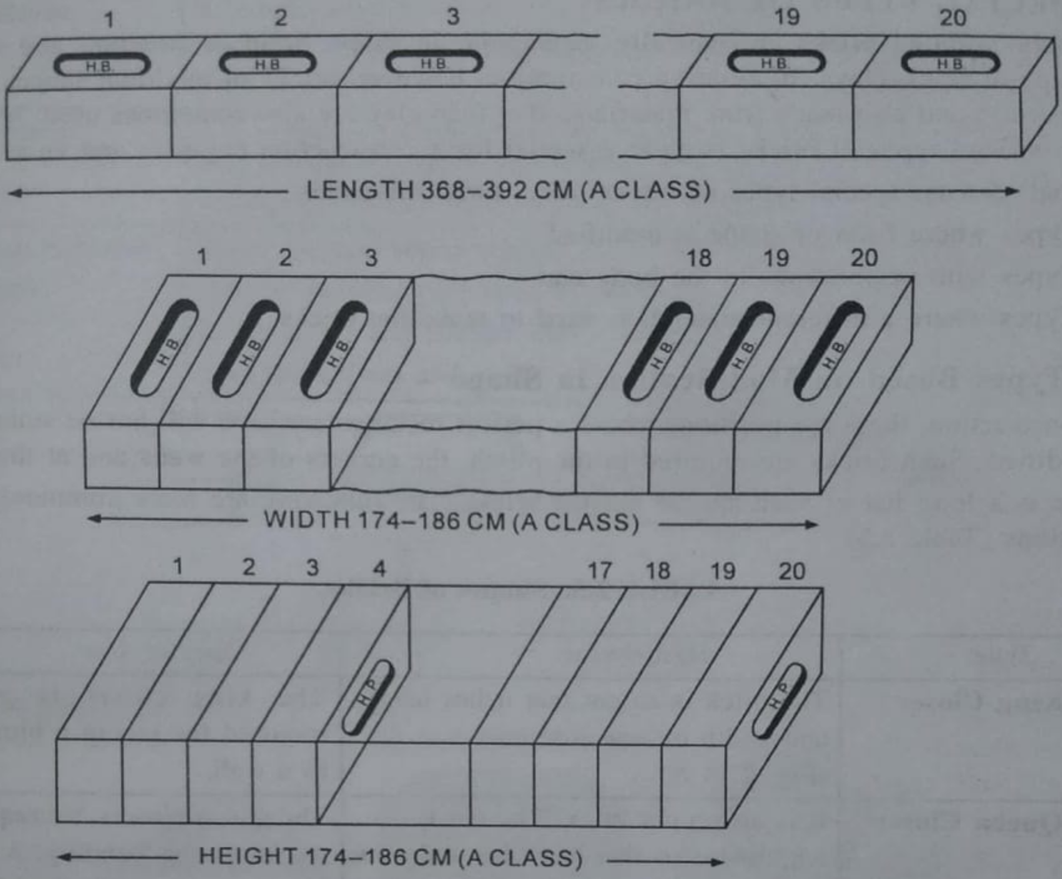


Fig. 2.13. Dimension Tolerance Test.

2.14. A NOTE ON SAMPLING OF BRICKS FOR TESTS

Since any one or more of the tests as described above can be performed only on a few specimens, it is essential that these specimens should be taken from **representative sample** of the brick.

A **representative sample** means a fixed number of specimens which will represent average qualities of the units that have been selected from the brick stock in a specified manner. The method of taking sample, therefore, requires utmost care. Otherwise results will always be non- representative

A. Samples from the Bricks in Transport

This method is used when the bricks are loaded or unloaded on trucks, cars etc.

(*i*) The batch is first divided **randomly** (*i.e.* **without pick and choose**) into a number of heaps or portions.

(*ii*) From each portion made as above, a minimum number of bricks is taken at random.

(*iii*) The total number of specimen bricks taken from the batch shall not be less than 50 bricks.

B. Samples from Stacks

Near kilns, bricks are commonly arranged in stacks after burning or cooling. From such stacks, samples are taken from the top, from the sides, and also from within the stack by removing bricks from the top. While taking samples the location should be selected at random and not with any consideration for the appearance. No guidance of the manufacturer or the supplier is to be accepted while taking samples from stacks or from batches.

2.15. SPECIAL TYPES OF BRICKS

Ordinary building bricks are typically rectangular in shape, solid in structure and made from suitable type of brick–clays. In building construction, however, bricks of modified shapes, porous or hollow structure and also made from materials other than clay are also sometimes used. A familiarity with these special types of bricks is quite essential for a construction engineer and an architect.

We shall discuss special types of bricks under three sub-heads :

(*i*) Types where form or shape is modified

(*ii*) Types with perforations in the body and

(*iii*) Types where a different material is used to make the bricks.

2.15.1. Types Based on Modification in Shape

In construction, there are positions where a perfect rectangular shape will not be suitable. It has to be modified. Such bricks are required in the plinth, the corners of the walls and at the copings.

There is a long list of such special shaped bricks. The following are more commonly required modifications (Table 2.5).

TABLE 2.5. Shapes of Bricks.

S.No	*Type*	*Description*	*Special Use*
1.	**King Closer**	The brick is so cut that it has length and width on one side only (Fig. 2.14 A)	The king closer is generally required for giving a blunt corner to a wall.
2.	**Queen Closer**	It is also a cut brick. The cut is lengthwise so that brick has only one half of the length of the full bricks. (Fig. 2.14 B)	The queen closers are required for use in giving bonding. A queen closer is generally placed next to the first header in the corner of a wall.
3.	**Squint brick**	It is also a cut brick. The portion of cut forms angles other than right angle. (Fig. 2.14 C)	They are required for giving shape in exterior or interior corners in a wall.
4.	**Splay bricks or Cant bricks**	These have a level or portion taken off, widthwise, lengthwise, or in both directions (Fig. 2.14 D, E, F).	The various shapes grouped under splay bricks or plinth bricks are made for use in jambs of doors and windows, and also in plinths (hence also called plinth bricks).
	Plinth Header	It has a full length on one face. On the other face, a slope (bevel) is made from 3/4th of the length (D)	
	Plinth Stretcher	It has slope from one half of the width that extends along the entire length (E).	
	Plinth Return	It is a combination of both the header and stretcher beveling (F).	
5.	**Coping Bricks**	When a coping is to be provided to a wall, a special shape may be desired. The chamfered brick, the half round brick and the saddle back brick are some common coping bricks. (Fig. 2.15)	Used for coping on walls in order to give them a nice appearance and also for easy drainage of water.

Continued

6.	**Bullnose**	It is otherwise a standard brick having one arris or edge rounded. (Fig. 2.14 G)	Bullnose bricks are used at turns of the wall (quoins) so that round corners are obtained.
7.	**Cownose**	It is similar to a bull nose but has both the edges on one side rounded. It may be called a double bullnose.	Cownose brick have same use as bullnose bricks but they give additional roundness. (Fig. 2.14 H)
8.	**Miscellaneous shapes**	These include bricks shaped for very specific purpose (not covered above) as for arches and circular walls, chimneys and culvets and wells.	Arches and circular columns.

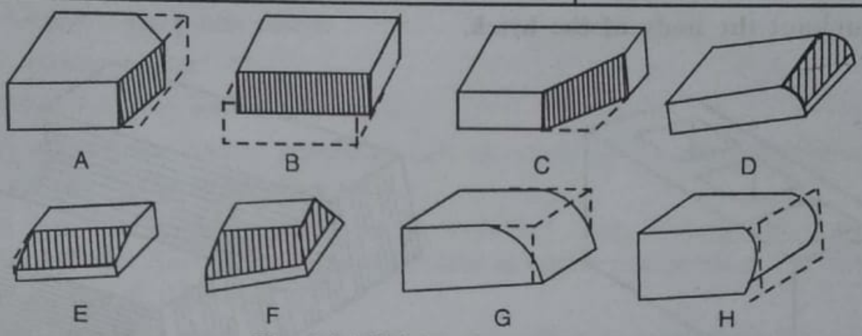


Fig. 2.14. Bricks shapes.

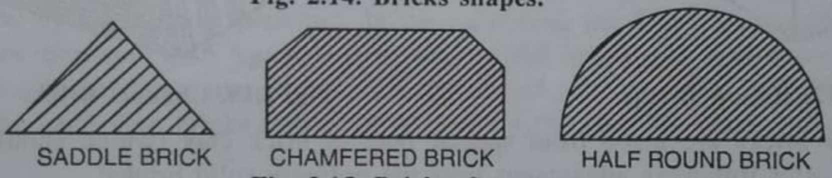


Fig. 2.15. Bricks shapes.

2.15.2. Types Based on Perforations or Cavities

Three types of bricks shall be discussed under this sub-head :

(*i*) **Perforated bricks**

(*ii*) **Hollow bricks**

(*iii*) **Channeled bricks**

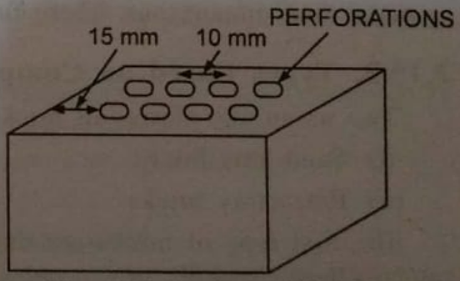


Fig. 2.16. Perforated bricks.

1. PERFORATED BRICKS. These form a modern class of building bricks that have many advantages over the ordinary solid brick. In perforated bricks cylindrical, rounded or rectangular holes are made in the bricks after the moulding stage. These holes are called **perforations**. They are properly spaced from the side of the brick, minimum distance being 15mm. Further, distance between any two perforations is not less than 10 mm. The volume of the perforations may be as much as 20-50 percent of the total volume of the brick.

The perforated bricks may be larger in size than the normal brick which is a distinct advantage in that work output is increased considerably with the use of perforated bricks.

The major advantages that perforated bricks offer over ordinary bricks are :

(*i*) These bricks are **light** in weight;

(*ii*) **Less quantity** of clay is required for their manufacture;

(*iii*) **Less time** is required for drying and burning of perforated bricks.

(*iv*) These offer **better resistance** against rain penetration and better insulation against heat. As such they are ideally suited for tropical countries.

(*v*) **Efflorescence** is least in perforated bricks.

(*vi*) These are specially suitable for construction of brick panels in multi-storeyed structures.

Perforated bricks have as yet to find popularity in our country although they are already widely used in Germany, France and America. The manufacture of perforated bricks requires a sophisticated technology. Its use is picking up in our country.

2. Hollow Bricks. A brick also called **cavity brick** or **cellular brick** has a few well-defined sets of cavities with specified dimensions made in the body of the brick. As a result, its net weight may be only one-third to one-half of the solid brick. It is important that the thickness of brick wall near the cavity should not be less than 2 cm. **This brick differs from perforated one in that the cavity extends throughout the body of the brick.**

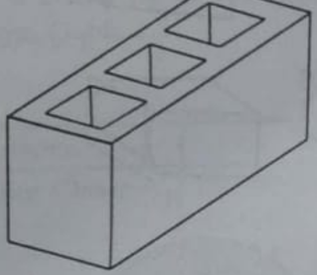


Fig. 2.17. Hollow Bricks.

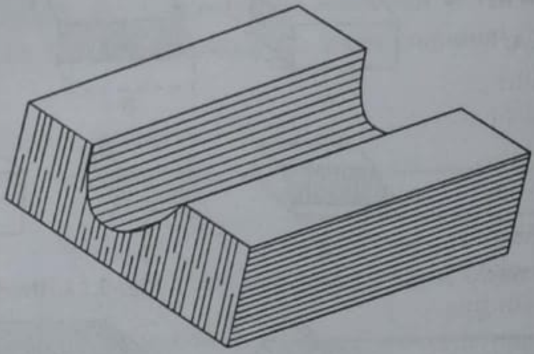


Fig. 2.18. Channel Brick.

The hollow bricks are made from special type of brick clay (which should have higher clay content). They offer following advantages over the ordinary solid bricks:

(*i*) Being light in weight, they can be handled more conveniently and the output of the mason may be three to four times compared with ordinary bricks.

(*ii*) They offer better insulation against heat and sound.

(*iii*) They are ideal and economical for **non-load bearing** walls, e.g. in partition walls.

3. Channel or Gutter Brick. They are actually special purpose bricks having a continuous central semicircular cavity or depression running through their length (Fig. 2.18). Very often they are glazed to make them impervious. These find use in the laying of drains.

2.15.3. Types Based on Composition

Two major sub-classes of bricks under this heading are :

(*i*) Sand-lime bricks

(*ii*) Refractory bricks

The first type of bricks are used as an alternative to the common building bricks. The second category has a specific use in industrial processes and will be mentioned only in outline here.

1. ***Sand Lime Bricks :***

Definition. These are building bricks made from sand and lime as the raw materials instead of clay. The clay content may be only negligible. They differ from ordinary clay bricks not only in composition but also in method of manufacture. They are, however, similar in shape and size to the ordinary clay bricks.

Manufacture. The principal raw materials for sand-lime bricks are:

(*i*) **Sand.** It must be free from harmful impurities like mica, chlorine, iron oxides black minerals and organic matter. Sand forms around 90 percent of sand-lime bricks.

(*ii*) **Lime**. It is sued in the form of slaked (hydrated) lime. Its content varies from 8-12 percent. The slaked lime used for brick making has high-calcium content and should be free from magnesium.

Besides the two essential components, some clay (up to four percent) in finely divided form is desirable. Pure, salt-free water (not sea-water) is another requirement.

For giving a required colour to the sand-lime bricks, some pigments are added in small percentages to the ingredients at the mixing stage. The following are commonly used:

- **Iron oxides** – for red and brown colour.
- **Chromium Oxide** – for green colour
- **Ochre** – for yellow colour
- **Carbon black** – for grey and black colour.

Moulding. After mixing the finally powdered raw materials in the desired proportion, a damp mixture is obtained adding 2-3 percent clean water.

From this damp mixture, brick-shaped units are moulded using Rotary Press under pressures ranging from 300-600 kg/cm^2. Such high pressure results in highly compressed and dense sand lime bricks which are almost dry at this stage.

Auto-claving. The moulded units are put into an auto-clave (a steel cylinder with closed end where heating is done by steam under pressure). In the auto-clave, the bricks are treated for 6-12 hours under steam pressure between 8-16 kg/cm^2. It is also in the auto-clave that sand and lime react chemically and form a chemical compound: **calcium silicate** which is the chemical composition of the **sand-lime brick**. The sand-lime bricks taken out from the auto-clave are ready for use.

Properties :

(*i*) The sand lime bricks have very smooth and uniform finish and a pleasing appearance.

(*ii*) They are quite dense, strong and hard.

(*iii*) They are least porous and hence free from efflorescence. Because of these properties, sand lime bricks offer many advantages.

(*iv*) They are uniform in shape, size and finish and hence require no plastering.

(*v*) The quantity of plaster when required is quite less because of the smooth surface of the brick.

(*vi*) They are water repelling and hence free from absorption related defects of ordinary bricks like efflorescence etc.

(*vii*) Since the materials required for sand-lime bricks are also quite common in occurrence, these can provide a suitable alternative to clay-bricks. We should know that most clay used in making bricks is obtained from agricultural lands and hence its conservation will help in increasing areas for food production.

Among the major disadvantages of sand-lime bricks may be mentioned :

(*i*) They can be manufactured only by using mechanized methods. Hence their production at village levels is almost impossible at present.

(*ii*) They are unsuitable for foundations and paving uses. In the first case, they get damaged in the presence of water, and in the second case, it is because they have a poor resistance to abrasion.

Scope of Use. In Western countries, sand lime bricks are used quite **widely**. They are being progressively introduced in our country also on a large scale.

2. *Fire Bricks or Refractory Bricks*

Definition. This is a separate group of bricks, which is capable of withstanding very high temperatures without undergoing any deformation in shape or size and without reacting with the material of a particular composition at these temperatures. Their use is restricted to making of inner walls of furnaces for manufacture of metals and for similar high temperature applications.

Classification. The fire bricks are classified on the basis of their **reactivity** towards melts at high temperatures:

(*a*) **Acidic Bricks.** They are resistant to the **melts of acidic composition** (but will react with the melts of basic composition). Example: Fire-clay bricks, silica bricks.

(*b*) **Basic Bricks.** They are resistant to the **melts of basic composition**. Hence they will not be suitable for use in those furnaces where acidic melts are being heated. Example: Magnesia bricks, Bauxite bricks.

(*c*) **Neutral Bricks.** They are **non-reactive to both the acidic and basic melts**. Hence these find application in heating either type of melts. Examples: Chromite bricks, Chrome-magnesite bricks.

Manufacture. Fire bricks are manufactured in the same manner as the building bricks. The four stages involved in their manufacture process are:

(*i*) Moulding of the units;
(*ii*) Drying of the units;
(*iii*) Burning of the units, and
(*iv*) Cooling of the units.

The raw materials are first crushed to the required size and then blended or mixed thoroughly in the presence of required quantity of water. From this **homogeneous** mix, brick shaped units are moulded manually or by using machines such as pressers. The moulded bricks are dried and then burnt to very **high temperatures**, generally between 1600-2000^{0}C. They are allowed to cool very gradually.

Description of important fire-bricks :

1. Fire Clay Bricks. These constitute an important class of refractory materials of acidic group. Raw material for manufacture of it can withstand very high temperatures without fusing or softening. Such clays are often available under the coal layers in nature. In these clays, silica (65-75 percent) and alumina (25-35 percent) are the two main constituents. They are free from impurities like oxides of calcium, magnesium and iron. (All these oxides, when present, lower the melting point of the clays and make them useless as refractory material). The maximum permissible upper limit for all of **such impurities** is 5 percent.

The fire clay bricks are manufactured in a manner similar to the common building bricks. The selected clay is crushed to the fine powder and moulded into the brick units. These are then dried and burnt in continuous kilns at very high temperatures (1600^{0}-1900^{0} C). They are cooled gradually before taking out from the kiln.

Types. Fire clay bricks are divided into three types on the basis of temperature they can withstand in the furnaces:

(*i*) High duty fire clays- 1482-1648^{0}C
(*ii*) Medium duty fire clays- 1315-1481^{0}C
(*iii*) Low duty fire clays-870-1314^{0}C

Properties. The fire clay bricks have high resistance to spalling (breaking under heat), high bearing capacity and low coefficient of thermal expansion.

Use. Fireclay bricks are commonly used as lining material in steel making furnaces, glass making furnaces and in reverberatory furnaces.

2. Silica Fire Bricks. These are acidic bricks made up mostly of silica, which may range from 95% and above. The remaining material is generally calcium oxide that acts as a brinding agent.

These fire bricks are acidic in character. Their raw material is pure quartz (SiO_2); or sandstone of high silica content. The moulded units are burnt to around 1500^0C. They find extensive use in Bessemer Converter as lining material because **slags** in that case are **acidic** in nature.

3. Magnesite Fire Bricks. They are classed among the **basic refractories**. Principal raw material is magnesium oxide for which the rock dolomite is a major source.

4. Bauxite Fire Bricks. These also form a very important class of **basic** refractories. They are made from the rock bauxite. ($Al_2O_32H_2O$) which may be mixed with some clay (fire clay type).

5. Chromite Fire Bricks. They belong to the **neutral class of refractories**. Raw material used for these bricks is a mineral called CHROMITE. This mineral is a double oxide of chromium and iron in its composition. For making refractories some alumina and silica are also added to make a typically neutral material. Chromite fire bricks are capable of resisting both the acidic and basic environments in a furnace. These find extensive applications in the steel making furnaces.

B. TILES

2.16. DEFINITION

These are structural units moulded from clays in suitable shapes and burnt to **vitrification** temperatures. They differ from ordinary building bricks in

(*i*) **Dimensions**
(*ii*) **Shape**
(*iii*) **Degree of burning.**

They have been extensively used throughout the world in a number of situations in building as drains, for flooring, for partition walls and for roofing. They are invariably thinner than bricks used for similar purposes.

2.17. MANUFACTURE OF TILES

Tiles are manufactured by methods that are similar in all respects to those for making bricks. The different stages in the manufacture of tiles are explained below:

2.17.1. Preparation of Clay

Only those clays which are **sufficiently plastic** are suitable for making tiles. These clays generally occur in the lower layers of the brick clays.

The tile clays are extracted and cleared from fragments, pebbles and organic matter if any. These are then **ground** or crushed to a fine powder, using even mills for crushing. It is a common practice to add a mixture of **finely ground glass** and broken pottery at the crushing stage. These materials add to the imperviousness and strength of the tile.

For ordinary type of tiles, the powdered clay is rendered into a homogeneous mix using a Pug Mill in a manner similar for brick making. For superior type of tiles, however, the crushed and powdered clays are thoroughly stirred in a tank. Some time is allowed for the coarse clay particles to settle in the tank. The water consists of fine-clay particles in suspension. It is separated and fine clay particles allowed to settle at a very slow rate. This is the **finest clay suitable for manufacture of delicate type of decorative tiles.**

2.17.2. Moulding

There are three different methods by which tiles are moulded. Selection of method would depend on the shape and size of the tile to be moulded.

(*a*) **Wooden pattern method**. It is similar to ground moulding of bricks. A wooden pattern (of the required shape and size) is made from a seasoned wood. Lumps of pugged clay are thrown into it by the moulder after he has thrown some ash on the inner side of the mould. Any surplus clay is removed by a wire string. The tile is removed from the pattern by applying pressure with fingers and thumb. Flat tiles are easily and commonly moulded by this process. Similarly, tiles which have non-uniform dimensions and non-circular shapes are best moulded by using wooden patterns. It is basically a manual method and requires **skilled** moulders.

(*b*) **Potter's wheel method.** This is also a manual method and is best suited for moulding circular tiles with uniform or varying diameter. In his method, the use is made of potters wheel on which a skilled labourer moulds tiles of required shape (other than flat) from the pugged clays using the same techniques as for moulding pitchers and other earthenware. The moulder makes deep cuts one on either side on the finally moulded pipe of clay before removing from the wheel. This helps splitting of two halves easily after burning.

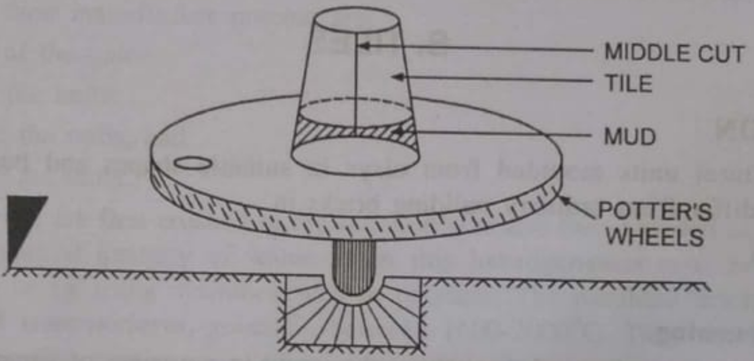


Fig. 2.19. Potter's Wheel.

(*c*) **Moulding by machines**. For large-scale manufacture of tiles having uniform sections, machine moulding is adopted. Clay that has been pugged to suitable consistency is fed into such a machine and pressed forward. It comes out from a die of requisite cross section from the other end in the form of a continuous band or ribbon. Suitable lengths are then cut from this clay band and taken for drying.

2.17.3. Drying

Tiles require greater care in drying them for two reasons :

(*i*) Being thinner, they are easily deformed when handled carelessly;

(*ii*) Non–uniform drying may result in **warping** and **cracking.**

To overcome these difficulties, tiles are collected and arranged in heaps (placing one tile above another) in the case of flat tiles and in rows, in the case of circular tiles, **near the place of moulding till they are hand-hard**. Small deformations that may result in the tiles during this period either due to careless handling or due to drying are generally corrected by using a flat wooden pallet. Thereafter the tiles are placed for full drying under a shed, which protects them from direct sun and rain. It is also essential that position of a tile is changed during drying period so that all areas get uniform exposure. Further, any pebbles and small grit that may stick to the **under surface** of the tile should be cleaned when the tile is still semi- dry. Once it becomes hard, such material will disfigure the tile on burning.

2.17.4. Burning

When required in small number, tiles can be burnt in brick kilns. In that case, they are placed on edge in the upper part of the kiln over and above the last row of the bricks. Generally two to three rows of tiles are burnt in a brick kiln. Very often it may be only a **tile-making unit**. In that case tiles are burnt commonly in specially designed intermittent type kilns called **Sialkot kilns**. These are circular in outline and have roofs over them. A typical Sialkot kiln for tile burning is shown in Fig. 2.20.

It consists of :

(*a*) **Outer wall**, made up of bricks, of a suitable thickness. The wall has two types of openings: one, doors for loading and unloading of tiles and second, doors through which fuel has to be filled for burning.

(*b*) **The floor**, which is divided into longitudinal, narrow channels at regular intervals, which are called the flues.

The roof, which is supported on posts covering the entire area of the kiln.

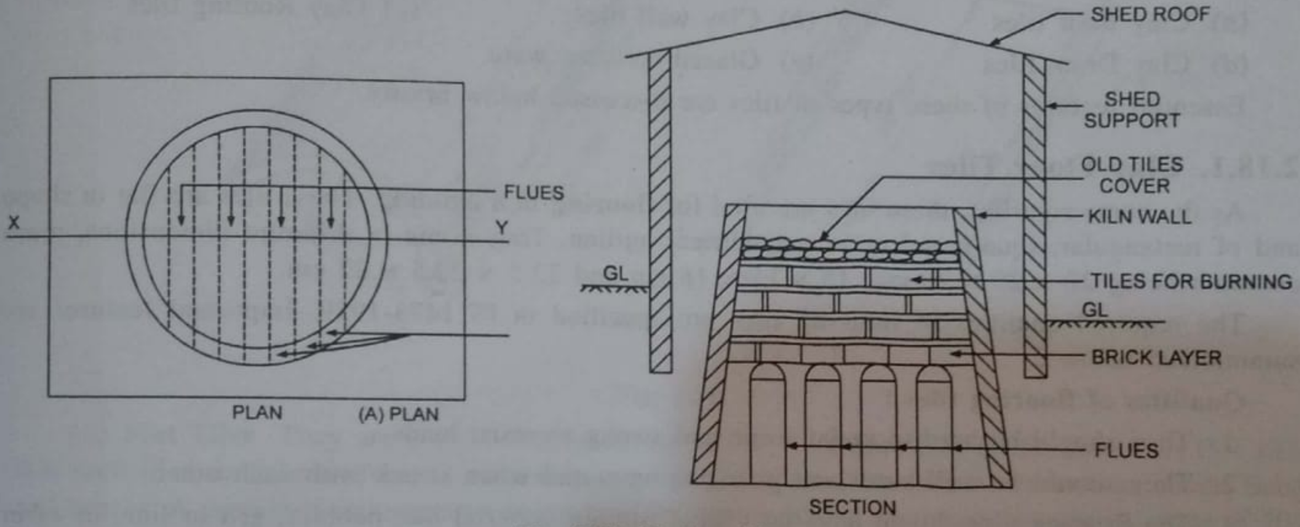


Fig. 2.20. Sialkot kiln.

The burning of a batch of 30,000 to 50,000 tiles are carried out in the following manner.

First step. The flues are filled with fuel and covered by a layer of burnt bricks that are laid flat wise. Sufficient space is left between any two bricks as to allow heat to pass upwards.

Second step. Tiles are stacked over the brick layer edge wise with space in between them, to the full height of the kiln. On the top course of dried tiles, a layer of ash and old broken tiles is laid to **conserve** maximum heat during burning.

Third step. Once the kiln is loaded as above, doors are closed by bricks laid in mud mortar.

Fourth step. Kiln is **fired** by igniting the fuel in the flues. The firing is continued for about 72 hours during which time temperature is increased and decreased in accordance with the following scheme:

(*i*) Very gentle fire is burnt to begin with. This is meant only to dehydrate or remove any moisture from the tiles.

(*ii*) Fire is increased to achieve temperature of **red–heat** around (800^0C). This results in initial baking of tiles. It is continued for 4 hours.

(*iii*) Fire is slackened for a period of 6 hours. This is to allow the baked tiles a time to adjust to a temperature shock.

(*iv*) Now, fire is increased once again, this time to **white–heat** temperature of 1300^0C. This high temperature is maintained for at least 3 hours. It is during this stage that baked tiles get converted to vitrified tile products.

(*v*) Fire is slackened for a second time for about 6 hours.

(*vi*) It is again increased to a **second white heat period**. This time, the white heat period is maintained for 4 hours.

(*vii*) Now the flues are filled with fuel for the last time and closed from outside with brick in mud mortar.

(*viii*) The kiln is allowed to cool very gradually before emptying.

It is obvious from above details that for burning of one batch of tiles, these are brought twice to the white heat temperatures with two intervening periods of slackened heating. **Regulation of temperatures during burning is, therefore, most important aspect of tile burning.**

2.18. TYPES OF TILES

Different types of tiles are distinguished on the basis of use they are put in a building. The five major classes of tiles are:

(*a*) Clay floor tiles
(*b*) Clay wall tiles
(*c*) Clay Roofing tiles
(*d*) Clay Drain tiles
(*e*) Glazed earthern ware.

Essential features of these types of tiles are discussed below briefly.

2.18.1. Clay Floor Tiles

As the name signifies, these tiles are used for **flooring** in a building. These tiles are flat in shape and of rectangular, square and other geometrical outline. They come in different dimensions, more common being 20 × 20 × 20 cm, 15 × 15 × 18 cm and 22.5 × 22.5 × 22 cm.

The required qualities of **flooring tiles** are specified in IS 1478-1959. Important features are summarized below :

Qualities of flooring tiles :

1. They should be hard to **resist wear** and strong to resist loads.
2. They should be well burnt and give ringing sound when struck with each other.
3. The flooring tiles should have no visible foreign material like pebbles, grit or lime or other fragments on the upper or under surface or on the sides.
4. They should conform to the dimensional specifications with tolerance of ±3 mm for length or width and ±1.5 mm for thickness.
5. They should have a uniform texture throughout their body as evidenced by broken surface.

2.18.2. Clay Wall Tiles

Tiles which are specifically designed and manufactured for use on walls are called **Wall Tiles.** They are broadly similar to flooring tiles in size, shape colour. In fact many floor tiles may be conveniently used on walls for decorative purposes. Mostly, wall tiles are used on the face work and for ceilings of special architectural designs.

2.18.3. Clay Roofing Tiles

These form the **single most important** and most commonly used class of tiles. They are used as alternatives to corrugated and plain G.I. (Galvanized iron) sheets and timber as **roofing material** for building construction–especially on sloping roofs.

Among the most essential qualities of roofing tiles, the following may be mentioned :

(*i*) They must be absolutely **leak proof**

(*ii*) They must be **very durable**

(*iii*) They must be **easy** to fix on the roof

(*iv*) Their **maintenance cost should be less.**

Roofing tiles are presently manufactured in a wide variety of types. Only a few common types are described below :

(*i*) **Pot Tiles**. It is an ordinary but common class of roofing tiles. The individual tile is semi-circular in outline and has tapering diameter which is 15 cm at one end and 10 cm at the other end. **Length** of such tiles is 20 or 25 cm and thickness from 1.5 cm to 2 cm. They come in **widths** of 20 and 25 cm and thickness from 1.5 cm to 2 cm (Fig. 2.21). They are also called "Pan Tiles". As the name applies, they are moulded by the potter (hand moulded) and hence are neither very dense not very strong. They often have high absorption values and hence suffer greater wear and tear. The Pan tiles differ from ordinary pot tiles in that they are first made as tiles and the curvature is given subsequently while the clay is still green (Fig. 2.21 A).

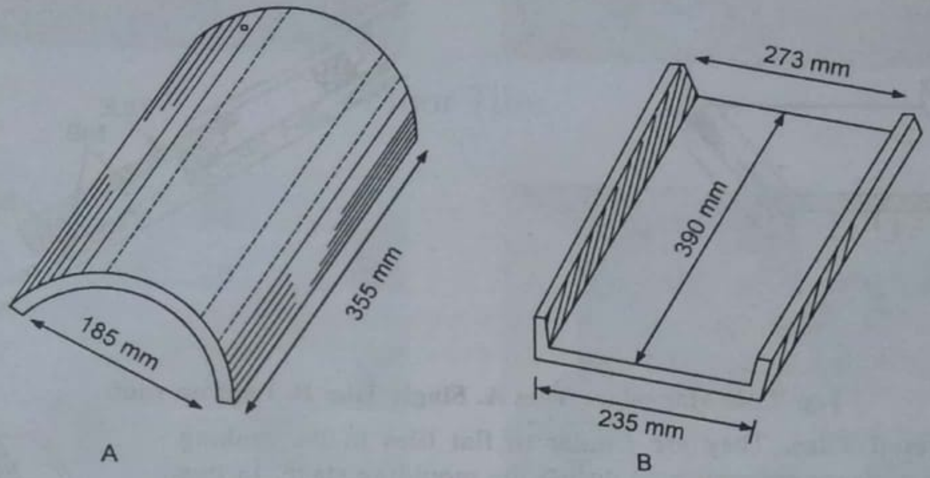


Fig. 2.21.

(*ii*) **Flat Tiles**. They are almost rectangular in outline. It is specified in ISI 2690 Part II – 1975 that such tiles shall be uniform in size, shape and shall be free from distortions such as bends, twists and cracks. A minimum compressive strength of 75 kg/cm_2 and a maximum absorption value of 20% are also among the requisite qualities of Flat Tiles.

They are used alone or in combination with semicircular pot tiles for roofing in common buildings.

(*iii*) **Allahabad Tiles**. They are a better class of roofing tiles, generally made from superior type of clays and by machine pressing. The essential part of an Allahabad tile is a flat tile provided with interlocking arrangements at the sides. The flat tile has a tapering dimension, the bigger end being 30 cm in width and the smaller end 25 cm. These tiles come in lengths of 40 cm (Fig. 2.21B)

While covering the roof with Allahabad Tiles, first flat tiles are laid side by side. Then the joint between the adjacent tiles are covered with half-round pot tiles which overlap each other. This results in an appealing roofing pattern.

(*iv*) **Mangalore Tiles**. They form a **very popular class of roofing tiles** in southern and western part of our country. They have been so named because of their early manufacture in Mangalore, South India. Their most important feature is their built-in interlocking arrangement. Due to this arrangement, a series of Mangalore pattern tiles can be easily fixed on a single rafter. These are claimed to provide better roofs and simple construction at economical costs (Fig. 2.22 A and B).

The most important characters of Mangalore-Pattern Roofing Tiles as specified by Bureau of Indian Standards IS 654-1972 are as follows :

(*a*) **Shape of Nibs**. The tiles shall be free from twists, bends, laminations, cracks and blisters etc. and shall have at least two nibs, each with a base width of not less than 19 mm and projecting above the surface not less than 10 mm.

(*b*) **Dimensions and Weight**. These tiles shall conform to the dimensions and weights as specified in the code for various classes. Thus, the length and width shall be as under :

410 mm × 235 mm; 420 × 250 mm; 425 × 260 mm. And, the weight of six tiles, when dried at $105^0C + 5^0C$ to a constant weight, shall not be less than 2 kg and not be more than 3 kg.

(*c*) **Classification**. Two types of Mangalore Tiles shall be recognized as under :

- Class AA – with a moisture absorption less than 10% by weight and an average breaking load of 102 kg/cm^2.
- Class A – with a moisture content not exceeding 24% and an average breaking load of 68 kg/cm^2

Fig. 2.22. Mangalore Tiles A. Single Tile; B. Laid on roof.

(*v*) **Corrugated Tiles.** They are similar to flat tiles in the making except that their surfaces are contorted during the moulding stage. In this way, these tiles resemble corrugated galvanized Iron (G.I) sheets. When used over the roof, a side lap of one or two corrugations is formed. The appearance of the roof is then pleasing to the eye. They have an additional advantage of quicker drainage of rain water. These tiles come in sizes of 40 × 35 cm (Fig. 2.23).

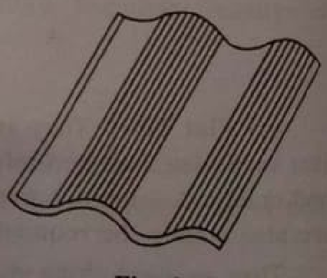


Fig. 2.23.

2.18.4. Clay Drain Tiles

Those tiles which are manufactured from clay for the special purpose of lining of drains are called **drain tiles**. In shape, they may be circular or semicircular. Their size is determined by the exact purpose for which they have to be used, e.g. in irrigation drains, in road drains or, in domestic drains. Their use, however, is now decreasing as better-glazed drainage pipes are available for the same purpose.

2.19. TERRA COTTA

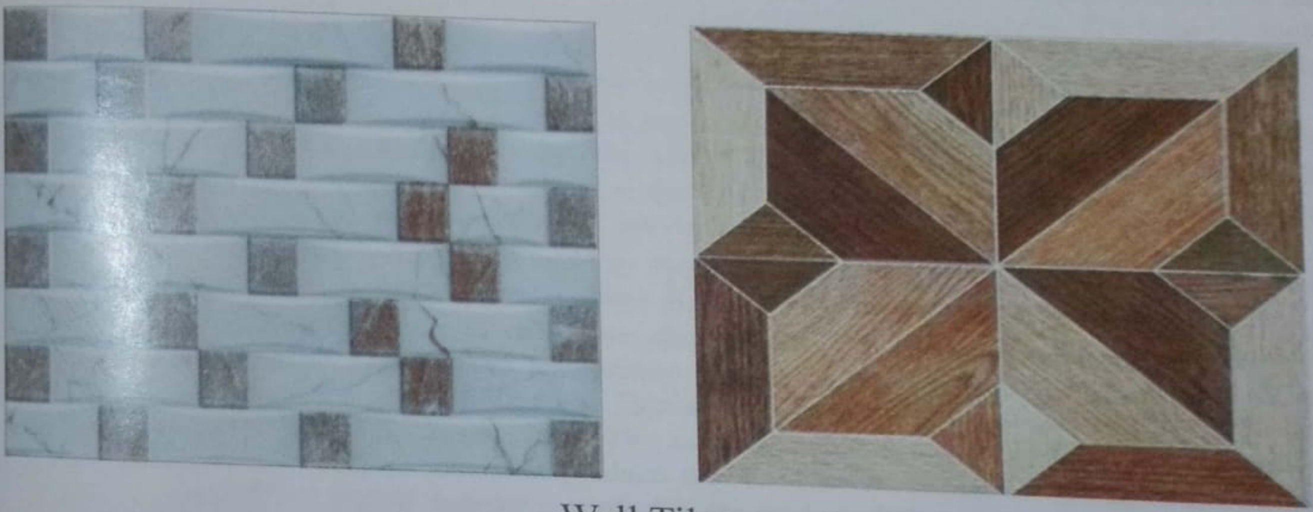
2.19.1. Definition

Terra Cotta literally means **burnt clay**. It may be defined as a clay product, which is made by very careful burning. Terra Cotta invariably requires a more homogeneous and purer type of clay than that is used for making bricks and tiles. The products of terra cotta include: hollow blocks, ornamental and decorative blocks.

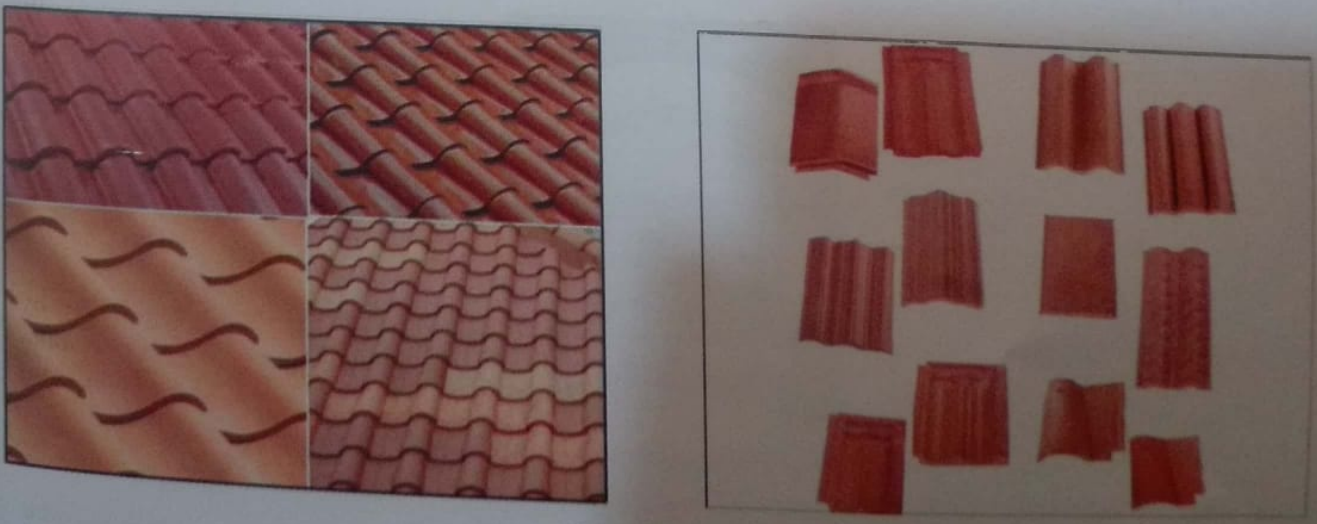
2.19.2. Manufacture

Terra Cotta is manufactured in the same four stages as applied for brick and tile making. The process, however, requires greater care, caution and skill at each stage, namely, preparation of clay, moulding of units, drying and burning of units.

Floor Tiles



Wall Tiles



Roofing Tiles

Preparation of Clay. The clay for terra cotta should contain higher proportion of alumina and iron oxides. It has less proportion of sand and lime. This type of clay is first cleared of impurities like pebbles, grit, free lime and organic material. Very often, ground glass, old terra-cotta and refined pottery are also added to the selected clay before crushing.

The selected clay and other materials are then **finely crushed and reduced to a fine powder using grinding mills**. Measured quantities of water are then added to this powder and the same is thoroughly mixed using spades. It is left for seasoning for a few days. Thereafter, it is thoroughly mixed in a mechanical device called Pug Mill (same type as used for pugging of clay), till it is converted to a **very homogeneous mixture of desired plasticity**. Since terra cotta is made in various colours, the colour-imparting pigments are also added at this stage so that they are thoroughly dispersed in the mass.

Moulding. Moulding is done for terra-cotta using both hand moulding and machine moulding methods. For intricate designs, only hand moulding is suitable.

The mould for terra-cotta is made up of Plaster of Paris, or of zinc. Wooden moulds are not suitable due to very sticky nature of the mix and the intricate shapes of terra cotta. The lump of finely mixed plastic clay is pressed into the moulds after the same is sprinkled on the inside with sand. Any **desired designs and patterns are given to the terra cotta only at the moulding stage.**

Drying. The moulded products are dried in two stages. **Initial drying** is allowed to take place in the mould itself. Since on drying the clay mix will shrink to some extent, it will come out of the mould easily on slight tamping. **Final drying** is done by placing the products in well-protected, airy sheds where sun, rain and stormy winds will not disturb the products.

Burning. Terra Cotta products are made by burning the above-moulded units in special furnaces called **Muffle furnaces**. In such a furnace, there is a **perfect control** over temperature.

The dried products are kept in rows, one above another, in the muffle furnace and burnt to temperatures as **high as 1200^0C**. The temperature is raised to the above level only **gradually but burning is continued for about four days**. Thereafter, burning is discontinued and the terra cotta products allowed to cool in the furnace itself. This may take another four to five days. In all, therefore, burning and cooling a batch of terra cotta products may need about ten days. When **glazing** (see latter section) is required, the glazed material is applied to the products **before** they are put into the furnace for burning.

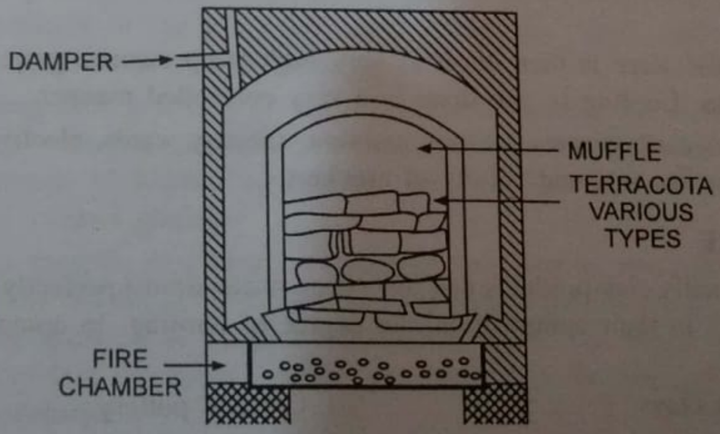


Fig. 2.24. Muffle Furnace for Terra Cotta

For large scale manufacture of terra cotta , specially designed tunnel kilns may be more useful.

2.19.3. Types and Uses

Terra cotta is manufactured in a variety of designs which may be conveniently grouped in two main classes:

1. Structural Terra Cotta. This is also called polished terra-cotta, fine terra-cotta or simply **faience**. It is made by burning the moulded units in two stages.

In the first stage, called biscuiting, the product is burnt only to a temperature of 650^0C. The product is taken out of the kiln and allowed to cool. It is then given a coat of the desired glazing compound and put into the kiln once again. In this second stage of burning, temperatures as high as 1200^0C are allowed to reach. The resulting terra-cotta is of fine finish.

Structural terra-cotta is made in the form of solid or partially hollow blocks with dimensions varying between 40-60cm and 80-120 cm. It has following advantages:

(*a*) Better insulation against heat and sound.

(*b*) Better resistance to wear, weathering and moisture.

(*c*) Light weight

(*d*) Relatively high strength and durability.

(*e*) Easily cleaning properties coupled with being available in variety of colours.

2. Architectural Terra-Cotta. This group includes a variety of simple and intricate designs of terra-cotta that are meant for use as decorative pieces in a building. The Porous Terra-Cotta (terra-cotta lumber) is a special variety of architectural terra cotta. It is made by mixing saw dust, powdered cork, or straw with clay. When such a mix is burnt, the organic matter burns out leaving pores within the end product.

2.20. EARTHENWARE

This term includes all the articles (other than bricks and tiles) made from refined type of clay mixed with other suitable materials. Such mixtures are burnt carefully and also cooled very slowly. They are porous in textures and soft in character. They can also be made hard and impervious by glazing their surfaces. Terra-cotta described already is a type of earthenware. A common use of earthenware is for making cable conducts.

The so-called **porcelain** is also a very fine type of earthenware. It burns white and depending on the composition, may be made in opaque, translucent and even semi-transparent wares. The required materials are: clay (of high plasticity and tenacity), felspar (alumino silicates of K, Na and Ca) and quartz (SiO2). These minerals are finely crushed and ground to powder. A little water is added to make a **stiff paste**. Desired articles like tea-sets, dinner-sets and other white ware are then moulded from this paste.

The so-called white ware is then burnt at very high temperatures, generally above 1300^0C, in special muffle furnaces. Cooling is also done in a very controlled manner.

Among the various earthenwares we may mention; sanitary wares, electrical insulators, crucibles and the dinner sets and tea sets and variety of crockery.

2.21. STONEWARE

Stonewares are actually clay products that have been made almost perfectly impervious and opaque by suitable adjustments in their composition and degree of burning. In composition, stonewares are made from:

(*i*) Refractory clays

(*ii*) Crushed pottery

(*ii*) Felspars

(*iv*) Powdered stone.

The above ingredients are **mixed together and crushed to a fine powder from which desired shapes are moulded by using pattern moulding**. The dried products are then burnt at very high temperatures. They are invariably glazed to make them impervious.

Besides being impervious, opaque and dense, stonewares are also highly resistant to the action of acids and other corrosive chemicals. It is for these properties that stonewares are very commonly used as sanitary wares (wash basins, tubs, sinks, drain pipes). They also find applications for storage of chemicals and food products etc.

2.22. GLAZING

Glazing may be defined as **protective treatment** given to a certain class of clay products with a view of improving their resistance against water and chemicals.

A glaze is the thin film or glassy coat formed on the surface of the clay products as a result of glazing. It is 0.1 to 0.2 mm in thickness.

Objectives. Glazing is done to achieve one or all of the following objectives in a clay article :

(*i*) To improve its resistance to water, chemicals and atmospheric gases.

(*ii*) To improve its durability.

(*iii*) To impart a pleasing finish and decorative design on its surface.

Glazing Processes. There are three types of processes commonly used for glazing.

Salt Glazing. This process is employed to impart a transparent lustrous finish to products of stoneware categories. It consists of throwing a sufficient quantity of common salt (NaCl) in the kiln where the products are being burnt at high temperatures. This is done only when temperature has reached 1200^0C or so. At these high temperatures, salt thrown in the furnace gets **vapourised** and the vapours spread over the entire surface of the articles being burnt. It forms a thin layer of sodium silicate or glaze on chemically reacting with the hot surface of the article. Salt glazing is not practicable in case of inferior type of clay products.

Opaque Glazing. It is a better and more common process of glazing articles meant for domestic applications like crockery and sanitary wares.

The glazing material consists of fine quality clay, felspar, flint, boric oxide and metallic oxide like those of tin, zinc and lead. These may be used alone or in suitable combinations as desired.

The process consists of **first preparing a very fine**, homogeneous lean paste (called slip) of the glazing compounds. Meanwhile the clay products are dried thoroughly. Each article is then dipped into the slip. It is put into the kiln for burning at high temperatures. During this firing process, the coating or glaze compositions get completely vitrified. They form a uniform glaze of desired colour over the surface of clayware which also gets baked simultaneously.

In case a transparent glazing is required with any one of these compounds, the clayware is **first burnt at a low temperature** in the kiln, then dipped into the "slip", and again burnt at high temperatures. The resulting glaze is of **fine quality**.

Porcelain Enamelling: This is a very common process of making the surface of some domestic and general appliances of metallic nature very smooth, resistant to chemicals and deterioration by dusting. Thus, a wide variety of kitchen utensils and sanitary ware of steel or iron are made more attractive and durable by enamel glazing.

Porcelain enamelling consists of giving a coating of clay slip on the articles. For this purpose, only the best variety of clay (kaolin or china clay) is commonly used. This is crushed to finest powder and mixed with calculated quantity of water to make a thin paste. The article to be enameled is then given a uniform coating of this slip using a spray gun. Sometimes the fine powder of clay is directly sprayed over the metal surface.

The article so treated is then subjected to heating in a furnace at very high temperatures, around 1500^0C. The glaze material gets uniformly dispersed and stuck to the metal surface very firmly.

TYPICAL QUESTIONS

A. ESSAY TYPE QUESTIONS

1. What are clays ? How are they formed in nature? Describe main characters of chief groups of clays ?
2. (*a*) what is the basic difference between the **soft** mud, the **stiff** mud and **dry press** process of BRICK MANUFACTURE?
   (*b*) Explain the salient features of any one of these processes for manufacture of bricks?
3. Explain with the help of neat sketches construction and working of any two of the following:
   (*i*) Allahabad kiln
   (*ii*) Clamp
   (*iii*) Bull's trench kiln
   (*iv*) Hoffman's kiln
   (*v*) Sialkot kiln for tiles
4. (*a*) Explain important qualities of an ideal brick ?
   (*b*) Describe, in brief, methods for testing the main properties of bricks as per BIS specifications.
5. (*a*) How do tiles differ from bricks ?
   (*b*) How are tiles classified ? Describe the essential characters of some common type of roofing tiles. Illustrate your answer with neat sketches.
6. Write short notes on:
   (*i*) Pug mill
   (*ii*) Pazwah
   (*iii*) Transport clays
   (*iv*) Perforated bricks
   (*v*) Sand lime bricks
   (*vi*) Frog
   (*vii*) Stoneware
   (*viii*) Coping bricks
   (*ix*) Salt glazing
   (*x*) Opaque glazing
   (*xi*) Efflorscence

B. OBJECTIVE TYPE

1. For brick making , clay should have composition of
   (*i*) clay 60-70%, sand 20-30% , lime5-10%
   (*ii*) sand 65-70%, clay25-30%, iron oxide 4-5%
   (*iii*) Iron oxide 60%, sand 20% clay 20%
   (*iv*) None of the above
2. Bricks will be **poor** in durability when the clay contains:
   (*i*) Free lime and alkalies beyond 2-3%.
   (*ii*) Free quartz beyond 2-3%
   (*iii*) Iron oxides beyond 2-4%
   (*iv*) None of the above
3. The **standard dimension** of an ideal Brick as per BIS are:
   (*i*) 19 × 9 × 9 cms
   (*ii*) 18 × 10 × 10 cms
   (*iii*) 22.5 × 11.5 × 7 cms
   (*iv*) none of the above
4. The recommend compressive strength of A-class Brick as per BIS is :
   (*i*) 250 kg/cm^2
   (*ii*) 200 kg/cm^2
   (*iii*) 140 kg/cm^2
   (*iv*) none of the above

5. The tolerable absorption value of bricks should be in the range of
   (*i*) 30-40 percent (*ii*) 25-30 percent
   (*iii*) 20-25 percent (*iv*) none of the above
6. FROG on a brick is :
   (*i*) A depression with a raised inscription mark
   (*ii*) A projection with a depression carrying a mark
   (*iii*) A level surface carrying raised mark of manufacturer
   (*iv*) None of the above
7. **Mangalore Tile** is the name of a tile
   (*i*) Which is made only in Mangalore
   (*ii*) Which has a special shape with projections on two faces for special tie up on roof
   (*iii*) Which is used for flooring
   (*iv*) None of the above
8. A **continuous kiln** for brick burning differs from an intermittent kiln in that
   (*i*) It is made under ground
   (*ii*) It has permanent walls and chimney
   (*iii*) It has more than one compartments and different compartments can be used for burning, cooling, loading and unloading etc
   (*iv*) None of the above
9. **Efflorscence** is seen on the bricks which are made from the soil containing too much of :
   (*i*) Alkalies (*ii*) Lime
   (*iii*) Silica (*iv*) Iron oxides
10. GLAZING makes the CLAY PRODUCTS:
   (*i*) Rough, tough and strong (*ii*) White, smooth, and beautiful
   (*iii*) Impervious, hard and shining

ANSWERS: **1.** (*ii*); **2.** (*i*); **3.** (*i*); **4.** (*iii*); **5.** (*iii*); **6.** (*i*); **7.** (*ii*); **8.** (*iii*); **9.** (*i*); **10.** (*iii*).

RELEVANT IS CODES ON CLAY PRODUCTS*

1.	CLASSIFICATION, general quality, dimensions and physical properties-Requirements of Burnt CLAY BRICKS.	IS: 1077-1976
2.	GUIDE for manufacture of hand –made common building BRICKS.	IS: 1077-1976
3.	HEAVY DUTY Burnt clay Building Bricks.	IS: 2180-1970
4.	BURNT CLAY FLAT TERRACING TILE.	IS:2690-1975
5.	Burnt clay Facing Bricks.	IS: 2694-1972
6.	CLASSIFICATION of burnt clay SOLID BRICKS	IS: 3102-1971
7.	Broken BRICK for lime concrete	IS: 3182-1975
8.	Burnt clay TILES for use in lining irrigation and drainage works	IS:3367-1975
9.	METHODS OF TEST for Burnt clay Building BRICK.	IS: 3425-1976
10.	Burnt clay PAVING BRICKS Requirements for size and physical properties.	IS: 3583-1975
11.	Hollow clay TILES for floors and roofs part I & part II	IS: 3951-1975

12.	Burnt clay HOLLOW BLOCKS for walls and partitions.	IS: 3952-1978
13.	SAND LIME BRICKS Requirements regarding dimensions, compressive strength and drying shrinkage.	IS: 1139-1976
14.	GUIDE for construction of BRICK KILN (for top fed coal fired continuous kiln working on natural draught)	IS: 4805-1978
15.	SEWER BRICKS-manufacture and properties	IS: 4885-1960
16.	METHODS for sampling clay building BRICKS	IS: 5454-1978
17.	DIMENSIONS for special shapes of CLAY BRICKS	IS: 6165-1971

[***Note:** Most of the above codes stand reaffirmed in 1995.]

❑❑❑

3

Limes

3.1. GENERAL

LIME is an important cementing material used in engineering construction. A cementing material may be defined as that material which has the capacity of **holding structural units** (like bricks, stones, aggregate) together with sufficient strength. Among this group are included lime, natural cements, gypsum, Portland cement as well as numerous other synthetic products. In this chapter we shall discuss only LIME.

Lime in its simplest form is an oxide of calcium, CaO. It has been used since ancient times in the construction of ordinary buildings and also massive monuments, palaces and forts. In fact, it was only after the advent of Portland cement in 1824 that its importance and use has reduced to some extent. Even in the present time, lime can be used as a reliable and economical cementing material where Portland cement is either costly or is not easily available as in hilly regions and remote villages.

3.2. CLASSIFICATION

Lime is available in the market in three main types which are named on the basis of its composition: **quicklime, hydrated lime** and **hydraulic lime**.

(1) **Quicklime.** It is also called **Fat** lime, **Rich** Lime or **Pure** lime. In it CaO content is always greater than 93 percent by weight, remaining being MgO and very little clay (not exceeding 5 percent in any case).

Quicklime is an amorphous (shapeless) white material which is highly caustic in character. It has a very high affinity for water and carbon dioxide. It will absorb the same quickly even from atmosphere converting itself to a carbonate of Calcium, as per following reactions

$$\boxed{\begin{aligned} CaO + CO_2 &= CaCO_3 \\ CaO + H_2O &= Ca(OH)_2 \\ Ca(OH)_2 + CO_2 &= CaCO_3 + H_2O \end{aligned}}$$

(2) **Hydrated Lime.** It is that lime to which sufficient quantity of water has already been added at the manufacturing stage to hydrate (slake) it completely. In composition hydrated lime is $Ca(OH)_2$. In structure, it may be a fine powder. It comes in **ready to use** form compared to fat-lime that has to be hydrated or slaked before using. Lime can also be converted to hydrated form at the place of construction. The method is then called **slaking of lime**.

(3) **Hydraulic Lime.** It is different in chemical composition form FAT LIME in that it contains a definite amount of clay in addition to CaO. The clay content in hydraulic limes may range form 10-30 percent by weight. This clay plus lime composition gives the hydraulic lime a property of **hydraulicity**, which may be defined as "the capacity to set and harden even under water and in the absence of air as **between very thick walls**."

The hydraulic lime is further classified into three sub-types on the basis of hydraulicity (which is actually related to the clay content) of the lime. Their essential characters are tabulated below:

TABLE 3.1. Classification of Lime (After IS: 712-1973)

Class & Name	*Clay Content %*	*Hydraulicity*	*Setting Time*	*General remarks on Quality and Use*
A **Eminently Hydraulic**	21-30	Eminent	Sets under water in 24 hours	Mortar made with this lime is quite sound for use in major structural jobs in place of cement.
B **Moderately Hydraulic**	11-20	Moderate	Sets in water in about a week.	Mortars made from this lime are quite satisfactory for strong masonry work.
C **Feebly Hydraulic**	5-10	Feeble	May take a month or more to set under water	It resembles fat lime in properties. Mortar made from it can be used for ordinary construction in dry conditions.

Besides above three classes, two or more types of lime, designated as class D and class E, are also recognized which do not possess hydraulicity. **The class D** lime is rich in magnesium and is suitable only for finishing coats. The hydraulic limes rich in magnesia and other impurities may be suitable only for masonry mortars where dampness is negligible.

Lime has also sometimes been classified on the basis of raw material used in its manufacture into types as **stone lime, shell lime** and **kankar lime**.

Similarly, lime is distinguished into a **building lime** and a **finishing lime**. The first type is required to possess good strength and ability to mix with sand. It is used for making mortars that are used in walls and foundations. The finishing lime, however, is required to possess sufficient plasticity, good colour and quick setting property. Such a lime is used for making plasters.

3.3. MANUFACTURE OF FAT LIME

3.3.1. Source Material

The essential raw material for the manufacture of quick lime (fat lime) is a rock called LIMESTONE ($CaCO_3$). Limestone is a sedimentary rock which occurs in nature in good abundance forming hill ranges, plateaus and also as outcrops in many plains of the world.

Common limestone rock has following constitution :

(*i*) **Calcium Carbonate** ($CaCO_3$)-60-65 percent. The higher the percentage of $CaCO_3$, the better suited is the limestone for manufacture of fat lime.

(*ii*) **Magnesium Carbonate** $Mg(CO_3)_2$-5-30 percent. It is almost a universal component of many limestones. For making Fat Lime, its content should not be greater than 5 percent, otherwise the lime would be of magnesium-lime category.

(*iii*) **Clay** – Its percentage may vary form 10-30 per cent. For the manufacture of fat lime, its percentage should be less than 10 percent. Limestones with higher clay content are more suited for manufacture of hydraulic limes.

(*iv*) **Iron, alkalies** and **sulphates** are present in small proportions in many limestones. When their total content is less than 5 percent and the $CaCO_3$ is above 90% the limestone is suitable for fat lime manufacture. But when present in excess amounts, these salts make the limestones **unsuitable** as a raw material for fat lime.

Besides Limestone, sufficient quantity of **fuel** is also required to manufacture lime.

3.3.2. Calcination

Lime is manufactured by a process of burning or **calcination** of limestone in suitable type of kilns. The term **calcination** signifies:

"Heating the material at red heat in the presence of air till it decomposes."

Theoretically, limestone dissociates when heated at 880^{0}C into its principal constituents: Calcium oxide and carbon dioxide, as per following reaction, which is reversible:

$$\underset{\text{Lime stone}}{CaCO_3} \xrightleftharpoons{880^\circ C} \underset{\text{Lime}}{CaO} + \underset{\text{Carbon dioxide}}{CO_2}$$

In order that this reaction should proceed **forward** so that we get lime, it is essential that

(*i*) all the carbon dioxide produced during the reaction is removed quickly from the kiln;

(*ii*) the dissociation temperature of reaction (880^{0}C) is not allowed to come down during the burning process.

Any magnesium carbonate present as an important constituent in the limestone also dissociates along with calcium carbonate:

The **BURNING** of Limestone is carried out (like bricks) either in **clamps** or in **kilns.** As we already know, clamps are temporary, make shift arrangements for burning in an ordinary manner and at a much lower cost. Kilns are, however, permanent structures built to carry out the burning operations at regular intervals or on continuous basis. We shall discuss all the three cases.

3.3.3. Clamp Burning

It is a common method for obtaining small supplies of quick lime. No permanent construction is needed. A small part of ground is cleared and limestone and fuel (wood) stacked loosely in alternate layers. The lower layer is always of fuel. When coal is the fuel to be used, it is mixed with the limestone instead of stacking in separate layers. The whole heap is then covered with mud plaster. Small holes are left at the top and bottom for establishing a draught and also for escape of carbon dioxide liberated during the calcination reaction.

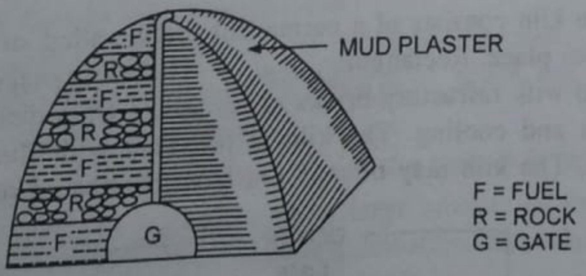


Fig. 3.1. Clamp burning.

The clamp is thus ready for operation. It is ignited from the base and allowed to keep on burning for 2-3 days. Burning is discontinued when blue flame (due to carbon dioxide) disappears at the top. This clamp is allowed to cool for another 2-3 days. It is then dismantled. Limestone gets disintegrated into small pieces or lumps of CaO or lime. Such lumps are separated from the ash by hand picking.

Clamp burning is a quick and cheap method for obtaining ordinary type of lime. It is, however, not suitable for the manufacture of large supplies of fat lime of good quality because:

(*i*) Burning is neither uniform nor complete;

(*ii*) Some stones may be overburnt and some may be underburnt, resulting in considerable wastage of the raw material;

(*iii*) There is considerable wastage of heat generated by burning of fuel. Some of it escapes from frequent cracking of the plaster on getting heated.

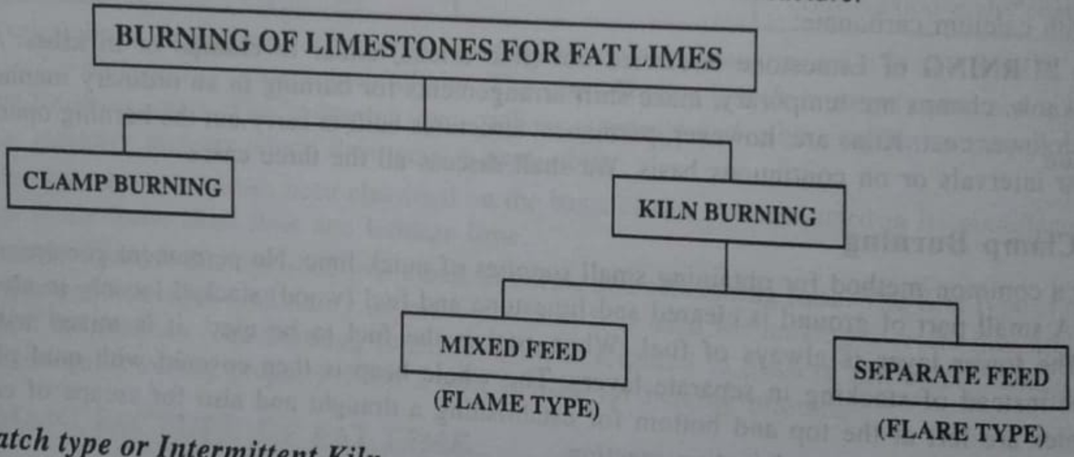
For the above three reasons, it is **not a feasible** method for producing fat lime on a **commercial scale.**

3.3.4. Kiln Burning

Most of the commercial lime is manufactured by burning limestone in **kilns**, which as defined earlier, are permanent structures. Kilns used for manufacturing lime are of great variety and different designs. In principle, however, they are either batch type (intermittent) kilns or continuous kilns. The first type of kilns have to be cooled every time after burning a batch of limestones. The continuous kilns, however, are kept in operation all the time unless they are required to be stopped for repairs.

Further, a kiln may be of mixed feed (**flame–type**) or separate feed (**flare-type**) design. In the first category, fuel and limestone are charged in alternate layers or in a mixed-together batch. In such cases, burnt lime is obtained mixed with the ash and has to be separated from it. In the separate-feed kilns, however, limestone and fuel do not come in contact with each other. The fuel is burnt separately. Only hot gases are allowed to heat the limestone. **Hence lime is obtained free from ash.**

The following chart summarizes burning methods for lime manufacture.



(1) *Batch type or Intermittent Kiln*

A typical batch type lime kiln consists of a permanent brick-walled structure. Its shape, size and design may vary from place to place. Rectangular, oval or cylindrical shapes are common. The walls of the kiln are generally lined with refractory bricks to save them from disintegration due to repeated heating at high temperatures and cooling. The kiln is provided with flues or openings meant for supply of air during burning. The kiln may or may not have permanent roof.

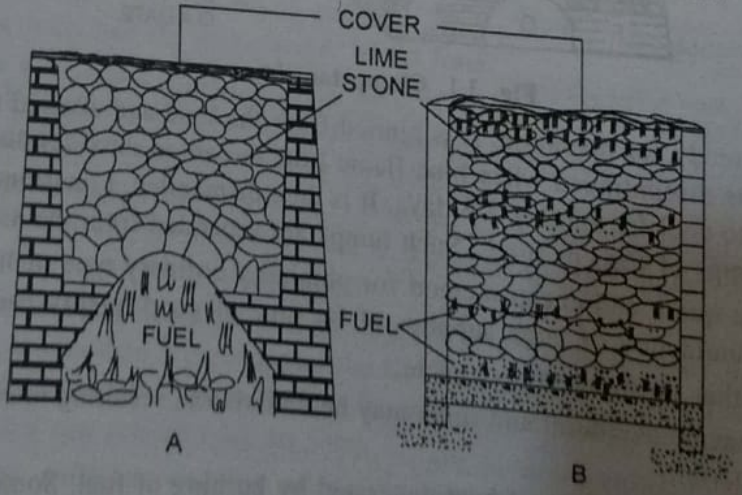


Fig. 3.2. Intermittent Kilns.

In the mixed-feed (or flame) kiln, loading of a batch of raw material is done in alternate layers. The lowermost and the uppermost layers are always of **fuel**. During loading process, openings (flues) in horizontal as well as vertical directions are formed so that combustion gases can move upwards easily and smoothly. (Fig 3.2A). The top layer of the fuel is covered with a thick layer of burnt material so as to form a cover for conserving heat.

After loading, kiln is ignited at the bottom layer. Fire travels upwards. It may take 3-4 days for the limestone to burn. Thereafter, the kiln is allowed to cool by itself. It is unloaded and cleaned, after which it is loaded with a fresh batch of limestone and fuel.

In the separate feed (Flare type) Intermittent Kiln, a few bigger limestone blocks are so arranged behind the gates as to form arches. Above these arches, limestone **broken into smaller pieces** is stacked loosely for allowing hot gases to freely circulate through them. For burning such a kiln, fuel is placed under the arches and ignited. In this way only heat travels upward, the fuel does not come in contact with the limestone. After the batch has been calcined, the kiln is allowed to cool. It is then unloaded, cleaned and reloaded with fresh batch of limestones. It is relatively convenient to manage.

(2) *Continuous Kilns*

The essential feature of a continuous lime kiln is that while it is charged regularly from one end with the raw material, the end product (lime) is taken out regularly from the **other end**. As such, there is no need to cool the kiln every time after burning a batch of limestone. Naturally, **its rate of production of lime** is considerably higher than the other type of kilns.

Continuous kilns are of various types such as shaft kilns, rotary kilns and circular kilns etc. Of these, the shaft kilns are most popular. These are made in different designs, shapes and sizes.

A shaft kiln may be either of mixed feed (flame type) or of separate feed (flare type) in design. In flame type kiln, fuel and limestone are **regularly charged** in alternative layers from above. The end product (lime) gets thoroughly mixed up with the ash from the fuel. In the flare type shaft kiln, fuel is burnt in separate compartments either within the shaft or outside but in such a way that it does not come in contact with the limestone. We describe below one typical design from each type of continuous kilns.

(A) *Mixed Feed (Flame Type) Continuous KILNS*

It may be constructed **partly underground** and partly over ground. The kiln consists of a shaft or a cylinder of suitable dimensions, the essential features of which are

(*i*) Diameter in the middle is the greatest;

(*ii*) Diameter at the top is **intermediate** and that at the bottom **is least**.

The variation in diameter serves accumulation of large amount of limestone in the central part, which is the hottest zone. Hence, it ensures complete calcination. The shaft (made of bricks or metal) is lined internally with **refractory bricks**.

Further, there is a grating plate at the base of the shaft, which is full of holes to allow the burnt lime pieces to fall down into the collecting chamber. The kiln is provided with a hopper type arrangement at the top for loading the charge and also draw-gates at the bottom for withdrawing the lime after it is cool enough. The body of the kiln is provided with opening in the lower regions for supply of fresh air. It is also provided with observation (peep) holes in the middle regions for keeping an eye on the reaction. Openings are also provided near the top of the shaft for leading the waste gases out of the kiln.

To begin with, the kiln is first loaded with calculated amounts of fuel and limestone in alternate layers. It is then ignited through burn holes. Fire is kept alive by supplying air from the basal zone. **Main calcination reaction takes place in the central burning zone of the kiln**. In the uppermost zone, the charge is mostly heated up. This helps in its quicker calcinations as it slides down. After some time, when limestone in the burning zone has been completely converted to lime, the latter slides down and falls into the collecting chamber through the holes in the grating. **Raking holes** are used to turn-about the charge during the burning ensuring complete calcination.

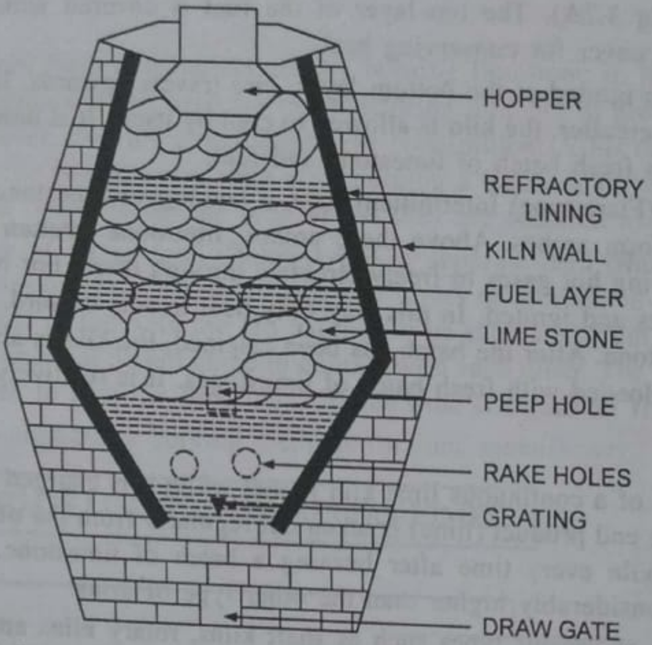


Fig. 3.3. Continuous Flame-type - Mixed Feed Kiln.

A calculated amount of fresh charge (limestone + coal) is then fed again through hoppers at the top.

Hot lime dropped in the basal zone is first cooled by introducing fresh air. It is then taken out for packing and distribution. The charging and emptying operations are continued in this manner in a regular sequence.

(B) *Separate Feed (Flare Type) Continuous Kilns.*

The design of a separate feed (flame type) continuous kiln is broadly similar to the mixed feed type. It consists of a shaft, made of steel or brick and lined internally with **refractory bricks** up to a certain height only. It has **bigger** diameter in the central region (the burning zone), an **intermediate** diameter in the basal zone and the small diameter at the upper **charging** end. Such a kiln is provided with **separate fuel chambers that** may be located within the main body or even outside the kiln. In the first case, these are placed as four or more box-type places around the periphery of the shaft where fuel is burnt to generate heat which is conducted into the kiln. In the second case, the fuel may be burnt in chambers outside the kiln and only hot gases are allowed to enter into it. In either case, **there is no contact between the fuel and the limestone**. The kiln is provided with peep holes for observation and with grating holes at the base.

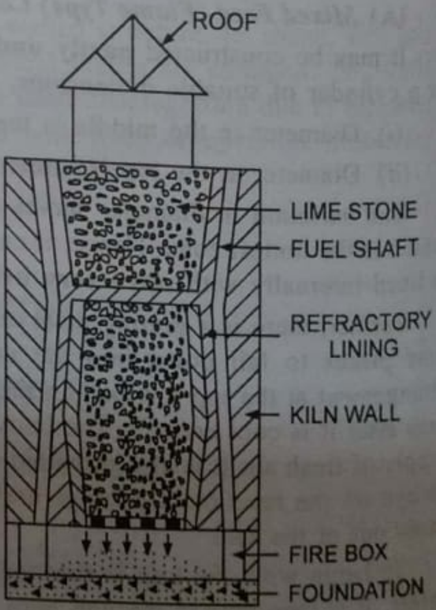


Fig. 3.4. Continuous Flare Type – Separate Feed Kiln.

The kiln is charged from above at regular intervals with calculated quantities of limestone. After a batch of limestone is completely calcined (which can be observed through the peep holes; it is **red hot** in that case) it is made to fall in the lower cooling zone through the grating with the help of raking rods. The hot lime is cooled by introducing fresh air in the basal chambers. This air becomes hot itself in the process and rises upwards into the burning zone of the kiln. There is, therefore, better utilization of heat in this kiln.

Rotary Kilns are also commonly used in advanced countries for the manufacture of lime. A typical rotary kiln for lime consists of a steel cylinder of suitable dimensions. It is placed in a slightly inclined position and rotates around its longer axis at 60-70 revolutions per hour. The kiln is charged from the **upper** end and **fired** form **the** lower end. **Hot lime** is taken out from near the lower end after regular intervals. It is first cooled, then crushed and then packed for supplying to the market.

3.4. MANUFACTURE OF HYDRAULIC LIME

As defined already, hydraulic lime has a clay content ranging from **10-30 percent**. For the manufacture of this type of lime, the process depends on the type of raw material available.

(A) **Natural Hydraulic Lime**. This is manufactured from a single raw material, an impure limestone rich in clay. Such a rock is called **kankar** and occurs in nature either in the form of blocks (block kankar) or making lower part of ground at many places. Kankar contains **10-40 percent** clay and 60-80 per cent calcium carbonate.

The raw material is first tested for its chemical composition. If the reserves are of suitable quality, they are extracted using hand tools (pick axe etc.) or by machines.

Calcination of kankar is done either in clamps or in kilns in a manner similar to that for fat lime. In the case of kankar, **temperatures are raised to higher degree** because of presence of enough of clay in it. The calcined kankar is then cooled and packed before it is marketed as natural Hydraulic lime.

(B) **Artificial Hydraulic Lime**. In this type of lime, two source materials are required :

(*i*) Limestone rock (*ii*) Clay

The limestone is of the same quality as used for the manufacture of fat lime: pure, free form impurities and available in abundance. The clay should not contain any free silica and other impurities like oxides of iron, sulphur and alkalies.

Calcination. There are two variations of calcination for the manufacture of artificial hydraulic limes depending on the quality of limestone.

(*i*) **When limestone is of SOFT type (e.g. chalk).** Such a stone is mixed with clay in the powdered form. Both are then burnt to red heat in any type of kiln. (Such a lime is not manufactured by burning in clamps.) The burnt mixture is slaked on cooling before marketing.

(*ii*) **When limestone is of HARD type (e.g. compact limestone).** It is first calcined alone in a kiln (similar to those used for calcination for Fat Lime). The quick lime so obtained is then cooled and powdered. It is mixed with predetermined quantities of clay (10-30 per cent by weight). The mixture is converted to ball shaped masses.

The balls are now similar to kankar in shape. These are once again charged into the kiln and burnt to a red heat. Obviously, the CaO is being fed into the kiln for the second time. It is for this reason that hydraulic lime obtained in this process is often referred as **Twice Kilned Lime**.

The hydraulic lime obtained as above is then commonly slaked before being packed for marketing.

3.5. PROPERTIES OF LIME

Following are the more important properties that determine the quality of lime as a structural material.

3.5.1. Physical State

Lime as obtained from kilns is generally in the shape of solid lumps. It is termed **lump lime** and is sold as such. Sometimes, however, lime is crushed and even screened through sieves to obtain a powder of required fineness. The latter is called **Pulverized lime.** Hydraulic lime is generally marketed as pulverized lime.

3.5.2. Slaking of Lime or Hydration

It is defined as the process of **chemical combination** of lime (CaO) with a definite quantity of water so that the resulting product is a hydrated oxide. The process is said to be completed when lime cannot absorb any more water. The new product, Calcium Hydroxide is formed as per following reaction:

$$\boxed{\underset{\text{Lime}}{CaO} + \underset{\text{Water}}{H_2O} = \underset{\text{Calcium hydroxide}}{Ca(OH)_2}}$$

The above reaction is attended by at least four processes :

(*i*) **Evolution** of a considerable quantity of heat which is of the order of 227 K-Cal/Kg. of lime

(*ii*) **Expansion** in volume to the extent of 2-3 times, and

(*iii*) **Development** of hissing and cracking sounds due to conversion of water into steam.

The rate of hydration differs with the type of lime. Fat limes hydrate quickly in 3-4 hours whereas hydraulic limes slake slowly taking 1-3 days. The **quantity of water** required for hydrating limes also differs with the type of lime. Theoretically, 100 Kg of pure lime requires only 32 liters of water. Practically, however, 100 liters of water may be required because considerable quantity is lost during the process of hydration.

Slaking of lime is of fundamental importance in the use of lime as a structural material. **All limes must** be slaked before use in **building construction.**

3.5.3. Methods

Fat lime is slaked by using any one of the following two methods :

- Tank slaking,
- Platform slaking.

(*a*) **Tank Slaking (Making Lime Putty).** In this method two brick lined tanks of suitable dimensions are constructed adjoining to each other and with a difference in level. The first tank is about 45 cm deep and is made at a height (Fig. 3.5) whereas the second tank is 60-75 deep and is made at a lower level. Any other material (steel or concrete) may also be used for making watertight tanks.

Water is filled in the upper tank to about 3/4th of its depth. Fat lime is then gradually added to it in small amounts at a time up to half of the depth of water. **Water is constantly stirred during the addition of lime**. The slaking reaction takes place in this tank, which can be observed by evolution of heat and hissing and cracking sound. This process takes 3-4 hours for complete hydration of the lime added to the first tank. The lime on reaction with excess water forms **milk of lime**. Screening tap called strainer (with openings of 0.25mm) of this tank is then opened and the hydrated lime in the form of milk of lime allowed to pass into the lower tank. It is allowed to stay in tank B for 2-3 days where it matures itself (gets concentrated) to the desired consistency. This is ready as **Lime Putty** and is taken out for use for making mortars and plasters.

Precautions :

(*i*) Only lime should be added to water and **not water to the lime.**

(*ii*) Keep water stirring and hoeing for sometime more even after the boiling and hissing sounds are over in the first tank.

(*iii*) Lime Putty should be taken out as soon as it becomes mature in tank B. It should not be allowed to stiffen and harden before use.

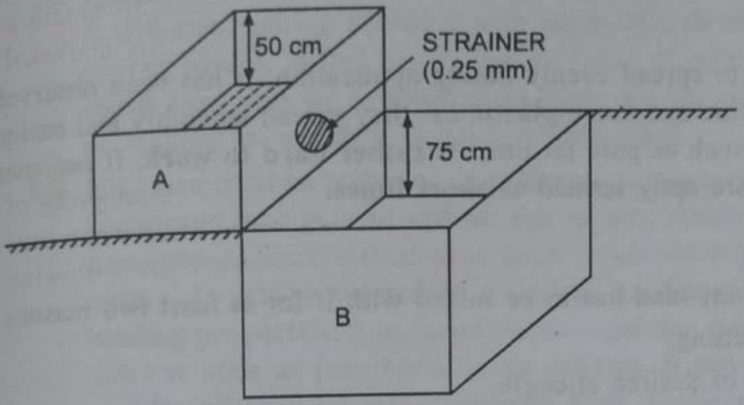


Fig. 3.5. Tank slaking.

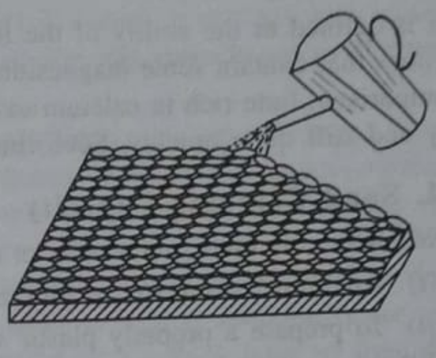


Fig. 3.6. Platform slaking.

(*b*) **Platform Slaking. (For powdered slaked lime).** In this method, a water-tight platform is built of masonry or cement-concrete. On this platform, fat lime is spread in the form of a thin layer of about 15 cm height. Small quantities of water are then sprayed over it **very cautiously** using a spray cane or a hosepipe. During the water-sprinkling process, the lime heap is turned over and over again using spades. When apparent slaking is complete (as indicated by absence of further hissing and cracking sounds), no further water is added. The heap is covered with boards so that any further heat liberated on slacking is used by the lime for its complete disintegration. It is left for itself for another 24 hours during which time slaking may be complete. After this time, lime which has by now turned to a powder form of **hydrated** lime is screened through 0.25 mesh sieve (IS: 320). It is ready for use for making mortars and plasters.

(*c*) **Slaking of Hydraulic Lime** is done by the following three methods :

(*i*) Platform Slaking.
(*ii*) Slaking under Pressure, and
(*iii*) Slaking by hydrators.

The basic difference in the slaking of Fat Lime and Hydraulic Lime lies in the fact that the latter is generally slow-slaking and requires less quantity of water. Heat evolved in its slaking is also much less compared to fat lime.

(*i*) **Platform Slaking.** A watertight platform is made similar to the one required for slaking of fat lime. The hydraulic lime, however, is first crushed and ground into fine powder that can pass through Sieve 240. Grinding is done by hand or by machines. The powdered hydraulic lime is then spread in the form of a thick layer on the platform and water is sprinkled over it using a hose can. The powder is turned over again and again during sprinkling of water. It is very important that only required quantity of water is sprinkled during slaking. Any extra water that does not combine chemically with hydraulic lime will help it to set and harden before it can be used.

(*ii*) **Slaking under Pressure.** This method is used in advanced countries for slaking of high magnesium limes. For this type of slaking, water is added to the lime under pressure in special machines.

(*iii*) In advanced countries, hydraulic lime is hydrated on a large scale in big plants, the hydrators, and from there it comes to the market in powdered form packed in bags in very much the same way as the Portland Cement. A typical Hydrator consists of a number of drums arranged one above another and each having a screw or paddle. Hydraulic lime, in the powdered form, is charged from above and made to come down through all the drums which contain water. The drums are kept rotating during this downward journey of lime which process keeps it in an agitated form. This ensures complete hydration of every particle of hydraulic lime before it comes out of the last drum. It is a sophisticated method requiring a complete control over the quantity of water required in each drum and also management of the heat resulting from hydration of the lime.

3.5.3. Plasticity

It is defined as the ability of the lime to spread evenly during application. It has been observed that limes that contain some magnesium oxide **are more plastic** *i.e.* they spread smoothly and easily. In comparison, lime rich in calcium oxide such as pure fat lime, is **rather hard to work**. It becomes sticky and stiff quite quickly. Such limes are aptly termed as **short limes**.

3.5.4. Sand Carrying Capacity

When lime is used in a mortar or plaster, sand has to be mixed with it for at least two reasons:

(*i*) To control shrinkage of lime on setting;

(*ii*) To prepare a properly plastic mix of desired strength.

All limes cannot mix with equal quantities of sand to give best results, This property defined as sand–carrying capacity is, therefore a basic quality of lime. Weight for weight, calcium-limes are found to have good sand-carrying capacity than magnesium-limes. They form more economical and strong mortars.

3.5.6. SETTING

The setting of **fat lime** in free state or in a mortar is essentially a chemical process which involves following two reactions:

(*a*) **Dehydration** or loss of water from the hydrated lime by evaporation.

$$\boxed{Ca\,(OH)_2 = CaO + H_2O\uparrow}$$

(*b*) **Carbonation** or combining of atmospheric carbon dioxide into lime, forming once again the origin material *i.e.* limestone.

$$\boxed{\underset{\text{Lime}}{CaO} + \underset{\text{Carbon dioxide}}{CO_2} = \underset{\text{Calcium carbonate (Limestone)}}{CaCO_3}}$$

The net result of setting of lime is that it is again converted into a **hard substance**, calcium carbonate. This carbonate acts as a binding material when used as a mortar and as a finishing surface when used as a plaster.

The **rate of setting** is different in different types of lime. Hydrated fat lime sets slowly compared to pure fat lime. The rate of setting of **hydrated lime** can be increased by drying the air and charging it with CO_2. But, as setting always involves a loss of water from hydrated lime, **shrinkage** takes place in the lime on setting. This effect has to be overcome by mixing some other material like sand or surkhi while preparing mortars.

The **setting of hydraulic lime** is rather a complex process. This is due to the fact that hydraulic lime contains, besides the oxides of calcium and magnesium, silicates and aluminates of calcium as well as some oxides of iron. During their setting, these compounds get further hydrated and form intricate crystalline structures. **It is for these reasons that hydraulic lime can set and harden under water also**. In this property they are more like Portland cement than Fat lime. The calcium hydroxide content of the hydraulic lime, however, gets converted to calcium carbonate in a fashion similar to that of fat lime. As such, setting of hydraulic lime is a process partly resembling setting of fat lime and party to that of Portland Cement.

3.6. HANDLING AND STORAGE OF LIME

Lime in its raw or unhydrated form requires **careful handling** to avoid accidents and losses.

(*i*) **Quick Lime** should be protected from water while handling for transport or during storage. It will start getting hydrated with the evolution of heat that can cause burn injuries of very serious nature. In fact, when lime stored in wooden **barrels comes in contact with water, so much heat may be evolved as to burn the barrels and also the store house or the trucks or wagons in which it is being transported.**

(*ii*) **Fat Lime** must be protected from direct contact with atmospheric moisture and carbon dioxide. Uncovered lime gets air-slaked, that is, gets slowly hydrated by absorbing moisture from the atmosphere. Such slaked–lime then combines with atmospheric carbon dioxide and starts setting. **It gets converted to a useless hard material which is left with very little or no binding properties.** It is, therefore, essential that quick lime is converted to lime putty (hydrated lime) as soon as possible after its delivery. It can be, however, stored temporarily for some time by piling it up into a compact heap which is covered with a thick layer of lime dust. This dust saves the **main heap** from the attack of moist air.

(*iii*) **Hydraulic Lime** is safer in transport and can be stored for longer periods as compared to fat lime. Even then it must be treated as a lime and not as a cement and same precautions taken while working with it.

Some of the precautions necessary to avoid burn injuries and accidents while working with lime may be summarized as follows :

(*a*) Workers handling lime must be asked to use goggles, respirators, rubber gloves and gum boots for protection of eyes, respiratory system, hands, and feet, respectively.

(*b*) Thorough bath in fresh water should be taken after working with lime. This will ensure that every **particle of lime** has been removed from the body.

(*c*) Any inflammable material should never be kept near a heap or bag of lime or where lime is being hydrated. This is important to avoid any accidental fires.

3.7. USES OF LIME

Lime is very useful material that finds extensive application in building construction, industry and agriculture. Its uses will be described under three headings.

(*a*) **As a material of construction**. As mentioned earlier, lime was used as main **binding material** in all types of construction till 19th century when Portland Cement was manufactured. Even now, lime can compete with Portland Cement quite satisfactorily in many types of construction. It is used:

- **as a mortar** (lime – mortar) mixed with sand or surkhi;
- **as a plaster** (lime-plaster similar to mortar but lean in composition);
- **as a whitewash**, when it gives sparking white finish at a very low cost;
- **as a lime-concrete**, which is similar to cement concrete and is made by mixing lime, sand and coarse aggregate in proper proportions.
- **as an important constituent** of **sand–lime bricks** which are quite popular in many countries.

(*b*) **As an Industrial material.** In Industry lime finds many applications, such as

- as a flux in the metallurgical industry;
- as a refractory material for lining metallurgical furnaces;
- as a raw material for the manufacture of glass;

(*c*) **An Agricultural input.** Lime is used for **improving** the productive qualities of soil. It is added to the poor soils to enrich their lime content. Lime has also been used for **soil stabilization.**

Table 3.2. Comparative study of fat lime and hydraulic lime

While selecting lime for use, following comparison in tabular form may be quite useful.

TABLE 3.2. Comparative Study Of Limes

Property	*Fat Lime*	*Hydraulic Lime*
COLOUR	It has white colour.	It is grayish white.
COMPOSITION	It is CaO when pure with subordinate amount of clay.	It is CaO with an **essential proportion** of clay ranging form 10-30 per cent.
SLAKING QUALITIES	(*i*) Slakes vigorously (*ii*) Enough heat is liberated that creates hissing and cracking sounds. (*iii*) Expands 2-3 times. (*iv*) Slaking completes in 3- 4 hours.	(*i*) Slakes gently. (*ii*) Not much heat is liberated; hence very little or no hissing sounds are produced. (*iii*) Expansion 1-2 times on slaking. (*iv*) Slaking is slow; takes 24-48 hours.
SETTING	Its setting involves absorption of carbon dioxide from atmosphere. The process is slow and resulting compound is calcium carbonate. It cannot **set under water**. As such it does not have the property of hydraulicity.	It has a double setting action. The CaO content may set as in fat lime. The clay content forms hydrated aluminates and silicates of calcium similar to cement on setting. **It can set under water**. As such it has the quality of hydraulicity.
STRENGTH	It is not very strong in mortars. Hence it may not be used where high strength binders are required.	It gives quite strong mortars that can be safely used in foundations and walls in place of Portland cement.
USES	If finds application for white-washing, for plastering and making mortars for common type of construction. It is also used as a flux, as a source of CaO in industry and for soil improvement	It is mostly used for making mortars in load bearing construction for both underground and over-ground superstructures

3.9. TESTS FOR LIME

Building lime is required to satisfy a number of tests before it is approved for use in constructio work. A building lime of good quality should confirm to specifications as laid down by Indian Burea of Standards: 712-1956/1973. Broad outline of these specifications is given in Table 3.3.

Following is brief account of the objects and methods of these tests :

1. Chemical Composition. Lime is tested for its chemical composition to determine ratio o different components such as CaO, Mg O, SiO_2,Al_2O_3 and iron oxides. The limits of differen components should be in accordance with the recommended values as given in Table 3.3.

2. Fineness. By fineness is understood the grain size of the finished product as determined by **sieve analysis**. The residue is weighed after the test and its weight expressed as percentage of lim sample taken for test. It is essential that the weight of the residue should not exceed the specifie limits.

3. Soundness. Soundness is defined as the **capacity of lime to resist expansion on setting**. This is tested with the help of Le Chatelier apparatus discussed under Portland Cement. The lime to be tested is mixed with predetermined proportion of sand and water. The paste so formed is filled in the mould of the apparatus. The distance between the indicator points is noted. After one hour, it is placed in a **steam boiler** where it is subjected to steam action for three hours. After this boiling action, the distance between the indicators is noted once again. The difference between the two readings gives a measure of the soundness of the lime under test. This must be within the prescribed limits.

4. Setting Time. It is define as the time that elapses between the preparing of lime paste of standard consistency and setting of the same paste after it has been filled in a standard mould (Vicat Mould) to a minimum specified depth. The initial and final setting time for lime are tested by Vicat Apparatus described under Portland Cement. The initial setting time is the time that has elapsed **from the gauging to the penetration** of the Vicat needle in the paste up to a specified depth : 35 mm (total depth: 40 mm) The final setting time is the time that has elapsed form the gauging to a time when Vicat needle can **no more penetrate the paste (because it is already set)** and makes only a mark on the surface.

5. Strength. The strength values (compressive and transverse strength) for lime are tested by preparing specimens from standard **sand–lime mortar**. For compressive strength, average of 12 specimens (each of the shape of a cube with side =5cm) is taken. The compressive strength is tested by a standard testing machine on specimens taken 14 days and 28 days after their preparation. For transverse strength, average of 6 specimens is taken. The tests are made on a standard transverse strength testing machine as described under Portland Cement. The setting time and strength tests are generally recommended for hydraulic limes only.

TABLE 3.3. Tests & Specification For Lime (After IS: 712-1973).

S.No.	*Properties & Tests*	*Class A*	*Class B*	*Class C*
1.	Chemical Composition			
	(*i*) Calcium and Magnesium Oxide %.	60-70	70	85
	(*ii*) Silica + Alumina + Iron Oxide – Minimum %	25	15	
	(*iii*) Maximum percent – age of insoluble matter in sodium carbonate solution.	5	5	5
	(*iv*) Cementation value to be calculated : $\frac{2\text{-}8SiO_2 + 1.1Al_2O_3 + 0.7Fe_2O_3}{CaO + 1.4MgO}$ - Should not be less than	0.6	0.3	
2.	**Fineness**			
	Residue % by weight on sieves nos.			
	(*i*) 240	Nil	Nil	
	(*ii*) 85	<5	<5	<5
	(*iii*) 30	<10	<10	<5
	(*iv*) 20			<20
3.	**Soundness**			
	As determined by Le Chatelier Apparatus (for Hydraulic Lime Only.) Expansion shall not exceed.	10 mm	10mm	

4.	**Setting Time** (for Hydraulic Lime only) Determined by Vicat Apparatus:			
	(*i*) Initial Setting time shall not be less than.	2 hours		
	(*ii*) Final Setting time shall not be more than.	**48 hours**		
5.	**Compressive Strength:** (for Hydraulic Lime only)			
	(*i*) Tested after 14 days shall NOT BE LESS THAN.	12.5 kg/cm^2		
	(*ii*) Tested after 28 days shall not be less than	28 kg/cm^2	17.5 kg/cm^2	
6.	**Transverse Strength :** (For hydraulic lime only) It is to be determined as *Modulus of Rupture* after 28 days, and shall not be less than	10.5 kg/cm^2	7.0 kg/cm^2	

TYPICAL QUESTIONS

A. ESSAY TYPE

1. (*a*) What is meant by **Fat Lime** and **Hydraulic Lime**?

(*b*) Give an account of various types of **Limes** as available in the market for construction purpose.

2. (*a*) How are **Limes** manufactured on a commercial scale?

(*b*) Describe, with the help of neat sketches, construction and working of a **Continuous Flare Type Lime Kiln**. How it differs from a flame type kiln ?

3. Compare and contrast the **Fat Lime** and **Hydraulic Lime** in all their aspects: manufacture, properties, and uses.

4. Discuss the following statement critically :

Limes, especially Hydraulic Limes, are as good as, if not better than, Portland Cement for ordinary type of Building Construction.

5. Write a brief essay on :

Limes, their properties, handling and uses.

6. Write short notes on :

(*i*) Slaking of lime

(*ii*) Double kilned Lime

(*iii*) Setting of Lime

(*iv*) Sand carrying capacity of Lime

(*v*) Intermittent kiln for lime manufacture.

B. OBJECTIVE TYPE

1. Pure Lime is made by:

(*i*) Crushing and grinding limestone into a fine powder;

(*ii*) Heating a mixture of limestone and clay in a kiln;

(*iii*) Burning limestone into a clamp or a kiln;

(*iv*) By none of the above methods

2. Fat Lime is

(*i*) the name given to a variety of lime that is quite bulky in size;

(*ii*) that variety of lime to which some fat is added while making mortar

(*iii*) a type of lime that contains more than 93 per cent of calcium oxide in its composition;

(*iv*) none of the above

3. Hydraulic Lime is

(*i*) the paste of lime with water

(*ii*) the lime powder to which water of hydration has been added in the factory:

(*iii*) a type of lime that contains a definite proportion of clay in addition to CaO in its composition;

(*iv*) none of the above

4. Hydrated Lime is

(*i*) the lime to which only required amount of water for hydration has been added;

(*ii*) a type of lime that has enough water so that it is in the form of a liquid;

(*iii*) only made from hydraulic lime by adding water into it;

(*iv*) None of the above.

5. Slaking of lime is

(*i*) an endothermic reaction, that is, we have to heat the lime and water;

(*ii*) an exothermic reaction, that is, heat is actually liberated when water is added to lime.

(*iii*) a reaction requiring some heat to start it and then it liberates heat;

(*iv*) none of the above.

6. A Flame type lime kiln is that kiln in which

(*i*) the fuel forms a part of the charge;

(*ii*) the fuel is burnt separately in fire boxes,

(*iii*) air is supplied to burn the fuel mixed with the charge;

(*iv*) None of the above.

7. Lime should not be transported along with other inflammable materials because:

(*i*) It is also inflammable, that is, it can catch fire;

(*ii*) It can absorb moisture and explode;

(*iii*) It will absorb moisture and get hydrated and liberate heat which can cause ignition of the inflammable material;

(*iv*) It is an explosive material.

8. FAT LIME should not be left exposed to the atmosphere because :

(*i*) It will mix with carbon dioxide and get converted to limestone;

(*ii*) It is an explosive material;

(*iii*) It will pollute the atmosphere;

(*iv*) It will be blown away by the wind.

ANSWERS: 1. (*iii*) **2.** (*iii*) **3.** (*iii*) **4.** (*i*) **5.** (*ii*) **6.** (*i*) **7.** (*iii*) **8.** (*i*).

RELEVANT ISI CODES ON LIMES

1.	Building limes Physical and chemical requirements.	: IS: 712-1973
2.	Methods of Sampling and Tests for Quick lime and hydrated lime.	: IS: 1514-1959/1978

3. Quick lime and Hydrated lime for chemical industry : IS:1540-Pt. I 1967
4. Methods of Field Testing of Building Lime. : IS: 1624-1974
5. Code of Practice for Field slaking of building lime and preparation of putty. : IS: 1635-1975
6. Guide for design and installation of vertical mixed feed kiln. : IS: 1849-Pt, I 1976
7. Guide for manufacture of lime in vertical mixed feed type kilns : IS: 1861-PtI 1975 : Pt. II 1977
8. Agricultural liming material : IS: 5409 -1969
9. Glossary of terms relating to Building : IS: 6508-1972
10. Methods of test for building limes. : IS 6932-1973

[**Note:** Most of these codes stand reaffirmed from 1995 to 1998.]

❑❑❑

4

Portland Cement

4.1. INTRODUCTION

Lime was the binding material used in building construction till the second quarter of 19th century. It was in 1824 that **Joseph Aspidin**, a bricklayer of Leeds, invented a new cementing material by burning together **fixed proportions** of limestone and clay at very high temperatures and reducing the burnt product to a very fine powder. He obtained a patent for the manufacture of this new product under the name of Portland Cement. The name was so chosen because on setting and hardening a mortar of this cement with sand resembled in looks with the famous limestone rock of Portland in England. The original formulation and method has since been considerably modified. The cement is now manufactured almost in all the major countries of the world. It has acquired a **global acceptance** being ranked next to iron and steel only. It is manufactured in about 40 varieties.

Definition. The name Ordinary Portland Cement (OPC) is reserved for a cement which is: **an extremely finely ground product obtained by burning together at high temperature specifically proportioned amounts of calcareous and argillaceous raw materials, adding nothing else to the burnt product except gypsum in small percentage.**

4.2. INGREDIIENTS OF PORTLAND CEMENT

4.2.1. General

It is clear from the above definition that the basic ingredients of ordinary Portland Cement are: **Calcareous**, which means calcium carbonate and **argillaceous** which means clay. All such cements contain minor proportions of alumina, iron oxide, magnesium oxide and calcium sulphate. The usual limits of these ingredients are as follows :

TABLE 4.1. Composition of Portland Cement.

S.NO	*Ingredient*	*Limits %*	*Average %*
1.	Lime (CaO)	60-66	62
2.	SILICA (SiO_2)	18-25	22
3.	ALUMINA (Al_2O_3)	03-08	05
4.	IRON OXIDE (Fe_2O_3)	01-05	03
5.	MAGNESIA (Mg O)	01-04	02
6.	CALCIUM SULPHATE ($CaSO_4$)	03-05	04
7.	SULPHAR	01-02	01
8.	ALKALIES	01-02	1.0
		TOTAL	100

4.2.2. Functions of Ingredients

The above ingredients impart certain definite properties to the end product - the cement. These are briefly discussed below :

Lime (CaO). This is the major constituent of cement. It must be kept within the permissible range. The calcium oxide of cement *combines with* silica from clay and forms the **tricalcium and dicalcium silicates** on burning which are mainly responsible for the setting and hardening properties of cement. When present in **excessive** proportions, lime makes the cement **unsound**. It expands too much on setting. This leads to disintegration of the cement. Similarly, when present in **smaller** amounts than the desired limits, the cement is poor in strength and sets quickly.

Silica (SiO_2). It is second most important constituents and is responsible for the strength of the cement. **Excessive** quantities of silica in the burning process will result in a cement that will be **stronger** but take **much time to set** and harden. The source of silica in the cement is clay which is hydrous aluminum silicate.

Alumina (Al_2O_3). It combines with other constituent to form **aluminates** that are responsible for quick setting of the cement. It also plays a positive role in the burning process by acting as **a flux**, that is, in lowering down the temperature at which different ingredients react to form clinker. When present **in excess**, alumina will render the cement **highly quick setting**. Moreover, such cement will be poor in strength. In lower proportions, the setting qualities of cement will be affected.

Iron Oxide (Fe_2O_3). It is responsible for the colour of the cement to some extent. Moreover, it forms compounds with other ingredients that give additional strength and hardness to the cement.

Calcium Sulphate ($CaSO_4$). It is added to the cement after the burning stage in the form of rock gypsum ($CaSO_4$, $2H_2O$). It acts as a **retarder**, that is, it prolongs the initial setting time of cement. In the absence of gypsum, the cement will be very quick setting: it will set within a few minutes after mixing with water. Such a cement will become very difficult to work within common construction where some minimum time is required to take the cement mortar from place of preparation to place of use.

Magnesia (MgO). When present in small proportions, magnesia is useful in imparting colour and hardness. In higher amounts, however, magnesia introduces undesirable qualities such as delayed setting and expansion resulting in cracking of the set cement. **Sulphur** and **alkalies** are considered impurities in cement and their content must not increase beyond the permissible limits. Alkalies may cause such effects as efflorescence in the cement work. When used in the making of concrete, the **alkalies** react with the aggregate (the alkali-aggregate reaction) which affects the quality of concrete adversely. Absence of these ingredients from the cement will not lower the quality of cement in any way.

The above mentioned ingredients of cement undergo complex reactions during the burning stage in the manufacturing process. The burnt product, as it comes out of the cement kilns is called **CLINKER**. Various compounds identified in this clinker and their functions are of basic importance in determining the quality of the **Portland Cement.**

(*i*) **Tricalcium Silicate.** (designated as C_3S, C for calcium and S for silicate; also written as $3CaO, SiO_2$): It is the main compound present in all types of Portland Cement. Its proportion ranges from 45 to 65 per cent. This compound imparts following three properties to the cement on setting.

- A **very good** binding quality;
- **medium** rate of reaction; and
- **medium** amount of heat liberation during the setting reaction.

The strength of the cement in **first 28 days** after laying is due mostly to this compound.

(*ii*) **Dicalcium Silicate** (designated as C_2S, also written as $2CaO.SiO_2$). It is the next main compound after tricalcium silicate and forms 25 to 35 per cent. Its main character is its *slow* rate of hydration reaction. This leads to slow *hardening* of the cement on setting. Whereas all the tricalcium silicate may set within first 28 days, this compound may begin hardening only after that time. **It may continue hardening for many weeks and months after the cement is laid.** It is therefore, a desirable compound in slow-hardening cement required for hydraulic structures. But when a rapid-hardening cement is required its content is kept to the lower side by adjusting the ratio of ingredients.

(*iii*) **Tricalcium Aluminate** (C_3AL: Al for aluminum; also written as $3CaO. Al_2O_3$). It is *third* major compound found in cements. Its proportion ranges from 5 to 15 percent, an average being 10 per cent in the ordinary cement. Tricalcium Aluminate is typically *fast reacting* with a lot of heat *evolution* during the reaction. It is therefore an important compound of all types of *rapid hardening* cements. In ordinary cement, with normal hardening time of 28 days, its content, however, has to be maintained around 10 percent. This is because evolution of too much heat during the reaction is an undesirable property in most types of construction.

(*iv*) **Tetra-Calcium-Alumino-Ferrite** (C_4ALFe: C for Calcium, Al for Aluminum and Fe for Ferrite; also written as: $4CaO.Al_2O_3.Fe_2O_3$): It is the *fourth* compound formed due to mutual reactions of ingredients during heating of the raw materials in the kilns. It is present from 8 to 18 per cent, but an average of 10 per cent is quite usual in ordinary Portland Cement. It is least important of the compounds of Portland Cements as it has poor cementing value and a **slow rate of reaction** during setting.

Table 4.2. Compounds in Clinker.

S.No	*Compound*	*Abbreviation*	*Range%*	*Average%*	*Typical characters*
1.	Tricalcium Silicate ($3CaO.SiO_2$)	C_3S	45-65	48	Medium reacting; Medium heat evolution; early strength
2.	Dicalcium Silicate	C_2S	20-35	25	Slow reacting; Slow hardening; gives trength after 28 days
3.	Tricalcium Aluminate ($3CaO. Al_2 O_3$)	C_3Al	5-15	10	Fast reacting; High heat evolution; Early hardening.
4.	Tetra-calcium Alumino-ferrite ($4CaO.Al_2O_3.Fe_2O_3$)	C_4AlFe	8-18	10	Slow reaction; least heat evolution; poor binding properties.

The percentage of above compounds can be adjusted by varying the proportions of basic ingredients mentioned under 4.2.1 above. Accordingly, the type of cement will differ in its qualities depending upon the final composition.

4.3. MANUFACTURE OF CEMENT

This can be discussed conveniently under two headings: Selection of Raw Materials and Manufacturing Methods.

A. Raw Materials

Most important raw materials required in the manufacture of Portland Cement are: *Limestone, Clay, Gypsum, Fuel and Water* (in wet process).

(1) **Limestones.** These are sedimentary rocks, made up of calcium carbonate ($CaCO_3$). Most commonly they contain small amount of magnesium carbonate also. The usual impurities in limestones are those of iron oxides, silica and alkalies. All *limestones, therefore,* are not suitable for manufacture of Portland Cement. It is essential that limestone selected for manufacture of cement **should not contain:**

(*i*) Magnesium Carbonate ... more than 5 per cent;
(*ii*) Free Silica ... even in small proportion;
(*iii*) Iron Sulphates ... more than 3 per cent.

(2) Clay Rocks. These are also sedimentary rocks made up mostly of hydrated silicates of Aluminum. Like limestones, they also contain some impurities as iron oxides, free silica, alkalies and magnesia. It is essential that clays which are to be used for manufacture of cement **do not contain these impurities** beyond the permissible limits.

Some limestones are rich in clayey matter to the extent of 30 per cent. They are called **cement rocks** because they can be used as a **single raw material** for the manufacture of cement.

(3) Gypsum. It is generally added in very small amount (2% by weight) to the burnt cement (called klinker) **after it is taken out from the kiln and before it is sent for grinding.** Gypsum is a sedimentary rock having a composition of calcium sulphate ($CaSO_4 2H_2O$). It is added for imparting a retarding effect in setting of cement. It is known that without gypsum, the cement would set **within minutes** after adding water into it. It will be, therefore, very difficult to work with such a cement. Addition of gypsum at the manufacture time, however, increases the initial setting time to desirable limits.

B. Methods of Manufacture

At present Portland Cement is manufactured by two processes: Dry Process and Wet Process. The main difference between two processes is that in the dry process, calcareous and argillaceous raw materials are fed into the burning kilns **in a perfectly dry state.** In the wet process, however, these materials are supplied to the kiln in the form **of an intimate mixture with water** called **SLURRY.**

4.3.1. Dry Process

Following are main steps in this process of manufacture :

1. Treatment of Raw Materials.
2. Burning of Dry Mix.
3. Grinding of the Clinker.
4. Packaging and Storage.

(1) Treatment of Raw Materials. The raw materials – limestone and clay, are subjected to such processes as crushing, drying, grinding, proportioning and blending or mixing before they are fed to the kilns for calcination or burning.

The crushing stage involves breaking the raw materials to small fragments that vary in size between 6-14 mm. Machines called **crushers** are used for this purpose.

The drying stage is typical of the Dry Process. Drying of crushed materials is essential and is achieved by heating these materials (separately) at temperatures sufficiently high to drive out uncombined water. Heating is done in drying kilns which are generally of rotary type.

The grinding of each material as obtained from the driers is done in two stages.

First, the **preliminary grinding** in which the materials are reduced to a fineness of 50 mesh. Ball Mills are generally used for preliminary grinding.

Second, the fine grinding **in which the size of the materials is reduced to 200 mesh. This is done by grinding in Tube Mills.**

Each raw material is thus reduced to a required degree of fineness and is stored separately in suitable storage tanks called **SILOS** or bins wherefrom it can be drawn out conveniently in requisite quantities.

Proportioning and Blending. Predetermined proportions of finely dried and ground raw materials are mixed together before they are fed into kiln. The different materials thus combined together are **mixed very thoroughly** either by mechanical or by pneumatic methods.

In the **mechanical blending** materials from different storage silos are **simultaneously drawn off** and fed into a single SILO that now contains mixed materials.

In the **pneumatic method**, dry, proportioned materials are **pumped under pressure** into a **blending silo**, wherefrom they are drawn in the mixed state. The blended materials are now ready for feeding into the burning kilns. From this stage onwards, there is practically no major difference between the dry and the wet processes, except in the design of the rotary kiln.

(2) **Burning or Calcination.** The well-proportioned finely powdered mixture is charged into a long steel cylinder, called the **Rotary Kiln**. The kiln is adjusted in an inclined position, making an angle of 15" with the horizontal and rotates around its longer axis (hence the name). It has a **charge end** and a **burner end**, the former for introducing the materials (called feed) and the latter for supplying fuel

Rotary kilns differ in design and dimensions in accordance with the production requirements. Thus, these may be 100-180 m in length, 3-5 m in diameter and have rotation of 60-90 revolutions per hour (Fig. 4.1)

Coal in finely pulverized form, fuel oil and gas are common fuels used in these kilns.

The raw mixture is burnt in the kiln till the proper burning is achieved. This is indicated by its taking a greenish black colour and vitreous (shining like glass) lustre. This burnt material, now called **CLINKER** is **cement in composition but not in size**: it is in about walnut-sized lumps when it comes out of the kiln.

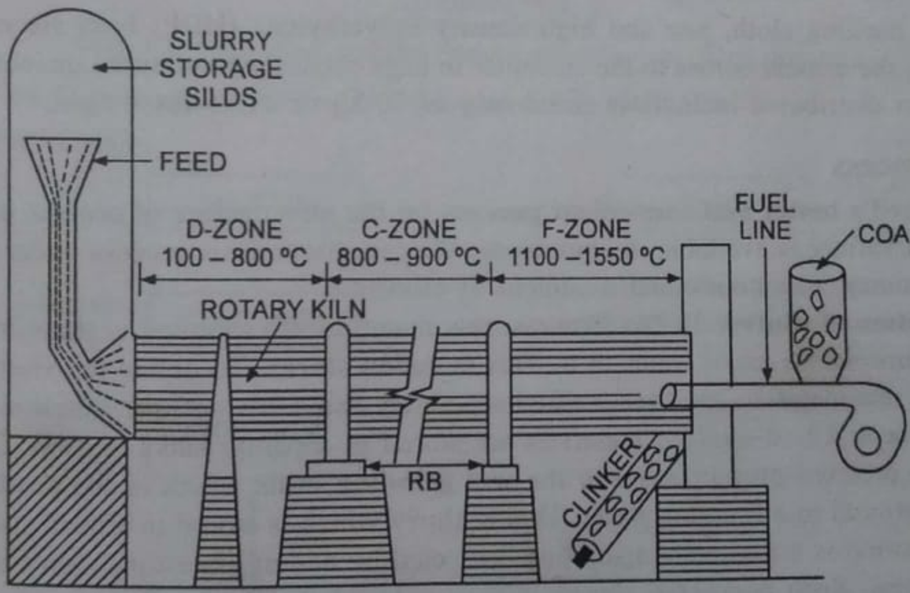


Fig. 4.1. Rotary Kiln.

At least following three reactions are believed to take place in the charge during the burning stage:

(*i*) **Complete dehydration.** Water is completely driven off at the very initial stage of burning at temperatures as low as 400^0C.

(*ii*) **Dissociation of carbonates.** Carbonates of calcium and magnesium are completely dissociated at temperatures between 800^0-900^0C, as per following reactions:

$$\boxed{\begin{aligned} CaCO_3 &= CaO + CO_2 \\ MgCO_3 &= MgO + CO_2 \end{aligned}}$$

(*iii*) **Compound formation.** Lime and magnesia as formed above are combined in the next stage with silica, alumina and ferric oxide to form the basic compounds of cement, namely, the tricalcium and dicalcium silicates, tricalcium aluminates and tetra calcium alumino ferrite. These compound formation reactions start at temperatures around 1200^{0}C and require temperature as high as 1550^{0}C for their completion. It is therefore, natural that they take place near the burner end of the rotary kiln. Alkalies, moisture and other harmful gases etc. are all expelled as water vapours during the burning of the raw materials of the kiln. (Fig. 4.1)

(3) Grinding of the Clinker. The completely burnt or calcined raw materials of cement are obtained in **lump-shaped** product, called **clinker** which is drawn out from the lower end of the rotary kiln. It is extremely hot when discharged from the kiln and is, therefore, first cooled in **clinker coolers**. A predetermined batch of gypsum ($CaSO_4 . 2H_2O$) is added to the cooled clinker and both (clinker and gypsum) are sent for **pulverizing**.

In the pulverisers the mixture is reduced to an **extremely fine powder** by grinding it in two stages: the **preliminary grinding** and the **fine grinding**. The preliminary grinding is achieved by using **gyratory type of crushers** whereas for fine grinding tube mills are used. The tube–mills are provided with **air separators** through which material of desired fineness can only pass. The coarser portion of the cement is fed back into the mill for further grinding.

(4) Packing and Storage of Cement. This also forms a very important operational step since cement needs very careful packing and storage arrangements. It is, in fact, a delicate product and when handled carelessly can deteriorate to a useless stone like set material. Cement is most commonly stored after its manufacture in specially designed concrete storage tanks called SILOS, wherefrom it is drawn off for the market in bags.

For cement packing cloth, jute and high density Polyethylene (HDP) bags are commonly used. For convenience, the cement comes to the customer in bags containing measured quantity. The standard bag of cement as distributed in India is commonly of 50 kg or 112.5 lbs weight.

4.3.2. Wet Process

It is considered a **better and convenient process** for the manufacture of cement, especially where limestone of soft variety is available in abundance. We can discuss this process under three headings: preparations of slurry; calcination and treatment of clinker.

(*a*) **Preparation of Slurry.** In Wet Process, raw materials are supplied to the kiln in the form of an intimate mixture with a lot of water in it. This is **called slurry**. To obtain the slurry of a standard composition, the raw materials are first crushed separately using crushers for limestones and grinding mills (wet) for clays. These crushed materials are stored in separate tanks or **silos**. They are drawn from the silos in prefixed proportions into the **wet grinding mills** where in the presence of a lot of water, these get ground to a fine thin paste. This is slurry which is stored in a third silo, the SLURRY SILO. Its composition is tested once again and corrected by adding limestone slurry or clay slurry in required proportions. Such **corrected slurry** is then fed into the Rotary Kiln.

(*b*) **Burning.** For burning of the slurry, a rotary kiln of almost similar type is used as described under dry process. In this kiln, however the length of drying zone is larger, because the material is fed into the kiln with abundant water. All the moisture is driven off from the slurry as it passes through the drying zone. In the subsequent zones it undergoes same transformation as mentioned under DRY PROCESS. **There is practically no difference**.

(*c*) **Grinding of Clinker.** As the lump-shaped clinker comes out form the kiln, it is extremely hot. It is, therefore, passed through air-cooling rotary cylinders. Thereafter, it is mixed with 3-4 per cent of gypsum and ground to a very fine powder as in the **dry process**. The fine cement so obtained is stored and packed in a way similar to that used in Dry Process (refer to article 4.3).

4.3.3. Flow Diagrams

A **flow diagram** is a schematic arrangement of various operations that take place in a manufacturing process. It gives a clear idea about the right place of any particular operation in the full sequence of the process. Following are the flow diagrams for the two different processes of Cement Manufacture.

A. DRY PROCESS

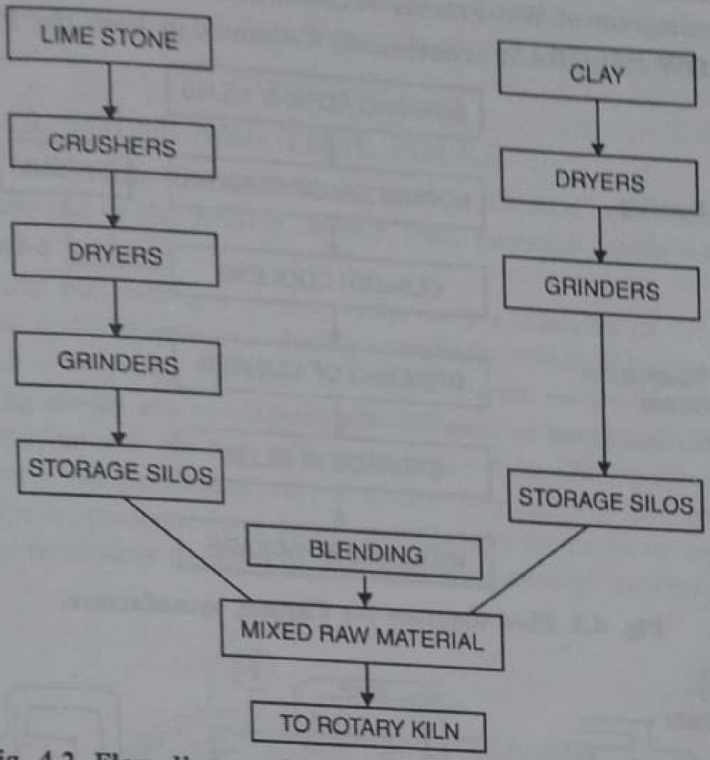
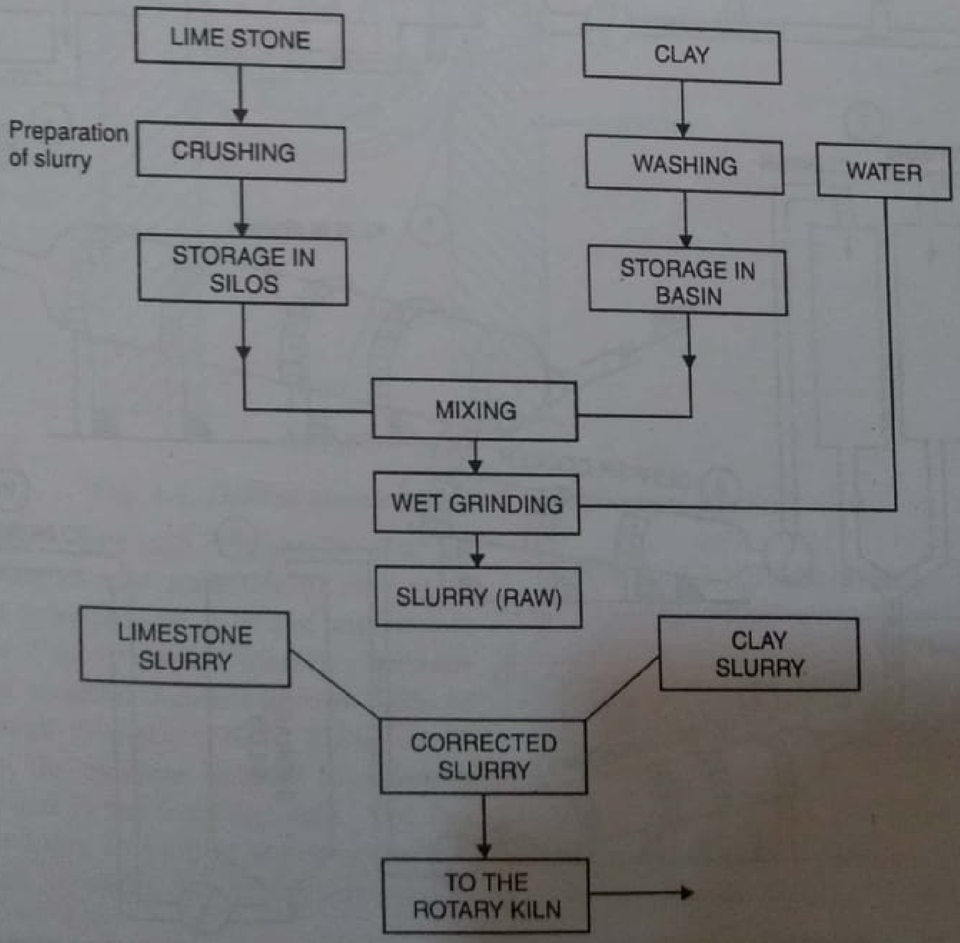


Fig. 4.2. Flow diagram for cement manufacture (Dry process).

Hereafter, the flow diagram is exactly similar to WET PROCES.

B. WET PROCESS



Hereafter the flow diagram of Wet Process is common with that of DRY PROCESS.

FLOW DIAGRAM (continued) Common in both the Processes

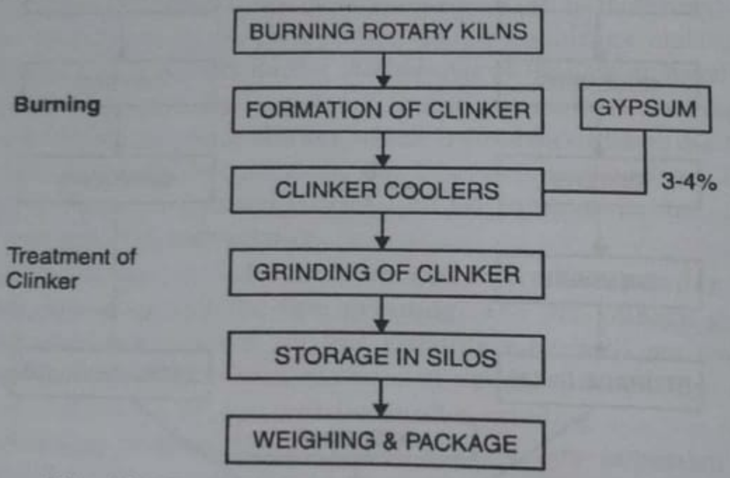


Fig. 4.3. Flow diagram for Cement manufacture.

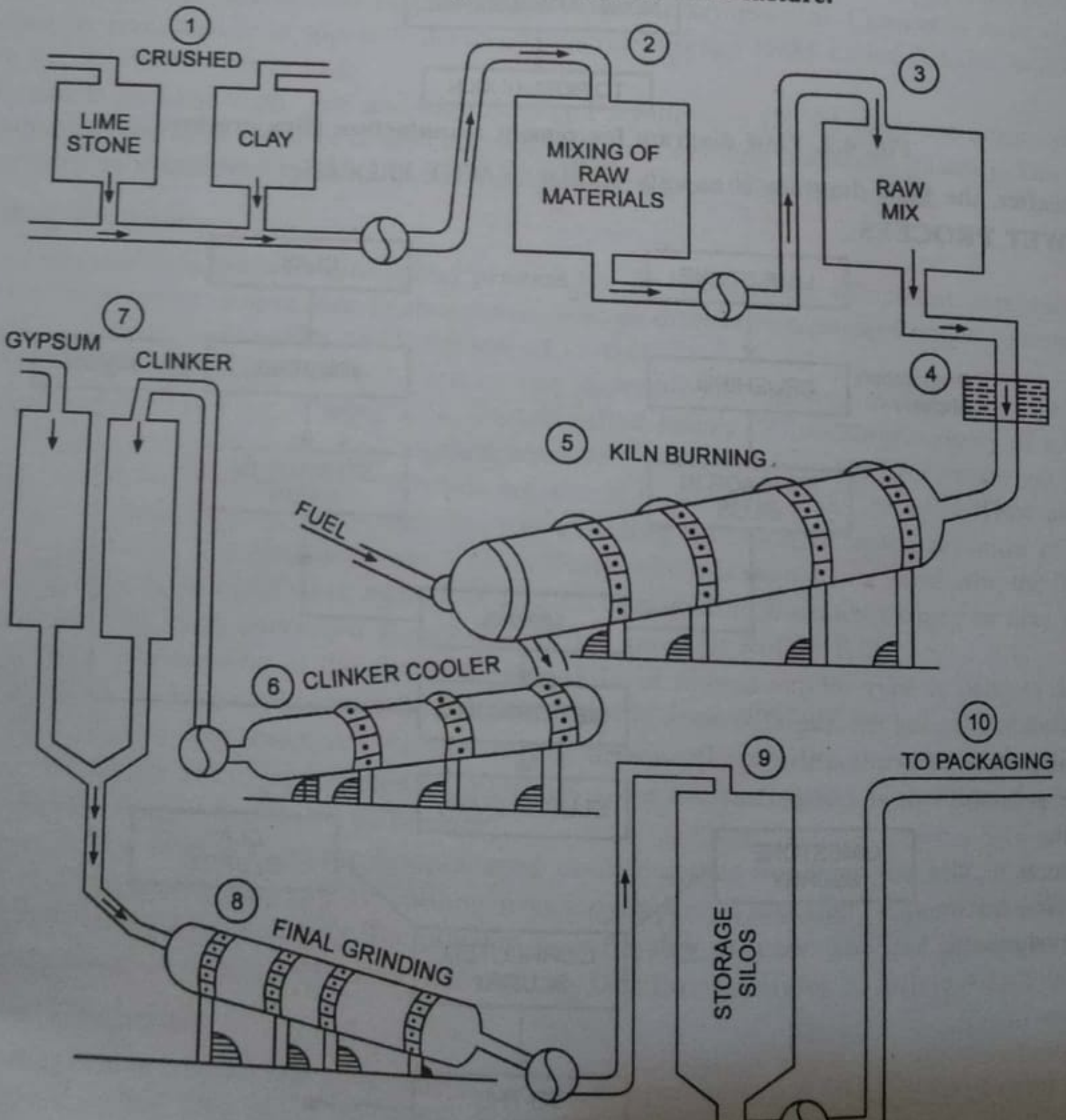


Fig. 4.4. Flow diagram (highly simplified-diagrammatic) for manufacture of portland cement.

As is evident from the flow diagram, main difference between the two processes is in the Treatment of the Raw Materials. As said earlier, the Wet Process is preferred to the Dry Process as it is

(*i*) easy to monitor; (*ii*) economical in cost.

4.4. NOTES ON BALL MILLS AND TUBE MILLS

The balls mills and tube mills are extensively used in Cement manufacturing plants both for grinding for raw materials and of the Klinker. Hence, their essential details will not be out of place here.

1. **Ball Mill.** A typical ball mill is a steel cylinder with a diameter of 2-2.5m and length of 1.8 to 2.0 m. It rotates around its horizontal axis during operations. Inside, it has curved, perforated plates fixed to its body in such a way that the ends of plates overlap each other. It is called a ball mill because in it, the **grinding media are small balls (50-120mm) of hardened steel**. The material is fed into the ball mill from the top and the ball mill is made to rotate. During this motion, the steel balls strike again and again with the perforated curved plates. Any material that comes in between them gets crushed and ground to a powdered form that passes through the perforations. The crushed material is collected after it passes from sieve plates. The ball mills are generally used for **preliminary grinding**.

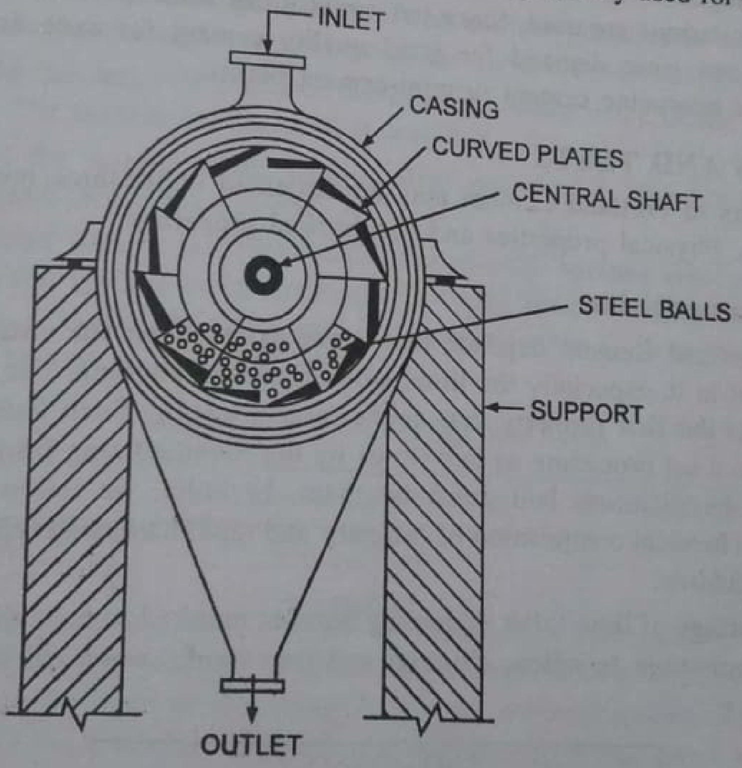


Fig. 4.5. Outline sketch of a Ball Mill (Vertical Section).

2. **Tube Mill.** A tube mill is generally used for **very fine grinding** of raw materials or clinker. A typical tube mill is cylindrical in shape with length varying between 7 to 10 m and diameter between 1-1.5 m. It also contains hardened **steel balls** of comparatively small diameter : 20 to 25mm. In its operational form the cylinder is fixed horizontally and the raw material is fed from one side. The fine material produced due to girding action of balls is separated through an outlet on the opposite end of the tube mill. (Fig. 4.6)

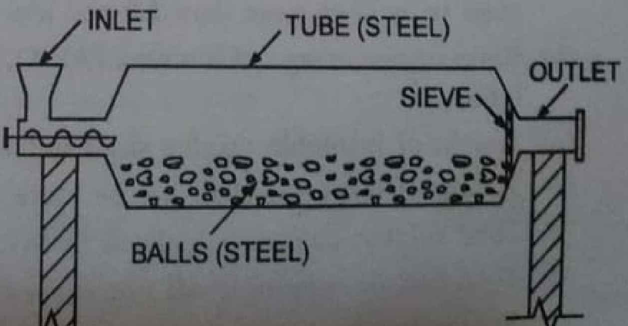


Fig. 4.6. Outline sketch of a Tube Mill (long section).

It may be noted here that size of the powdered material depends to a great extent on the **size of the grinding balls** – the smaller the balls, the finer the size. In some mills, both coarse grinding and fine grinding are achieved in the same machines: the first compartment has bigger and the next compartment has finer balls. These are called **multiple chamber mills**, or compartment mills.

4.5. A NOTE ON MINI CEMENT PLANTS

A mini cement plant is essentially a small –capacity plant in which small tonnage (generally 1000 tons per month) of cement is produced using **DRY PROCESS.** Two basic objectives of a mini-cement plant are :

(*a*) utilization of small deposits of good quality resource materials, limestones and clay, occurring locally.

(*b*) production of cement in many parts of the country ensuring its supply at economical cost even in remote areas.

At present, the concept of mini cement plants has few enthusiastic supporters. In a typical mini-cement plant, the kiln is of a vertical–shaft type or even of a rotary inclined type. Only Dry Process is applied as it is thought to be more economical. Jaw crushers, ball mills, tube mills and rotary coolers of suitable dimensions are used. Since our country has wide spread deposits of limestones in almost all the states and since demand for good quality cement far exceeds the supply, there is considerable scope for producing cement in mini-cement plants.

4.6. PROPERTIES AND TESTS

Properties and tests of Portland Cement may be discussed under three broad headings, namely, Chemical composition, Physical properties and Mechanical properties.

4.6.1. Chemical Composition

The quality of Portland Cement depends to a great extent upon **the ratio** in which the major components are present in it, especially the lime, silica, iron and alumina. The chemical composition of cement, therefore, is the first property that needs careful testing. Such tests should be invariably performed according to a set procedure as laid down by the Standardizing Institutions and the results must conform to the specifications laid down by them. In India, we follow the IS specifications (ISS:269-1973) for the chemical composition of ordinary and rapid hardening types of Portland Cement. According to these standards:

(*a*) Ratio of **percentage of lime** (after deducting amount required to neutralize sulphuric anhydride present) to **percentage to silica**, alumina and iron oxide, when calculated according to the formula :

$$\boxed{\frac{CaO - 0.7SO_3}{2.8SiO_2 + 1.2Al_2O_3 + 0.65Fe_2O_3}}$$

shall be neither more than **1.0** nor less than **0.66**

(*b*) Ratio of percentage of alumina (AL_2O_3) to that of Iron Oxide (Fe_2O_3) shall not be less than 0.66.

(*c*) Weight of insoluble residue **shall not exceed** 1.5%.

(*d*) Weight of magnesia shall not be more than 5%.

(*e*) Total sulphur content calculated as SO_3 shall not be more than 2.75%.

(*f*) Total loss on ignition **shall not exceed** 4%.

For the **low heat cement**, however, it is specified that the percentage of lime to be calculated after deducting the amount required to neutralize the sulphuric anhydride present shall not be more than:

$$\boxed{2.4\,SiO_2 \quad + \quad 1.2\,Al_2O_3 \quad + \quad 0.65Fe_2O_3}$$

and also, shall not be less than:

$$\boxed{1.9SiO_2 \quad + \quad 1.23Al_2O_3 \quad + \quad 0.65Fe_2O_3}$$

4.6.2. Physical Properties

Included under this heading are colour, fineness and soundness. Setting of cement, although a chemical phenomenon, is also discussed under this heading as cement on setting results into a physical mass with definite characters.

(1) Fineness. This is the next most important property of cement after chemical composition that determines, to a great extent, the **quality of the cement. Generally speaking, the finer the cement in grain size, the better is its quality**. It is for this reason that in cement industry there is a consistent effort towards finding methods for obtaining the **finest grain size** in grinding the Klinker. It is believed that in finer grain size, the cement particles react with water more quickly and thus reduce the time for hardening thereby producing a cement of **high early strength**. However, it is also established that very fine size does not improve the ultimate strength of the cement in any way.

Quantitatively, Fineness defines grain size of the cement particles of which large proportion must be fine enough to pass through specified tests: the sieve test and the specified surface test.

The Sieve Test. In this test 100 grams of the cement specimen are sieved on IS Test Sieve NO. 9 for fifteen minutes. The residue on the sieve is weighed.

It is required that the weight of the residue shall not exceed 10% for the ordinary Portland Cement, and 5% for rapid hardening cement.

The Specific Surface Test. It involves finding the **specific surface area** of the cement particles by either Air Permeability method or by Wegner's Turbidity meter Method- in accordance with ISS 269-1973. It is obvious the **area per gram will be greater** for the finer particles. It is specified that recommended surface area shall be as follows :

TABLE 4.3. Specific Surface Area.

Cement Type	*Air Permeability Method*	*Turbidity meter Method*
1. Ordinary	2250 cm^2/gm	1600 cm^2/gm
2. Rapid hardening	3250 cm^2/gm	1700 cm^2/gm

(2) Soundness. All cements **expand to some extent on setting**. This expansion is sometimes responsible for cracking of cement after setting. This is an unsound quality. By soundness of cement is, therefore, understood its **capacity to form a non-disintegrating, hard and uniformly strong mass on setting**. This depends on its original composition, proper burning and grinding. Presence of lime in free state, an excess of sulphate or magnesia and a very fine size may be the cause of unsoundness in a cement.

The Bureau of Indian Standards has specified the Le Chatelier Test – the same as adopted by British and American Standards for testing the soundness of the cement.

Le Chatelier's Test

(*a*) **Apparatus.** It consists of a small split, metallic cylinder having an internal diameter of 30 mm. It is 30mm in height, with the thickness of wall being 0.5mm. It is fixed with two indicators, one fixed on either side of the split. The distance from the end of the indicator to the center of the cylinder is 165 mm (Fig 4.7) (*b*) **Specimen.** The cement to be tested is made into paste of specified consistency. In common practice, 100 gm of neat cement are mixed with water calculated at 0.72 (P) where P is the percentage of water required for making a paste of normal consistency.

(*c*) **Method.** The paste of the known consistency is filled in the cylindrical mould, covered with glass sheet and kept under water (at 27^{0}C to 32^{0}C) for 24 hours after which the cylinder is taken out and the distance between the two indicators is measured (say it is *x*). It is again immersed in water.

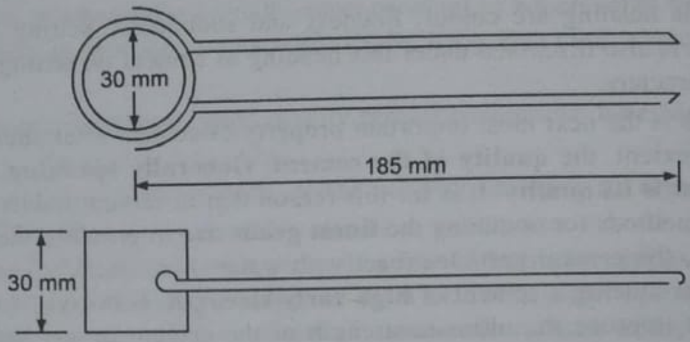


Fig. 4.7. Le Chatelier's Apparatus.

The water is then brought to boiling point in 15-30 minutes and kept boiling for 1 hour after which the distance between the two indicators is again measured (say it is now *y*). The difference *y-x* gives expansion of the cement specimen on setting. It is specified that this distance shall not exceed **10 mm for the cement to qualify as SOUND.**

(3) Setting of Cement. By Setting of cement is understood conversion of a plastic paste of cement and water to a non-plastic and rigid mass. This change from a plastic mass to a non-plastic and rigid mass may take any time between few minutes to an hour or more.

The setting of cement is rather a complicated chemical phenomenon and is believed to take place in following three stages.

(*i*) **Hydrolysis and hydration stage.** It is the first stage and starts immediately after addition of water. In this process the four compounds of cement (C_3S, C_2S, 3CaI, 4CaFe) **get hydrated**. The first compound also undergoes hydrolysis. As a result complex hydro silicates are formed:

$$\boxed{\begin{aligned} 3CaOSiO_2 + (n+1)H_2O &= 2CaISiO_2nH_2O + Ca(OH)_2 \\ 2CaO\ SiO_2 + nH_2O &= 2CaISiO_2nH_2O \\ 3CaOA_2IO_3 + 5H_2O &= 3CaOAL_2O_3 \,.\, 6H_2O \end{aligned}}$$

(*ii*) **Colloid Stage.** In this stage, the intricate system of hydro-silicate crystals formed as above separate out in the form of a gel which gets gradually thickened and acts as a glue around other particles thereby initiating the setting of the cement. During this stage, the mortar (cement – water-sand paste) becomes **fully saturated** and cannot take any more water.

(*iii*) **Crystallization stage.** In this stage most of the components get transformed from a gel or colloidal state to crystalline state. The least stable colloids of tricalcium hydroaluminate and calcium hydroxide are **first** to pass into a **stable crystal phase**. Calcium hydro silicate gel also hardens almost simultaneously. This nearly simultaneous development of crystals and hardening of gel results into a strong and intergrown mass of crystals and gels.

Hardening of cement is different than **setting** of cement. It may be defined as the capacity of the set cement to **withstand loads without disintegrating** or cracking. Thus whereas a cement may require only a few minutes and hours to set, it may become sufficiently hard only after a considerable time, measured in days, weeks, months and even in years.

Setting Time

Some cements set quickly, **within a few minutes** whereas others may take comparatively longer time. Moreover, setting is not an abrupt process which may complete immediately after it start: it is rather a **progressive phenomenon**, which has beginning, full development and an end. It is on this latter basis, setting is distinguished into initial and final setting, qualified by the time required in each case.

Time required for setting is greatly influenced by following factors:

(*i*) **Temperature** at which cement paste is allowed to set; very cold temperatures retard the time of setting.

(*ii*) **Percentage** of water mixed to the cement in making the paste; it must be right quantity for complete hydration and crystal formation. Less water will result in incomplete hydration; extra quantity will bleed out after the cement is set.

(*iii*) **The humidity** of the atmosphere in which setting is allowed to take place. It acts through temperature and moisture conditions.

It is, therefore, essential that all the tests for setting time are performed at standard conditions of temperature and humidity and on cement paste of known consistency.

Tests

The Bureau of Indian Standards (BIS) has specified the use of **Vicat Needle Apparatus** for this test, which is conducted as follows :

(*a*) **Apparatus :**

(*i*) It consists of a frame having a movable rod with a cap.

(*ii*) A needle of 1mm^2 cross section attached to the lower end of the rod for determination of initial setting time only. The total weight of the rod along with the needle is 300 gm.

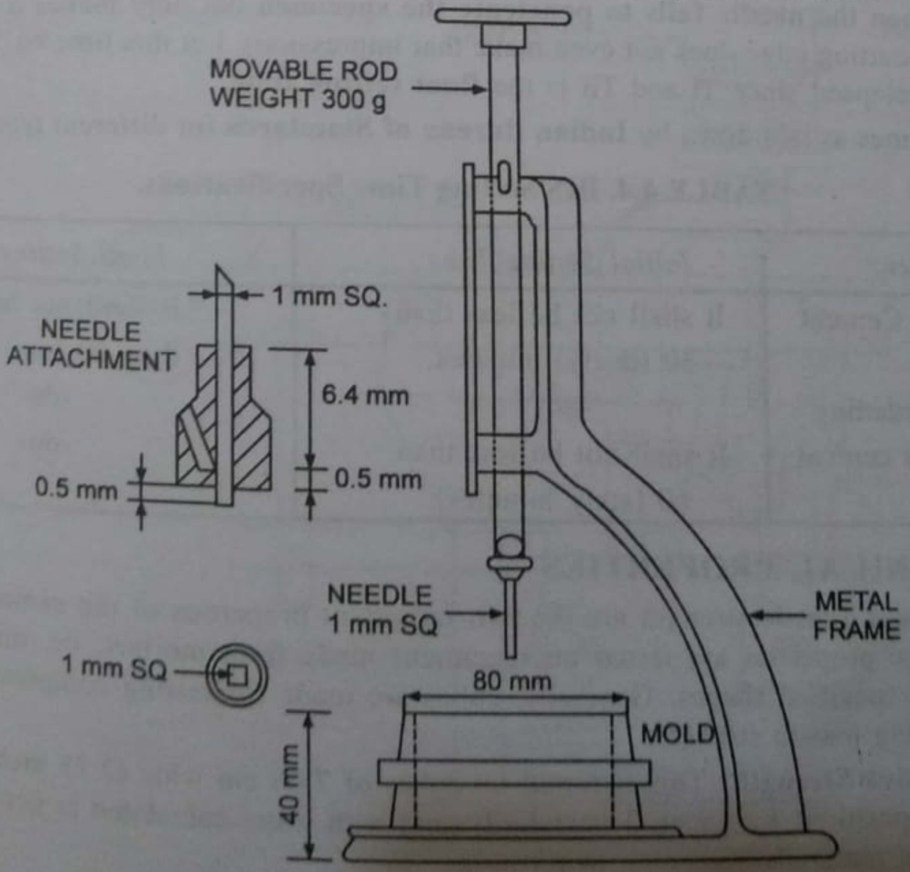


Fig. 4.8. Vicat Apparatus.

(*iii*) Another needle, like the above, but with hollow metallic attachment with a circular **cutting edge of 5mm** in diameter and having 0.5 mm projecting end of the needle. It is attached to the lower end of the rod **when final setting time** is to be determined.

(*iv*) A standard **Vicat Mould** in which the test specimen is allowed to set.

Test Specimen. Test specimens are prepared in the following manner from the lot of cement to be tested.

(*i*) Take 300 gm of cement and form a paste by mixing 0.85 P water (where P denotes percentage of water required to make paste of normal constancy.) **Note the time** when the water is added to the cement with the help of a stopwatch; let it be Ti.

(*ii*) Fill the Vicat Mount completely with the paste so prepared under the standard conditions of temperature and humidity, ($27^{0} \pm 2^{0}$C and at least 90% relative humidity.)

(*c*) **Procedure :**

(*i*) **Initial Setting Time**. Fix the specified needle (for initial setting time) with the rod. Place the mould with the test specimen under the rod and lower the rod gently till it comes into contact with the block. And then release the rod quickly.

Note the depth to which the needle penetrates the paste. Repeat the experiment (of releasing of rod) till the depth of penetration is **35 mm above the base of the mould**. This means, the needle penetrates up to 35 mm and cannot penetrate the last 5 mm at the base of the mould. When this happens, note the time once again. Let it be Tii. The time that has elapsed between Ti and Tii is **initial setting** time for that sample of the cement.

(*ii*) **Final Setting time.** The needle with a circular cutting edge is used for this purpose. It is attached to the rod. Using the same sample that has been used for finding the initial setting time, the rod with this needle is released again and again. In the beginning the contact edge may pierce in the paste but a time **would come when it fails to pierce at all**. The time is noted when the **needle fails to penetrate the specimen** but only makes a slight impression (and the cutting edge does not even make that impression). Let this time be Tii. Then the time that has elapsed since Ti and Tii is the **final setting time.**

The setting times as laid down by **Indian Bureau of Standards** for different type of cements are :

TABLE 4.4. BIS Setting Time Specifications.

Type of Cement	*Initial Setting Time*	*Final Setting Time*
1. Ordinary Cement	It shall not be less than 30 (thirty) minutes.	It shall not be more than 10 (ten) hours.
2. Rapid hardening	-do-	-do-
3. Low Heat cement	It shall not be less than 60 (sixty minutes)	-do-

4.6.3. MECHANICAL PROPERTIES

Compressive and Tensile strength are the two important properties of the cement that fall under this heading. These properties are tested on specimens made from mortars, *i.e.* mixture of cement, sand and water in specified shapes. Generally, cubes are made for testing compressive strength and briquettes for testing tensile strength.

(1) Compressive Strength. This is tested on cubes of 7.06 cm wide (2.78 inches) made from a mortar of the composition: 1 cement: 3 (standard) sand with water calculated in percentage terms for total dry weight of materials according to formula

$$\boxed{P = \frac{Pn}{4} \times 3.5}$$

where *P* is the quantity of water (in percentage terms) required in this case. *Pn* is, as usual quantity of water required for making a paste of normal consistency.

The value of Pn is first found by separate tests in a specified manner (described later on.). In all 9 cubes may be made: 3 to be tested after 3 days, 3 after 7 days and 3 after 28 days. **Average of three values in each test** is taken as the compressive strength of that cement after so many days. These values should conform to the specified standards. The test is performed on a standard Universal Testing Machine (UTM) as prescribed in the codes.

(2) **Tensile Strength.** It is defined, as usual, the resistance of a material (in this case cement) to tensile forces. The usual method of testing tensile strength of cement involves preparation of a number of test specimens made in the shape of briquettes with specified dimensions as shown in figure 4.9. These briquettes are prepared from a cement sand mortar of 1:3 and water percentage given by values 0.195Pn ± 2.5 where Pn is the percentage of water required to prepare a paste of normal consistency.

After preparation, the briquettes are kept in a moist atmosphere (27^{0}C ± 2^{0}C; humidity of 90%) for **twenty four hours.** After this, they are kept submerged in water at the same temperature till they are taken out for testing.

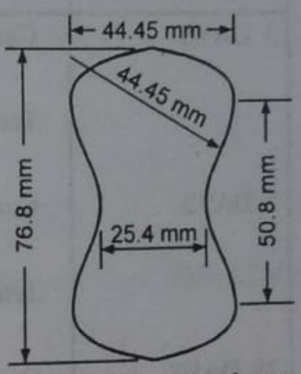


Fig. 4.9. Briquette shape for tensile strength.

The tests are carried out after 3 days, 7 days and 28 days, for a particular lot of cement. At least six briquettes are tested in each test and the average of these is taken as the tensile strength after so many days. The testing machine **consists of jaws** which make a firm grip on the sample. The upper jaw gets stretched when the pan assembly is filled with lead shots. A stretching or **tensile force** is thereby exerted on the briquette.

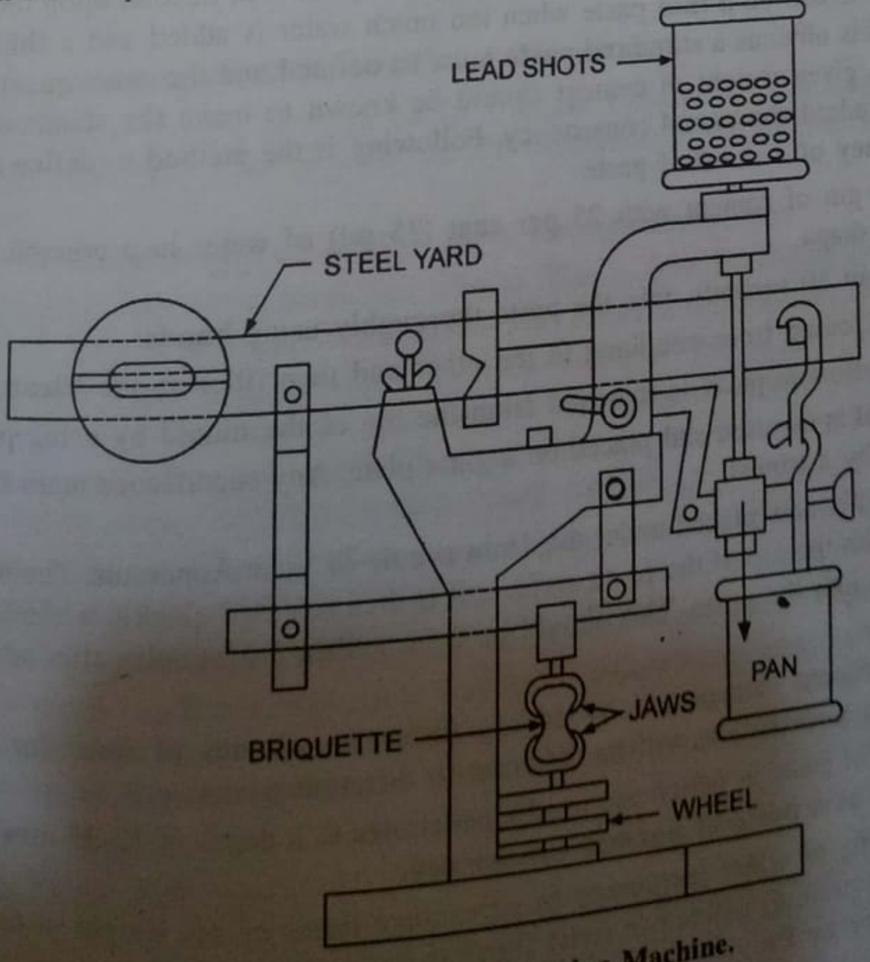


Fig. 4.10. Tensile Strength Testing Machine.

The value obtained in these tests should conform to those laid down in Indian Bureau Specifications: IS: 8041 E-1976.

TABLE 4.5. BIS Specifications for Compressive and Tensile Strength.

Time of testing After-	*Strength*	*Type of Cement*		
		Ordinary (OPC)	*Rapid Hardening*	*Low Heat*
3 DAYS	**Compressive**	Not less than 115 kg. cm^2	Not less than 210 kg/cm^2	Not less than 70 kg/cm^2
	Tensile	Not less than 20 kg /cm^2	Not less than 30 kg/cm^2	———
7 DAYS	**Compressive**	Not less than 175 kg /cm^2	———	Not less than 115 kg/cm^2
	Tensile	Not less than 35 kg/cm^2	———	———
28 DAYS	**Compressive**	———	———	Not less than 265 kg/ cm^2
	Tensile	———	———	

4.7. A NOTE ON PASTE OF NORMAL CONSISTENCY

In all tests of cement, a paste has to be made by mixing thoroughly a given weight of cement with most appropriate quantity of water. The **thickness** of the paste will depend upon the quantity of water added to cement: it will be a **thin** paste when too much water is added and a **thick** paste when less water is added. It is obvious a **standard paste** must be defined and the exact quantity of water which must be put to a given weight of cement should be known to make the standard paste. This paste should have a standard or **normal** consistency. Following is the method to define and determine this **normal consistency** of a standard paste

(*i*) Mix 300 gm of cement with 25 per cent (75 ml) of water in a crucible. Use a spatula of standard shape.

(*ii*) After about 30 seconds, mix the paste thoroughly using **hands.**

(*iii*) It is then tossed from one hand to the other and then filled in the **Vicat mould.**

(*iv*) The superfluours paste is removed from the top of the mould by using palm.

(*v*) The mould is inverted and placed on a glass plate. Any superfluous mass from the top is now removed by a trowel.

(*vi*) The mould is now placed under the 1mm needle of Vicat Apparatus. The needle is brought in contact with the top of the paste surface; it is then released quickly without a jerk. The needle penetrates into the paste. This should be done **within** 3-5 minutes after adding water to make the paste.

(*vii*) The experiment is repeated by adding different volumes of water-for making the paste. Obviously, **penetration** will be different in different pastes.

(*viii*) That type of paste in which the needle penetrates to a depth of **33-35 mm** in the Vicat mould is defined as a **paste of normal consistency.**

(*ix*) The quantity of water (expressed in percentage terms of dry weight of cement) which gives a standard paste as defined in (*viii*) above **is defined as water required for paste of normal consistency or Pn.**

Example: We take 3 cases

Case I : Weight of cement : 300 gm
Weight of water : 30% (90 ml.)
Penetration : 40 mm.

Case II : Weight of cement : 300 gm
Weight of water : 20% (60 ml.)
Penetration : 20 mm.

Case III : Weight of cement : 300 gm
Weight of water : 25%(75ml.)
Penetration : 30 mm.

In the above example, **Case III** paste is the paste of Normal Consistency and **P_n = 25% of dry weight of cement.**

4.8. TYPES OF CEMENT

Besides the Ordinary Portland Cement (OPC), a number of other types of cement are also manufactured by varying the ratio of the raw materials and/or by adding some additional materials. Among them some common special purpose cements may be mentioned: **rapid hardening** cement, **low-heat** cement, **quick setting** cements, and the **high alumina** cement. Another group of cements, distinguished primarily on the basis of raw materials used includes the **Blast Furnace** Slag-Cement, **Pozzolana Cements** and **white cement**. Only a brief description of salient features of some of these cements will be given here.

(1) *RAPID HARDENING CEMENT (RHC)* :

Definition. It is also known as High Early Strength Cement. It is manufactured with such adjustments in the proportions of raw materials so that the cement produced attains maximum strength within **24-72 hours.**

Properties. Two essential features of High Early Strength cement are:

(*i*) It contains **relatively more** tricalcium silicate. This is done by adding greater proportion of limestone in the raw materials compared to that required for ordinary cement.

(*ii*) It is **more fine grained** (air permeability surface area = 3250 sq. cm/gm) than the ordinary cement. This factor helps quicker and complete hydration of cement particles during setting and helps in gaining early strength. The extra fineness, however, may be often the cause of development of cracks, which have to be taken care of.

The **setting time** for rapid hardening cements, are, however the same as for ordinary cement. Moreover the ultimate strength values may also be almost similar to the ordinary cement.

Use. It is special purpose cement **used only when time is the most important factor in a project.**

In advanced countries, an **Ultra-high early strength cement** is produced by separating the **finest fraction** from the rapid hardening cement at the manufacture stage itself. This is achieved by using special devices called **cyclone air elutriator**. Such a cement is used for **making very high early strength concrete.**

(2) *LOW HEAT CEMENT (LHC)* :

Definition. It is a type of Portland Cement in which **very low amount of heat of hydration is liberated** during setting and hardening. This cement is most commonly used in massive concrete structures as **dams and pillars.**

Properties. In the low heat Portland Cement

(*i*) The proportion of dicalcium silicate (C_2S) is increased to almost **double than** in ordinary Portland Cement.

(*ii*) The proportion to tetra calcium alumino ferrite (C_4ALFe)is also increased to **one and one half time** than in ordinary Portland Cement. This is because the above two are least heat-liberating compounds in the cement.

(*iii*) The proportion of tricalcium silicate (C_3S) and tri-calcium aluminates (C_3 AL) are **reduced by about 50 per cent** than in Ordinary Portland Cement. This is because both these compounds are known to liberate **very high amounts of heat during hydration.**

Most **important qualities** of low-heat cement are summarized as follows :

(*a*) **Fineness**. The residue in the Sieve Test shall not exceed 10 percent.

(*b*) **Setting Times**. The initial setting time shall not be less than 60 minutes (1 hour). The **final setting** time shall not be more than ten hours.

(*c*) **Strength**: It should develop a compressive strength not less than 70 kg/cm^2 in 3 days; 115kg/cm^2 in 7 days; and 265 kg/cm^2 in 28 days.

Use. The low-heat cement is **the ideal cement for such mass construction works as concrete DAMS**. If Ordinary Portland Cement in used is such structures, **cracks** will develop in the cement concrete work due to great amount of heat liberated during setting and hardening. A Dam having cracks in its body would be a defective and often dangerous structure.

(3) *QUICK SETTING CEMENT (QSC) :*

This is quite different than rapid hardening cement. It is characterized with a quality to set into a stone like mass **within a period of less than 30 minutes**. This properly of setting as quickly as possible is achieved by following controls in the manufacture process:

(*i*) The **quantity** of **retarding** agents like gypsum is **reduced** to bare minimum.

(*ii*) The quantity of alumina-rich compounds is increased.

(*iii*) The clinker is ground to **extreme fineness**, much greater than in ordinary Portland Cement.

Quick setting cement is used only in very specific situations **such as while constructing piers and other structures in** running or standing water.

(4) *HIGH ALUMINA CEMENT (HAC) :*

Definition: It is **special purpose** cement which contains alumina in considerably large proportions (average 40 per cent) than usual. **This cement is specially useful against corrosive action of sea water**. As such it is the most favoured cement for use in concrete structures in coastal areas.

Manufacture. High alumina cement is manufactured by calcining a well proportioned mixture of **Limestone and Bauxite** (AL_2O_3. n H_2O). No other raw material is added; not even gypsum is mixed to the clinker during grinding. The total alumina content is generally above 32 per cent.

Properties. The more important properties of high-alumina cement are summarized below :

(*a*) It is greatly resistant to **corrosive action** of acids and salts of sea water.

(*b*) The **ratio** of alumina to lime is kept between 0.85 and 1.30.

(*c*) Although it has a higher initial setting time (more than 3.5 hours.), its final setting time is much lower only: 5 hours. These setting characteristics give ample time for working with high alumina cement.

(*d*) The shorter final setting time is accompanied with a rapid gain in both tensile and compressive strength. Thus, it gains a compressive strength of 400 kg/cm^2 within 24 hours and 500 kg/cm^2 after 72 hours.

(*e*) **It evolves great heat during setting.** As such it is not suitable for use in massive construction. At the same time, this property (of evolution of great heat) gives an advantage to high alumina cement for use in frost forming areas.

(*f*) This cement reacts quickly with free lime or even with ordinary Portland Cement. It must not therefore, come in contact with them.

Use. Because of the manufacturing process and raw material (bauxite), the high alumina cement is **more costly** than ordinary Portland Cement. It is, therefore used only in situations, where resistance against corrosive situations and sea water is required. **It is, therefore, commonly used for good qualify construction work near and along seashore.**

(5) *PORTLAND (BLAST FURNACE) SLAG CEMENT :*

Definition. It is modified type of Portland Cement which contains besides Portland cement, 25-65 per cent by weight of **blast furnace slag**. It is manufactured by grinding together the cement clinker with specific amounts of blast furnace slag. The slag, as we know, is a **waster product** from the **blast furnace** used in the **manufacture of Iron**. The slag is first converted to **granulated form** and is then ground with clinker. A small percentage of **gypsum** is also added for controlling the setting time of the slag cement.

Properties. The **slag-cement** offers a number of advantages over the ordinary Portland cement, of which the following are more important :

(*i*) The cement possesses better **workability**, **cohesiveness** and **plasticity** than the ordinary Portland cement. These quantities are explained to be due to lesser specific gravity and greater specific surface area of the slag cements that result as a consequence of slag component.

(*ii*) The slag cement has **better resistance to sulphate** of alkali metals, alumina and iron. As such, it is better suited for use in marine structures as in docks, harbours and jetties. It is also an **ideal type of cement** for use in road construction in marshy and alkaline soils.

(*iii*) It has **low heat** of hydration. This property makes it useful for mass concrete work.

(*iv*) It is **economical** compared with Ordinarily Portland Cement because slag used in its manufacture is **essentially a waste product.**

For manufacture, properties, uses and tests for Blast furnace slag cement, IS Codes 455-1978 may be referred.

(6) *POZZOLANA CEMENT :*

It is the type of cement in which Portland Cement clinker has been mixed with definite proportions of **Pozzolanic material** such as volcanic ash, fly ash, powdered burnt bricks etc. The Pozzolanic materials do not have any cementing qualities when used alone, but when mixed with Portland Cement, they react with cement components and form compounds having cementing properties.

The pozzolana cement has many properties similar to Ordinary Portland Cement; it offers the following additional advantages:

(*i*) It produces **less** heat of hydration (and is **therefore suitable** for mass concrete work.)

(*ii*) It offers **great resistance to sulphate and corrosive action** of sea water. These qualities make such a cement more useful for construction near or along the coast and also in sulphate soils. It is also suitable for use in sewage works and for under-water construction.

(7) *COLOURED CEMENTS :*

Any desired colour can be imparted to the Portland Cement **by mixing with it a definite proportion of a mineral pigment. The mixing of the pigment in the finest powdered state and the cement is done generally at the factory so that the product is available as ready to use colored cement. The amount of pigment used depends upon the shade of the desired colour. It is, however, generally less than 10 per cent by weight, and most commonly between 2-5 per cent.**

Pigments used to obtain coloured cements are :

(*i*) Chromium oxide for green colour;

(*ii*) Cobalt for blue colour;

(*iii*) Iron Oxide for various shades of red, brown and yellow;

(*iv*) Manganese dioxide for black and deep brown colours.

Coloured cements are extensively used for top coat in flooring and for decorative purpose in various places in a building.

(8) *WHITE CEMENT :*

It may also be defined as a special type of Portland Cement which on use gives a milky or snow-white appearance.

White cement is manufactured from pure limestone (chalk) and clay that are totally free from oxides of iron, manganese and chromium. The kiln is fired by oil rather than by coal to avoid any contamination. It has properties of strength and setting times etc. similar to Ordinary Portland Cement. White cements are the most favoured material for use in making highway curbs and for variety of ornamental work. They are also used widely for making cast stones of appealing appearance. White cement is comparatively a costly cement and is, therefore, used only selectively.

(9) *HYDROPHOBIC CEMENT*

It is special type of cement containing admixtures which reduce the affinity of cement grains for water. **Such cements are specially useful for application in cold, frost-forming conditions. Admixtures of naphtha, a soap and acidol are generally added to achieve this property.**

(10) *SUPER SULHATE CEMENT*

This variety of cement is manufactured by adding quantities of calcium sulphate and blast –furnace slag to the ordinary Portland Cement. The resulting cement is specially useful for mass-concrete work **especially in sulphate–rich environments and marine conditions. Besides, it is comparatively economical.**

(11) *LOW ALKALI CEMENT*

In circumstances where aggregates available for making concrete are suspected to contain reactive silica, use of low-alkali cements is recommended. Such cements are specially made Portland Cements in which **alkali content** is kept below a specified minimum by exercising a very strict control over the composition of the raw materials used.

TYPICAL QUESTIONS

A. ESSAY TYPE

1. Explain the difference between :

   (*a*) Quick Lime and Portland Cement.

   (*b*) Hydraulic Lime and Portland Cement.

   (*c*) OPC and LHC

2. Give an account of the various ingredients of ordinary Portland cement as they are present in

   (*a*) Raw Materials

   (*b*) In Clinker.

   Discuss the functions of each of these major components.

3. Explain briefly manufacture of Portland Cement by **DRY PROCESS.** How it differs from Wet Process ?

4. Explain briefly manufacture of Portland Cement by **WET PROCESS.** When and why it is considered a better process than the dry process?
5. Draw a **FLOW CHART** for the manufacture of Portland Cement in Dry Process as well as Wet Process. Explain very briefly salient features of:
   - (*i*) Blending.
   - (*ii*) Burning.
   - (*iii*) Grinding of Clinker.
6. Explain construction and working of following with the help of neat sketches :
   - (*i*) Rotary kiln for cement manufacture.
   - (*ii*) Ball Mill.
   - (*iii*) Tube Mill.
   - (*iv*) Le Chatelier's Apparatus.
   - (*v*) Vicat Needle Apparatus.
7. Write Short Notes on :
   - (*i*) Setting of Cement.
   - (*ii*) Clinker
   - (*iii*) Soundness of Cement.
   - (*iv*) Fineness of Cement.
   - (*v*) Initial Setting Time
   - (*vi*) High Alumina Cement.
   - (*vii*) Low Heat Cement.
   - (*viii*) High Early Strength Cement.

B. OBJECTIVE TYPE

Tick the right answer :

1. Ordinary Portland Cement is defined as a
   - (*i*) **fine powder** obtained by grinding limestone, clay and gypsum in tube mills.
   - (*ii*) fine power obtained by burning together mixture of predetermined quantities of limestone and clay and then pulverizing the product along with a small percentage of gypsum;
   - (*iii*) fine powder obtained by burning together mixture of predetermined quantities of limestones, clay, gypsum, iron oxide, silica and then powdering the klinker so obtained.
   - (*iv*) None of the above.
2. The four essential constituents of ordinary Portland Cement are, in order of **decreasing** proportions:
   - (*i*) Lime, Silica, Alumina and Fe Oxides
   - (*ii*) Silica, Alumina, Fe oxides and lime;
   - (*iii*) Alumina, Silica, Lime and Fe Oxides.
   - (*iv*) Fe oxides, Alumina and Silica.
3. The four essential constituents of CLINKER in OPC are in **decreasing** proportions;
   - (*i*) Tricalcium alumino silicate, dicalcium silicates, tricalcium silicates and tetra calcium alumino ferric.
   - (*ii*) Tetra calcium alumino ferrite, tricalcium silicate, dicalcium silicate and tricalcium alumino silicate.
   - (*iii*) Tricalcium silicate, dicalcium silicate, tricalcium alumino silicate, tetra calcium alumino ferrite.
   - (*iv*) Tricalcium silicate, dicalcium silicate, tetra calcium alumino ferrite and tricalcium alumino silicate.

4. The **Dry Process** of cement manufacture is so named because :
   (*i*) The clinker obtained in this process is in dry state.
   (*ii*) Limestone is added to the kiln essentially in dry state, clay may or may not be in dry state.
   (*iii*) both limestone and clay are fed into the kiln in a dry powdered state;
   (*iv*) the fuel is in dry state.

5. According to the IS 269-1973 in the chemical composition of ordinary and rapid hardening cements, the ratio of percentage of lime to percentage of silica, alumina and iron oxide, when calculated according to the following formula:

$$CaO\text{-}0.7SO_3 \longrightarrow 2.8SiO_2 + 1.2\ Al_2O_3 + 0.65Fe_2O_3$$

   shall be:
   (*i*) neither more than 1.50 nor less than 0.50.
   (*ii*) neither more than 1.00 nor less than 0.66.
   (*iii*) neither more than 1.60 nor less than 0.55
   (*iv*) none of the above.

6. The Initial Setting Time for Ordinary Portland Cement, as specified.
   (*i*) shall not be less than 30 minutes.
   (*ii*) shall not be less than 45 minutes.
   (*iii*) shall not be less than 25 minutes.
   (*iv*) shall not be more than 30 minutes

7. The Final Setting time for O.P.C as specified.
   (*i*) shall not be less than 10 hours
   (*ii*) shall not be more than 10 hours
   (*iii*) shall be exactly 10 hours.
   (*iv*) shall not be less than 24 hours.

8. For construction work along sea-shore, we should specify.
   (*i*) Ordinary Portland cement.
   (*ii*) Rapid hardening cement.
   (*iii*) Quick Setting cement.
   (*iv*) High alumina cement.

9. For construction of gravity dams and other massive structures, we should specify a cement containing high percentage of:
   (*i*) Tricalcium silicate
   (*ii*) Dicalcium silicate.
   (*iii*) Alumina
   (*iv*) Iron Oxide.

10. Portland Blast Furnace Slag Cement is manufactured by
   (*i*) Burning together mixtures of limestones, clay and blast furnace slag.
   (*ii*) Adding blast furnace slag to the Portland cement and grinding them together.
   (*iii*) Mixing very finely ground blast furnace slag with Portland Cement.
   (*iv*) None of the above methods.

ANSWERS: 1. (*ii*); **2.** (*i*); **3.** (*iii*); **4.** (*iii*); **5.** (*ii*); **6.** (*i*); **7.** (*ii*); **8.** (*iv*); **9.** (*ii*); **10.** (*iii*)

RELEVANT I.S CODES ON PORTLAND CEMENT

1. Ordinary Portland Cement	IS: 269-1976
2. Portland Blast Furnace Slag Cement	IS: 455-1976
3. Portland Pozzolana Cement	IS: 1489-1976
4. TESTING Apparatus	IS: 5513-1976
(Vicat type and le Chattelirer type,	IS: 5514-1976
Air Permeability Apparatus.)	IS: 5516-1996
5. High Alumina Cement.	IS: 6452-1972
6. Rapid Hardening Portland Cement.	IS: 8041-1978
7. White Portland Cement.	IS: 8042-1978
8. Hydrophobic Portland Cement	IS: 8043-1978
9. High Strength Portland Cement.	IS: 8112-1976
10. Rotary kilns for Portland Cement	IS: 8125-1976

[Note: Most of these codes stand reaffirmed in 1992 and 1999.]

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5

Mortars & Plasters

5.1. INTRODUCTION

In building construction different masonry units like stones and bricks are bound together with the help of an intervening layer of a paste of cementing material like lime or cement. **This paste of cementing materials is termed as a MORTAR and is made by thoroughly mixing together definite quantities of cementing material, sand and water.** In this mix or paste, the cementing material (lime or Portland cement) is termed the matrix. It binds the grains of the sand (adulterant) and the surfaces of the stone or brick in such a way that the adjacent units form a continuous structure offering strong reaction to the loads from above and the sides.

The safety, strength and durability of the resulting wall or any such structure, therefore, depends on the quality of the mortar used as a binding medium. The mortar possesses the essential property of hardening into a rock like mass soon after its application.

Plaster is also essentially a lean mortar that has been prepared for the specific use of providing a **protective covering** on the inner or outer faces of construction.

A. MORTARS

5.2. FUNCTIONS AND QUALITIES OF MORTARS

Mortar serves following three functions in building construction:

(*a*) It provides a **binding force** or cohesion between the structural units, *i.e.* bricks or stones. This is achieved by its sticking to the units and drying and hardening there thus holding the units together with considerable strength.

(*b*) It acts as a medium for **distributing the forces** throughout the structure uniformly. A non-uniform distribution of forces would invariably result in the collapse of structure.

(*c*) It imparts to the structure **additional strength** and resistance against rain penetration and other such weathering agencies.

Following are considered essential qualities or properties of a good mortar :

(1) The mortar mix should be **easily workable**, that is, it should be of such a consistency that can be easily transported to the place of application. It should be neither too stiff nor too lean. This is achieved by mixing together right proportions of the mortar ingredients: lime (or cement), sand and water.

(2) The mortar should be **sufficiently plastic** as to get easily placed on the bed of construction in the form of a thin, smooth and uniform layer.

(3) The mortar should be **capable of retaining sufficient water** during its application. In the absence of this water-retention quality, water may get easily drained off leaving behind a semi-dry mix (rather than a paste) which will neither set nor harden properly. This requires full knowledge of preparing the right type of mortar.

(4) The mortar should result, on drying and hardening, into a material that is durable and **strong in itself**. At the same time, it **should not react** in any way with the construction units (bricks or stones) to affect their strength or durability.

(5) It should **set and harden quickly** so that construction could be done with speed.

(6) It should not develop any cracks on drying.

(7) It should be **economical to make** without compromising on any one of the essential qualities and functions as listed above.

5.3. CLASSIFICATION OF MORTARS

Mortars are commonly classified on following considerations :

(*a*) **Type of binding** material;

(*b*) **Nature** of application;

(*c*) **Density** of the mortar.

5.3.1. Type of Binding Material

Depending on the nature of job a mortar may be made by using any one or more of following available cementing materials:

(*i*) Lime Mortar	(*ii*) Cement Mortar
(*iii*) Surkhi Mortar	(*iv*) Gypsum Mortar, and
(*v*) Gauged Mortar.	

In **Lime Mortar,** fat lime or hydraulic lime is used as the **binding material.** Since setting of fat lime in a mortar requires loss of moisture as an essential condition, it is **not suitable** for construction in damp and moist conditions. But mortars made from hydraulic lime are quite suitable for use even in damp situations. Since the lime mortars form a very important class, we shall discuss them in detail in a subsequent article.

Cement Mortar contains Portland cement as a binding material, sand being the inert adulterant. In recent years, most of the quality construction work has been done only with the cement mortar; lime mortar has been relegated to a second place. This mortar will also be discussed in detail in subsequent paragraphs.

Surkhi Mortar: It is ordinary type of mortar where sand is partly or wholly replaced by surkhi (crushed burnt bricks) as a filling material in lime mortars. As such, the surkhi mortar is basically a variety of lime mortar containing:

Lime + Sand (1/2) + Surkhi (1/2) or lime + Surkhi

The ratio of lime to surkhi will depend on the nature of job where the mortar is to be used. It may be **mentioned here that surkhi cannot be used to make mortars with cement as it is reactive towards some cement ingredients**. Surkhi mortars are quite commonly used in foundation works.

Gypsum Mortars are rarely used in tough construction. They find applications as plasters (for covering coats). In these, gypsum cements (building gypsum and anhydrite) are the binding materials.

Gauged Mortars are made by adding Portland cement and Lime **together** in **properly determined proportions** as binding materials. Such mortars are stronger, denser and durable than ordinary lime mortars. These are, however, **inferior** to cement mortars.

5.3.2. Nature of Application

Mortars are divided into two main classes on this basis ;

(*i*) **Brick laying or masonry mortars.** These are the main mortars used as binding medium between the brick masonry units in the construction of foundations and walls of the buildings.

Depending upon the nature of construction, we may use lime-mortars, lime-surkhi-mortars and cement mortars of various compositions. When we talk of mortars, we generally mean brick laying or masonry mortars.

(*ii*) **Finishing Mortars or Plasters.** These are **lean mortars** used as protective covering over walls and also in ornamental work and for creating architectural fancies. Among their main requirements, capacity to form a **homogeneous mix** which acquires a uniform and smooth surface are most important. These are discussed separately as **Plasters** in a subsequent article.

5.3.3. Density of Mortar

Two general types of mortars are distinguished on the basis of **density**:

(*i*) **Heavy Mortars.** These are general-purpose mortars used for load bearing construction. Their **bulk density** is generally greater than 1500 kg/cm^3. In their preparation it is quartz-rich sand that has to be used. In a special type of heavy mortar designated as **X-rays shielding mortars**, a bulk density of 2200 kg/cm^3 or more may be desired. In that case high-density rocks crushed to the sand size are used with Portland cement as the binder. These mortars are used as protective coverings on walls of X-ray rooms and the cabinets.

(*ii*) **Lightweight Mortars.** In these types of mortars, bulk density is generally kept below 1500 kg/cm^3. This is achieved by using sands poorer in quartz and also crushed lightweight rocks such as pumice. Blast furnace slag and cinder are also used to obtain lightweight mortars. A special type of lightweight mortar having **bulk density** varying between 600-1000 kg/cm^3 is useful in making soundproof ceilings and walls.

5.4. LIME MORTARS

Lime Mortars are defined as homogeneous mixes of LIME with various proportions of fine sand and/or surkhi, pumice, ash, cinder, etc, in water. **These are the most common mortars used for ordinary type of building construction work.**

5.4.1. Preparation

Following are the main stages in the preparation of lime mortars :

(*a*) **Selection** of raw materials;

(*b*) **Proportioning** of the raw materials;

(*c*) **Mixing** of the raw materials.

A brief account relating to these stages is given below :

(*a*) **Selection of Raw materials.** Lime, sand surkhi, and cinder and pumice form the common materials used in lime mortars. Of these, lime is the essential binding material. Of the other materials, sand is more commonly used for mortar making although it may be partly or wholly replaced by any one or more of the other materials in proper proportions.

Fat Lime may be selected for making such mortars that have to be used in dry type of construction. Where construction is to be made in damp grounds or in water-rich areas, **hydraulic lime** should only be selected for making lime mortars. All the types of lime have to be slaked (if not already hydrated) before mixing with sand for making the mortar.

Sand. The sand for making a strong and durable mortar must be of **good quality**, *i.e.* it must be pure in composition, free from impurities and sharp grained in structure (see the note on sands in a subsequent article). The recommended fineness modulus of sand for mortars is 2.0-3.0. Sand is added to the mortars for at least three purposes :

(*i*) **To bear the load.** Cementing material alone may not be strong enough to bear the loads in construction at the bonds and joints. Sand when combined with lime (or cement) makes a very hard **stone-like mass** that can bear heavy loads without getting crushed.

(*ii*) **To resist shrinkage and cracking** of the mortar on hardening. As is known, lime (or cement) may shrink on hardening (with loss of water).Such a shrinkage may cause **cracks**, but when sand is present in the mortar, this tendency is greatly **overcome**.

(*iii*) **To increase the bulk** of the mortar. Pure lime (or cement) mixed with water will no doubt form pastes with **excellent binding qualities.** But when such pastes are to be used in huge building construction, enormous quantity may be required. It will become a **very costly affair**. As such, sand also serves the purpose of increasing the **bulk** of the mortar material besides bearing loads and resisting shrinkage. It is, essential, however, that the proportion of sand to be added is **limited** within a fixed range. Beyond that range, sand may make a very poor grade mortar.

When used in appropriate quantities, sand forms a **porous structure** in the final mortar. Each sand particle gets surrounded by a film of lime. On application, the porous structure allows atmospheric carbon dioxide to penetrate into the mortar and facilitate setting and hardening of lime mortars.

Pozzuolana Materials. These include a variety of natural and artificial materials that exhibit some **binding properties** when used with lime or cement. Among them pumice, cinder, surkhi and ash have been found particularly useful for making lime-mortars of special qualities. These are used along **with sand** or even **without sand** for making lime mortars.

(*i*) **Surkhi** is obtained by finely grinding **well-burnt bricks** (or specially burnt clay balls). Material passing through a sieve having 8 meshes to a linear inch (ISS: 320) is used in place of sand.

(*ii*) **Cinder.** It is the **fine residue from the burning of coals in railway engines**. It is primarily a waste material available in thousands of tones per month from steam-engine locomotives. It has been found quite suitable for making lightweight mortars. The cinder is first cleared and then crushed to the required fineness (ISS: 320) before use for making mortars.

(*iii*) **Pumice**. It is a natural highly porous volcanic rock formed by **accumulation and compaction of ash from volcanoes**. Pumice is highly porous, siliceous in composition and very light in density. It is also used in place of sand for making lightweight mortars. For that purpose, the rock is first finely ground in grinding mills.

Water. All that water which is suitable **for drinking purpose** can be used for making mortar. Care has to be taken to see that the water is essentially **free from alkalies, acids and organic residues**. All these impurities adversely effect the qualities of the mortars.

Depending upon the type of aggregate used, lime mortars are further distinguished into: lime-sand mortars, lime-surkhi mortars, lime-sand-surkhi mortars, and so on. Sometimes cement is also mixed in small quantities to lime mortars. These are called lime-cement mortars or **gauged mortars**.

(*b*) **Proportioning of the Raw Materials.** The main aim of proportioning is to fix such ratios of the ingredients (lime, sand etc.) that give a mortar of desired qualities, i.e. required strength, durability, finish and cost.

Mortars used in different places in a construction are subject to different forces. Hence, no **general rule for proportioning a mortar mix** can be framed. We give below (Table 5.1) commonly adopted proportions for making mortars for use in different places.

The following **additional facts** should also be remembered while selecting ratios for a mortar mix:

(*i*) If **more sand is added than recommended**, the resulting mortar will be **short** in workability. It will be difficult to place such a mortar. Moreover, it will be **weak** in character.

(*ii*) If **less sand is added than recommended**, the mortar will be **very stiff** and will stick with the working implements. It will show **considerable shrinkage** on drying. This may cause development of cracks.

(*iii*) When in doubt, add a **little more** – (rather than little less) sand than recommended.

(*iv*) The **amount of water** to be added to the mix for making mortar should be carefully fixed after trials. The mortar should be neither **too lean nor too stiff**.

TABLE 5.1. Recommended Proportions For Lime Mortars.

Construction situation	*Recommended Mortar composition (Ratios by volume)*	*Remarks*
(A) Foundations : 1. In DRY sub-grade, where water level is 2.4 meters below the foundation level. Loading less than 44 tonnes/m^2	Any one of the following mixes: (*i*) 1 lime, 2 sand (*ii*) 1 Lime, 1 sand and 1 surkhi (*iii*) 1 lime, 2 surkhi (*iv*) 1 cement, 3 lime and 12 sand	These mortars are quite satisfactory for buildings up to 3 storey height. For moist subgrade only cement and sand mortar (1:3) should be used.
2. Foundation work in medium and heavy loading in **dry sub-grade** (Loading **more** than 44 tonnes/m^2)	1 cement 1 lime and 6 sand	
3. Foundation work in medium and heavy loading in dry sub-grade (Loading more than 44 tonnes/m^2) - but when subgrade is **moist**.	Only **cement-sand mortar,** with 1 cement: 3 sand should be used.	
(B) Superstructure: 4. **Load bearing walls** with brick masonry		
(*i*) Light Loading	1 Lime, 1 sand, 1surkhi 1 lime, 2 sand	Load **below** 44 tonnes/m^2
(*ii*) Medium Loading	1 lime, 2 sand 1 lime, 1 sand, 1 surkhi 1 lime, 1 sand, 1 cinder 1 lime, 2 surkhi 1 cement, 2 lime, 9 sand 1 cement, 3 lime, 12 sand	Load **between** 44-66 tonnes/m^2
(*iii*) Heavy Loading	1 cement -2 lime and 9 sand or cement 1 lime and 6 sand	Load **above** 66 tonnes/m^2 (generally) below 88 tonnes/m^2
(*iv*) Very Heavy Loading	1 cement, 1 lime and 6 sand	Between 88-110 tonnes/m^2
5. Cavity Walls	-do-	
6. Arch work in stones	1 cement, 3 sand	
7. Non-load bearing walls	1 lime, 3 sand	
GENERAL PURPOSE MORTAR	1 cement, 1 lime and 6 sand.	Suitable for most of masonry work.

(c) **Mixing of Mortar Ingredients.** It is of great importance that the ingredients of mortars are mixed **as thoroughly as possible**. There are two methods used for this purpose: manual mixing and mortar-mill mixing.

(i) **Manual Mixing.** This is the common method of mixing in **ordinary construction**. It is done either on a watertight platform made of masonry or in a tank of suitable dimensions dug in the ground. A spade is the main tool required. First, measured volumes of slaked lime and sand and/or surkhi are placed on the platform (or in the tank). They are thoroughly turned over and again to ensure mixing in a dry state. Then water is added **in small quantities at a time**. Mixing is continued till a mortar of **uniform consistency** is obtained. It is taken for use and fresh batch of lime and sand are placed for mixing.

(ii) **Mortar Mill mixing.** A mortar mill is a mechanical device for grinding the mortar ingredients in the presence of water. It is run either by an animal or by motor power.

The animal driven mill is the traditional form. It is called a **lime chakki**. It consists of a circular brick-laid channel of suitable dimensions (generally 40 cm deep, 35cm wide and 8m in diameter). In this channel a stone-roller is placed in the centre and the other free end is tied to the neck of the bull or camel or buffalo (Fig. 5.1)

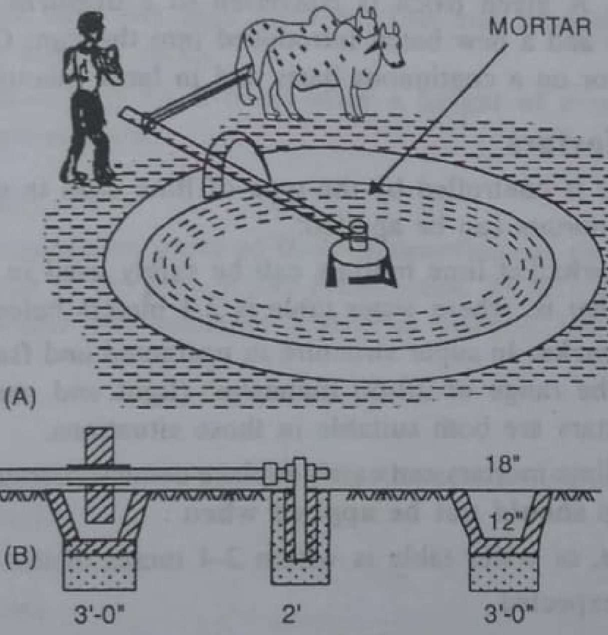


Fig. 5.1. Mortar Mill (Manual).

The ingredients *i.e.* lime (in slaked form) sand, surkhi and water etc. are placed in the channel in pre-determined proportions. The roller is then moved by driving the animal. The mixture is **continuously raked** by the attendants during the grinding process. This process is continued till a mortar of uniform consistency is obtained. This may take 80-180 revolutions by the animal and 1-3 hours in time depending upon the size of the roller, the depth of the channel and volume of mortar.

In large-scale construction where a continuous supply of mortar is essential a power-driven **grinding mill** is used. It comes in a variety of designs and capacities. In a typical power-driven grinding mill, there is a **central pan** supporting two rollers. The diameter of the pan and the roller vary depending upon requirements. Further, in one design, the **rollers are fixed** and the pan is revolving. In common designs, however, **pan is stationary** and the rollers are revolving (Fig 5.2)

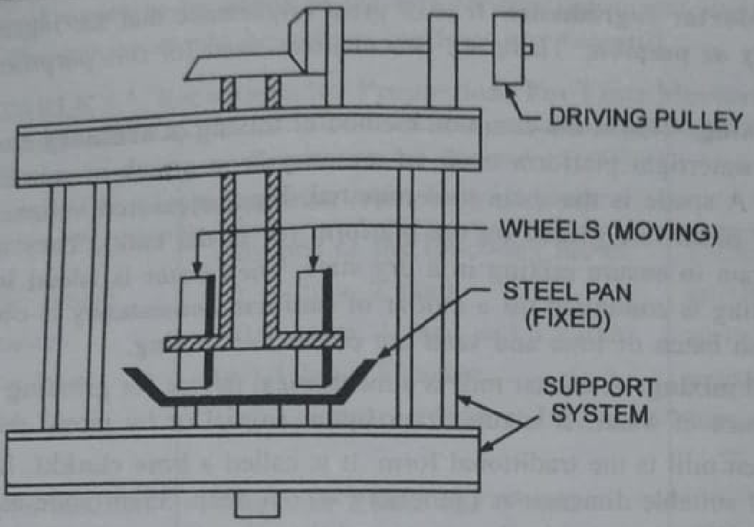


Fig. 5.2. Power driven grinding mill.

The ingredients in **predetermined proportions** are placed in the pan and the rollers are made to move using power supply. A given batch is converted to a **uniform paste** of mortar by 200-300 revolutions. It is taken out and a new batch introduced into the pan. Obviously, power driven mills give better quality of mortor on a continuous basis and in large quantities.

5.4.2. Uses of Lime Mortars

The use of lime mortar is controlled by the type of lime used in the mortar and proportions of various ingredients. Lime mortars can be applied:

(*i*) **For foundation works:**Fat lime mortars cab be safely used in all types of foundation work in dry sub-grade, that is, where water table is 2.4 meters below the foundations level.

(*ii*) **For all masonry works:** In super structure in unframed and framed buildings where loading conditions are in the range of 20-60 tonnes/m^2 (light and medium loading). Fat lime and hydraulic lime mortars are both suitable in those situations.

In the above situations lime mortars can easily replace cement mortars and prove to be economical also. However, lime mortars **should not be applied when** :

(*i*) **Sub-grade is moist**, or water table is within 2-4 metes of the foundations level.

(*ii*) **Heavy loading** is expected.

(*iii*) Construction is massive and **very thick.**

It is because lime requires atmospheric carbon dioxide for its setting and hardening which must be accompanied by a concurrent loss of moisture. Further, strength of lime mortars is lower than that of cement mortars.

5.4.3. Hardening of Lime Mortars

Mortars made of fat lime set and harden by a two-fold process :

(*i*) **Loss of moisture.** Water mixed in the mortar and with the lime during hydration is lost by evaporation.

$$\boxed{Ca(OH)_2 = CaO + H_2O\uparrow} \quad ...(1)$$

(*ii*) **Carbonate Formation**. The calcium oxide formed in the above reaction **absorbs** carbon dioxide form the surrounding environment. It gets changed into calcium carbonate.

$$\boxed{CaO + CO_2 = CaCO_3} \quad ...(2)$$

It is the carbonate formed in the above reaction that gives the strength, bond and durability to the dried mortar.

The setting of hydraulic-lime mortars is similar to those of cement-mortar. Formation of crystalline gel of hydrous calcium silicate as a reaction of calcium and silica compounds in the presence of water is the main cause.

It may be mentioned here that fat lime mortars used in **thick** construction or deep below the ground **may not gain full strength even after many years of their application**. This may be attributed to the **non-availability** of carbon dioxide in these situations. It is why samples taken from the **innermost portions of walls of some ancient forts show unset lime** even after many years after their construction.

5.4.4. Precautions

The Indian Bureau of Standards (BIS) has specified (vide ISS 1625-1966), following precautions while using lime mortars.

(*a*) Mortars with **eminently** hydraulic lime (Grade A), as a constituent, should be used **within 4 hours after mixing.**

(*b*) Lime mortars with surkhi or other pozzuolana should be used **within 24 hours** after mixing.

(*c*) Composite (lime and cement) mortars should be used within **two hours** after making.

(*d*) All lime mortars shall be **kept wet** after grinding. This may be done by covering the ground mortar with wet gunny bags or sacks.

(e) A time of **2 days** or more may be allowed **after a height of every 1.5 meters** for setting while working with lime mortars.

5.5. CEMENT MORTARS

A cement mortar is a homogeneous paste of fixed proportions of cement, sand and water. It is the most commonly used mortar in the present day construction. In fact, in all types of construction activities, where a strong, durable and resistant mortar is desired, the cement mortar becomes **indispensable.**

5.5.1. PREPARATION

The preparation of cement mortar involves following three steps (similar to lime mortar):

(*i*) **Selection** of raw materials:

(*ii*) **Proportioning** of these materials:

(*iii*) **Mixing** of the ingredients.

The **Portland cement** for making mortar must be pure, unadulterated and **undamaged.** Since there are many types of Portland cement available, it must be ensured that only **right type** of cement is selected on the basis of the construction. For common construction, ordinary Portend cement is most suitable. Lime may be used in making composite motors.

Sand for use in cement mortar must be of good quality (see note on sands). It must be free from impurities like oxides of iron, clay, mica, organic residues, alkaline salts and free lime. It must be **thoroughly cleaned** before actually mixing with the cement. Functions of sand are the same as in the lime mortar. *i.e.*

(*i*) It provides the **required strength** in mortar.

(*ii*) It forms the **bulk** of the mortar and hence makes it economical.

(*iii*) It provides **resistance against shrinkage** and cracking on setting of cement mortar.

No other aggregate can replace sand **completely** in cement mortars.

Proportioning. By proportioning we understand deciding the relative volumes of different ingredients that have to be mixed to make cement mortar of good quality and reliable strength.

Following proportions are commonly recommended for Cement Mortars.

TABLE 5.3. Proportions Recommeneded For Cement Mortar.

S.No	*Type of Work*	*Recommended Proportions*
1.	For **ordinary masonry work** with brick/stone as structural units.	1 Cement, 3 Sand to 1 Cement 6 Sand
2.	For **reinforced brick work** and for all work **in moist** situations	1 Cement 2 Sand to 1 Cement, 3 Sand
3.	Architectural work	1 Cement 3 Sand
4.	Load bearing structures	1 Cement 2 Sand, to 1 Cement 3 Sand

Mixing of Ingredients, For small jobs, manual mixing (as described under lime mortars) is commonly practiced. But for large-scale construction work where large quantities of mortar are required, the **mill–mixing** using power-driven mills may become indispensable.

5.5.2. Precautions

1. In most cement mortars, the setting process starts **even within the first hour** of its preparation. It is, therefore, laid down under ISS: 1625:1966 that cement mortar shall be used **within 30 minutes** after adding water to cement and sand mixture.
2. The **Structural units**, i.e. bricks and stones must be **soaked in water** before laying on the walls. This is because setting of cement requires good quantity of moisture on the walls. If **dry units** are placed, they will absorb moisture quickly leaving behind almost dry cement sand mixture. No or **very little** setting will take place and mortar will be unable to perform its function.
3. Further, where **cement-sand mortar** is used, the place should be kept wet **at least for seven days**. This is necessary to ensure final setting of cement and its gaining minimum workable strength. (Cement takes 28 days to **gain almost full strength** when used in a mortar.)

5.6. GAUGED MORTARS

These mortars contain both cement and lime as cementing materials. The third essential ingredient is mostly sand. Basically, these may be lime-mortars to which some cement is added for improving the qualities of these mortars. In some cases, these may be cement–mortars to which **some lime** is added for making them **more economical** without compromising with the quality.

Following are the common methods of making the **gauged mortars** :

(*a*) **The three ingredients.** Lime, cement and sand are first mixed together in dry condition in pre-determined volumes e.g. 1 cement, 1 lime, 1 Sand or 1 Cement, 2 Lime, 6 Sand and so on. They are thoroughly shuffled in presence of small quantity of water. The quantity of water is gradually increased while **wet-mixing is continued.** This is done till a homogeneous paste of desired consistency is obtained.

(*b*) **Lime Sand Mortar** is prepared as usual. To a fixed volume of this mortar, a predetermined volume of **cement** is added in **dry state** and then mixed thoroughly. A small quantity of additional water is also mixed.

(*c*) **Cement-Sand Mortar** is prepared as usual. To a fixed volume of this mortar, a predetermined amount of **slaked lime in finely powdered form**, or in the form of lime-putty is added. Thereafter the entire mixture is thoroughly mixed to obtain a mortar of uniform consistency.

Proportioning. The usual composition of gauged mortars for different works is as follows :

(*i*) **Heavy and Medium Loading:** 1 Cement: 1 Lime: 6 Sand
(Above 44 tonnes/m^2)

(*ii*) **Lighter Loading:** 1 Cement: 3 Lime: 12 Sand (Dry Sub-grade)
(Below 44 tonnes/m^2) 1 Cement: 1 Lime: 6 Sand (Moist Sub Grade)

5.7. TESTING OF MORTARS

Following **three tests** are commonly carried out to determine the quality of mortar :

(*i*) **Crushing** Strength.
(*ii*) **Tensile** Strength.
(*iii*) **Adhesiveness** or Bond Strength.

5.7.1. CRUSHING STRENGTH

The mortar to be tested is applied **uniformly and horizontally** on a set of bricks. The brickwork so formed is allowed to set and harden

The brickwork is then loaded under a **Universal Testing Machine**. The load at which crushing of the brickwork takes place is divided by the area of the mortar. It gives the crushing strength of the mortar. The crushing strength of mortar will depend on:

(*i*) Type of mortar
(*ii*) Mix design (ratio of cementing material to sand)

This will vary between 40 tons/m^2 for lime mortars to 70 tons/m^2 for cement mortar.

5.7.2. TENSILE STRENGTH

For this test, the mortar of standard mix (1:3) is first cast into specific briquette-shaped test specimens. These briquettes are allowed to set and harden. They are then tested in a tensile testing machine similar to that used for testing tensile strength of cement.

5.7.3. TEST FOR ADHESIVENESS

A uniform thin horizontal layer of mortar is placed between two bricks laid upon one another at right anglers. Once the mortar is completely set, the upper brick is suspended from an overhead support. Weights are attached to the lower brick. The loads are increased gradually till the two bricks separate out along the mortar joint. The load divided by the area of the **horizontal mortar joint** gives a measure of adhesiveness of the mortar.

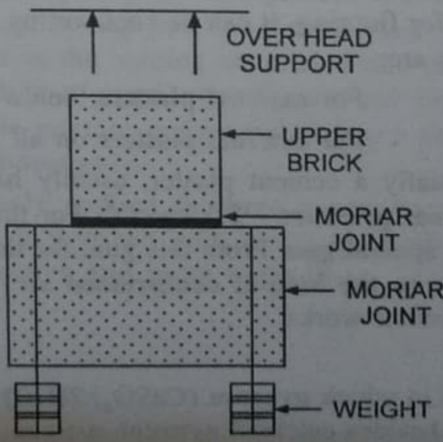


Fig. 5.3. Test for determining adhesiveness.

5.8. PLASTERS

5.8.1. Introduction

Plasters may be defined as **lean mortars used mostly for covering masonry surfaces.** They are **lean mixes** of cementing materials with fillers such as sand, surkhi and crushed stone. Sometimes jaggery, white of eggs and soured curd etc are **also** added to plasters for obtaining some special effects.

Plasters are specially prepared for use either as **protective plasters** or as **decorative plasters.** In protective covering, the plaster saves the brick or stone, over which it is applied, from **direct and destructive attacks** of the atmosphere and also from wind, rain and harmful industrial gases. As a **decorative finish**, plasters are used to give many appealing shades and finish designs to the construction. The decorative plasters find commonest application in the **interior** of walls whereas protective plasters e a must on the **exterior** walls in good quality building construction.

8.2. Types of Plasters

Following types of plasters are most commonly used in building construction: Lime Plasters, Cement Plasters, Gypsum Plasters and Stucco Plasters.

1. Lime Plasters. These are made by mixing thoroughly **slaked lime** and **sand** (or surkhi or both) in the ratio of 1 lime to 2-3 sand surkhi by volume with good quantity of water till a **homogeneous lean paste is obtained**. They are specially useful as protective plasters on the inner side of the walls.

Moghul Plasters are special type of lime plasters having 1 lime: 3 sand: 1 surkhi (by volume) to which some jaggery, or white of eggs and /or some fibrous materials have been also mixed. These latter materials serve to improve the adhesive property of the plasters on the one hand and also add to its strength and beauty on the other hand.

It is essential that **lime used in plasters** should be thoroughly slaked and practically free from unburnt lime particles, grit and pebbles. This is necessary to avoid such defects in plastered surfaces as **blistering**, peeling and popping and **uneven** finish.

2. Cement Plasters. These are **homogeneous lean mixes** of Portland cement and sand with water. Cement plasters have been found suitable for all type of plastering work such as protective covering and decorative finish.

The most common proportion for all-purpose cement plaster is: **1 cement: 3 sand.**

However, the ratio of sand can be increased to as much as 8 sand (for 1 cement) depending upon the nature of construction. Cement plaster is generally given only **in single coat.** It is important that the surface of the plaster **is kept wet for at least 3 days** after its application by sprinkling water on it at regular intervals. When used for flooring, it can be kept wet by maintaining a layer of water over it for best results. Common ratios are:

1. Cement: 1 Lime: 6 Sand	For external plasters, below damp proof course.
2. Cement: 2 Lime: 9 Sand	For external plasters on all walls.

The Guniting Plaster is actually a cement plaster, usually having a proportion of 1 cement: 3 sand which is applied **under great pressure** - 2.5 kg/cm^2. For this purpose, the cement, sand and water **are all mixed together in a special gun**. From this gun, the thoroughly mixed plaster is thrown out on the surface of application with **the help of compressed air**. Such a mortar is used for lining walls to tunnels, aqueducts and similar works.

3. Gypsum Plasters :

Definition. These are plasters in which **gypsum** ($CaSO_4$, $2H_2O$) is the binding materials in place of cement or lime. They contain, besides calcined gypsum, a fixed proportion of **fine sand.**

The gypsum plasters are commonly used for making **architectural fancies** and decorative designs on walls and roofs. Their most important properties are:

(*a*) The gypsum plasters have great **resistance to fire**.

(*b*) They provide comparatively **better insulation** against heat and sound.

(*c*) They set and **harden quickly**.

(*d*) They undergo **very little expansion** or contraction.

Preparation. Gypsum plasters are made from natural **Gypsum rock**, which is a hydrate sulphate of calcium – $CaSO_4.2H_2O$. This rock is burnt in suitable ovens or stoves at a temperature of 110^0C. At this temperature most of the water of crystallization is driven off. The resulting product is an Anhydrite, called commonly **Plaster of Paris (POP)**. Calcination of gypsum is done very carefully because both **over burning** and **under burning** will result into a plaster of unsound qualities.

The calcined gypsum is powdered. When it is mixed with water, it forms a paste, which begins to set and harden quickly. The setting reaction is quite simple :

$$\boxed{\begin{array}{l} \underset{\text{Gypsum}}{CaSO_4.2H_2O} \xrightarrow{\text{Heat}} \underset{\text{Anhydrite}}{CaSO_4 + 2H_2O} \\ CaSO_4 + 2H_2O \longrightarrow \underset{\text{Gypsum}}{CaSO_4.2H_2O} \end{array}}$$

Types. Following are more commonly used types of gypsum plasters:

(*i*) **Ready Mix Plaster.** This consists of plaster of Paris and fine aggregate such as sand in a dry-mix form in predetermined proportions. It is available as such so that it requires only mixing with water at the time of use. It has been shown that this **type of plaster possesses three times better insulation properties** than the ordinary cement or lime plasters.

(*ii*) **Gypsum Neat Plaster.** It is prepared by mixing commercial grade plaster of Paris with desired quantities of sand in **dry state**. The dry mixture is then reduced to a **homogeneous paste** with simultaneous addition of water and shuffling with the help of trovels. Any **fibrous material** is also added to gain additional adhesive qualities. The Gypsum-Wood-Fiber plaster is made by mixing 0.75% by weight of non-staining wood fibers. Such a plaster having a proportion of 1 Plaster of Paris: 1 Sand is considered quite useful as a **base coat** for insulation purpose.

(*iii*) **Keen's Cement**. It is **high density gypsum plaster** that is capable of taking fine polish on its finished surface. Gypsum gauged plasters are made by mixing suitable proportions of gypsum plaster with lime putty (hydrated lime). **They are considered specially useful for providing a hard surface at the base within a short time.**

(*iv*) **Stucco Plaster.** It is essentially a **decorative plaster**. It is applied on the external surface of construction and gives a marble like finish to the structure. The stucco plaster is made either **with lime** or **with cement** as the binding material. Fixed proportions of sand, crushed rock, marble and soapstone, white of eggs, soured curd and fibers are mixed in dry state with cement or lime. The whole mixture is then reduced to a **thick paste by adding water and mixing the ingredients thoroughly.**

The Stucco plaster is commonly applied **in three coats**: base course, middle course and the finishing coat. The finishing coat is polished with a soft cloth till brilliant shine is obtained. **The resulting surface is strong, protective and quite appealing.**

5.9. A NOTE ON SAND

5.9.1. Definition

Sand is an important construction material of natural origin. Mixed with cement and lime, millions of tons of sands are used every month for construction as mortars, plasters and concrete.

The term sand is used for **rock particles that range in grain size between 2mm and 1/16mm.** In composition, they are predominantly an **oxide of silica** (SiO_2). Mineralogically, they consist mostly of broken grains of mineral **Quartz** (SiO_2) produced as a result of breakdown of granites, sandstone and similar rocks by natural processes of weathering and erosion.

5.9.2. Classification

Sands are classified variously on the basis of their mode of origin, their composition and their grain size.

(*a*) According to **mode of origin**, sands are of **three types**, namely, pit sands, stream sands, and marine sands.

The **pit sands** are generally sharp and angular in outline. They are **generally deposited by winds** and form accumulations in soils that may be covered by clays. These sands when cleaned and washed make **good mortars.**

The **river sands** occur as accumulations of great extent along the base and banks of all the rivers in plains and semi-hilly areas. The shape of the sand grains in river sands is **almost round** (due to considerable transport in river waters). These are generally free from clay, salt encrustations and organic impurities. These are the most commonly used sands for making **mortars, plasters and concrete.**

The **marine sands** occur on beaches and along sea-shore. Like river sands they consist of rounded grains of quartz. A common difficulty with these sands is that their grains are often covered with coatings of salts from seawater. These salts **are not easily separable**. Hence if used in mortars or concrete, the salts react with the binding material - cement - creating a lot of difficulties. Moreover the salt encrustations are often hygroscopic, i.e. they absorb moisture from atmosphere. This also results in delayed settings, dampness and efflorescence of the mortar or concrete made with these sands. Hence, **marine sands are considered of inferior quality** and should be better avoided. When these become the only source available, marine sands must be **thoroughly washed before use.**

(*b*) According to **composition**. Following three categories of sand are recognized in engineering fields:

Clean sands. These are **well-graded** containing entirely or mostly quartz (SiO_2) particles in wide range of grain size.

Silty sands. These are **poorly graded** sands, which have considerable proportion of silt (particle size between (1/16 – 1/256mm) and other non-plastic fines.

Clayey Sands. These are **poorly graded** sands having a prominent clay fraction (particle size below 1/256 mm) and also plastic fines.

Obviously, for use in making mortars, plasters and concrete, sand of "category" **clean sands** must only be used. Sand is **also obtained artificially by crushing natural quartzite rock to the required grain size.**

(*c*) According to **grain-size**, sand is classified as coarse, medium and fine sand : 2-1mm, 1-0.25mm, 0.25-0.15mm, respectively.

5.9.3. Bulking of Sands

It is established that **volume of sand will be more when water is present in it even in small quantities.** In other words, two batches of sand, one dry and other moist, that may have same weight will have **different volumes**. The volume of moist sand will be more than that of dry sand.

This change (increase) in volume of sands on getting moist is termed as bulking of sand. Full knowledge of bulking of sands is important for a construction engineering because sands is sometimes used for mortars, plasters and concrete by volume. **All the mix designs denote proportion of sand in essentially dry state**. As such if this fact is ignored and sand in moist condition is added with the cement or lime, the resulting mortar will be **containing lesser amount of sand than required.** Hence a correction factor for bulking of sand has to be applied after determining the **rate of bulking** for the sand to be used in mortar and concrete making.

As regards the rate of bulking, it has been observed that it is related to two factors :

(*i*) **percentage of moisture content** in the sand.

(*ii*) **grain-size** of the sand particles.

Thus, bulking effect is **at its maximum when moisture content in sand is between 4-6 per cent** (Fig. 5.4). As the water-content increases, **this effect goes on decreasing,** becoming negligible at 15-20 per cent moisture content. Similarly, other things being same, the **fine sand** (particles size 0.25 to 0.15 mm) show **higher bulking rate** compared to the coarse sands (particle size around 2 mm). Bulking may be to an extent of 30 per cent of original dry volume of sand in the fine sands and 15 per cent in the case of coarse sands. (Fig 5.4)

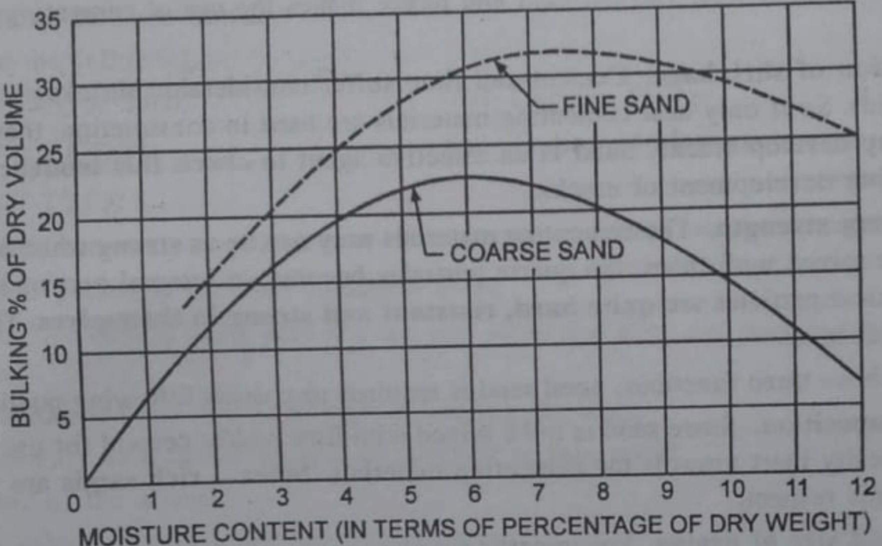


Fig. 5.4. Bulking of Sands.

A quick method to determine bulking of sand containing some moisture is as follows :

(*i*) Take a clean glass cylinder and fill it about ¾ with the sand sample. Note down its volume. Say it is $V_1 = 30$ cm.

(*ii*) Now carefully take the sand out and place it on a glass plate. Fill the glass cylinder with water to 3/4 of its volume.

(*iii*) Put the sand sample back into the glass cylinder very slowly, stirring the water while adding sand into it. This is essential to make all the sand grains settle fully in the cylinder.

(*iv*) Note down the new volume of **sand sample**; let it be V_2. If $V_2=V_1$, it will mean sand sample has retained its original volume, *i.e.* it has shone no bulking.

But let us say in this case $V_2=24$ cm. then bulking of sand sample is:

$$\boxed{\frac{V_1 - V_2}{V_1}\times 100 = \frac{30-24}{30}\times 100 = \frac{6}{30}\times 100 = 20\%}$$

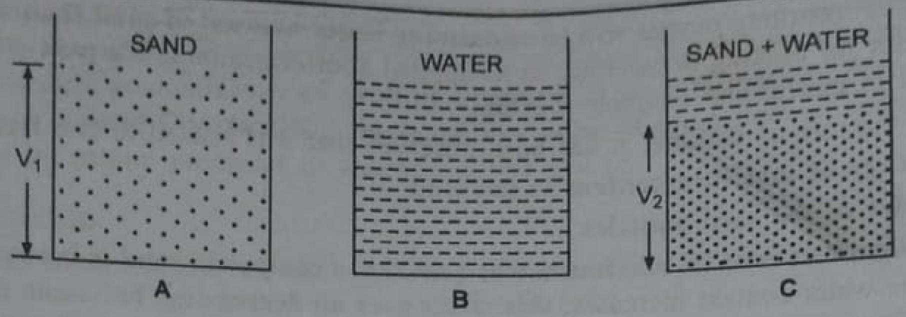


Fig. 5.5. Bulking of Sand

5.9.4. Functions and Properties of Sand

The main function of sand in mortars and concrete are three-fold:

(*i*) **Increase in bulk.** Sand is a useful adulterant which increases volume of mortar or concrete form 50 per cent to more than 100 per cent and hence makes the use of cementing materials **highly economical.**

(*ii*) **Prevention of shrinkage.** Cement and lime suffer considerable shrinkage on setting (when used without sand). So if only neat cementing materials are used in construction, they will shrink and consequently may develop cracks. Sand is an effective agent to **check this tendency to shrink** and helps in preventing development of cracks.

(*iii*) **Imparting strength.** The cementing materials **may not be as strong** when used alone. When sand (grains) are mixed with them, the quartz particles become an integral part of the set mortar or concrete. These sand particles are **quite hard, resistant and strong in themselves.** They impart these qualities to the set mix.

To perform above three functions, good sand is required to possess following qualities (properties.)

(*i*) **Inert composition.** Since sand is to be mixed with lime and/or cement for use in construction, it must be chemically inert towards the cementing materials. **Silica – rich sands** are practically inert and the best in this respect.

(*ii*) **Shape and size of grains.** For imparting an interwoven and strong base, sands should have **angular** and **sharp-edged** outlines. Rounded grains will result in too porous mortars and concrete. Generally, sands passing and retained on IS No. 15 sieve are considered suitable. The desired fineness modulus of good quality sand should be between 2 and 3.

(*iii*) **Freedom from impurities.** Good quality sand must necessarily be free from impurities like clays, oxides of iron and salts. These impurities are present in free state or as **encrustations** over the sand grains. **In either case, they make the sand unfit for use in good construction.** The impurities do not allow the cement to stick to the sand grains fully and hence cause defects.

5.9.5. Tests for Sands

Sand is often contaminated with clay, organic remains and harmful salts. Some field tests which can be easily performed on the sands are as follows :

(*a*) **For Clay.** The sand sample is taken in a glass jar and water is added. The sand is thoroughly stirred and then allowed to settle. Any clayey matter present in sand will form a layer at the top of sand mass in the jar.

(*b*) **For Organic Impurities.** The sand sample is taken in a test tube and a solution of caustic soda (sodium hydroxide) is added. The mixture is thoroughly stirred. If organic matter is present in the sand sample, the solution will take a brown colour.

(*c*) **For Salts.** Pure quartz sand is tasteless. The presence of sulphates and other alkaline salts in it will give it a **bitter taste**, which can be easily detected.

TYPICAL QUESTIONS

A. ESSAY TYPE

1. (*a*) Define a 'Mortar' and a 'Plaster'.
   (*b*) What are the functions of a 'Mortar and a 'Plaster' ?
   (*c*) Discuss the most important qualities of a Mortar and a Plaster.
2. Give an account of classification of Mortars. Describe in detail the process of preparing a LIME MORTAR for use in different situations in a building.
3. Write brief note on :
   (*i*) Functions of sand in a mortar.
   (*ii*) Proportioning in a Cement Lime Mortar.
   (*iii*) Mixing of Lime Mortars.
4. Explain the following :
   (*i*) Bulking of Sand. (*ii*) Gypsum Plaster.
   (*iii*) Stucco Plaster. (*iv*) Testing of Mortars.

B. OBJECTIVE TYPE

Tick the right answer:

1. **A mortar** placed in between structural units:
   (*i*) provides only a bond between the two units and does not play any role in bearing the load
   (*ii*) provides a bond and takes part in bearing the load;
   (*iii*) acts only as a device against penetration of rain water
   (*iv*) none of the above
2. Where subsoil is moist, we should use only
   (*i*) Pure Cement mortar (*ii*) Pure Lime mortar
   (*iii*) Lime + Cement Mortar (*iv*) Gypsum Mortar
3. Surkhi should not be used to make a mortar with
   (*i*) Pure cement (*ii*) Lime
   (*iii*) Gypsum (*iv*) Cement + Lime

ANSWERS: 1. (*ii*); 2. (*i*); 3. (*i*)

RELEVANT B.I.S. CODES ON MORTARS AND PLASTERS

1.	Burnt clay Pozzolana	IS: 1344-1968
2.	Sand for Plasters	IS: 1542- 1977
3.	Code of Practice for Preparation of Lime Mortar for use in buildings:	IS: 1625-1971
4.	Code of Practice for application of cement plasters.	IS: 1661-1972
5.	Sand for masonry mortars	IS: 2116-1965
6.	Method of Test for gypsum plaster, concrete and Products.	IS: 2542-1978
7.	Methods of tests for permeability of cement mortar and concrete.	IS : 3085-1965

□□□

6

Concrete

6.1. INTRODUCTION

Fresh concrete may be defined as a **plastic mixture of cementing materials (like cement or lime) with sand and crushed stones or gravels in the presence of water**. Certain other materials called admixtures are also added sometimes to obtain specific effects. The essential ingredients of concrete are, therefore:

- Cement,
- Sand,
- Gravels (or crushed stones), and
- Water
- (Admixtures, if required).

All the ingredients are mixed in **pre-determined proportions** and in accordance with a set procedure.

The essential property of such a material is that it sets and hardens into a strong, rock like mass within a short period of time. The ultimate strength and other properties of concrete depend on a **number of factors like the nature of aggregate materials used, the quality and proportions of cement, aggregates and water used for making the mixture** and last, but not the least, on the **workmanship**. The composition of concrete is generally expressed in terms of relative volumes of cement, the fine aggregate (sand) and the coarse aggregate (gravel etc.) Thus, a 1:2:4 concrete indicates a mix having 1 part by volume of cement, 2 parts of sand and 4 parts of gravel or crushed aggregates. (In actual mixing, the relative volumes may be converted to weights of respective materials.)

6.2. CONCRETE–VERSATILE MATERIAL

We are virtually living in the Concrete Age. Concrete has become so important a material that it is used in almost every type of construction: buildings, roads and highways; tunnels, water conducting canals, storage dams and power-generating plants, airports and atomic power reactors.

Thus, in buildings concrete finds application right from foundations to topmost storeys in multi-storied structures, through floors at all levels and windowsills, and cantilevers and architectural fancies. In **transportation**, concrete is used in street walks, pavements, streets, highways, airports, traffic tunnels and foundations for ropeways. Concrete is also a material used extensively for **water storage and transport** such as in lining of canals and reservoirs, making of concrete dams, water treatment plants, water storage tanks (tube wells) and water conducting tunnels. In additions to the above **primary uses**, concrete is also used as a **coating material** for specific purposes such as for water proofing, fire proofing, sound proofing and shielding against radiations in X-ray plants and atomic power plants.

6.3. CONCRETE INGREDIENTS

As said above, the **essential** ingredients of concrete are

(*i*) **cement** or lime

(*ii*) Sand or such other **fine** aggregate

(*iii*) gravel, crushed stone or such a **coarse** aggregate, and

(*iv*) Water. A mixtures are added when required and are considered as optional ingredients.

The **function** of a cementing material (lime or cement) in the concrete is **to bind the coarse and fine aggregate particles together by setting and hardening around such particles.** Although Portland Cement is the most common cementing material used in concrete making, much research has been done to prove that lime (especially **hydraulic lime**) can also be used successfully for making concrete for **common type of construction.** Lime concrete is economical and is as strong for ordinary type of construction as cement concrete.

The **function** of the **coarse aggregate** is to act as **the main load-bearing component of the concrete.** When a good number of coarse aggregate fragments - all more than 6.35 mm in diameter are held together by a cementing material, their behavior towards the imposed loads is just like a **very strong rock mass.** Gravels and crushed stones are commonly used for this purpose.

The **fine aggregates** serve the purpose of **filling all the open spaces in between the coarse particles.** This way the porosity of the final mass is decreased considerably. The resulting set concrete is, therefore, quite massive, dense and hard besides being almost impervious. The maximum particle size in fine-aggregates is always less than 4.75 mm. However, **sand is commonly and universally used as a fine aggregate**, and its grains size is around 2mm.

We have already discussed in detail manufacture and properties of the cementing materials (lime and cement) in the preceding chapters. Some important details about aggregates are given in the following articles.

6.4. AGGREGATES

6.4.1. Qualities

As already defined, **aggregates are the inert materials that are mixed in fixed proportions with a cementing material to produce concrete.** These act as fillers or volume increasing components on the one hand and are responsible for strength, hardness and durability of the of concrete on the other hand.

Following are most important qualities of an aggregate for concrete :

(*i*) **It should be** chemically inert, *i.e.* **should not react with cement or any other aggregate or admixture used for concrete making.**

(*ii*) It should possess sufficient hardness to resist scratching and abrasion in the set and hardened concrete.

(*iii*) It should possess sufficient toughness to withstand impact and vibratory loads.

(*iv*) **It should be** strong enough to bear compressive and normal tensile **loads in ordinary concrete.**

(*v*) **It should be** free from impurities, **inorganic or organic in nature, which can effect adversely on the quality of concrete.**

(*vi*) **Last, but not the least, it should be capable of producing** an easily workable plastic mixture **(the concrete) on combining with cement, water and other aggregates.**

6.4.2. Classification

Aggregates are variously classified on the basis of their grain size, origin and volume/weight as follows:

(*a*) **Grain Size as basis.** This is the most common classification wherein two types of aggregates are distinguished: **fine** and **coarse** aggregates.

In the **fine aggregates**, the grain-size lies between 4.75 mm and 0.15 mm. In other words, these pass through sieve with mesh size of 4.75 mm and are retained on as sieve of 0.15 mm mesh size. Sand is the universally available and commonly used **natural** fine aggregate.

Coarse aggregate are those that are **retained** on the sieve of mesh size 4.75 mm. The upper size is generally around 7.55 mm. **Gravels** from river beds form the best coarse aggregates in the making of common concrete. In situations where these are not available easily, suitable rock types are crushed to the desired particle size for making coarse aggregates.

(B) Origin as basis. There are three types of aggregates recognized on this basis :

(*i*) **Natural aggregates**. These includes all those types of fine and coarse aggregates that are available in almost ready to use form from natural resources. Examples are sands from riverbeds, pits and beaches and gravels from riverbanks.

(*ii*) **Bye-product aggregates**. These include materials obtained as wastes from some industrial products which are suitable for being used as aggregates. Cinder obtained from burning of coal in locomotives and kilns and slag obtained from blast furnaces as scum are the best examples from this category.

(*iii*) **Processed aggregates. These are specifically manufactured for use in making quality concretes** and include burnt clays, shales, vermiculites and perlite. They are essential ingredients of **lightweight concrete**.

(C) Density as basis. Three types of aggregates are distinguished on the basis of their weight per unit volume :

(*i*) **Standard or normal aggregates**. These give concrete of standard strength and weighing around **2300-2500 kg/m^3**. Gravels, sand and crushed stone are all classes of standard aggregates.

(*ii*) **High–density aggregates** are those which when used in standard proportions yield heavy-concretes. Such concretes are specially useful as shields against X-rays and radiations in atomic power plants. **Barite**-a natural mineral with specific gravity of 4.3 is an example. **Concretes with such aggregates usually weigh above 4000 kg/m^3.**

(*iii*) **Lightweight aggregates**. These consist of natural and artificial materials of very low density so that the resulting concrete is also quite light in weight, generally within a range of **350-750 kg/m^3**. These concrete types find special application in **sound proofing** and **heat proofing** construction. They are also used extensively in the manufacture of light weight pre-cast concrete blocks.

6.4.3. Description of Common Aggregates

1. SAND. It is the most commonly used fine aggregate. Sand occurs as a natural product of rock disintegration and may occur in huge and thick deposits (pit sands), as riverbed deposits and as marine (beach) sands. Pure sand is made up predominantly of mineral Quartz (SiO_2, which is quite hard, H=7) and resistant to all types of chemical deterioration. The grain size of sand varies between 2 mm and 1/16 mm. The sand grains show variation in shape, size and purity depending on their mode of formation.

2. GRAVELS. Rounded and smooth surfaced pebbles with diameter greater than 2 mm are classed as gravels. These are generally deposited by river and glacial melt waters. River gravels are considered high quality coarse aggregates for concrete making. This is because they are uniform in thickness and outline. Moreover, they are free from salt encrustations.

Gravels may also occur in flood-plains along the sea coast (beach gravels) and in outwash plains (fluvio-glacial gravels). **All the above types may require thorough cleaning before they can be used for concrete making.**

3. CRUSHED STONES. All hard and strong types of rocks like granites, traps, sandstones and limestones are suitable for use as coarse aggregates when they are crushed to the desired size.

Trap rock (Basalt) and Granites are the best-suited rocks for making crushed coarse aggregates. They possess all the desirable properties like hardness, strength, toughness and resistance to deterioration in good measures. As such these rocks are crushed where available, in volumes of millions of cubic meters every year to be used as coarse aggregates for concrete. They are specially suitable where concrete is subject to a lot of abrasion as in floors and road surfaces.

Limestones and dolomites. These are sedimentary rocks of greatly varying properties. Some limestones (chalk) are very soft and unfit for use in quality concrete. Other (massive) are as good as any strong type of rock. Limestones, however, do not form a good aggregate for road-concrete. Their resistance to abrasion under traffic loads and also stability in frost conditions is comparatively very poor.

Sand stones. These are **very common sedimentary rocks** that form **excellent** concrete aggregates when available in pure form. The typical sand stone is made up of sand (SiO_2) particles naturally cemented, compacted or welded together. It is hard, tough and strong. There are varieties of sandstones in which sand particles are cemented together (naturally) by ferruginous, siliceous, calcareous and to some extent, argillaceous cements – siliceous sandstones should only be crushed for use as concrete aggregates. The other varieties will yield poor aggregates for obvious reasons.

From among other rock types, shales, slates and schists are particularly unsuitable as concrete aggregates. Marbles, quartzites and gneissic rocks are, however, quite suitable when found in massive and dense varieties. Marbles behave like limestone, quartzite like sandstones and gneisses like granites as concrete aggregates.

4. BLAST FURNACE SLAG. It comes under **artificial aggregates**. Slag is produced in blast furnaces during the process of manufacture of pig iron. Chemically, slag consists of silicates and alumino-silicates of lime. During last few decades millions of tons have been successfully used in different countries for making good quality concrete. Such a slag, however, has to pass a series of tests for its

(*i*) **chemical** composition.

(*ii*) **soundness** with respect to lime and iron, and

(*iii*) water absorption and bulk density.

Slag is generally a porous material. Only slags with bulk density of more than 1200 kg/m^3 are deemed suitable as an aggregate for use in concrete making. Of course, for making light-weight concrete, blast furnace slag is a very **suitable aggregate**.

5. BROKEN BRICKS. Concrete for ordinary type of construction may also be sometimes prepared by using **crushed burnt bricks** as coarse aggregates in place of gravels or crushed stones. For this purpose, the bricks should be of good quality and free from sulphates. These are first crushed and saturated before mixing with cement and sand.

6. LIGHTWEIGHT AGGREGATES. These are either natural materials like pumice, scoria and wood waste or artificial materials like clinker, fly ash, foamed slag and burnt clay which have been frequently used to manufacture light-weight varieties of concrete. In fact, **lightweight concrete has become an important material of construction because of its insulation characteristics.** As such many materials are specially processed to convert them into lightweight aggregates. Some are used because of their **inherent porosity** coupled with adequate strength. Following are a few light-weight aggregates:

(*i*) **Foamed Slag.** When blast furnace slag is treated while yet in hot stage, with a jet of water, **foam** is produced at its top. This is removed and forms the **foamed slag** on cooling and hardening. It is generally of white to grey colour. It consists of, beside the silicates, infinite number of minute air cavities which are **not** interconnected. The bulk density of such a slag is generally between 600-1000 kg/m^3. Such a slag has been successfully used to produce concrete for both structural and insulating applications.

(*ii*) **Cinders.** These are actually residues left after the burning of coal or coke at high temperature. They become available in large quantities on a regular basis in **thermal power plants**, railways and metallurgical plants. Cinder has been used in powdered form as fine aggregate in place of sand with satisfactory results. It is essential that **cinder should be practically free from unburnt carbon,** when recommended for use in concrete making. Bulk density of cinder varies between 800-1200 kg/m^3

(*iii*) **Hyalite.** It is an artificially processed aggregate. Hyalite is a trade name for **burnt crushed shales**. The shales are burnt in rotary kilns at temperatures around 1100°C. The resulting product is **hard and porous** and can be used both as coarse and fine aggregate on crushing.

(*iv*) **Lelite.** It is also obtained by burning shales but at much higher temperature around 1500^{0}C. The material becomes almost a **cellular mass** at that temperature because of escape of some constituents in gaseous form. Lelite concretes are good insulators. They are exceptionally resistant to heat. Their weight is between 1400-1600 kg/m^3.

(*v*) **Tufflite.** It is **light–weight** aggregate obtained by burning of clays of special type in sintering machines and the resulting porous mass is crushed to the desired grain size. The bulk density of concretes with tufflites varies between 1600-1630 kg/m^3.

(*vi*) **Perlite.** The processed perlite consist of **extremely lightweight aggregate made by burning natural volcanic rock**. Concretes made with processed perlite are suitable only for insulation purpose. Bulk density of perlite is very low - 90-160 kg/m^3. Another identical product is obtained by heating **vermiculite**, which is natural mica-like mineral; its **bulk density** is also very low: 96-192 kg/m^3.

6.4.4. Testing of Aggregates

It is now an established fact that the **nature and quality of aggregates effects to a great extent the quality and ultimate properties of the concrete**. It is, therefore, essential that aggregates are selected after thorough testing. Among the most important properties of aggregates that are commonly determined may be mentioned: resistance to abrasion, toughness, hardness, strength and soundness. A brief account of these tests is given below. For detailed information, the reader is referred to relevant BIS codes given at the end of the chapter.

1. **Resistance to Abrasion.** It is an important property for concreter aggregates especially **where it is subject to wear and tear**. It is determined by Los Angeles Test. A weighted quantity of the aggregate sample is put in a cylindrical drum of standard dimensions (diameter: 71 cms; length: 50.8 cm). This cylinder is revolved for 500 revolutions at a rate of 30-33 r.p.m. At the end of these **revolutions**; material is thoroughly cleaned of all the fines. The remaining aggregate (totally free from fines) is again weighted.

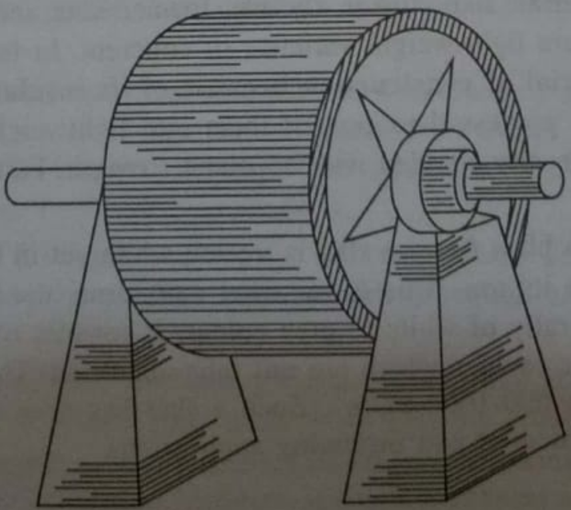


Fig. 6.1. Abrasion Resistance (Los-angeles Test).

The loss in weight (in percentage terms of the original weight) is calculated. **Best grade aggregates** are those which do not show a loss of weight more than 20 per cent of their original weight.

2. **Toughness**. This is defined as **resistance of the aggregates against impacts and pounding action**. It is determined by the Impact Test.

   In this test, a weighed quantity of the aggregate crushed to specified size is placed in a cylinder. This sample is then subjected to an impact of a hammer of 5 kg weight which is made to fall on the sample from a height of 50cm.

   After that, the sample is sieved through **specified sieve**. The weight of fines so obtained is recorded in percentage terms of the original weight of the aggregate sample.

   It is recommended that the percentage weight of fines shall not exceed the **specified limits** for different grades of aggregates.

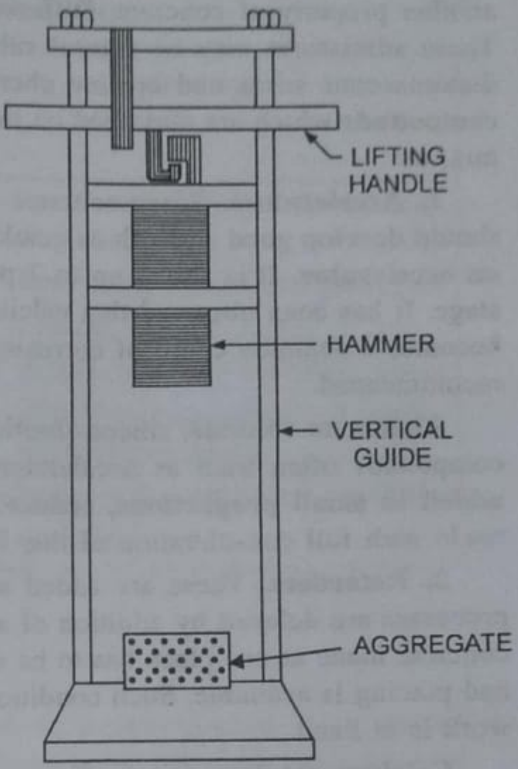


Fig. 6.2. Impact Test.

3. **Soundness.** It is defined as resistance of aggregates to disintegration due to **weathering agencies**. It is tested by subjecting the aggregate to repeated cycles of **freezing and thawing** and calculating the loss of weight due to disintegration. In another method, the aggregate is immersed in solutions of magnesium or sodium sulphate for **16-18 hours** at a time. It is taken out, dried and reweighed. Such a process may be repeated for 20 or more cycles. Total loss in weight after so many cycles will give a measure of the resistance of aggregate against deterioration by weathering agencies or sulphate action.

   It is agreed that a good aggregate **should not suffer** a loss of more than ten per cent after 15 cycles of any one of the above tests.

4. **Reactivity test**. In many parts of the world, **serious failures of concrete have been attributed to reactions between cement and some mineral aggregates**. Such reactions commonly result in the expansion of the concrete leading to its partial or complete disintegration. The reactivity in most cases is due to alkali content of the cement. Aggregates rich in cryptocrystalline silica such a **opal, tridymite, chalcedony** and some **rhyolites** are reactive towards alkalies of the cement. Their presence, therefore, needs thorough examination and testing at the selection stage.

6.5. WATER

It must be emphasised that **water is as essential a component of concrete as aggregates and cement.** Great care has to be exercised in selecting the **right quality** of water and adding **exact quantity** of water in the preparation of good quality of concrete. As regards quality of water, it is essential that it must be free from organic and inorganic impurities and soluble salts, especially from sulphates. Exact quantity of water to be added in concrete making is determined by using **cement–water ratio** principles as discussed in a subsequent article.

6.6. ADMIXTURES

Any material added in concrete making **besides three principal ingredients**, namely cement, aggregates and water is termed as an **admixture**. Such an admixture may be added to improve one or another property of concrete. **Different types of admixtures are used to obtain different results.** These admixtures may be natural substances like finely crushed glasses, silts, shales, volcanic ash, diatomaceous silica and opaline chert. Another category may consist entirely of **special chemical compounds** which are classified on the basis of function they are required to perform in the concrete mix, as:

1. **Accelerators.** When concrete is used for construction in **cold climates**, it is desirable that it should develop good strength as quickly as possible. **Calcium chloride has been used extensively as an accelerator.** It is added up to 2 per cent by weight of the cement in the concrete at the mixing stage. It has been observed that calcium chloride when used as an accelerator in reinforced concrete becomes a common cause of corrosion of reinforcement. Hence its use in R.C.C construction is not recommended.

Aluminum chloride, silicon fluoride, sodium carbonate and some silicates are few other chemical compounds often tried as accelerators in specific situations. **Almost all accelerators, even when added in small proportions, reduce the ultimate strength of concrete.** Hence, their use must be made with full consideration of this fact.

2. **Retarders.** These are added to **gain time in setting and hardening of the cement.** These processes are delayed by addition of a retarder in small proportion. This may become essential when concrete made at one place has to be used at some distance so that some additional time for transport and placing is available. Such conditions arise commonly in hot climates and where massive concrete work is at hand.

Calcium sulphate is an effective retarder. It is generally added in the form of **finely ground gypsum rock** of very high purity. Starch, sugar and some acids containing a hydroxyl group are other examples that serve to slow the rate of setting and hardening of concrete.

3. **Plasticizers.** These are also called **water reducing admixtures**. They are added to the concrete mix for making it more plastic without any further addition of water. In other words, they reduce the quantity of water required to make a concrete mixture of better plasticity. Since less quantity of water (about 5-10 percent less) is consumed, the resulting concrete also shows better ultimate strength.

Salts of hydroxylated acids are used commonly as water reducing agents. They are added in vary small proportions, generally below 0.5 per cent by weight of the cement in the concrete.

In some countries as Japan and Germany, special chemicals known as **super plasticizers** have been used to prepare highly plastic–almost **flowing concrete**. They are useful when concrete has to be placed very quickly in special situations.

4. **Air Entraining Agents.** Many properties of concrete such as frost resistance and durability are improved if it is made to contain a small quantity of air in the form of fine bubbles. The air-entrainment can be achieved by adding a small proportion of some chemicals at the time of mixing. Common compounds used for this purpose include:

(*i*) resins;

(*ii*) fatty acids and oils;

(*iii*) aluminum and zinc powders;

The volume of air-entrainment may cause considerable loss of strength of the concrete. In lightweight concrete, where insulation is a more desired property than strength, air–entrainment may be beneficially increased up to 30 per cent of the volume of the concrete.

The chief features of admixtures used in concrete are summarized in Table 6.1.

TABLE 6.1. Common Admixtures For Concrete.

S.No	*Admixture Name*	*Common Materials*	*Approximate amount/m^3 of concrete*	*Advantages*
1.	**Accelerators**	Calcium Chloride	1.2 to 6 kg	Accelerates setting and hardening of cement
2.	**Retarders**	Gypsum (Calcium Sulphate)	0.3-1 kg	Retards hydration and setting of cement.
3.	**Plasticizers (water reducing)**	Salts of hydro-xylated acids	0.3-1 kg	Reduce water cement ratio without effecting strength. Give highly workable concrete.
4.	**Air-Entrainments**	Fatts acids, oils, metal powders.	10-30 g of solids	Improve durability and insulating qualities.

6.7. PROPORTIONING CONCRETE MIXES

6.7.1. General

All important properties of concrete depend to a great extent on the **proportioning** of ingredients for the mix. This is also commonly referred as **mix-design**. By proportioning, therefore, is understood **"The process of deciding relative proportions of cement, sand and coarse aggregate and water."**

Although the quantity of water to be added to prepare a concrete mix is also of **utmost importance** and is determined thoroughly, in the final mix design only volumetric proportions of cement, sand and coarse aggregate are mentioned in that order such as 1:1:2, 1:2:3, 1:2:6 etc.

Different methods have been applied for deciding the best proportioning. The ultimate aim is to satisfy following three conditions:

(*i*) **Quality.** The mix will harden to a concrete of desired strength, durability and dimensional stability.

(*ii*) **Workability.** The designed mix will be sufficiently plastic in nature and mobile in character. This is essential that various components **should not segregate** during transport and placement. It should be **neither too stiff nor too soft**, but just of required consistency.

(*iii*) **Economy.** The designed mix must yield a construction material **which can easily compete** with other materials in terms of cost. Proper proportioning is said to have been achieved when concrete of **required quality** and **workability** can be prepared at **minimum cost**.

Following is a general account of different methods used commonly to determine Volumetric proportions for trial mixes of concrete. Often, more than one method may be used to prepare a trial mix for better results.

6.7.2. Arbitrary Proportioning

It is a common method adopted for proportioning at small jobs. It involves arbitrarily fixing the proportions of fine and coarse aggregates for 1 volume of cement. Obviously, it is the **experience of the worker** which will determine the quality, workability and economy of the resulting mix. It has been observed that for the common types of aggregates available in an area and for the general type of construction, an experienced hand will be able to fix proportions that will be **by and large satisfactory**. Arbitrary proportioning is, however, neither recommended nor used for **major construction**.

6.7.3. Water Cement Ratio

The **quantity of water** added to cement while preparing concrete mixes has been known to exert tremendous influence on the **quality of concrete**. It was first discovered in 1918, when D. A. Abraham evaluated this aspect of concrete proportioning and stated:

"For all plastic mixes using sound aggregates, strength and other desirable properties of concrete under given job conditions are governed by the net quantity of water used per sack of cement."

As said earlier, water performs **two essential functions** in concrete :

(*i*) It **hydrates the cement** which is an essential chemical reaction for formation of **complex silicate crystalline** gels that are responsible for the strength of the cement.

(*ii*) **It lubricates all the concrete ingredients** by passing around them in the form of films. Hence, it is responsible for the **plasticity and mobility** of concrete which define its workability.

It has been established from theoretical studies and experimental investigations that for ordinary Portland cement, 1 part (by weight) of cement will require about 0.25 parts (by weight) of water for **complete hydration, setting and hardening**. Naturally, while preparing a concrete mix, this much water is sufficient only for hydration. For lubrication and workability of the mix, **additional water must be added**. This additional quantity of water varies form **0.15 to 0.45** percent by weight of cement and has to be determined with great caution.

Most important aspect of this additional (lubricating) water is that it evaporates after the concrete is placed. This is also **released** during compaction. Both these processes (of escape of additional water) result in voids in the concrete. **And development of voids always reduces the strength of the concrete on setting**. Hence, an attempt is made to keep the ratio of water to cement **as low as possible to obtain a strong, dense concrete**. Any extra amount of water added to concrete ingredients at the time of mixing also favours segregation of aggregates during transport and placement. **This is another defect due to extra water** added to a concrete mix.

In order to determine the **water cement ratio** for the particular type of aggregates, trial mixes are made keeping in view the water–cement strength ratio. A lot of data is available on the latter relationship in all works on concrete construction. One such relationship is produced below in Table 6.2 as an illustration.

TABLE 6.2. Water-cement-strength-relationship for Concrete.

Water cement ratio	*Compressive Strength*
0.38	450
0.42	400
0.46	340
0.50	320
0.55	300
0.60	250
0.70	200
0.80	150

The above effect of **decrease in compressive strength with an increase in water cement ratio** is also illustrated graphically in figure 6.3. For a given type of cement, aggregates of same type and size, and same methods of mixing, the concrete develops a maximum compressive strength of 380 kg/cm^2 at a W/C = 0.4. When this ratio is increased to 0.5, 0.6 and 0.7 etc. the resulting batches of concrete show considerably **less compressive strength**.

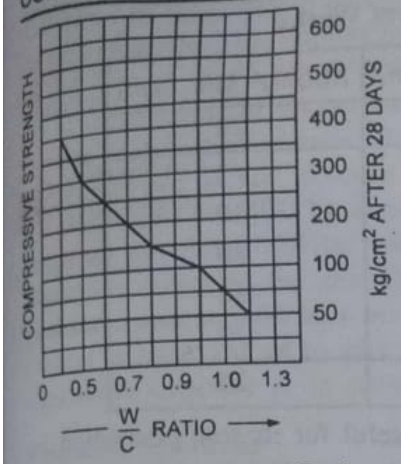


Fig 6.3. **Water-Cement Ratio Vs compressive Strength**

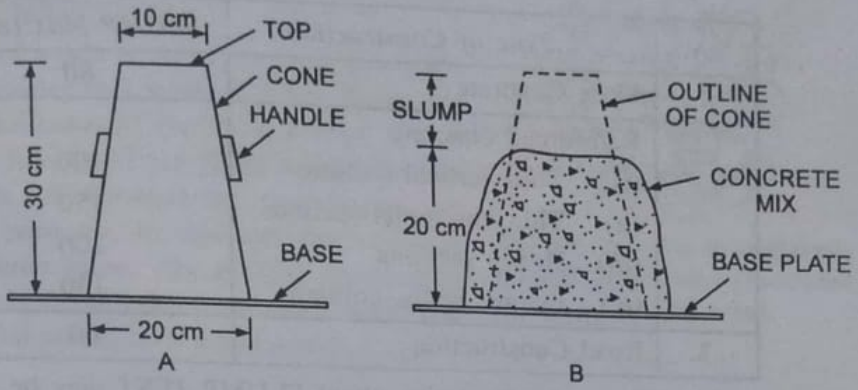


Fig. 6.4 (A) The Cone filled with concrete paste. (B) The Settled paste after the cone is removed

6.7.4. Slump Test

It is a common and quick test to determine the properties of various ingredients for preparing a concrete of desired consistency. The apparatus consists of a metal cone of 30 cm height and having diameter of 20 cm at the base and 10 cm at the top (Fig. 6.4) . A tamping rod of 60 cm length and 1.6 cm diameter is also required.

A **batch of concrete** for which consistency is to be tested is filled in the cone in a set manner. First, a layer of 10 cm is filled and rammed 20-30 times. Then second and third layers are also filled in the same manner and rammed. After filling the cone completely with the **fresh concrete**, the top is made smooth by removing any surplus concrete. **Immediately after this the cone is lifted up gradually without a jerk.** Since the concrete mix is yet in the form of a paste, it will not stand to its original height after the cone is removed. **It undergoes some subsidence, which is called slump**, before it finally becomes stable. This loss in height (original height – new height) of heap is called the slump. It is **indicative of consistency of the concrete sample.**

The consistency of concrete is usually described by such terms as **dry, stiff, medium, wet and sloppy** according to the slump recorded, as given in Table 6.3.

TABLE 6.3. Qualitative Description of Slump.

S.No.	*Consistency*	*Slump (in mm & inches)*
1.	Dry	Less than 25.4 (1)
2.	Stiff	25.4 - 68.5(1-2.5)
3.	Medium	68.5 - 137.0(2.5-5)
4.	Wet	137.00 - 203.20(5-8)
5.	Sloppy	More than 203.20(8).

Recommended Slump

No **hard and fast rules** are available for slump that should be adopted in concrete for different types of construction. There has been a tendency based mostly on experience, to recommend slump values for different types of works. These are, however, to be taken only as **general guidelines** and not as essential specifications.

TABLE 6.4. Recommended Slump For Different Works.

S.No.	*Type of Construction*	*SLUMP Max (mm)*	*SLUMP Min (mm)*
1.	Mass Concrete	80	20
2.	Reinforced concrete		
	(*i*) Thin vertical sections	100	40
	(*ii*) Thin horizontal sections	150	80
	(*iii*) Heavy sections	200	80
	(*iv*) Beams, walls, columns	130	70
3.	Road Construction	60	20

Following additional information about SLUMP TEST may be useful for its true perception :

1. Since its first development by Chapman in USA in 1913, the test has become a popular method to quickly determine the quality of concrete.
2. Despite its popularity, it is not **completely suitable** for deciding mix designs of concrete.
3. The shape of the slump is not consistent in all cases. In fact three types of slumps have been observed to occur.

   (*a*) **True Slump.** Where sliding is equal throughout the cone.

   (*b*) **Shear Slump.** Where one half from the top fails by shear and slides to one side; reduction in height is different in different directions.

   (*c*) **Collapse Slump.** This occurs in concrete of high water content; the material almost flows unequally in all directions.

   Considerable errors may creep in while determining the slump. To eliminate such errors, tests may have to be repeated a number of times.
4. Although commonly slump is understood to give an idea about workability of concrete, actually it does not do so. **Workability** is related to amount of work that is applied to obtain maximum density in concrete. Slump is not related to work. Same slump may be obtained with mixes that require different work to compact them. This is a major disadvantage of slump.
5. Slump has been shown to **decrease with an increase in the temperature of mixed concrete.**

In spite of above difficulties with the slump test, it is a cheap, quick and convenient method to establish quality control of some sort on concrete mixes.

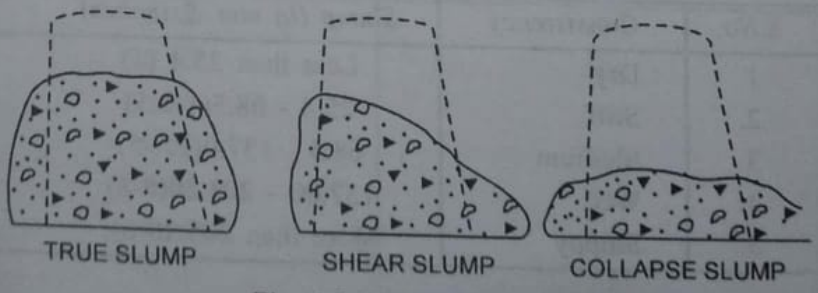


Fig. 6.5. Types of Slump.

6.7.5. Grading of Aggregates

When some materials of equal size are packed together, voids or open spaces are always left within the pack. The percentage of voids may be as high as 45 per cent of the total volume of stones. It has been observed that this result (presence of voids) is **independent of size of stones** used in packing, whether coarse, medium or fine. Only stones should be of **equal size,** that is, of same grade.

Either all of them should be coarse, or all of them should be medium or of fine grade. This implies that even if sand alone is packed, voids to the tune of 40-45 per cent are left.

This principle of **formation of voids is the governing principle for the preparation of concrete under this method**. When the coarse aggregates are packed to make the concrete the voids formed within the mass must be filled by some finer material. Sand is used for that purpose. But there will be voids left between the sand grains too. These are filled by the cement particles. In this way, the resulting concrete mass is **void less** or dense mass. The binding property of cement is made use of to give this dense mass a **cohesive stone like character.** Concrete is an artificial stone, in a broad sense.

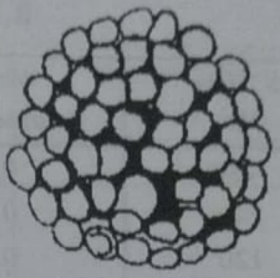


Fig. 6.6. Porosity in uniformly graded sand grains (indicated by shaded area).

Fineness Modulus

Grading of aggregates is aimed at determining the **mean size of the particle in a given batch of aggregates**. This is commonly found by the Method of **Fineness Modulus**. The method can be used to determine fineness modulus of coarse aggregates, fine aggregates and all - in aggregates or mixed aggregates. In this method a convenient weight of the sample is taken and passed through a set of sieves one after another. The number of sieves **is five for the coarse aggregates**, and ten for **all-in-aggregates**. It is only six in the case of **fine aggregates**.

Coarse Aggregates (five): 80mm, 40mm, 20 mm, 10mm, IS Nos. 480
Fine Aggregates (six): ISNo.480, 240, 120, 60, 30 and 15.
All-in aggregates : 80mm, 40mm, 20mm, 10mm
Nos (ten): 480, 240, 120, 60, 30 and 15.

It will be noted that each successive sieve has the diameter of mesh reduced to 50 per cent. Calculations involve dividing the cumulative percentage of weights retained on these set of sieves by 100. The resulting figure gives fineness modulus of the respective aggregate. This is illustrated in the following example. A weight of 10kg of **Coarse aggregate** and 5 kg of fine aggregate has been taken to determine fineness modulus in each case separately. Let us assume that the weight of aggregate retained in each case and the calculated cumulative percentage of retained weights are as follows :

TABLE 6.5. Fineness modulus.

A. COARSE AGGREGATE (Weight of sample: 10 kg)

IS Sieve No.	*Weight Retained (Kg)*	*Cumulative Weight*	*Retained (%)*	
80mm	0	0	0	Cumulative %age of weights retained on all the ten sieves = 675 Fineness Modulus of coarse aggregate = 675 / 100 = 6.75
40mm	0	0	0	
20mm	2	2	20	
10mm	4	6	60	
480	3.5	9.5	95	
240	0.5	10	100	
120	-	-	100	
60	-	-	100	
30	-	-	100	
15	-	-	100	
	10 kg		**675**	

B. FINE AGGREGATES (Weights of sample: 5 kg)

IS Sieve No.	*Weight Retained (Kg)*	*Cumulative Weight*	*Retained (%)*	
480	0.2	0.2	4	Cumulative %age of weights retained on all the six sieves = 292 Fineness Modulus of Fine aggregate = 292 / 100 = 2.92
240	0.8	1.0	20	
120	0.5	1.5	30	
60	1.2	2.7	54	
30	1.5	4.2	84	
15	0.8	5.0	100	
	5 kg		2.92	

Now, when it is desired to obtain a combined aggregate of a definite (required) fineness modulus F the amounts of fine aggregates (X) to be mixed with 1 volume of coarse aggregates of given fineness modulus can be easily determined from the relationship.

$$\boxed{X = \frac{F_c - F}{F - F_f}}$$

Where X = amount of fine aggregate (by volume) for 1 volume of coarse aggregate.

F_c = Fineness modulus of coarse aggregate.

F = Fineness modulus of desired combined aggregate.

F_f = Fineness modulus of fine aggregates.

The above relationship is illustrated in following example :

Required modulus of combined aggregates: $F = 5.5$.

Fineness modulus of fine aggregate; $f_f = 2.92$

Fineness Modulus of Coarse aggregate: $F_c = 6.75$.

To determine: Volume of fine aggregate (X) in percentage terms of volume of coarse aggregate:

$$\boxed{X = \frac{F_c - F}{F - F_f} = \frac{6.75 - 5.5}{5.5 - 2.92} \times 100 = 48.5\% \text{ Approx.}}$$

Limits of Fineness

Repeated trials with mix designs using different aggregates have shown that following limits of fineness moduli hold good for obtaining concrete mixes of good workability. Cement consumption is also reasonable when these limits are followed :

TABLE 6.6. Limits Of Fineness Modulus.

S.No.	*Aggregate*	*Max. Size (mm)*	*Recommended modulus Min.*	*Recommended modulus Max.*
(*a*)	Fine	–	2.00	3.5
(*b*)	Coarse	20 mm	6.00	6.90
		40 mm	6.90	7.50
		80 mm	7.50	8.00
		160 mm	8.00	8.50
(*c*)	Mixed	20 mm	4.70	5.10
		25 mm	5.10	5.5
		32 mm	5.2	5.7
		40 mm	5.4	5.9
		80 mm	5.8	6.3
		160 mm	6.5	7.0

The upper limit of fineness modulus is, therefore, always below **8.5** for coarse aggregates and 7.0 for mixed aggregates.

6.7.6. Minimum Void Method

In this method, the percentage of voids is determined **separately** for coarse and for fine aggregates. To balance the effect of voids, it is necessary to add some additional quantities of sand and cement.

Thus, for example, in two aggregates to be mixed, voids percentage is 40 and 30 for coarse and fine aggregates, respectively. Then the proportions of different ingredients would be decided as follows on the basis of minimum voids theory.

(*a*) Voids in coarse aggregate = 40 per cent

Sand required for 100 Parts (of these aggregates) = 40 parts.

Additional allowance = 10 percent = $\frac{10}{100} \times 40 = 4$ parts

Total proportion of sand = 40 +4 = 44 parts. ...(*i*)

(*b*) Voids in sand = 30 per cent

Cement required for 44 parts of sand (calculated at *i*) = 44 × 30/100 = 13.2

Additional allowance = 15 per cent =13.2 × 15/100 = 2.0(about)

Net proportion of cement = 13.2 + 2.0 = 15.2 ...(*ii*)

(*c*) Therefore, proportion of constituents may be fixed as :

Cement	: Sand	:	Coarse aggregate	
15.2	: 44	:	100	
1	: 2.8	:	6.5	...(*iii*)

6.8. MIXING OF CONCRETE INGREDIENTS

The main object of mixing the concrete ingredients (cement, sand, coarse aggregate and water) is to obtain a **uniform and easily workable concrete paste**. In such a mix each grain of aggregates is covered uniformly with a thick paste of cement with water. Mixing of concrete aggregates with water is done either manually or with the help of machines called mixers.

6.8.1. Hand Mixing

This is as yet the most common method applied for common construction. In this method, a **watertight platform** is made from bricks, steel or wood at a convenient distance from the actual **place of construction**. The cement and aggregates are first placed in predetermined proportions on this platform. They are mixed thoroughly in **dry state** using shovels. After this, water, also in predetermined quantity is added gradually while mixing is continued. This process is continued till concrete mix of **designed consistency** is obtained.

Only such **volumes of ingredients** are mixed in a batch so that the prepared concrete is used **within 30 minutes after adding water**.

6.8.2. Machine Mixing

For major construction jobs with concrete, machine mixing is an absolutely essential method. Concrete mixers of several designs and capacities are available

A simple concrete mixer essentially consists of a central drum, which can be rotated about an axis. It may be of titling or non-tilting design. It is invariably power driven. (Fig. 6.7) This ensures thorough mixing. The drum in the mixer is provided with steel blades fixed at various angles.

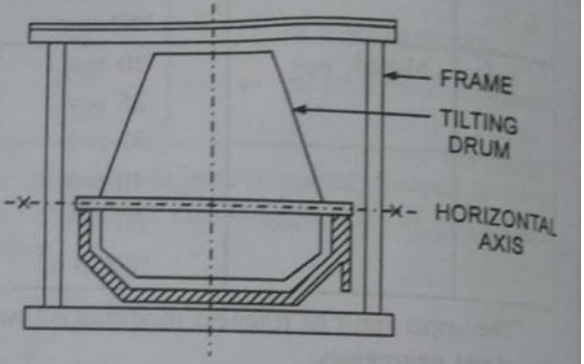


Fig. 6.7. A simple concrete mixer.

Concreter mixers are of **two** general designs: the **batch mixer** and the **continuous mixer**. In the batch mixer only a small quantity of concrete is prepared at a time. In the continuous mixer, predetermined proportions of ingredients are **continuously fed** from the top and volumes of concrete ready for use are available on regular basis.

Following **precautions** are necessary while mixing ingredients with mixers :

1. All the ingredients **are fed into the drum before mixing is started. And this is especially true for water, which must be added simultaneously with sand, cement and coarse aggregate.**
2. Great care must be taken about the time spent **on mixing the batch. It must be neither more nor less than required for complete blending. In either case, the quality of concrete will be effected adversely.**
3. After one batch of concrete mix is removed, **the interior of the mixer drum must be cleaned thoroughly. Otherwise, lumps of hardened concrete from earlier batches may form a part of next batch, and thus spoil the quality of concreter. This condition is valid for batch type mixers. In continuous mixers,** regular cleaning **after fixed intervals is necessary.**
4. Concrete from the mixer must be used within 30 minutes from the time of its preparation (that is when ingredients and water were added to the drum).

6.9. LAYING OF CONCRETE

Concrete from platforms or mixers has to be transported to the job place. There it is laid or deposited in the form work of suitable material according to the design requirements. Great care has to be taken in handling concrete from mixing place to the job as well as while placing it in the formwork. Following are main points :

6.9.1. Handling and Transport

The **coarse aggregates** are most likely to separate out (called segregation) quickly from the mix during transport. Hence great care must be exercised to prevent their segregation. **All sorts of jerks**

to the transporting medium must be avoided. Further, no water should be mixed with concrete while it is being transported. This will destroy the effect achieved by mixing the ingredients. **Careless dropping** at the place of construction will also result in segregation of coarse aggregates. This must also be avoided.

Common methods used for transporting concrete are: manual transport in iron pans; in wheelbarrows, in concrete buggies and in pipelines, belt conveyors and chutes. Selection of a particular method is decided according to the nature of job and type of concrete mix being transported. An experienced engineer is the best judge to take a decision in this regard.

6.9.2. Formwork

When concrete is to be placed in a building under construction for particular members as **floors, walls, beams, columns, arches** and **sills** etc, proper **formwork** is first made from suitable material to hold the fresh concrete. The role of this formwork is **no less important in the ultimate quality of concrete** work than any other aspect of concrete making. It is necessary that:

(*i*) The form work is **correctly designed** and properly tied up.

(*ii*) The form work is **perfectly watertight so that there is no loss of water** from the fresh concrete-after it is placed in this formwork.

(*iii*) The formwork is quite **rigid and strong** as to bear the load of the concrete.

(*iv*) **Before placing** the concrete, the inner surfaces of the formwork must be cleaned and wetted. This last precaution is necessary to prevent loss of water from fresh concrete.

(*v*) **While placing**, it is necessary that concrete is **dropped vertically** into the form work. **Inclined placing increases chances of segregation** of coarse aggregates. Further, it is essential that concrete is dropped directly, as for as possible, to its final position (rather than shaping it subsequently to position).

In addition to above general considerations, concrete is commonly placed in horizontal layers varying from 25 cm to 50 cm thick. For **massive concrete jobs**, enough care has to be taken for assuring bond between successive layers. For **placing concrete under water**, special considerations have to be kept in mind.

6.9.3. Consolidation

After its placement, concrete has to be compacted and consolidated. This is essential in order to make the **set concrete** perfectly dense and voidless. **Compaction is also essential in reinforced concrete to develop complete bond between the concrete and steel bars**. Incomplete compaction result in a concrete that is very weak in strength despite use of best materials in its making. Thus, a well proportioned concrete that has been carefully placed, may not develop full strength, even if only 3-4 per cent voids have been left in it during the setting process. **Voids cannot be removed once the concrete has become hard.** Hence, compaction and consolidation have to start soon after its placement.

There are at present two methods available for consolidation of concrete: consolidation by hand and consolidation by vibrators.

The **hand consolidation** uses common techniques such as delivering impacts on the freshly laid concrete with the help of suitable tools. Tamping, rubbing and spading are some of such methods. These methods can be applied for ordinary type of construction. For hand consolidation, the concrete mix has to be **sufficiently plastic**, with slump between 200-75 mm. **Stiff concrete mix offers resistance to consolidation by hand.**

In **modern concrete practice**, however, mechanical devices called **vibrators** which are run by power, diesel or compressed air are commonly used for the compaction and consolidation wok. These vibrators are available in number of designs falling in following three categories:

(*i*) Internal vibrators; (*ii*) Form vibrators; (*iii*) Surface vibrators.

(*i*) **The Internal vibrators** usually consist of **tubes** provided with small vibrating units. For achieving compaction, the vibrating head is inserted vertically into the freshly laid concrete. A number of such units may have to be inserted almost simultaneously at suitable distances from each other. These distances vary from 500 – 700 mm. The vibrators can give **300-10000 vibrations per minute** depending upon the type of vibrator. The energy released from such vibrations is usually high enough to compact the concrete before it is completely set. Thus, it is found that an internal vibrator of 50 mm diameter may be able to compact about 6 cubic meter of concrete with a slump around 50 mm.

(*ii*) **Form Vibrators**: They are called **external vibrators**. They impart vibrations through the form work to which they are thoroughly tied up. Such vibrators are used only when internal vibrators cannot be used because of the type of construction. Since in these vibrators, vibrations are first given to the rigid form work which in turn imparts them to the concrete, there is considerable loss of energy. Hence cost per unit volume for compaction with external vibrators is higher. These vibrators require very firm and rigid formwork. Vibrating tables, which are used for the manufacture of pre-cast concrete, are a class of external vibrators.

(*iii*) **Surface Vibrators:** These come in the form of **plates, pans and beams** and are used for compacting floor slabs, dams, bridge abutments, road surfaces and such exposed, flat surfaced concrete constructions. Their effective use requires that the thickness of the freshly laid concrete should not be more than 300mm. Otherwise; the basal layers of concrete may not get completely compacted.

Great care and caution are necessary for compacting the concrete properly. It requires very well trained and skilled manpower. Workmanship is the key word for assuring quality concrete work, especially, with respect to compaction. **Undercompaction and overcompaction** are both equally dangerous. They may destroy totally an otherwise very nicely designed and properly placed concrete structure.

6.10. CURING OF CONCRETE

Definition. Cement concrete has to be kept wet for a few days after its placement to ensure complete setting and hardening of cement. **Curing is the term used for the job of keeping the fresh concrete wet till the desired purpose of ensuring complete setting and hardening of cement in the concrete is achieved.**

6.10.1. Object of Curing

It is known that all the properties of good concrete are related to **perfect setting** of cement. It is also known that the process of setting involves complex **hydration reactions** which require a lot of water. A good quantity of water is added to the concrete ingredients while making the mix. After placing the concrete, some water from concrete may be lost due to evaporation. Hence, the first and foremost object of curing is to **provide enough quantity of water for cement to hydrate and set completely.**

Another object of curing is to maintain a **proper temperature in and around the concrete during the setting process.** This is because both freezing and drying temperatures hamper the process of setting of cement in a normal manner.

The **third and most important object** of curing is to ensure a concrete of good quality when set: strong enough to stresses, hard enough to abrasion and resistant to chemical attacks. Such a concrete is quite durable.

6.10.2. Methods of Curing

Different methods or procedures have been adopted for curing. A method is selected keeping in view:

(*i*) **The type of construction:** Such as those involving large horizontal surface areas as in roads, floors and airfields, or those involving **formed concrete** in walls, slabs, columns, beams, cantilevers and arches etc.

(*ii*) **The place of construction:** Whether indoor and damp situations (as inside a building) or outdoor.

(*iii*) **The weather conditions:** Whether concrete is being laid in cold climates or in dry and hot weather.

Depending on above factors, one or more of the following methods are used for curing of concrete.

(*a*) **Spraying of Water.** This method is ideally suited for almost all types of construction in most conditions. It involves spraying water with the help of hosepipes connected to main water supply lines. Its disadvantage lies in that in tall structures, **water spraying at top levels may hamper work on the lower floors**.

(*b*) **Ponding of Water.** It is next common method suited best for horizontal surface areas such as roads, floors and slabs. Small ponds, not more than 5 cm deep are made over the surface by raising temporary barriers. These ponds are kept filled with water for a number of days. **In hot weather, ponding is ideal method.**

(*c*) **Wet Covering.** It is another method suitable for flat surfaces and also for columnar and vertical surfaces after the form work is removed from them. In this method, covering made of straw, burlap, hessian and jute are soaked in water and placed over the concrete. These are kept moist for the entire period of curing. They are thought to be double-action. They prevent the evaporation from within the concrete, and supply the additional water required for hydration.

(*d*) **Use of Curing Compounds (Membrane Method).** This may be broadly described as chemical curing. In this method, some suitable chemical compounds dissolved in solvents are sprayed over the fresh concrete to be cured. The **solvent evaporates** leaving behind a thin film of the chemical compound spread over the concrete surface. This film has the characteristic property that it allows little or no evaporation from the concrete. Thus, if sufficient quantity of water has already been added at the time of preparation of **concrete**, it will **hydrate and set** and harden satisfactory without much additional water.

The thick film of chemical compound starts peeling off after sometime (2-4 weeks) leaving behind the properly cured concrete. Most curing compounds consist of different types of resins. A major disadvantage with the curing compounds is that continuous concreting is not possible with them. The cured surface will not make a firm bond with the new layer or thickness unless it is completely peeled off or removed from it. Still, on flat surfaces of single thickness the membrane method is used extensively in concrete constructions.

6.10.3. Time Required for Curing

This varies with the type of construction, place of construction and the type of cement used in concrete. Normally, curing of ordinary Portland cement concrete may take a **minimum of two days** after placement. On an average curing for 5 to 7 days gives better results in terms of achieving the objectives. Longer periods of curing are recommended for exposed surfaces to obtain a uniform finish in the concrete work.

6.11. PROPERTIES OF CONCRETE

6.11.1. General

Concrete is a **versatile construction material** of the present age. It has already considerably replaced use of stones, bricks, steel and timber - the traditional materials - in construction. In fact, by the term modern construction, we invariably mean concrete construction. This is because of following general qualities of concrete:

(*i*) Fresh concrete can be easily moulded into any designed shape in construction.

(*ii*) It can be prepared **on the spot** and given wide range of properties from easily available raw materials.

(*iii*) Hardened concrete is **quite strong, hard and resistant to chemical attacks.** In fact, the strength of concrete increases with age up to a certain time.

(*iv*) With incorporation of steel reinforcement, it can be made **very strong in tension also.**

(*v*) It is an economical material of construction.

For the right type of concrete construction, certain properties of this material must be tested. These properties can be best studied under two headings:

(*a*) Properties of fresh concrete;

(*b*) Properties of hardened concrete.

6.11.2. Fresh Concrete

Workability. The fresh concrete which may be expected to give the best results must possess the property of **workability.** This most important property of fresh concrete is considered to be the sum total of qualities like plasticity, mobility, slump and compatibility.

Workability, in simplest language, **is the ease with which freshly prepared** concrete can be **transported and placed for the job and compacted to a dense mass.** Obviously, such a concrete should be a **homogeneous mix** having the desired consistency. It should be capable of **spreading easily and uniformly** without inducing any segregation of the aggregates. While defining workability, the suitability of the concrete for a particular job is the most important factor. Thus,

(*i*) A concrete which is thoroughly plastic and contains high percentage of entrained air may be quite suitable (workable) for surface work and for vertical columns and walls. This is, however, not a concrete with right workability for tunnel lining work. In that situation, it may not be able to reach to the curves and corners of the lining. It lacks mobility because of less amount of water added to it.

(*ii*) **A concrete which is** quite mobile, *i.e.* **which can spread easily, may develop segregation** of **coarse aggregates from the rest of constituents during its transport and placing. This** is **also not a workable concrete.**

A workable concrete, therefore, should have a right balance between the plasticity and mobility for a particular job in hand. To develop such a balance, all the care has to be taken for selecting right type of aggregates, proper proportioning of cement, sand, coarse aggregates and water and a **thorough mixing** of the constituents.

Besides plasticity (or consistency) and mobility, the **third most important aspect** considered to define workability is the ease with which the **freshly placed concrete can be compacted** without developing any defects. This is called **compactability.**

Since workability depends on a number of factors, no single test is thought to be sufficient to express this property of freshly prepared concrete. For quality construction with concrete, following **three tests** are required to be carried out.

(*i*) Slump Test,

(*ii*) Compacting Factor Test, and

(*iii*) V-B Consistometer Test.

The slump test has already been described. It gives an idea about the consistency of the mix.

Compaction Factor Test. In this test (developed in UK by Glanville), samples of concrete are weighed first when partially compacted, and then weighed again after full compaction. The sample is compacted using specified techniques and apparatus. **The ratio between partially compacted weight**

to the fully compacted weight gives a measure of compaction factor. It is always less than 1. The reliability of this test has been questioned by many. Still, for very stiff and dry concrete, the test is often considered to be a good indicator of workability.

V-B Consistometer Test. In this test, developed by Bahrner in Sweden, **fresh concrete sample** taken in a metallic cone is compacted by a specified vibrator to an ultimate shape of a flat cylindrical mass. Total time taken for this transformation, in seconds, is recorded. This is called V-B time and gives a measure of compatibility of the concrete.

The test is by and large useful in determining workability of concrete mixes with aggregate size up to 20 mm. It is expensive compared to other two tests and is used generally in **precast concrete works**.

6.11.3. Properties of Hardened Concrete

Workability and related properties of **fresh concrete** are important for transport and laying of the fresh concrete. The properties which determine the quality of the **hardened concrete** broadly fall into following three groups :

1. Strength.
2. Durability.
3. Dimensional Stability.

A good quality concrete must meet the specified standards laid down for such properties.

1. STRENGTH. In simple language, by strength of concrete we understand maximum load the concrete can carry as expressed in terms of per unit area. In fact, high strength concrete is synonymous with good quality concrete in concrete work. These are the compressive strength and tensile strength which are considered most important properties of concrete.

Compressive Strength. It may be defined as the **maximum compressive load that can be taken by concrete per unit area without breaking**. It has been shown that with special care and control, concrete can be made to bear as high loads as **800 kg/cm^2** or even more. In practice, however, concrete with compressive strength between **100-500 kg/cm^2** can be easily made on the site for **common type of construction**.

The compressive strength, (also called the crushing strength of concrete) is determined by loading axially cube shaped (or cylindrical shaped, in USA) specimens made out of the concrete. The tests are carried out 3 days, 7 days and 28 days from a given batch after the casting of the samples. **It is the 28 days compressive strength which is taken as a standard value for concrete of a particular batch.**

It has been observed that the compressive (crushing) strength of concrete is influenced by a large number of factors, their number being mentioned in some books as high as 50. The most important of these factors are:

(*i*) **Type of Cement.** The composition, quality and 'age' of the cement used in making concrete influence the strength of the concrete made with it. Thus cements that have been stored for **considerable time** make concretes of **lower strength** despite all the other factors being the same. Cements with higher proportions of tri-calcium silicate produce concrete that show higher strengths, at least in earlier stages. Similarly, **finer** the particle size of the cement, **higher** is the ultimate compressive strength.

(*ii*) **Nature of Aggregates.** Sand and coarse aggregates form the other two essential components of concrete. A good bond between cement and the aggregates is possible only when the latter have **sharp edges, clean surfaces** and **rough texture**. Smooth and rounded aggregates result in comparatively poor bonds. Similarly, the aggregates used in concrete making should have in themselves good compressive strength. For example if chalk (very soft limestone) is used in making concrete instead of massive limestone, the resulting concrete will be weak in compressive strength because of the poor strength of the aggregate.

(*iii*) **Water Cement Ratio.** The compressive strength decreases, in general, with increasing water cement ratio (other things being the same). Hence, when minimum water has been used just to ensure complete hydration of the cement, the resulting concrete will give maximum compressive strength on proper compaction.

(*iv*) **Curing Conditions.** Great importance is attached to proper curing of concrete after its laying for obtaining maximum compressive strength. **Incomplete curing** and intermittent drying of concrete during the curing period may **cause a loss in the compressive strength** to the extent of 40 per cent or even more.

(*v*) **Weather Condition.** The same type of concrete placed in different weathers such as in extremely cold weather and dry hot weather may develop different strength values. The cause is related to **incomplete hydration** of the cement in the concrete.

(*vi*) **Admixtures.** Certain admixtures are added to the concrete at the **mixing stage** for achieving some specific purposes. It has been observed that **certain admixtures** especially calcium chloride increase the compressive strength. Some other admixtures (e.g. air entraining agents), however, effect the compressive strength **adversely** if proper controls are not maintained on water-cement ratio.

(*vii*) **Method of preparation.** Improper mixing of the concrete and **careless** transport and placing may result in poor strength despite best cement and aggregates used in it. It is the **workmanship** that determines the quality of the concrete work in ultimate analysis. A skilled worker can produce best concrete works despite some other deficiencies. An incompetent worker, however, may spoil the entire work despite being given the best designed concrete mix. The voids left in the concrete on compaction and curing have a profound influence on the strength of the concrete.

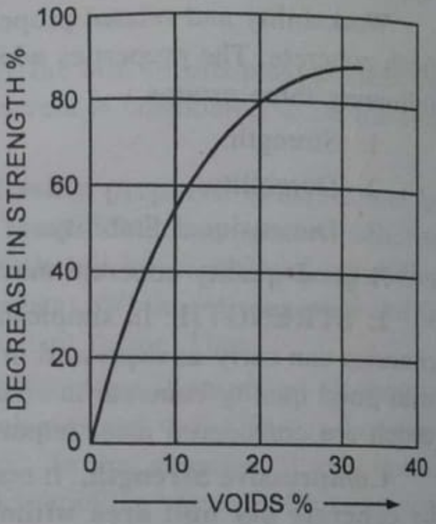


Fig. 6.8.

Tensile Strength. Plain concrete (without steel reinforcement) is **quite weak in tensile strength which may vary from 1/8th to 1/20th of the ultimate compressive strength**. It is primarily for this reason that steel bars (reinforcement) are introduced into the concrete at the laying stage to get a concrete **which is very strong in compression as well as in tension**. In plain concrete, tensile strength depends to a great extent on the same factors as the compressive strength.

Tensile strength of concrete becomes an important property when it is to be used in road making and runways. It is determined by using indirect methods. In one of such methods, it is deduced from the **flexural strength tests**. In these tests a beam of concrete is cast in standard dimensions depending upon the nominal size of the aggregate. The beam is properly cured and tested after 28 days. It is simply supported from below and loaded at its third point till failure. The bending moments, obviously, induce compressive stresses at the top and tensile stresses at the bottom of beam. The beam fails in tension. Modulus of Rupture or flexural strength is then calculated by using the usual beam formula:

$$\boxed{F_c = \frac{FL}{bd^2}}$$

where F_c = Flexural Strength ; F = maximum applied load.

L = Distance between supports; b = breadth; d = depth.

In the second indirect method, called the **split cylinder method**, cylinder of specified dimensions is made to fail under tension by applying compressive load across the diameter (Fig. 6.9). This is termed **Splitting Tensile Strength**. The testing machine is adjusted to distribute the load along the entire length of the cylinder. From the load at failure, tensile strength is calculated using following relationship:

$$\boxed{ft = \frac{2p}{ld}}$$

where : ft = splitting tensile strength in N/mm^2

p = maximum applied load in N.

l = Length of the cylinder (mm.)

d = diameter of the cylinder (mm.)

For approximate use, tensile strength of concrete may be taken between 10-12 per cent of its compressive strength as determined in methods already described.

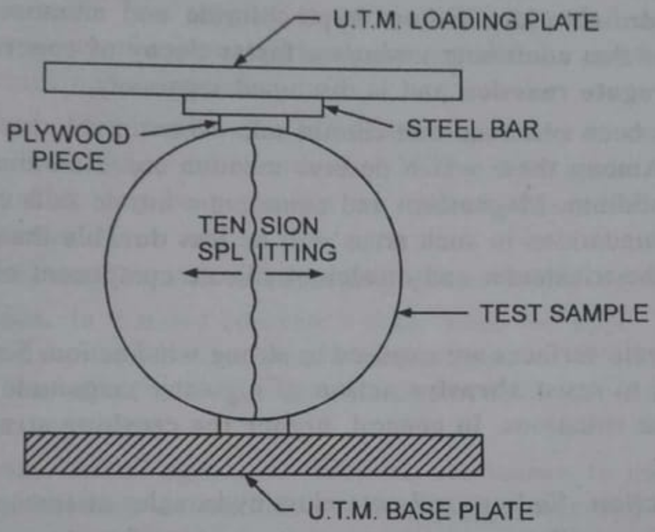


Fig. 6.9. Split Cylinder Testing for Tensile Strength.

2. DURABILITY. This is the second most important quality of hardened concrete. It may be defined as the **capacity of hardened concrete to withstand all the forces of deterioration that are likely to act on it, after setting, in a given environment.**

Among these forces, the following are more likely to act :

1. Frost Action.
2. Chemical action
3. Abrasive forces.
4. Alkali-aggregate reaction.

Frost Action. This is a major cause of deterioration of concrete in cold climate. It takes place due to freezing of water within the concrete pores and cavities during extreme cold. Water on freezing expands and exerts pressure on walls of the pores. Next summer the ice crystals formed melt (thaw) but freezing cycle is repeated in the following winter. **This cycle of freezing and thawing of ice crystals within the pores is responsible for development of cracks of various nature in the concrete.**

The concrete is known to have pores of various types, such as those called **gel cavities, capillary cavities** and **cavities due to entrained air.** This complex void system present in hardened concrete is the real cause of deterioration of concrete in cold weather. Methods have to be applied to minimize the development of these cavities. Among such measures, following may be mentioned :

(*i*) In cold weather, the water-cement ratio should be kept as low as possible. This will not allow any surplus water to remain within the concrete pores. Hence frost formation may be minimised.

(*ii*) Good drainage be used for removing any surplus water from staying in the concrete during curing process.

Chemical Attack. Concrete is liable to attack to various degrees by acids, alkalies and salt solutions. Among the acids hydrochloric, sulphuric, nitric and hydro-fluoric acid, acetic acid, lactic acid and formic acid are quite harmful to concrete.

The sources of theses acids can be from within or outside the environment in which concrete has been used. Thus, hydrochloric acid and sulphuric acid may be present in industrial and domestic sewage. They will destroy gradually the calcium hydroxide components of concrete used in sewage channels. In buildings where acids of one type or another are actually manufactured, care must be taken to protect concrete work from their leakage or vapours.

Similarly, traces of organic acids are common in food processing factories and dairy farms. Concrete works used in these buildings will gradually deteriorate from these acids at a fast rate.

Alkalies. Sodium hydro-chloride, sodium hypo-chloride and ammonium hydroxide are some common alkaline solutions that contribute towards a **faster decay of concrete**. Their destruction is mostly due to **alkali-aggregate reaction** and is discussed separately.

Salt Solutions. It has been observed that certain salts when in solution are quite harmful to the stability of the concrete. Among these which deserve mention are: aluminium chloride, sulphates of ammonium, calcium and sodium. Magnesium and ammonium nitrate salts commonly form a part of alkaline soils. Concrete foundations in such areas will be **less durable** than in alkali-free soils. The **salt solutions** react with the tricalcium and dicalcium silicate component of the cement and destroy its structure gradually.

Abrasion. Open concrete surfaces are exposed to strong wind action. Similarly, concrete used for flooring and pavement has to resist **abrasive action** of a greater magnitude. It will wear soon if not specially designed for those situations. In general, **higher the crushing strength of concrete**, higher is its abrasion resistance.

Alkali Aggregate Reaction. Sodium and potassium hydroxides of cements are capable of reacting with silica. Since **amorphous silica** is a common component of many coarse aggregates, such an alkali-aggregate reaction may create **harmful effects** on cement concrete. This is because the gel-like silicate structures produced by the above reaction are quite weak and unstable and result in **greater expansion**. These may be the cause of frequent cracking in some concretes. For avoiding this reactions, either the percentage of alkalies (K_2O and Na_2O) **has to be kept very low in** the Portland Cement (the low alkali cements) or great care has to be taken for **selecting aggregates free of amorphous silica** like opal, chert, cristobalite etc.

3. DIMENSIONAL STABILITY :

Creep. This is defined as the long time behavior of concrete under continuous load. It is now well established that concrete is not a truly elastic material. Also, it is not an entirely plastic material. When concrete is loaded, it deforms partly as a result of

(*i*) elastic strain (which is recovered on the removal of the load);

(*ii*) non-elastic (plastic) strain (a permanent deformation)

This latter non-elastic time dependent deformation is a typical property of concrete and is commonly referred as **creep.** Among the various causes of the creep, the following may be mentioned :

(*i*) **Closure** of the void - structures of concrete on application of load.

(*ii*) **Squeezing of water** from within the cement gel when the concrete is loaded;

(*iii*) **Flow of cement-water paste**, in a viscous state, causing a permanent shrinkage under load.

(*iv*) **Readjustment of aggregates** under load.

It is believed that the **proportion of mix and the type of cement used in concrete have profound influence on rate of creep**. Concrete mixes with higher water-cement ratio will also show higher creep rates.

Creep is thought to be **beneficial in some cases** and harmful in other cases. In reinforced concrete, **it helps in transferring stresses to the reinforcement** and thereby reduces chances of failure by stress concentration.

SHRINKAGE. Concrete undergoes **three types of shrinkage** that are important with respect to its dimensional stability: plastic shrinkage, drying shrinkage and thermal shrinkage.

(*a*) **Plastic Shrinkage.** This is the shrinkage that the freshly placed concrete undergoes till it sets completely. It may be also called **initial shrinkage**. Such a volumetric change is due obviously to loss of water from the fresh concrete due to evaporation, bleeding, seepage and soaking by form work. Excessive shrinkage at initial stage may develop extensive cracking in the concrete on setting. Therefore, all precautions should be taken to avoid excessive loss of water due to evaporation.

(*b*) **Drying Shrinkage.** When the concrete has completely set and hardened, some further shrinkage may result because of contraction of gel structure due to **further loss of moisture,** or drying (against the term evaporation used in the first type of shrinkage). This type of shrinkage is practically an essential and irreversible property of concrete. It has to be met with by careful design of reinforcement to avoid its bad effects (cracking of concrete.)

(*c*) **Thermal Shrinkage.** This may be due to fall in temperature of concrete from the time it is laid till it sets completely. Thus, when concrete laid at $30^0C \pm 5^0C$, cools down to 15^0C-18^0C, **some shrinkage** may be expected. It may be negligible on its own account. But when added to drying shrinkage, it becomes important.

EXPANSION. Concrete may expand on hardening due to following two reasons :

(*a*) **Thermal Expansion.** In massive concrete works, when the upper layers are laid before the lower layers have completely set, there can arise a phenomenon of thermal expansion in the lower layers. This is because the heat of hydration gets accumulated in those layers and may attain **magnitudes beyond acceptable limits**.

(*b*) **Chemical Reactions.** Alkali aggregate reactions are known to cause definite expansion in the concrete. The reaction between amorphous silica of aggregates and oxides of potassium and sodium from the cement used in aggregate results in crystalline structures of bigger volumes. This volumetric change becomes harmful because these gel-structures are not as stable and strong as those formed by reaction between calcium oxide and silica. They become the **cause of cracking and quicker deterioration of concrete.**

6.12. TYPES OF CONCRETE

The classification of concrete is based on three factors:

(*i*) Types of materials used in making of concrete.

(*ii*) Nature of stress conditions.

(*iii*) Density of concrete.

1. Plain Or Ordinary Concrete. It is the most commonly used type of concrete. Unless otherwise specified, by concrete is understood only ordinary concrete. **In this concrete the essential constituents are cement, sand and coarse aggregates designed and mixed with a specified quantity of water.** The ratio of essential constituents can be made to vary within limits. A very commonly used Mix Design, commonly referred as **Nominal Mix Design is 1:2:4.**

Plain Concrete is the most common material of construction for pavements and in building **where not very serious tensile stresses are involved.** It is also used for massive construction as in dams.

Among the most important properties of Ordinary Concrete, following may be mentioned :

(*i*) Density : 2200-2500 kg/m^3

(*ii*) Compressive Strength : 200-500 kg/cm^2

(*iii*) Tensile strength : 50-100kg/cm^2.

(*iv*) Durability : Very satisfactory.

2. Air Entrained Concrete. It is specially prepared plain concrete in which air is entrained in the form of thousands of uniformly distributed air globules by adding a small quantity of foaming agents at the mixing stage. Fatty acids, fatty alcohols and resins are some common air-entraining agents.

Air–entrained concrete is more resistant to :

(*i*) Scaling.

(*ii*) Deterioration due to freezing and thawing.

(*iii*) Abrasion.

3. Light Weight Concrete. Any type of concrete having a **density less than 1920 kg/m^3** is **classed as lightweight concrete**. Various types of aggregates that are used in manufacture of light-weight concrete have been already discussed. These include **natural materials** like pumice and scoria, **artificial materials** like expanded shales and clays and **processed materials** like perlite and vermiculite.

The single important property of lightweight concrete **is its very low thermal conductivity.** For example, thermal conductivity- the k value, for plain concrete may be as high as 10-12. Compared with this, the **thermal conductivity** of lightweight concrete is of the order of 0.3.

Light weight concretes are used, depending upon their composition, for thermal insulation, for protecting steel structures, in long span bridge decks and even as building blocks.

Aerated concrete is variety of extremely **light weight concrete** (density 480-800 kg/m^3). This is obtained by using a cement-sand-and powdered fuel ash as constituents. Blocks cast from this mix with proper quantity of water are then cured in an **autoclave** which is like **giant pressure cooker.**

4. High Density Concrete. It is also called **heavy weight concrete**. In this type of concrete the density varies between 3000-4000 kg/m^3 (against 2000-2500 kg/m^3 of plain concrete). Such a concrete is prepared by using high-density **crushed rocks** as a coarse-aggregate. Among such materials, **barytes** ($BaSO_4$) is the most **commonly used** mineral, which has as specific gravity of 4.5.

High density concrete is of immense value in atomic power plants and in other similar structures. It provides **good protection from all types of radiation.**

5. Reinforced Concrete. This is the most commonly used form of concrete and is designated simply as RCC meaning "Reinforced Cement Concrete". In this concrete, steel in various forms is used as **reinforcement** to give very high tensile strength to the concrete. In fact, it is because of the combined action of plain concrete (having very high compressive strength) and steel (having very high tensile strength) that this material (RCC) has been designated as a **revolutionary material in construction industry**. In India its use started in the third decade of the twentieth century. The steel reinforcement is cast in the form of rods, bars, meshes and many other conceivable shapes. It is placed in a pre-planned fashion over which concrete paste is poured carefully. Every care is taken to ensure maximum bond between the reinforcement and the concrete during the setting and hardening process of the latter. The resulting material is R.C .C capable of bearing all types of stresses in any type of construction. The reinforced concrete being the most important type of **concrete** has been described in some details in a subsequent article.

6. Precast Concrete. The real term should be "Precast Concrete Products". This refers to numerous types of concrete shapes that are cast into moulds either in a **factory** or on the **site**. These shapes, however, are not used in the desired construction **unless and until they have completely set and hardened under controlled conditions.**

Among the shapes that can be precast from concrete mixes, any conceivable form may be mentioned. For example: precast poles, fence posts, concrete lintels, stair case units, concrete blocks and cast stones. These structural and decorative members are prepared in a well-equipped place where all arrangements are made for:

(*i*) perfect proportioning of the **concrete constituents**;

(*ii*) **thorough mixing** of the cement, aggregates and water to obtain the mix of the desired design and consistency;

(*iii*) **careful handling during** transport and placement in the perfectly designed moulds and

(*iv*) perfect curing, under controlled conditions of temperature and humidity.

Even steam curing is used to obtain precast products having high strength in much less time.

The latest trend in construction industry is to use prefabricated concrete units in building construction. In India, precast concrete factories are coming up fast. The Hindustan Prefab Limited (established in 1951 and earlier known as Hindustan Housing Factory) New Delhi is a major unit engaged in the manufacture of prefabricated components of plain and prestressed concrete.

7. Prestressed Concrete. It is a special type of reinforced concrete in which **the reinforcement bars are tensioned before being embedded in the concrete**. Such tensioned wires are held firm at each end during the process of placing the concrete. The result is that when concrete sets and hardens, the **whole of the concrete member so cast is put into compression.** This sort of arrangement makes the lower section of the reinforced concrete also stronger against tension which is the principal cause of development of tension cracks in un-tensioned reinforced concrete

Since prestressing involves use of jacks and tensioning equipment, the prestressed concrete is also cast in the factories. As such it is mostly a **type of precast-prestressed reinforced concrete in its full description.**

Among the principal advantages of pre-stressed concrete may be mentioned:

(*i*) The **potential** compressive strength of concrete gets considerably increased;

(*ii*) The **risk** of development of tension-cracks in the lower sections of beams is considerably reduced;

(*iii*) The resistance to shear is greatly reduced. This eliminates the necessity of stirrups to a great extent;

(*iv*) Lighter members than the un-tensioned (normal) can be used in reinforced concrete.

The prestressed concrete is greatly favoured in the construction of :

(*i*) Concrete bridges.

(*ii*) Long-Span roofs.

(*iii*) Most structures with heavy dead weight.

6.13. REINFORCED CEMENT CONCRETE–R.C.C

6.13.1. General

The ordinary concrete has very high compressive strength but **it is low in tensile strength.** Thus when in construction, only the compressive loads are predominant this type of concrete may be quite safe. But where tensile forces are also involved, as in beams and slabs, there is every risk of its failure when plain concrete is used. Steel has very high tensile strength. When steel is incorporated as a part of concrete before it is set and hardened, reinforced cement concrete is obtained. This material, abbreviated as R.C.C has proved extremely useful and reliable in engineering construction.

6.13.2. Nature

The main principle in the preparation of the reinforced cement concrete is to make a structural material in which

(*i*) Steel serves the purpose of bearing the main **tensile stresses;**

(*ii*) Concrete bears the main **compressive forces,** both acting in complete unison.

Concrete and steel are compatible in following aspects :

(*a*) Concrete is basically alkaline in nature, (the principal component being calcium hydroxide) and this prevents rusting of the steel reinforcement used within it.

(*b*) The bond or grip between the steel and concrete is established easily; and,

(*c*) The **co-efficient of thermal expansion of concrete is almost identical** with that of steel. This prevents the risk of cracking due to expansion at different rates.

6.13.3. Types of Reinforcement

Reinforcement used in concrete is principally made of steel of different types. Further, it may be made in required shape and volume. Some common types of reinforcement are :

(*a*) **Mild Steel (MS) Bars.** These come in different diameter and are required to possess a characteristic strength in tension which is specified in relevant codes. The steel bars used as reinforcement can be commonly bent easily without cracking at the bends.

(*b*) **Hot Rolled Bars and Cold Worked Bars** are specially prepared reinforcement. The first type has a very high strength in tension which is almost double than that of mild steel bars. Further, as these come commonly in thick sections, they can be bent by heating (up to 100^0C) without developing any defects. This is not possible with the ordinary mild steel bars. Similarly, the cold worked steel bars come in twisted or stretched forms having elongated ribs or such structures along their length. They also have a much higher characteristic strength of the order of 425 N/mm^2 against 250 N/mm^2 of mild steel bars. **Such bars are not to be heated for binding.**

(*c*) **Steel Fabric.** This is made from a variety of bars and wires. These may include plain round wires, indented and deformed wires, deformed steel bars of cold–worked type. The mesh from such wires is made by welding together straightened lengths very carefully and strictly in accordance with the specifications. Otherwise, the mechanical properties of reinforcement may be effected adversely.

6.13.4. Placement of Reinforcement

It requires **very complex and careful designing considerations for each member** of **reinforcement concrete**. Thus, the size, shape, spacing and location of reinforcement will be entirely different in a slab or beam or a column. In beams, for example, steel bars may be required more in the lower sections. In fixed beams these are needed in the end sections as well where the tensile stresses are most operative. **The topmost section of the beam may need no reinforcement. The horizontal reinforcements are often tied up with square stirrups at suitable intervals.** These stirrups also provide additional strength to the RCC against shearing stresses. The reinforcement requires minimum prescribed covering of concrete. The covering is essential to protect the reinforcement from deterioration under attack from weathering agencies and also from casual fires. The concrete covering varies from 25mm to 80mm depending on the environment in which the RCC member has been placed. It is also important that the reinforcement must be clear of **rust, dust** and **grease** at the time of placement. This will ensure a **better bond** between concrete and reinforcement.

The subject of Reinforcement Concrete is a highly specialized civil engineering activity. The reader should study standard books on the RCC.

TYPICAL QUESTIONS

A. ESSAY TYPE

1. Give an account of desirable and undesirable qualities of aggregates for concrete. Describe main types of natural aggregates for concrete.
2. Explain the logic behind proportioning of ingredients in concrete making. Discuss some important methods for proportioning of aggregates.

3. Water-Cement Ratio is the single most important factor governing the quality of the concrete. Discuss the statement critically with the help of illustrations.
4. Better concrete work does not depend only on better calculations; It depends equally on better workmanship. Elaborate the statement.
5. Write critical notes on any two :
   (*a*) Curing of concrete. (*b*) Consolidation of concrete.
   (*c*) Dimensional stability of concrete. (*d*) Reinforced concrete.
6. Write short notes on any four :
   (*i*) Admixtures (*ii*) Air Entrainment (*iii*) Concrete Mixer
   (*iv*) Light weight concrete (*v*) Water-cement ratio (*vi*) Slump.

B. OBJECTIVE TYPE

Tick the right answer :

1. Plain concrete is made up of :
   (*i*) Cement + Sand + Coarse aggregate + Steel
   (*ii*) Cement + Sand + Coarse aggregate + Water
   (*iii*) Cement + Gravels + Pumice + Surkhi
   (*iv*) Coarse aggregate + Fine aggregate + Water.
2. The Water-Cement-Ratio indicates :
   (*i*) Volume of water to be mixed with 1 volume of Portland Cement.
   (*ii*) Volume of cement to be mixed with 1 volume of water.
   (*iii*) Volume of cement + water to be mixed with 1 volume of sand.
   (*iv*) Volume of water to be mixed with 1 volume of cement + sand.
3. As a general rule, with increasing water-cement ratio, the strength of the set concrete will:
   (*i*) increase (*ii*) decrease
   (*iii*) remain constant. (*iv*) fluctuate; *i.e.* has no definite relationship.
4. The aggregates are called fine aggregates if any they pass from and are retained completely on following set of sieves:
   (*i*) 4.75 mm – 0.15 mm (*ii*) 3.75 mm – 0.10 mm
   (*iii*) 2.75 mm – 0.5 mm (*iv*) None of the above.
5. All aggregates that pass from and are retained on flowing set of sieves are classified as COARSE AGGREGATES :
   (*i*) 7.55 – 4.75 (*ii*) 10 mm – 5.50 mm
   (*iii*) 15 mm – 6.75 mm (*iv*) None of the above
6. Curing of concrete is a process
   (*i*) For mixing the aggregates with cement, in presence of water;
   (*ii*) For careful transport of concrete from on place to another;
   (*iii*) For keeping the freshly laid concrete moist for a specific number of days.
   (*iv*) None of the above.
7. Steel reinforcements are added to the concrete primarily :
   (*i*) to gain tensile strength in the concrete.
   (*ii*) to improve the compressive strength of the concrete.
   (*iii*) to increase the shear strength of the concrete.
   (*iv*) none of the above.
8. Light weight concrete is made by
   (*i*) Reducing the percentage of coarse aggregates:

(*ii*) Increasing the air-opening in the concrete.
(*iii*) Using specific low-density aggregates;
(*iv*) None of the above

9. The fineness modulus of an aggregate is mean size of an aggregate as obtained by taking the percentage of the aggregate retained in a standard set of IS Sieves and then
(*i*) dividing the sum with the original weight of the sample;
(*ii*) dividing the sum with 100.
(*iii*) dividing the sum with 50.
(*iv*) dividing the sum with number of sieves through which it has passed.

ANSWERS: 1. (*ii*); **2.** (*i*); **3.** (*ii*); **4.** (*i*); **5.** (*i*); **6.** (*iii*); **7.** (*i*); **8.** (*iii*); **9.** (*ii*).

RELEVANT I.S CODE ON CONCRETE

1.	Coarse and fine aggregates form natural sources for concrete.	IS: 383-1970
2.	Code of Practice for plain and reinforce concrete.	IS: 456-1970.
3.	Code of Practice for general construction of Plain and reinforced concrete for dams any other massive structures.	IS: 457-1957.
4.	Methods of test for strength of concrete.	IS: 516-1959
5.	Method s of sampling and analysis of concrete.	IS: 1199-1959
6.	Code of practice for prestressed concrete.	IS: 1343-1960
7.	Burnt clay Pozzolana for concrete.	IS: 1344-1968
8.	Plain hard drawn steel wire for prestressed concrete.	IS: 1785-1966
9.	Batch type Concrete Mixer.	IS: 1791-1968
10.	Methods for sampling of AGGREGATES for concrete (8 parts.)	IS: 2386-1963
11.	Methods for sampling of aggregates (for concrete.)	IS: 2430-1969
12.	Code for Practice for bending and fixing of bars for concrete reinforcement.	IS: 2502-1963
13.	Concrete vibrators-immersion type.	IS: 2574-1970
14.	Concrete vibrating Tables.	IS: 2571-1970
15.	Code of Practice for laying in situ cement concrete flooring.	IS: 2572-1963
16.	Code of Practice for constructing hollow concrete block masonry.	IS: 2770-+1967
17.	Methods of Testing Bonds in RCC.	IS: 2770-1967
18.	Methods of tests for permeability of cement Mortar and concrete.	IS: 3085-1965
19.	Load Bearing Light weight concrete blocks.	IS: 3590-1966
20.	Concrete batching and mixing Plants.	IS: 4925-1968
21.	Ready Mixed concrete.	IS: 4926-1976
22.	Compaction Factor Apparatus.	IS: 5575-1969
23.	Glossary of Terms relating to cement concrete –in 12 parts.	IS: 6461-1972 1973
24.	Concreter Slump Test Apparatus.	IS: 7320-1974
25.	Code of Practice for extreme weather Concreting.	IS: 7861-1971

(The list is only partial.)

[Note: Most of these codes stand reaffirmed from 1990 to 1999.]

□□□

7

Timber

7.1. INTRODUCTION

Timber is one of the oldest materials of construction. Parts of trees were the first to be used by man for shelters even before he entered the age of civilization. From the prehistoric times till date, timber has been used in a variety of ways in building construction, bridge construction, in tunnels and many other engineering activities. Even at present, timber compares well with many other artificially made construction materials such as concrete and steel in many engineering properties. Among many qualities of timber, the following may be mentioned.

(*a*) It is a **natural material** and a **renewable resource**. With proper planning, trees can form inexhaustible source of construction materials. For concrete and steel, this is not true. Their manufacture depends upon such raw materials (rocks, ores and fuel) which once used are not created again within manageable time. They require millions of years to form again.

(*b*) It has **quite satisfactory engineering properties**. Thus, weight for weight, it has better strength than concrete and steel. Interestingly it is better in **fire resistance** than steel or reinforced concrete. Steel on heating softens and yields whereas in timber, as a structural member, heat travels from outside to inside at a slower rate and an inner unburnt part of timber beam may stay intact without collapsing if designed with a good factor of safety.

(*c*) It is **easily workable**. Any convenient shape can be given to timber by simple wood working processes.

(*d*) It is **durable**. If used with care and caution, timber parts can stay faithfully on their places for **many centuries**.

Timber is obtained from trees which are "living beings" in the real sense of the term. They are characterized with the processes of "birth, growth and death", almost in the same sense as applicable to other living organisms. Further, trees also pass through childhood, youth, maturity and old age. It is only the mature trees that are cut for obtaining good quality timber, which is strong and durable. The important parts of a **mature** tree are :

(*i*) a well developed **root system**;

(*ii*) a very strong and rigid **trunk**;

(*iii*) a well developed system of branches and leaves-called collectively as crown.

These parts are illustrated in Fig. 7.1.

Important functions of each system are :

(*i*) **The Root System** provides the support to the tree in the soil. It also supplies the essential minerals, salts and moisture required for the health and strength of the trees.

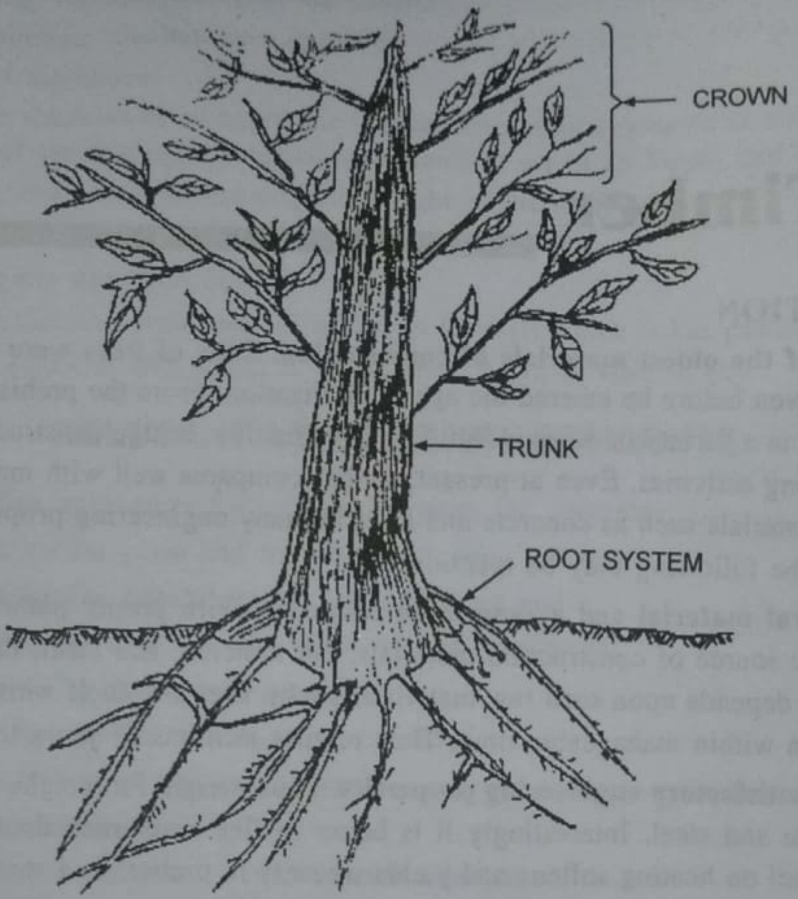


Fig 7.1. Major parts of a mature tree.

(*ii*) **The Trunk System.** It is the tree itself which is a part of living system of the nature. It is from this (trunk) that timber for use in construction (structural timber) is available. It is made up of a variety of tissues, which are themselves constituted by cells arranged and held together in a systematic manner.

(*iii*) **The Crown.** It includes branches and leaves spread around the trunk. They serve as receptacles (receiving stations) of essential raw materials for the tree from nature in the form of sunlight, carbon dioxide and moisture. The process of manufacture of food with the help of sunlight is called **"photosynthesis"** and is very important for life of the tree. Carbon dioxide absorbed from the air in the presence of moisture and light is converted into the carbo-hydrate compounds that form the living matter of the tree. In the process oxygen is released (during the day time only, because no photosynthesis can take place during night when there is no light). This released oxygen and the capacity of plants to use carbon dioxide make trees as most important natural assets of the environment on the earth.

7.2. GROWTH OF WOOD

There are two ways in which trees grow up: the endogenous growth and the exogenous growth.

In the **endogenous growth**, a plant grows by the **addition of new cells only at the end (tip) of the previous year's plant height**. (Fig. 7.2). Such a tree, obviously, grows **upwards** without becoming thicker and broader. They remain thin, slender and knotted. Examples are Bamboos, Palms and Yuccas. Endogenous timbers are **practically useless** as structural timber.

In the **exogenous growth,** the plant grows by the addition of a new layer of cells all around those grown in the previous year. This process naturally results in increase in the height as well as diameter of the plant. Result is a big, tall, fat-type of tree. Such trees have very well developed root systems and crown systems (because they require a lot of food). **Almost all the structural timber is derived from the trees having exogenous growth.** Among them we can mention the pines, deodar, walnut, teak, mango, shishum, spruce etc.

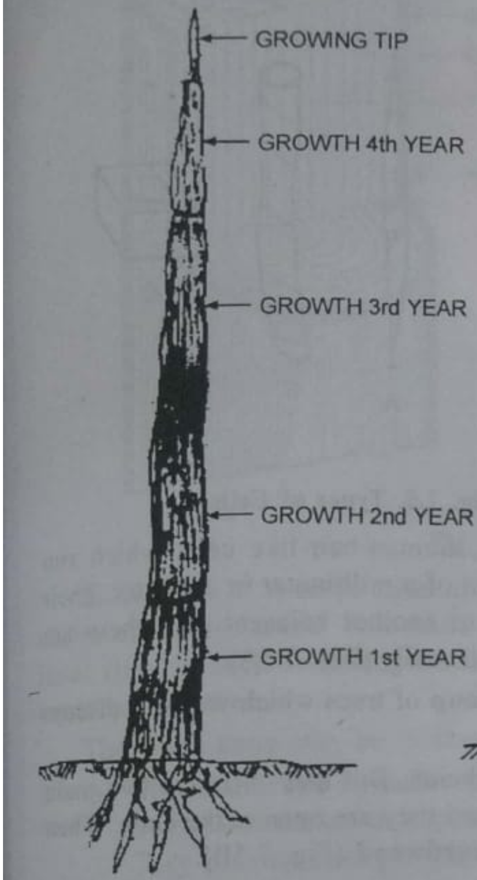


Fig. 7.2. Endogenous growth.

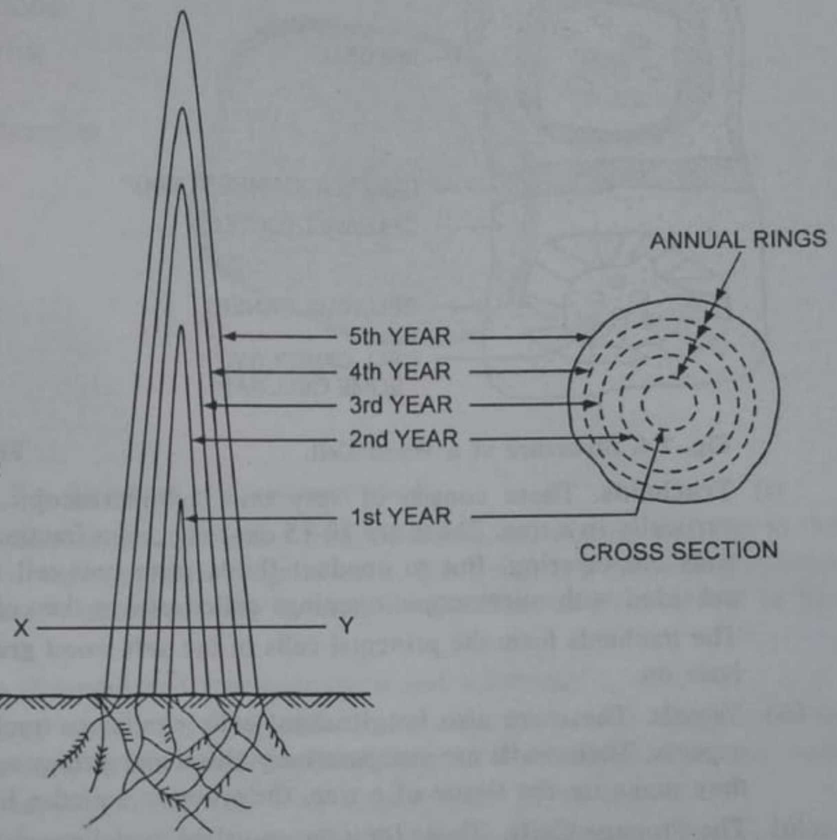


Fig. 7.3. Exogenous growth - Annual Rings.

As we shall see later on, these trees grown by exogenous process can further be classified depending upon the nature of the tissue of which they are made up. At this place, it may be mentioned that the **rate of growth** of trees varies with the season, the soil and the types of tree. **Spring is the season of fastest growth.** In winter growth almost stops.

7.3. STRUCTURE OF EXOGENOUS WOOD

The structure of exogenous wood may be conveniently studied under two headings: the **wood elements** (the units which make up the wood tissue) and the **arrangement** of these elements.

(*a*) **WOOD ELEMENTS**. The fundamental element in all types of wood tissues is a **cell**. It is a microscopic to sub-microscopic structure of different shapes and sizes. A typical (wood) cell consists of:

An outer wall, called the **cell wall** which is made up of lignin, starch and glucose. It is cell wall that is most important from engineering point of view. A cell wall may be **single or multi-layered**. In a multi-layered cell wall, the inner most layer is then called a **secondary wall** compared to outer layer called **primary cell wall**.

Within the (inner) cell wall is enclosed the cell cavity (also called **lumen**). It is filled with sap in the living cells.

Since wood tissue consists of thousands of such cells held together, the adjacent cell walls are separated by thin layers of tissue called **middle lamella**. (Fig. 7.4)

As said above, the actual size, shape and function of cell may differ in different parts of the wood tissue. Three primary type of cells of wood tissues are: (Fig. 7.5)

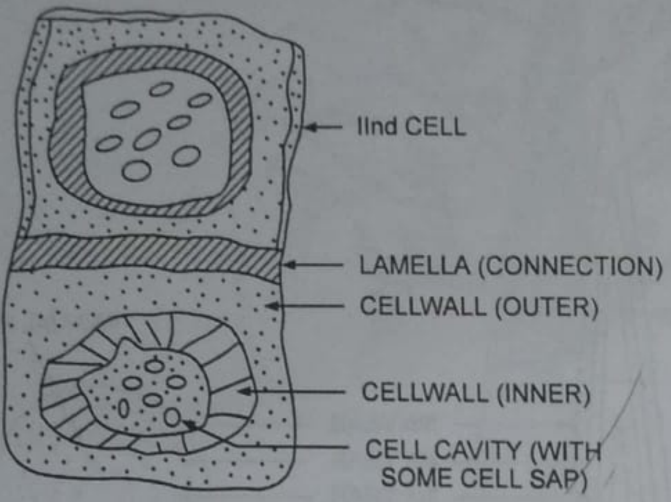


Fig. 7.4. Structure of a Wood Cell.

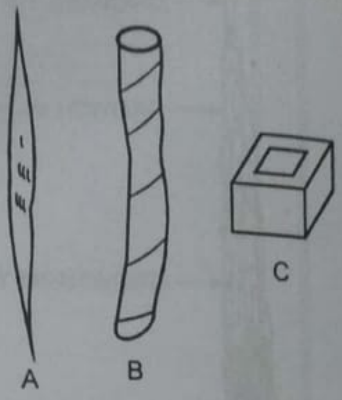


Fig. 7.5. Types of Cells.

(*i*) **Tracheids**. These consist of very thin, submicroscopic, human-hair-like cells which run vertically in a tree. These are 10-15 cm long and a fraction of a millimeter in diameter. Their ends are tapering. But to conduct fluids from one cell to another adjacent cell, these are provided with microscopic openings called pits in the cell walls (Fig. 7.5A).

The tracheids form the principal cells of the **soft wood group** of trees which we shall discuss later on.

(*ii*) **Vessels**. These are also **longitudinal cells** similar to tracheids. But they differ in two main aspects: Their **walls** are comparatively **thick** and strong; and they are open at the ends. When they make up the tissue of a tree, the wood is called a **hardwood** (Fig. 7.5B).

(*iii*) **The Storage Cells.** These form the so-called medullary rays that are developed radially (rather than longitudinally) and connect the outermost layer of the longitudinal cells with the inner layers. They are also referred as **Parenchyma.** In fact these are believed to serve a double function of **storage** and **conduction** of food through the wood tissue on the one hand and also, **holding of the longitudinal cells together** (Fig. 7.5C).

In a living tree, growth is achieved by the natural processes of cell division in a special layer of cells called cambium which is located just under the skin (or bark) of the tree trunk.

(b) Arrangement of Wood Elements

The wood elements namely the tracheids, vessels and rays are arranged in a definite manner to give rise to a typical structure of the wood. Following structural zones may be recognized in the stem of a mature tree (Fig. 7.6A, B).

1. BARK. It is the **outer most zone of wood structure** which can be described as **skin** of the tree. It is hard, rough and thick in some trees. In others, it may be comparatively smooth and soft.

The bark is further distinguished into an outer bark and an inner bark. This latter part forms only a thin, soft, moist membrane like structure. The function of the bark is to protect the inner wood tissue from heat, rain, wind and any injuries.

The Cambium. In the living trees, there is always present just inside, the inner **bark a delicate layer of special cells.** This layer is called cambium. It is in this layer that the process of growth of tree takes place by cell division. In old and cut trees, the cambium is no longer distinguished from the rest of the wood.

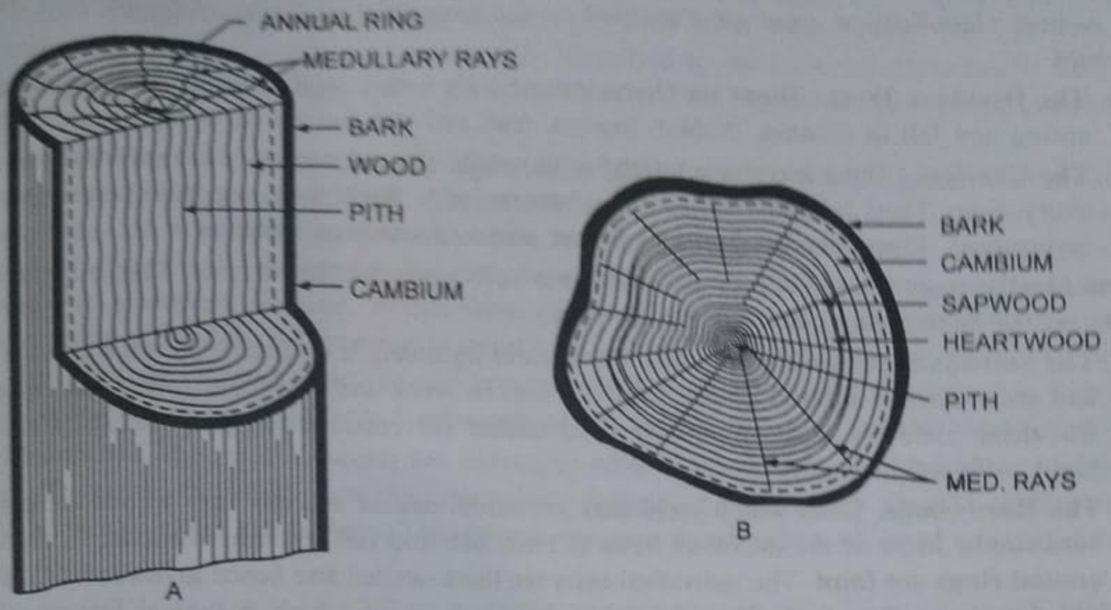


Fig. 7.6. Structure of Exogenous wood.

2. WOOD. It is **main zone** of the tree tissue. It starts from cambium and extends right up to the centre of the tree trunk. It is made up of concentric rings of cells. Each ring is surrounding another inner ring. In such an arrangement, the **youngest ring** is near the cambium and the **oldest in the centre of the tree.**

The **wood zone** may be further distinguished into heartwood and sapwood.

(*i*) The **heartwood** is made up of wood cells lying close to the core of the tree. They are older in age and darker in appearance. In the heartwood, cells almost **become inactive** and rigid. They provide strength and support to the tree. They contain little or no sap.

(*ii*) The **sapwood** is made up of new and light tissue that ties close to the skin or bark. In this zone, cells are **yet active** and alive and full of sap. They are, therefore, lighter in shade. In fact the very name 'sapwood' is because of their high sap content.

In **younger trees**, the ratio of sapwood may be much greater compared to heartwood. But as the age increases, more and more rings of cells get added to the heartwood zone. It is why the timber of mature tree is harder, stronger and better for use in construction.

(*iii*) **The Pith.** The innermost cells of heartwood become **practically inactive and dead** with the passage of time. These cells being in centre of the tree, receive little or no food (sap) in later years. Hence, they start deteriorating and decaying. The innermost zone of such decaying cells forms **pith zone of the tree.** The older the tree grows, bigger the pith zone becomes in size. This is the reason that older trees do not give sufficient yield of good timber.

3. THE MEDULLARY RAYS. These are made up of rectangular cells which arise from cambium and spread **towards the inner parts** of the tree. As said earlier, these rays besides making the food storage zone and sap conducting cells also serve the purpose of **binding of longitudinal cells** (tracheids, vessels etc.) together. (Fig. 7.6)

7.4. CLASSIFICATION OF WOODS

Botanically, trees are divided into two main subdivisions: the angiosperms and the gymnosperms. In the former, the seed is enclosed within a fruit (mango) or a nut. In the gymnosperms, however, the seeds have no such cover; they are produced naked. Pines are the best example of this group of trees.

In another classification, trees are classified on the basis of their leaves (foliage), into following two groups :

(*i*) **The Decidous Trees.** These are characterized with broad, well-defined leaves which grow in spring and fall in autumn. Walnut, mango, teak and oak belong to this group.

(*ii*) **The Conifers.** These are characterized with needle-shaped, very thin leaves which do not fall every year. They fall only when they become old. Such trees are also commonly called 'evergreen'. Pines, deodar, kail and fir are some of common conifers.

Structurally, trees are sometimes classified into softwoods and hardwoods. This may be treated, in a way, as the engineering classification of trees.

(*i*) **The Softwoods** comprise such trees which yield lightweight timber. They are lighter in shades and show distinct **annual rings**. They are soft to work and comparatively weak in strength. But these yield the most commonly used timber for construction purpose. All the conifers yield softwood.

(*ii*) **The Hardwoods.** Trees which yield dark coloured, denser and stronger woods are classed as hardwoods. Most of the decidous trees as teak, ash and oak yield hardwoods. In these trees, **annual rings are faint**. The individual cells are thick-walled and hence give additional strength and density to the wood. They do not yield much resins which is typical feature with soft woods.

Since structural timber may be derived either from the softwoods or from hardwoods, a few points of distinction must be on the fingertip of an engineer using the timber. Most important distinctive features are summarized in the table:-

TABLE 7.1. Distinction Between Softwood and Hardwood.

S.No	*Character*	*Soft Woods*	*Hardwood*
1.	**Structure**	(*a*) Made up of **tracheids** (*b*) The cells have thin walls and bigger cavities. (*c*) Wood is **soft**, less dense, and light in shades. (*d*) Annual rings are **quite distinct** and broader.	(*a*) Made up of **vessels.** (*b*) The cells have thick walls and open ends. (*c*) Wood is **hard**, denser and darker in shades. (*d*) Annual rings are thin, **faint and closer.**
2.	**Foliage**	Leaves are mostly sharp, needle shaped. They are not shed annually. The trees are evergreen.	Leave are broad, with well-defined leaf structures. They are **shed in every autumn.** The trees are decidous in nature.
3.	**Seeds**	Seeds are borne commonly in cones, where individual seeds are naked.	Seeds are borne either **within a fruit** or within a nut
4.	**Bark**	The outer bark is rough, tough, thick and strong. It **exudes resins.**	The outer bark is soft and smooth. **No resin** is exuded in most cases.

7.5. PROPERTIES OF WOOD

Most important properties of wood may be discussed under following general headings.

1. **Colour And Odour.** Most trees are characterized with a typical colour and odour. Thus, walnut wood is distinguished by its typical dark brown colour. Similarly, a freshly cut teak wood has a

golden yellow shade. The softwoods like deodar and pine show light (white) colours. As regards odour (smell), quite a few woods are immediately identified by their characteristic smell. Teak wood, for example, has an aromatic smell. The pines smell of resins. The colour and odour, however, may show variation.

2. Specific Gravity. Wood is a very **light material**, its specific gravity **being always less than 1 (that of water)**. Hence wood floats in water. It is interesting to note, however, that if the wood tissue is compacted in such a way that not even a few pores are left in it, then its specific gravity will approach [1.5] (*i.e.* it will become heavier than water and sink in it). **Such a compression is, however, not possible as a natural process.** Woods show good deal of variation in their specific gravity. Some varieties may be as light as 0.3 whereas in other varieties of timber the specific gravity may approach to 0.9. This depends on their structure and presence of pores in them. The heartwood is heavier than sapwood in the same tree. Similarly, hardwoods are always denser than soft woods as a group.

3. Moisture Content. All woods are porous to some extent. Further, all woods are hygroscopic in nature. They gain moisture from the atmosphere depending on moisture content of their cells vis-à-vis the humidity in the atmosphere. The natural moisture content, Mc, of wood is easily determined from the relationship :

$$\boxed{Mc = \frac{W_1 - W_2}{W_2} \times 100}$$

where W_1 = Weight of the natural wood sample.

W_2 = Weight of the same sample after it is **oven dried**.

The cell walls and hence the cell cavities of many woods are quite easily stretched when filled with water. As such, wood may absorb moisture more than 2 to 2.5 times than its own weight. Hence Mc values of natural (green) wood may sometimes be as high as 250 per cent.

Wood that has been lying in the air for quite some time (six months to one year) after felling, however, loses most of its moisture to the atmosphere. It loses further moisture by prolonged exposure (up to four years). **A moisture content of 12-15 percent of air-seasoned woods is considered quite safe for timber in any construction**. Woods can be seasoned in kilns to reduce their moisture content further, say, to less than 6-7 per cent of their dry weight.

4. Grain. By grain is understood the arrangement and direction of growth of the wood elements (tracheids and fibers and vessels) in the wood. In the normal wood, the tracheids and vessels (called collectively as **fibers**) grow parallel to the length of the tree trunk. This type of structure is called a **straight grain**. The fibers may be very **tightly and closely packed** giving rise to a fine-grained texture in wood. In other cases, they may be comparatively broad and quite wider. The structure is then termed coarse grained. Sometimes the fibres do not grow essentially parallel to the trunk. These may be arranged in a twisted, spiral or interlocked manner. This type of structure is called 'cross grained'.

5. Shrinkage and Swelling. The newly cut wood loses moisture when subject to drying naturally or artificially. On drying, the wood undergoes shrinkage. Similarly, dry wood on getting rain soaked or wetted may undergo considerable swelling.

It is known that in the **drying process**, moisture from the wood is lost **first from the cell cavity** and then from the cell walls. It is only when the water **is lost from the cell walls that the wood starts shrinking.**

Conversely, when dry wood is wetted, the water is first received by the cell walls. Only when the walls become saturated, water goes to the cell cavities. Hence, **on wetting, the swelling starts quickly.**

Thus, shrinkage and swelling are related to the behavior of cell walls of wood tissue towards water. It is now fairly established that:

(*i*) **Thick walled cells shrink more than the thin walled cells.** It is for this reason that the hardwoods shrink more than the softwoods.

(*ii*) **Shrinkage in longitudinal direction is least (0.1 to 0.5 per cent) whereas it is highest (7 to 15 per cent) in a direction tangentail to cell walls.** It is because in the latter case 'full width' of the cell walls is involved. In the radial direction, it is of an intermediate order.

(*iii*) **Deformation is caused in the board cut from timber due to shrinkage and swelling.** The extent of deformation will depend on the direction in which it has been cut with respect to the grain of the tree.

6. Strength. The most important fact about strength of timber is that it **is not the same in all directions**. This is because wood is an **anisotropic** material (having different structure in different directions.). Hence, the strength of wood is determined with reference to the **direction of grain of the wood** under load. Besides grain, many other factors also influence the strength of timber. These are:

(*a*) **Density**. Higher the density of timber, greater will be its strength. This is because high density of timber is a result of **thicker cell walls** *i.e.* greater amount of wood substance per unit volume.

(*b*) **Moisture Content**. Higher the moisture content, lower is the strength of the timber. This is because **water in itself has no load bearing capacity**. Its increased volume in the cell simply decreases the volume of the wood tissue. Moreover, higher amount of water in the cells may invite fungal and insect growth which destroy the wood tissue. They tend to reduce the strength in an indirect manner.

(*c*) **Presence of defects**. There may be a number of natural and artificial defects in timber such as cross –grain, knots and shakes etc. All of them cause a decrease in the strength of the timber.

Compressive Strength

Timber from most of the trees is amazingly strong under compressive loads-500 kg/cm^2 to 700 kg/cm^2. It is however to be noted that other things being same, the **compressive strength parallel to grain is always less than that determined at right angles to the gain in the same type of wood.**

Tensile Strength

Wood is **very strong to tensile forces acting parallel to grain** but very weak when these forces are made to act perpendicular to the grain. Thus, the tensile strength of some woods ranges form 500-2000 kg/cm^2 **parallel to the grain** whereas same values lie between 10-100 kg/cm^2 for the same varieties when tested perpendicular to the grain.

Transverse or Bending Strength

The most important use of timber **as beams** is based on the fact that wood has very high bending strength. It may vary from **300 to 900** km/cm^2 or more.

7.6. DEFECTS IN WOOD

A 'defect' in timber may be defined as any undesirable character-natural or artificial – that lowers its strength, durability or quality. Defects in timber are generally distinguished as natural defects and artificial defects.

(A) Natural Defects

This group includes all those defects (form engineering point of view) that are developed in a tree during its growth. Their development, therefore, cannot be generally controlled by man. Most common natural defects are: knots, shakes, cross grain, crookedness, rind galls, burr and curl.

Annual Rings

Shake Free & Sapwood-Heartwood Demarcation

Heart Shakes

Heart Shakes & Star Shakes

Ring Shakes

Knots as seen in Sawn Timber

1. KNOTS. A knot marks the position of growth of a branch on the tree. On the cut boards, it is most easily seen by its conspicuously darker appearance and harder character. A knot is **essentially a discontinuity** in the timber and hence a place of weakness.

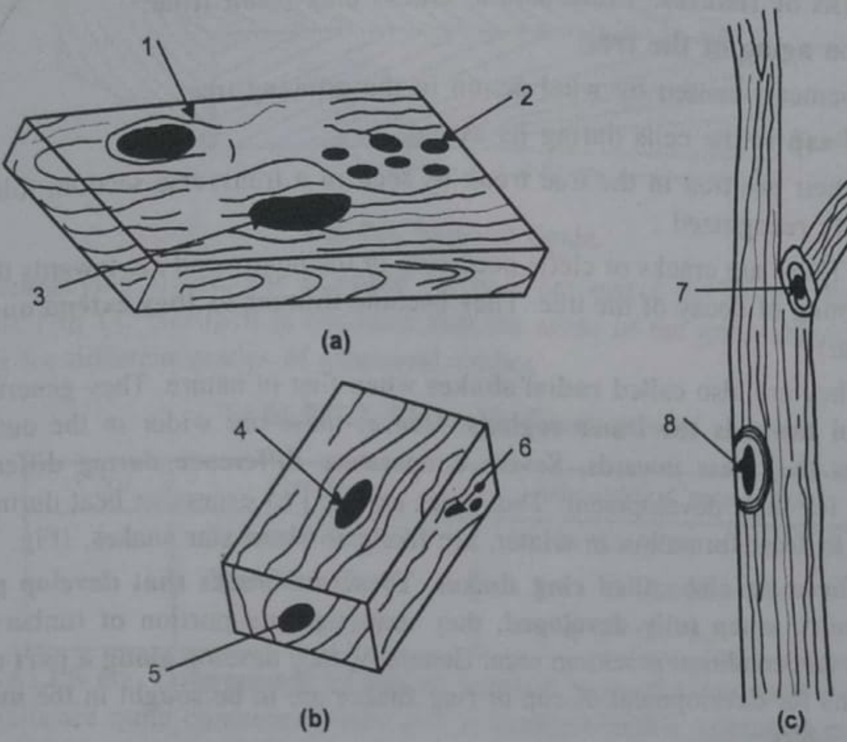


Fig. 7.7. Some types of knots.
1. Rounded; 2. Knot Cluster; 3. Elongated; 4. Face Knot; 5. Edge Knot; 6. Pin knot; 7. Live knot; 8. Dead Knot

Knots show great variation in their size, shape and stage of development. A few common types of knots are: pin knots, small knots, medium knots and large knots. This distinction is based on their diameter, which is, respectively less than 6.50mm, between 20-400mm and larger than 40mm. Similarly on the basis of shape, knots may be described as rounded, oval and spike knots. On the basis of their mode of occurrence, we may classify them as single knots, knot clusters or groups. Knots may also be distinguished into a tight knot and a loose knot, and so on. Some of the above types are defined as follows :

(*i*) **Live knot.** It is the part (root) of the branch that becomes completely enclosed within the growing trunk of a tree. In such a knot, there is complete structural continuity between the fibers of branch and the main tree.

(*ii*) **Dead knot.** In such a knot, the continuity of structure is almost lost or is only up to 25 per cent.

(*iii*) **An intergrown knot.** This is a term used when almost three-fourths of the fibers of the knot (perimeter) show continuation with the main tree.

(*iv*) **Encased knot.** It is a knot surrounded entirely by bark.

(*v*) **Edge knot.** It is seen only in sawn timber, on one edge of the cut portion.

(*vi*) **Face knot** is also seen on cut timber on the face of the board.

Knots of whatever type and shape are always to be considered as defects. They influence the quality of timber at least in two ways:

Firstly, they make the **workability of timber quite difficult.** They are harder and offer greater resistance to planing and polishing

Secondly, they **reduce the tensile strength of the timber**. Compressive and shear strength are, however, not affected badly.

2. SHAKES. After knots, shakes are more serious and common defects. In simple language they are also called **cracks or fissures**. These natural cracks may result from:

(*a*) shrinkage on **aging of the tree**;

(*b*) due to movements caused by wind action in the growing tree;

(*c*) **freezing of sap** in the cells during its ascent.

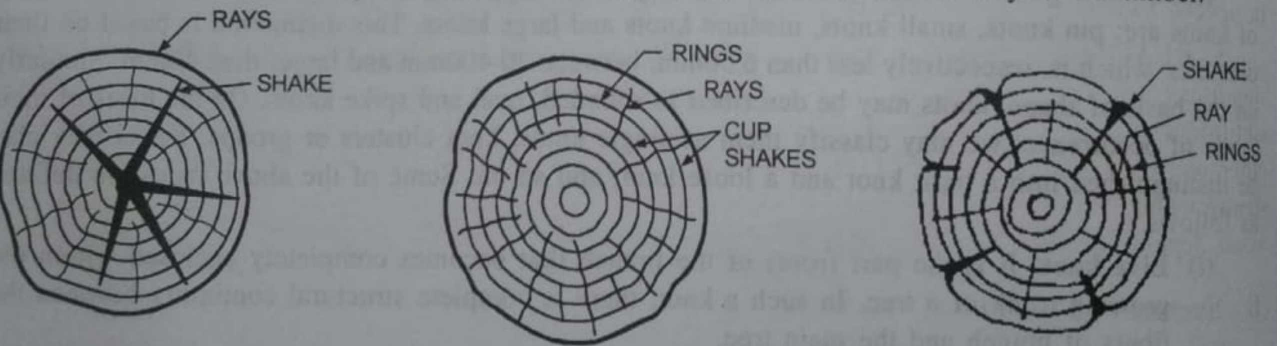
Depending on their position in the tree trunk as seen in a transverse section, following types of shakes are commonly recognized :

Heart shakes. These are cracks or clefts occurring in the heartwood *i.e.* towards the inner region. They indicate beginning of decay of the tree. They become **thinner as they extend outward** (towards sapwood). (Fig. 7.8*a*)

Star shakes. They are also called **radial shakes** when fine in nature. They generally arise in the sapwood and extend **towards the inner regions**. Hence, these are wider in the outer regions and become narrower as they pass inwards. Severe temperature difference during different seasons is generally the cause for their development. Thus trees exposed to excessive heat during summer and sever cold, leading to frost formation in winter, are likely to show star shakes. (Fig. 7.8*c*)

Cup shakes. These are also called **ring shakes**. These are cracks **that develop parallel to the annual rings**. As such, when fully developed, they may separate portion of timber longitudinally along the rings. But this condition is seldom seen. Generally, they develop **along a part of a particular annual ring**. Reasons for development of cup or ring shakes are to be sought in the **unequal growth** of the timber. (Fig. 7.8*b*)

The most important effect of the shakes on the timber is that the shakes **reduce its resistance to shear considerably**. As such, it is necessary to avoid use of timber containing shakes where severe shear stresses are involved. Another effect is that shakes allow an essay access of moisture and air to the interior of the tree along with insects and fungi. This reduces the durability of the timber.



(*a*) (*b*) (*c*)

Fig. 7.8. Various types of Shakes.

3. CROSS GRAIN. As said earlier, fibers of the wood in a normal tree are usually parallel to the axis of growth (length of timber). This structure is called **straight grained**. In some, cases, however, these fibers are not straight; they make angle or slope with the axis of the tree. The structure is then called **cross-grained**. In fact a minor slope (of grain) may be seen in most trees it may be quite harmless. The slope of grain becomes harmful (or a defect) when it **exceeds specified limits**. This is because the strength properties (especially compressive and tensile strength) are closely related to the direction of the grain vis-a vis direction in which the load is applied on timber.

The slope of grain is determined easily from a simple relationship :

$$\boxed{\textbf{Slope} = \frac{e}{L}}$$

where e is the maximum height (above a reference plane) of a reference grain or fiber, and L is the length of the same plane where the same fiber meets a horizontal line.

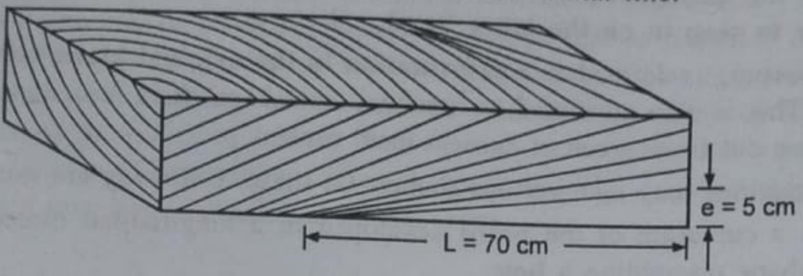


Fig. 7.9. Slope of Grain.

In the accompanying figure, for example 'e' is 5 cm and L is 70 cm. So, the slope in this particular case is 1 in 14. (5/70). It is desirable that the slope of the grain should be well within the allowable limits for different grades of structural timber.

TABLE 7.2. Allowable Cross-grain.

S.No.	*Grade*	*Allowable Cross Grain*
1.	Selected Grade	1 in 20 (5%)
2.	Standard Grade	1 in 15 (6.66%)
3.	Common Grade	1 in 12 (8.3%)

4. RINDGALLS etc. **Overgrowth** of timber in some parts of a tree may result in some typical defects. Rind galls are quite common. A rind gall is simply a highly thickened, enlarged wood cover developed over an injured part of the tree. It is a defect because it will have to be **removed first** of all for conversion of tree.

Burr and Curl are generally developed as **thickened overgrowths** on junctions betweens the tree trunks and a branch or between one branch and another branch. **Such overgrowths commonly result in severe twisting of fibers in the board cut from this portion.**

5. REACTION WOOD. In the growing trees strong winds commonly cause "shaking" of the standing trees again and again. As a reaction to such shaking action, wood in these trees develops additional strength in those parts where bending action is most severe and repeated very often. In other words, **within a tree there may be zones of normal wood and also zones of exceptionally strong wood.** These zones of reaction wood are further distinguished into tension wood and compression wood depending on which side of a bending tree they have been developed.

(B) Secondry (Artificial) Defects

These include such defects that develop in the timber **after its felling and conversion to different sizes.**

1. CHECKS. These are **cracks or clefts** developing longitudinally in the logs after their felling. These cracks or checks are **often cutting across the annual rings of the log**. In most cases, their origin is due to a simple cause of unequal drying. Thus, when a log of wood remains exposed to atmosphere only on one side, the upper side will lose more moisture than the under side.

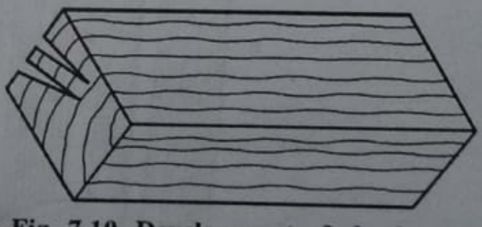


Fig. 7.10. Development of check in timber.

This will result in shrinkage in the exposed region to such an extent that tensile forces sufficient to cause a crack or cracks in the wood will be easily developed. The development of such checks could be avoided by changing the position of the timber log at regular intervals. This will ensure **uniform shrinkage** which will not allow the checks to develop. The effect of checks on the quality of timber is **that they reduce their strength on the one hand and allow the moisture to seep in on the other hand.**

2. WARPS. Warping is defined as a **deformation in the original plane surface of a board cut from the timber**. This is also attributed to 'unequal' shrinkage. It is most commonly developed in those boards that are cut from green or 'unseasoned' timber.

Warping deformations may take various shapes. Of these, following are more common:

(*i*) **Bow**. It is a curvature of the board developed in a longitudinal direction. The thin board takes the shape resembling **a bow**.

(*ii*) **Cupping**. It is distortion **developed transversely**. Length of the board remains unaffected but the width suffers distortion.

(*iii*) **Twisting**. It is a complex type of distortion in which one end of the board is so much distorted that it comes to lie over a part of the other edge.

The above distortions may be developed wholly or partly depending upon the thickness of the board and also on the extent of drying.

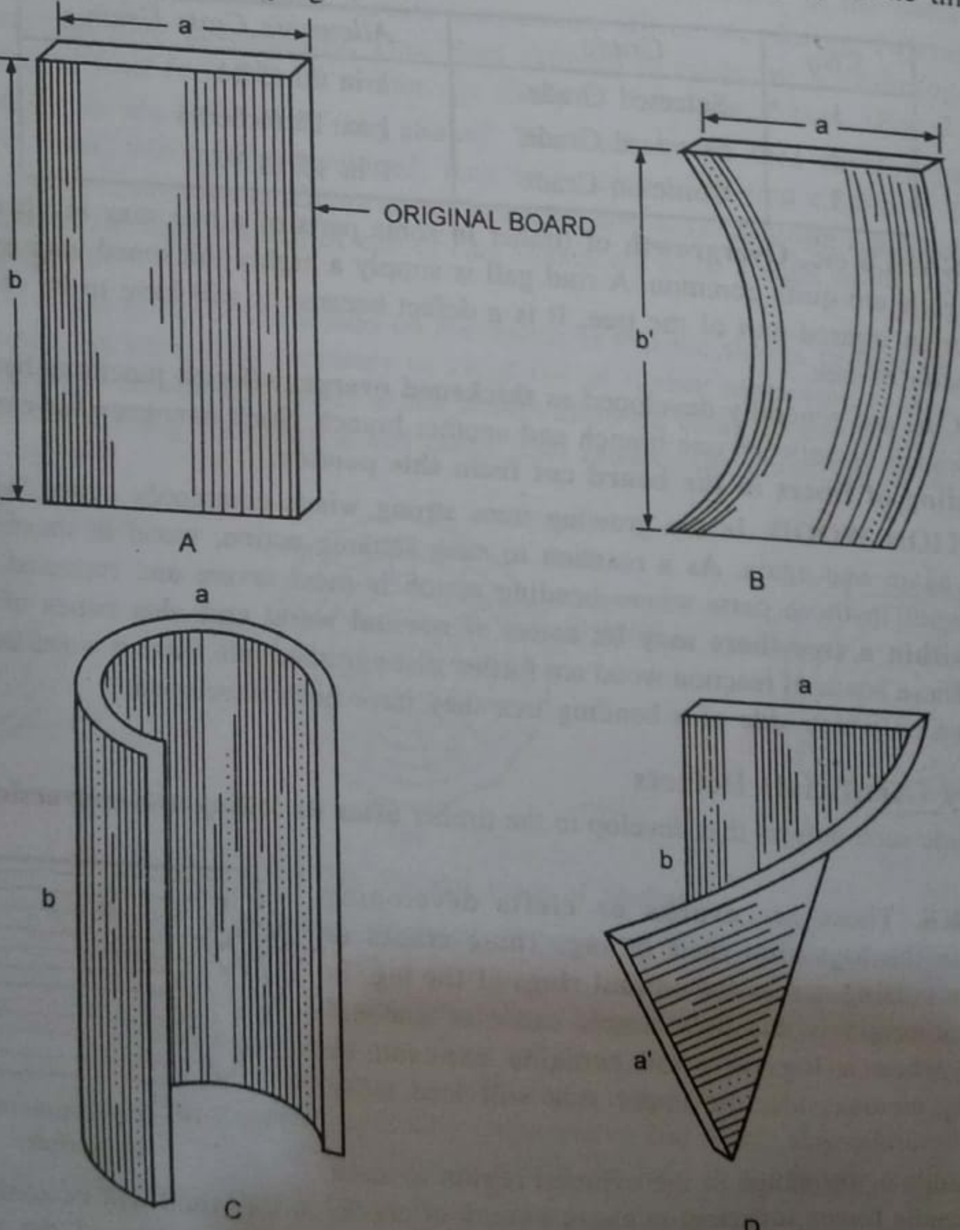


Fig. 7.11. Drying defects. A-Original; B-Bowing; C-Cupping; D-Twisting.

General Note on Defects

It is nearly impossible to obtain 'defect free' timber from natural wood. As such mere presence of so-called defects (natural or artificial) should not always lead to summary rejection of timber. It is the **magnitude of the defects** that has to be critically examined. Not only that, the intended use for timber will determine if the timber with some obvious defects deserves rejection. Thus, for instance, the presence of knots or shakes in a beam (L-B-D) will be harmful mostly **in the critical zones** of compression (C), tension (T) and shear (S) as shown in the Fig. 7.12. Outside and away from these zones, such defects may not be "defects" in real terms.

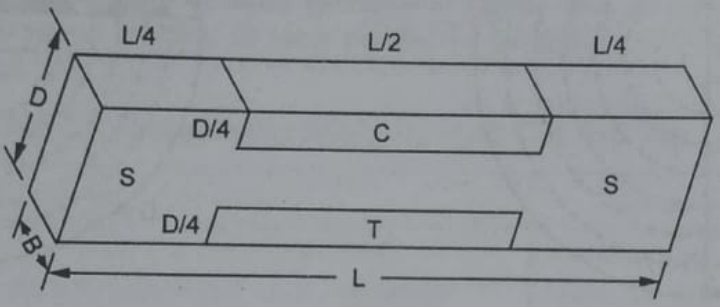


Fig. 7.12. Critical zones with respect to defects (see text).

Even in these critical zones, presence of just one or two such defects may be of not much significance. Their size, number and depth has to be determined carefully.

7.7. CONVERSION OF WOOD

Before the wood is actually used in construction, certain operations such as felling of trees, sawing them to logs and poles and beams etc, becomes essential. All these processes are described under the heading of 'conversion' of timber.

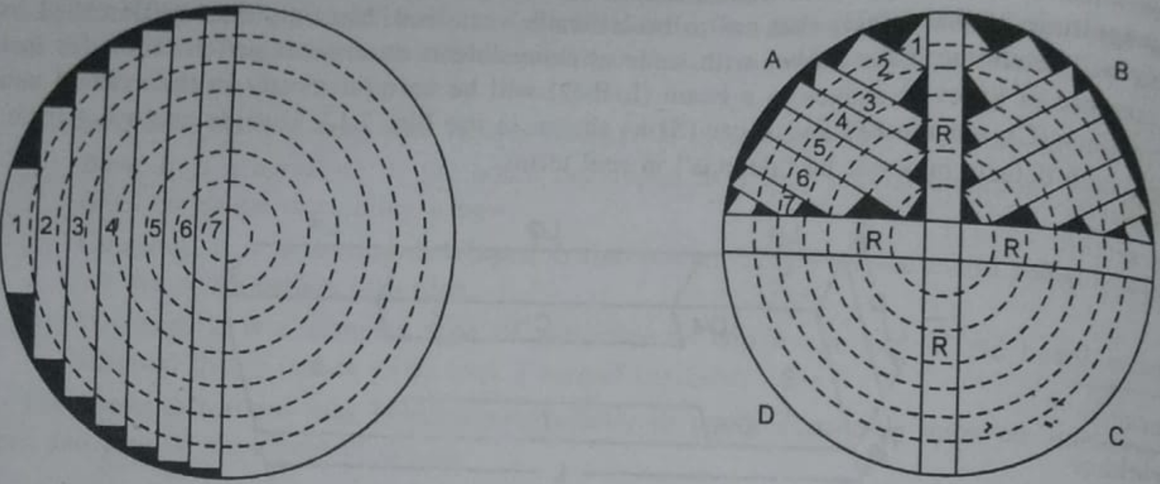
1. FELLING. Following two factors should be given due consideration before felling trees for use as structural timber.

(*i*) **Maturity**. Trees become mature only after certain years when there is a good **balance established between their heartwood and sapwood**. In mature trees, growth rate is reduced considerably, and they have achieved height and girth of standard characteristic for their species. **Only such trees should be felled for use in conversion.** Felling young and immature trees will give mostly sapwood. Moreover, these will prove uneconomical as these could have still grown to give **greater volume of timber** if left intact for a few more years. **Too old trees will also give poor quality of timber** as their inner part (heartwood) starts decaying with age. Hence, **the mature trees are the best bargain for construction timber.**

(*ii*) **Time of Felling.** Spring and summer are always "bad seasons" for felling of trees. This is because spring is the season of active growth for most trees. The cells are rich in sap. Summer is bad because the trees will lose sap at a much faster rate during this period after felling. This "fast drying" is likely to cause development of a large number of shrinkage defects. Obviously, the best time for felling trees is **autumn and beginning of the winter**. There is no growth of the tissues in living trees on the one hand during these months and also, after felling the shrinkage defects will be minimal. The local working conditions also form an important consideration in choosing time for felling of trees for construction.

2. SAWING OF TIMBER. After their felling, trees are usually cut diametrically in convenient lengths. These are called "logs". Collectively, these are called **Round Timber.** The round timber or logs are first air seasoned for some period and then further cut into transportable parts. The main methods of sawing of the logs are: through and through sawing and the selective sawing.

(*a*) **Through and Through Sawing.** In this method, **the log is cut lengthwise into pieces of suitable dimensions**, one after another, without giving it any rotation during sawing. **All the cut surfaces are thus essentially parallel** (Fig. 7.13*a*).



(a)

(b)

Fig. 7.13. Sawing methods (*a*) Through & Through (*b*) Selective Sawing.

(*b*) **Selective Sawing.** In this method, the **log is rotated** in different directions after one or more successive cuts in a particular direction (Fig. 7.13*b*). The log is first cut into four sections A, B, C, D by sawing along R-R. This may be done to eliminate defects during sawing itself or for obtaining specific types of boards containing wood from particular wood zones (heartwood-sapwood). This method is also used to obtain wood board of a particular grain. Two varieties are :

(*i*) **Slash-cut** (Flat grain or plain sawed). These are the boards that **have been cut in a direction tangential to the annual rings**. In such boards, the annual rings make an angle of less than 45^0 with the face. Such boards are also termed as flat grained, giving a plain appearance (Fig. 7.14).

(*ii*) **Rift Cut** (Vertical or Edge Grain). These are boards in which the **annual rings make an angle of more than 45^0 to the face**. Such boards are obtained making parallel cuts through the central parts of the log traversing through the annual rings.

Slash cut and rift cut boards differ in their important properties to a good extent. In fact, **the type of 'cut' of the board is important in determining its use in some cases.**

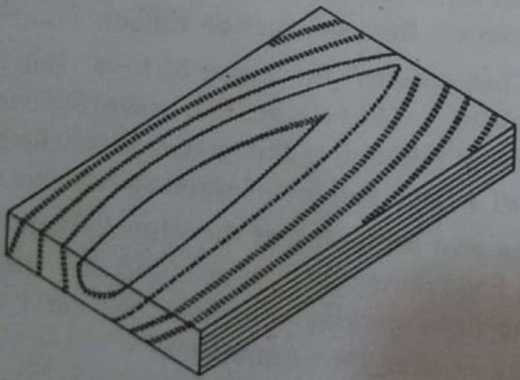


Fig. 7.14. Slash Cut.

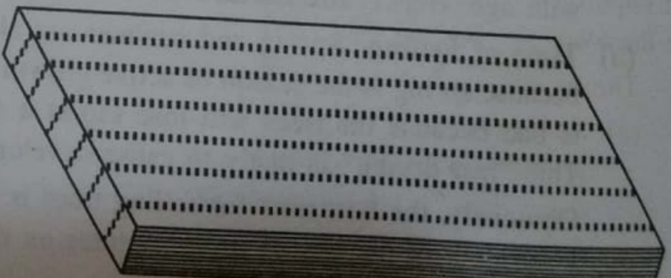


Fig. 7.15. Rift Cut.

A brief comparison between the properties of the two types of boards is, therefore, given in the Table 7.3

③ **QUARTER SAWING.** It is a process of **selective sawing of the logs**. The main aim in this type of sawing is to obtain specially attractive boards. In quarter sawing, boards are cut in such a way that each board has **one edge from the centre** of the log and the other edge from the **peripheral part** of the log. The process consists of

(*i*) Cutting the log into two-halves by a central cut;

(*ii*) Each of the two halves is given one cut again. This results in four parts of the log.

(*iii*) Boards are then cut from each of the four parts by parallel cuts.

Quarter sawing is applied only in those varieties of timber that give beautiful appearance in cross section and longitudinal section. In such woods, the medullary rays and the annual rings are developed very conspicuously.

TABLE 7.3. Comparative Study Of Slash Cut And Rift Cut.

Character	*Slash cut (Flat Grain)*	*Rift-cut (Edge Grain)*
Shrinkage	Highly susceptible to shrinkage and also to defects associated with shrinkage.	Shrinkage is comparatively less, hence, shrinkage defects are also less.
Wear	**Poor in resistance to wear**. Further, wears unevenly, producing splintery surface. This makes the board unsuitable for use in stairs and for flooring.	**More resistant** to wear. Since wear is of uniform nature, this type of board is suitable for flooring and stairs.
Stiffness	Less stiff	More stiff
Appearance	Surface of board gives **appealing appearance** because the annual rings make a pattern.	Appearance is rather simple and uniform.
Uses	Well seasoned flat grained boards are ideal for interior decoration	Suitable for special purpose where greater stiffness and resistance to wear are the required qualities.

7.8. SEASONING OF WOOD

7.8.1. Water in Wood

As already said, trees contain a lot of moisture in the standing condition. The mode of occurrence of water in wood tissue is rather complex and must be understood thoroughly. It is because a number of important properties of timber depend on its **moisture content** and the way in which it is present in the wood.

The wood tissue stores water in **cell walls** and the **cell cavities**.

(*a*) The water present in the **cell walls is called the bound water**, the hygroscopic water or the imbibed water. It is this water, loss or gain of which will affect the dimensional stability of the timber. It makes **25-30 percent** of the dry weight of the wood tissue when all the cell walls are fully saturated with water. This situation, **in which all the cell walls of wood are fully saturated with water** (and the cavities are empty) **is termed fiber saturation point**.

(*b*) The water present in the cell cavities of the wood tissue is called the **free water**. Its presence effects the **mechanical properties** of the timber. If the total moisture content in a species of timber is 75 per cent, and its fibre saturation point is 30 per cent, then, the **free water** is 45 per cent.

Whenever a freshly cut wood log is loaded for drying, it is the free water (from the cell cavities) that is lost first. Once cell cavities are empty, and drying is continued, then the water from the cell walls will start moving out due to drying effect. It is only the loss of water from the cell walls that causes shrinkage in the wood.

Similarly if a **dry piece** of wood is left out in a humid atmosphere, wood will start **absorbing moisture**. (Because, as already said, wood is a hygroscopic material). Supposing the original moisture content of the dry wood is only 6 per cent and the humidity of the atmosphere is 40 per cent, then wood will go on absorbing moisture till its moisture **content is the same as that of the atmosphere in which it is exposed**. This is called the "**equilibrium moisture content** "of the wood.

When water is absorbed by the wood, it is the cell walls that must be saturated before the cell cavities are allowed to get any water. This is the reason doors and windows made of wood show swelling effect during rainy seasons **immediately after a few days of rains**, especially when they are located where rain water can fall directly on them.

After having obtained the above information about the water content of wood, we shall have no difficulty in understanding **seasoning of timber**.

7.8.2. Objects of Seasoning

By **seasoning** of wood is understood lowering its moisture content to acceptable proportions before putting to any use.

There are five major objects of seasoning :

First. Reduction in weight. If the moisture content of freshly cut logs is 50 per cent, it means that the 50 per cent weight of wood is due to water only. And if these timber logs are **to be transported** in this green condition, it will mean we are paying quite huge money for transport of useless water stored in the timber. Therefore, **logs must be seasoned as near to the felling place** as possible before they are transported. The additional weight due to water will be also an additional load in the building if the green wood is used in the building as beams.

Second. Increase in Strength. Moisture content in the cell walls and the cell cavities **decreases the strength of the timber**. Volume for volume, there is much higher quantity of wood tissue in dry wood than in green wood. It is the wood tissue that bears all the load; water, whether in cell walls or cell **cavities cannot bear any load**. Hence, other things being same, **higher the moisture content of a variety of timber, lower will be its strength characteristics.**

Third. Improvement in workability. Timber has to be cut into smaller boards and planks and other parts for various uses. **Green timber** will be more difficult to work with compared to seasoned timber. Further, it will be more economical to work with dry seasoned timber because it will involve less effort, less wastage of tools and better workmanship. Moreover, it will be **almost impossible to give a good varnish or paint on green timber.**

Fourth. Freedom from shrinkage defects. If the green timber is sawn into thin boards and planks, it will get deformed within a short time. This deformation described as **warping** etc, will make the timber almost useless for further working. Such defects will not appear if the thin boards are cut from the seasoned timber.

Fifth. Longer life or durability. Moisture in timber invites a number of micro-organisms and insects to thrive on its sap. The fungi and insects have a special taste for cell sap. Hence, the green timber is attacked by these organisms quite easily. They destroy the wood tissue to reach to the sap, thus cutting short the durability of timber.

We may summarize the objectives of seasoning in five sentences:

Seasoning :

(*i*) **Reduces** much of the useless weight of timber;

(*ii*) **Increases** its strength considerably;

(*iii*) **Improves** the workability of the timber;

(*iv*) **Decreases** the chances of development of shrinkage defects, and.

(*v*) **Increases** the life of timber, *i.e.* makes it more durable.

7.8.3. Methods of Seasoning

At present timber can be seasoned by a number of methods. These can be conveniently discussed under two headings :

- Natural Seasoning, and
- Artificial seasoning

1. **Natural Seasoning (Air-Seasoning).** This is as yet the most common process of seasoning used throughout the world. In this process, timber sleepers, planks and scatlings etc, cut from the wood logs are stacked **in open air**. The method requires careful preparation of

(*a*) **Stack ground.** It should be level, free from debris and on dry land. It may be a few cm below the ground level.

(*b*) **Stack Pillars.** These are constructed at regular intervals out of bricks or masonry or concrete and may be of 50 cm height from the ground level. Their top surfaces should be flat and level with each other.

(*c*) **Stack Proper.** These are made of **sawn timber shapes** (sleepers, planks, scantlings, poles). One stack should have timber of one shape and same length and width.

The timber shape to be seasoned is stacked in layers in such a manner that enough space is left between

(*i*) one layer and another layer above it;
(*ii*) one part and another part in the same layer;
(*iii*) one stack and another stack.

The stack length and height depend upon the length of the wood part being seasoned. A single stack may be 3 to 4 meters in height.

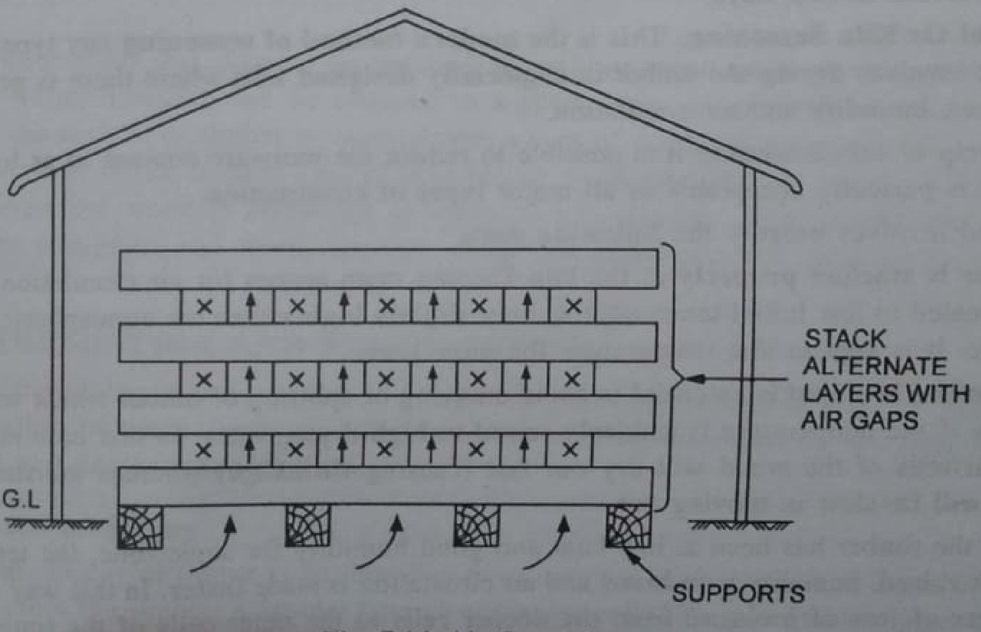


Fig. 7.16. Air Seasoning.

The most essential consideration in making such a stack is ensuring free circulation of air around each part of wood placed in a stack. It is also essential that the stack should be safe from direct winds and direct scorching heat. This is because in air seasoning, the loss of water is due to evaporation. The rate of evaporation will depend to a great extent on the atmospheric conditions. Efforts should be made to maintain a **uniform rate of evaporation.** Scorching heat and strong winds can cause **excessive evaporation** that may lead to development of shrinkage cracks. The seasoning stack should also be protected from rains because wood being hygroscopic material can absorb moisture quickly.

Outline of stacking arrangement. The time taken for air seasoning depends on climatic conditions and thickness of the timber. **It may take 1-4 years to bring down the original moisture content of 30 percent to a desirable 16-17 percent level.**

The **advantages** of natural (air) seasoning are :

(*i*) It is highly economical;

(*ii*) It requires little supervision;

(*iii*) It is applicable to thicker timber parts as well as thin section.

Among the major **disadvantages**, following are more important:

(*i*) It is a very **slow process;**

(*ii*) It keeps valuable **land and timber blocked for longer periods** ; and hence in some cases may be uneconomical.

(*iii*) Moisture content **cannot be brought below** a certain limit (16-17 percent).

(*iv*) Seasoning is **not always uniform** in all the sections of timber.

Water Seasoning. This is a process of natural seasoning that gives good results with logs of freshly cut trees. When the logs are placed **in running water**, the sap from the cells can be easily washed out. In place of sap, the cells get filled with ordinary water. When such logs are taken out and placed for air seasoning, it takes comparatively less time to become dry. The timber logs can also be placed in stagnant water if running water is not available nearby. In such a case, the water should be replaced every week. Placing the logs in water also saves them from **unequal shrinkage** (at the cut ends and along the length) if left for more time in the open without sawing into smaller pieces. Hence it is a useful process in two ways.

2. Artifical Or Kiln Seasoning. This is the **modern method of seasoning** any type of timber in a short time. It involves drying the timber in a **specially designed kiln** where there is perfect control over temperature, humidity and air circulation.

With the help of kiln seasoning it is possible to reduce the moisture content to as low level as 6 percent, which is perfectly acceptable in all major types of construction.

The method involves broadly the following steps :

(*a*) **Timber is stacked properly** in the kiln keeping open spaces for air circulation. The kiln is then heated to low initial temperatures, only slightly higher than the atmospheric temperature outside. It is kept at that temperature for some time.

This **initial low heat is essential** to avoid cracking or splitting of timber which would become certain if the temperature is suddenly raised to high drying rates. In that case moisture from the surfaces of the wood will dry out fast (causing shrinkage) whereas moisture in deeper cells will be slow in moving out.

(*b*) Once the timber has been at low heat and good humidity for some time, the temperature of kiln is **raised**, humidity is **reduced** and air circulation is made **faster**. In this way a continuous process of loss of moisture from the deeper cells to the outer cells of the timber and from there to 'outside' the kiln starts.

(*c*) During the heating process, all efforts are made to maintain a uniform circulation of the air so that all the parts of timber in the pile receive same amount of heat. This aspect is the most difficult one in kiln seasoning and requires **expert handing** for good quality seasoning.

Many modifications of kilns for seasoning timber are available. It is a costly method, no doubt. But the quality of seasoned timber is highly satisfactory.

3. Chemical Seasoning (Salt Seasoning). In this method, the timber piece to be seasoned is treated with a chemical solution like **sodium chloride, sodium nitrate or urea**. The essential quality of such a solution is that it reduces the vapor pressure on the surface of application. Once such a treated timber is exposed to natural drying, it is the water (sap) from the inner cells that moves to outer cells at lower vapor pressure. The wood surface remains moist while moisture from the interior goes on diffusing to the exterior. In other words, chemical seasoning enables the timber to **dry first from inside**. It is definitely an advantage as it prevents the risk of cracking of outer shell.

4. Seasoning by Boiling. This is also a quick method of removing sap from within the cells. The timber to be seasoned is immersed in water and the water is heated to boiling temperature. **It is kept boiling for four to five hours**. The sap is washed out by this process. On placing in air such treated timber dries quickly. But, at the cost of the strength and elasticity of the fibers. Hence, this method is also rarely used.

5. Electrical Seasoning. It is of theoretical importance only. Dry wood is a non-conductor of electricity. But when a high alternating current is passed through a piece of green timber, heat generated is enough to dry out the moisture of the cells which do conduct some electricity. In this way, the timber pieces are dried quickly. The technique involves costly equipment and even the consumption of electricity is so high that the process is uneconomical. Moreover, heating of cell walls causes considerable weakness in them.

Fire Proofing of Timber

All types of timber are combustible. Some catch fire quickly (e.g. soft woods like pines, deodars, kails etc.). Others burn with some difficulty and may take some time before catching fire- e.g. hardwoods. But the fact remains that every type of timber is liable to damage due to fire. It is, therefore, desirable that besides treating the timber for preservation, it should also be treated for **fire proofing**.

It has been found that there is **no method of making wood perfectly fire-proof**. The **rate of burning** of wood, however, can be retarded to a good extent by applying certain chemicals on it. Thus, when the surface of timber is covered with a coat of a fire-retarding salt like, **sodium silicate**, sodium arsenate or borax, it takes enough time before it can catch fire for the fire to reach the timber. Similarly, when the wood is immersed in solutions of salts like mono-ammonium phosphate and diammomium phosphate and dried, the **rate of spread of fire** through such timber is considerably reduced.

7.9. DETERIORATION AND PRESERVATION

While using timber in construction, the engineer is always concerned with the problem of decay and deterioration of timber with age. This problem may be discussed in two headings: **causes of deterioration** and **preservation** of timber.

7.9.1. Causes of Decay

(*a*) **Fungi**. Decay of timber is attributed in most cases to small plants and organisms that live on and spread within the timber. A special type of organism, called **fungus** (plural fungi) starts growing on the timber, especially when it is placed on a moist ground or is used in a **damp situation**. Three main types of fungi are known to destroy the wood tissue and cause its decay. These are:

(*i*) **The White Rot**. This type of fungus destroys (by consuming) the lignin part of the cell tissue leaving behind the fluffy light coloured cellulose part in **rotten form**. Hence the name.

(*ii*) **The Brown Rot**. Unlike white rot, it eats up (and destroys) the **cellulose** part of the cell tissue leaving behind **brownish lignin** part in a rotten form.

(*iii*) **The Blue Stain**. It is a fungus that lives on **sugars and starch** in the cell tissue. Such a fungus causes staining or discolouration of the original board.

(*iv*) **Mold**. It is a **cotton-like** growth of fungus spread over various parts on the surface of the board. It may not spoil the **inner portions** of the wood but its appearance on the surface is also quite displeasing.

"Dry rot" and "Wet rot" are the names given to decay-causing fungi. The first group attacks wood stored in places where there is **no circulation** of air. The wet rot, however, requires **presence of moisture** for its growth.

(*b*) **Insects**. A few types of insects are known to actually spoil huge quantities of timber within a short time of few years. The **white ants so commonly found attacking wood furniture in homes are the best example**. The white ants belong to a group of insects called **termites**. Other insects that attack timber are: pole –borers and marine-borers or ship worms. Decay by termites is encountered commonly in timber used in building construction. The marine borers attack the wooden base of ships in the sea.

The following few facts are interesting and noteworthy regarding decay of timber :

(*i*) **No timber variety is immune to attack by fungi or insects**. The environment of use, however, may favour or disfavour the decay. **Moist conditions invariably inviter decay.**

(*ii*) The **strength of timber** has no relation towards its resistance to decay.

(*iii*) The **effects of attack** by such organisms often become observable only after some time, when the timber has already been diseased. At that time timber becomes friable, spongy, pitted, stained and even exceptionally soft. Its colour, structure and appearance all get changed for the worse.

7.9.2. Preservation of Timber

Various methods have been used to preserve the timber from decaying. The main objectives of such a treatment is to ensure a longer, trouble free life of timber.

There are **three types** of methods used for preserving timber :

(*a*) **Application** of some chemical substances (called the preservatives) on the **surface** of the timber.

(*b*) **Injection** of the preservatives **into the body** of the timber;

(*c*) **Construction** of **protective covering** or shields around timber used in construction.

We shall discuss each of these methods in some detail. First of all we should know a little about a suitable preservative and its qualities.

A Preservative may be defined as a **chemical compound that when used on or injected into the timber makes the timber 'poisonous' for insects and fungi without effecting the structural properties of timber.**

All the wood preserving chemicals are classed under three groups :

1. The Oil-Soluble Salts. Such compounds are soluble only in oils. The most commonly used wood-preservative, coal tar creosote oil, belongs to this category. It is obtained by destructive distillation of coal.

Following are important qualities of this preservative:

(*i*) It has a high degree of permanence *i.e.* it stays **within the cells** for quite a long time.

(*ii*) It penetrates quickly and easily into the wood tissue.

(*iii*) It is highly destructive for "fungi".

Among the **negative properties of coal tar creosote** preservative, the most important is its unpleasant appearance. Moreover, it does not allow paint over it and has a bad smell too. Hence it cannot be used for preserving timber parts.

2. The Water-Soluble Salts. Such salts make an easy solution with water. There is an advantage in it. They can be easily dissolved and used. But there is a disadvantage too. These can be easily "washed away" if the timber happens to be in **moist condition**. Among the water-soluble salts are included: zinc chloride, copper sulphate, sodium fluoride, sodium fluosilicates, sodium dinitrophenoxide and compounds of arsenic.

3. Volatile Base Salts are those which make solutions with substances like petroleum. The creosote petroleum blends are typical examples of this category.

7.9.3. Methods of Preservation

Preservatives are used by different methods depending upon the **extent of preservation** required. Starting from the simplest to complex, these are: Brush applications; dipping, open tank immersion and pressure application.

(*i*) **Brush Application**. In this method, timber is given **one or two** coats of the preservative with the help of a brush. This is used for painting coal tar at the ends of beams that are embedded in the walls or **base** of poles and posts that go to the ground with coal tar. The method is quite cheap. At the same time, it is not very effective.

(*ii*) **Dipping Application**. The timber part to be treated is made to dip in the preservative and kept immersed in it for various periods from a few hours to few days. It is used when organic preservative solvents are to be applied.

(*iii*) **Open Tank Application**. In this method, the timber is kept immersed in a suitable metallic tank of proper size till a proper saturation is obtained. The tank containing the timber is then heated at about 70° - 80°C for several hours; this ensures deeper penetration of the preservative into the timber. After this, the timber is allowed to cool **within the tank** in the presence of preservative. In this way, the timber may actually **suck a lot of preservative** and ensure complete penetration.

Softwoods (conifers) receive this type of treatment in a remarkable manner because their cells are **more permeable**. The treatment has the disadvantage that it increases the weight of the treated timber considerably.

(*iv*) **The Pressure Process.** This is the **best and commonly applied method** for preserving costly timber varieties. It involves the passage of preservative into the timber under pressure, and is achieved by either of the two processes:

The Full-Cell Process. The timber is placed in a large steel cylinder acting as a pressure vessel. Vacuum is first created and maintained for about one hour or more. After this, coal tar creosote oil or any other suitable preservative, preheated to a specified temperature is **forced into the cylinder** under sufficient pressure. This is continued till the required quantity of preservative has been introduced into the timber. Thereafter, pressure is reduced and after giving some vacuum, timber is taken out.

In the **Empty Cell method, no vacuum is created in the beginning**. Instead, timber placed in the pressure vessel is subjected to initial pressure while preservative is being introduced into the cylinder. Once the vessel is full of preservative, sufficient pressure is applied which forces the preservative from the tank into the timber. After this, pressure is released. This causes the air compressed in the cells of the timber to **come out along with any excessive preservative**.

The **main advantage** of pressure processes (of one type or another) is that they ensure a **proper and deeper penetration** of preservative into the timber in a controlled manner. Even those timbers which may not absorb preservative in open-tank process can be filled with preservatives by this method.

The main **disadvantage** is that these are as yet **costly processes** involving use of pressure vessels and require skilled operators for better results.

Charring. It is a common method used for preserving timber poles and posts that are to be dug into the ground. The outer part in the lower ends is charred (**incompletely** burnt) before insertion into the ground. The charcoal layer so formed is an **easy safeguard against attacks by fungi** or termite (as these organisms do not find any food in charcoal).

Termite Shields. The base of major timber columns may be preserved **against organic** attack by constructing suitable barrier between the timber and the ground. These barriers of proper design and shape are called **termite shields**.

7.10. SPECIAL TIMBER PRODUCTS

7.10.1. Veneers

Definition. A veneer is essentially a thin sheet of timber with a thickness varying between 0.4mm to 6mm. It is also sometimes called a **ply**. From veneers a number of wood products of specific applications can be prepared easily.

Manufacture. Veneers are obtained from suitable type of timber logs using any one of the three **methods**: sawing, slicing and rotary cutting.

(*a*) **Sawing**. It is the earliest method. Firstly, the logs are cut into smaller units called **flinches**. Each flinch is then subsequently sawn carefully to obtain veneers of required thickness. **Circular saws are used for veneer sawing**.

(*b*) **Slicing.** Here **a fixed knife** is used to cut veneers as **slices** for a flinche. The flinch is **held tightly** in a mechanical grip. It is then adjusted against the fixed knife and pressed through the same.

There are two type of slices in use. The **vertical slices** in which the flinch slice is pressed vertically downwards against an upward pointing knife.

The **horizontal slices** are designed in such a way that the flinche is pressed horizontally against the knife.

(*c*) **Rotary Cutting.** It is a modern method by which good quality of veneers can be cut quickly. In this method special type of **lathes are used** for making veneers. In this method:

(*i*) **Bark** is first removed form the log and it is cut into required length (of the veneer), called a **bolt**.

(*ii*) The **bolt** is then held tightly between two spindles of the lathe. In this position, the bolt can be made to rotate about its axis.

(*iii*) It is given the **continuous rotation on the lathe**. During the rotation, the surface of the bolt comes in contact with a veneering knife edge which removes a thin sheet or veneer in a continuous length. **The process looks as if a thin sheet of paper is being unrolled**. Subsequently, the veneer sheet can be cut into suitable length.

USES. Veneers form the **starting point** in the manufacture of plywood, laminated board and battern boards.

7.10.2. Ply Wood

Definition. It is the most **common type of processed wood** containing thin sheets (or plies) glued together. In any type of plywood, the **number of plies is always odd** and the grain of adjacent layers are perpendicular to each other.

Structure. In the **simplest type** of plywood the board consists **three layers** of plies arranged in such a manner that :

(*i*) One ply lies in the middle and is referred as **central** ply;

(*ii*) One ply each lies on the either side of the central ply. One of these **side plies** is called the **face ply** and the other as the **back ply**. The grains of the outer plies are perpendicular to the central or core ply.

Plywood panels may consist of any odd number of plies, *i.e.* 5 ply, 7 ply and 9 ply, etc. **It is essential that plies holding identical positions on either side of the core ply must be of same thickness and of same wood.**

Properties. Following are most important properties of plywood compared to ordinary wood.

(*i*) It has a better resistance to **shrinkage defects** like swelling and warping. This is because the grain directions are mutually at right angles in adjacent plies, and hence there is a **perfect balancing in amount of shrinkage**, if any.

(*ii*) The plywood is **free from splitting defects.**

(*iii*) It has **uniform mechanical properties** in both the directions.

(*iv*) It has a **better strength** than the ordinary wood of equal thickness

(*v*) It is **light in weight** and easy to handle and convenient for using.

Manufacture. The manufacture of plywood on a **commercial scale** involves following stages:

(*a*) **Veneering**. This involves obtaining thin sheets or plies or veneers (as they are variously called) from **selected type of timber**. Veneers may be obtained by sawing or slicing or rotary cutting. The thickness of veneers varies between 0.4 mm to 6 mm. Veneers so obtained are **sorted and dried** to a moisture content level of **below ten per cent**.

(*b*) **Bonding**. This stage consists of applying an **adhesive** (the bonding material) or glue over the surface of the veneers. This is achieved by passing the veneers through a Roller Coater. **Animal** glues, **vegetable** glues and **synthetic** resin glues are variously used for bonding the plies together.

(*c*) **Stacking.** This consists of arranging the glued plies around a core ply in such a manner that grain in adjacent plies runs at right angles to each other.

(*d*) **Pressing.** The stacked plies are either **hot pressed or cold pressed** depending upon the type of adhesive used in bonding. **Cold pressing** is applied when vegetable glues have been used whereas hot pressing is essential when synthetic resin has been used. In hot pressing, the material is raised to a temperature where glue is perfectly liquefied and then a pressure varying between 7-14 kg/cm^2 is applied through hydraulic presses.

The pressed wood as obtained after the above four stages is called the plywood. It is subjected to such finishing processes as trimming of edges, sanding of surfaces and grade marking before marketing.

Uses of Plywood. Plywood is used extensively in construction and furniture making and many other fields. Plywood is made in two types: the **exterior type** and the **interior type** plywood. In the former, a practically **water proof glue** is used for bonding at the manufacturing stage. Such plywood is stable for external applications in building constructions, e.g. doors and windows. The inferior grade plywood uses common glues that are liable to get damaged by humidity and direct moisture.

Among various uses of plywood following few may be mentioned: For roofs and walls; sheathing, flooring, box-beams, containers, for wall and ceiling **tile backings**, cable-reels and floor coverings; for truck bodies and streamlined train and boat interiors.

7.10.3. Laminated Timber

It is another type of processed wood, It consists of suitably selected wood sheets or veneers that have been glued together in such a way that grains of all the sheets or laminations are **parallel longitudinally**.

Each lamination used in the manufacture of laminated timber has a uniform thickness, not exceeding 51 mm. Each lamination is itself prepared by gluing together thin pieces of timber having no defects in them. As such laminated timber is broadly similar to natural timber in structure **but without any of its defects**.

The laminated timber comes in wide variety of shapes and appearance. It is manufactured in three qualities: Industrial, Architectural and Premium grades.

In the **Industrial grade** laminated timber, small voids are allowed but one face is **made free of loose knots and holes**. It is used in garages and industrial plants.

The **Architectural grade,** has a very smooth external surface in which all knots have been removed and voids so created filled with clear wood tissue.

The **Premium grade** is manufactured with great care and is used where **highly appealing and smooth external finish is required.**

7.10.4. Fibreboards

These are made by pressing together fibrous materials such as fibers of wood, cane and even vegetable matter. The fibre mass is first heated and then pressed hard in that hot state. On cooling, a rigid material of **light density** and good utility is obtained. Its thickness varies between 3 mm to 10 mm.

Uses. The fiberboards are used as :

(*i*) Insulating boards for both heat and sound insulation;

(*ii*) Partition wall panels;

(*iii*) Parts of flushed doors;

(*iv*) Finished flooring, etc.

7.10.5. Impreg and Compreg Timbers

It is a class of **processed timber products**, indicating use of an advanced technology than plywood In the impreg and compreg timbers, the veneers are treated with **suitable types of resins**. The type of resin used, the method of treatment and the type of raw material (veneers) used give rise to a variety of such treated timbers.

In the **impreg timber**, for instance, the veneers are **immersed** in resins, commonly phenol formaldehyde at ordinary temperature and pressure. Once the tissue is saturated and the resin is set, the consolidated mass is cured at **raised temperature** (at 150^0C). It is then finally given proper finishing treatment and is marketed under trade names such as **Sunmica**.

The **compreg timber** is a variety of impreg timber which is prepared by curing the resin impregnated **timber at high temperature and high pressure**. This type of curing results into a timber of high density and strength that is quite durable.

Among the various advantages of impreg and compreg timber may be mentioned :

(*i*) Very beautiful appearance;

(*ii*) Almost impervious outer surfaces;

(*iii*) Resistance to acids and solutions.

(*iv*) High strength, low shrinkage and much increased life (durability)

7.11. COMMON INDIAN TIMBER

More than 22 per cent of the total land of India is under forestation. Although there are more than 100 species of wood standing in the Indian forests, only about a **dozen species are used in construction on a large scale**. A brief account of the more commonly used timber types is given below.

(A) Softwoods

1. DEODAR. Deodar (Botanical name: Cedres deodar). It is also known as God Tree, and belongs to the famous 'Cedar 'group of conifer trees.

Distribution. Deodar is a very common tree of the mountains of N-W Himalayas where if forms extensive forests. The tree is also found in the forest of Afghanishtan and Blauchistan. Normally it grows at 1500-4000m above sea level.

Tree Characters. The tree has a tall and straight trunk. Its height varies between 20-30 meters and the **girth** between 0.5 to 1.50 meters. The tree remains **ever green**. The branches bear pale green, narrow, long and **slender pointed leaves**.

Wood Characters. Deodar timber is a light coloured and light weight (density 560 kg/per cubic meter) material with a close-grained and long-fiber texture. **The timber is highly resinous** (contains resins) and gives the odour of the resins.

The deodar timber is quite **strong and durable**. It is resistant to decay under moist conditions to a good extent. It is easy to wok and takes a nice polish and varnish.

Use. Deodar timber is considered as one of the **most valuable timbers of the country**. It is extensively used in making railway sleepers and in various parts of building.

2. KAIL. Its botanical name is *Pinus excelsa* and belongs to the pines group. Like Deodar, it is an evergreen tree of Himalayas

The Kail wood is of light colour and light weight with a **density of 480 kg/cm^3.** It is similar to deodar in many properties but is considered slightly inferior to that. The **timber is close grained and seasons well.**

Kail wood is used in building construction, for sleepers for railway lines and also for making furniture.

3. CHIR. Its botanical name is *Pinus longifolia*. It is similar to Kail and deodar in its appearance and grows abundantly in Himalayas

The Chir wood is **highly resinous and very profusely knotted**. It is light brown in colour with a density of about 560 kg/cm^3. Being very much **full of knots**, the chir timber is considered inferior to Kail and Deodar.

Use. Chir timber is commonly used for making **packing cases** and for interior work where not much load is involved.

4. SIMUL. Simul, also referred as **cotton tree**, is a common tall tree of the plains of India. It grows naturally and abundantly. The tree bears beautiful red flowerer and inferior quality cotton.

Simul timber is of very light density (368 kg/m^3). It is coarse grained and of low strength. Hence it is not used as structural timber in load bearing parts of the building. It is, however, a commonly used wood for making **packing cases, toys** and **match boxes**.

(B) Hard Woods

I. TEAK :

Botanical name. *Teetona grandis*. Teak yields one of the most valuable timber types of the world. Its Sanskrit name is **saka**. Records show that teak has been most widely used timber of India for more than two thousand years.

Tree Characters. The teak is usually a big tree with very big leaves, 70-90 cm in length. It has a spreading crown and four–sided branchlets. The teak tree bears white flowers and drupe fruits. The leaves fall in autumn.

Wood Characters. The teak wood is **hard, strong and durable**. The sapwood of teak is white whereas its heartwood shows a golden yellow colour when fresh and mottled brown on seasoning. It density is 750 kg/cm^3.

The most typical character of teak wood is its strong aromatic odour. Further, teak wood is **most durable**. Teak wood beams several centuries old but yet in perfect condition have been found from ancient building of India, Burma and Afghanistan.

Another useful character of teak wood is its **extremely good dimensional stability** *i.e.* Its resistance to shrinkage defects.

Use. **Teak wood is quite suitable for all types of structural work**. Besides, it is eminently suitable for general woodwork, such as ship building, furniture making and in making of railway cars.

Distribution. Teak tree is native to India, Burma and Thailand. Most valuable forests grow on low hills, up to 1000 m from sea level. In India, teak wood forests are distributed extensively in Madhya Pradesh, Mysore, Madras, Coorag, Cochin and Bombay.

2. SHISHUM :

Botanical name. *Delbergia sisoo*. Shishum is a beautiful tree of northern and central India growing abundantly in plains up to 2000m above sea level. It is classed among the broad-leaved deciduous trees.

Wood Characters. Shisum timber is classed **among the strongest timbers of the World**. It is very hard also. At the same time, it is **most difficult to work with**. Its density is 770 kg/m^3. The Shishum sapwood is of light brown shade but the Shishum heartwood is deep brown in shade. It has

(*i*) Close grained structure.

(*ii*) Very fine medullary rays.

(*iii*) Faint annual rings.

Shishum wood is very heavy and durable. It take brilliant polish and seasons without shrinkage defects.

Use. Shishum is used extensively for household furniture, carriage and cartwheels, boats and for making handles of agricultural implements.

Distribution. The tree is found commonly in the plains of northern and central India.

3. SAL :

Botanical name *Shorea Robusta*. It is also considered a valueable tree of our country. Sal resembles in many ways to the teak.

Wood. Sal wood is very **hard and close-grained**. It has a density of 880 kg/cm^3. It has a dark brown colour. Sal wood is very durable and resistant to attacks of termites. At the same time it is difficult to work and does not take fine polish easily.

Use. Sal Wood is used extensively in building construction, ship–building, bridge construction and as sleepers for railway lines.

It is not much used in furniture making because it is difficult to work and does not take good polish.

Distribution. Sal is of abundant occurrence all along the base of the Himalayas. It is found in U.P, Bihar and Assam. The tree also grows in central India and south India.

4. BABUL

Botanical name. *Acacia aracbica*. It is one of the most common hardwoods of India growing in almost all parts of the country. The tree is usually of medium height (less than 16m) and bears thorns. It has small leaves and bears yellow flowers.

Wood. The timber of Babul is

(*i*) Close–grained in structure; (*ii*) light red to brown in colour;

(*iii*) hard and tough in nature; (*iv*) having a density of 880 kg/m^3

(*v*) resistant to wear.

Use. The structural uses of babul timber include as beams and rafters, frames of doors and windows and lintels.

In common usage, babul timber finds application for making cartwheels and bodies, tools, handles and other parts of agricultural implements.

5. SIRIS :

Botanical name. *Abizzia oddoraisima*. Like babul, siris is also a common tree of Indian subcontinent.

Wood. Siris, timber is classed among hard and durable timbers. It is much difficult to work. Its density is 800kg/m^3 ; the wood seasons well.

Use. Siris timber is used for both the structural and general purposes. Thus it finds applications in house construction, and also in the making of heavy furniture and agricultural implements.

Distribution. Siris is found almost in all parts of the county in the plains and sub-mountainous regions.

TYPICAL QIUESTIONS

A. ESSAY TYPE

1. Discuss critically use of timber as **material of construction**. It is stressed that use of timber should be avoided to preserve forests. What about use of steel made from non-renewable sources such as **iron and coal**? Which would be a better preposition in the ultimate analysis-steel or timber?
2. (*a*) Explain structure of **Exogenous trees**.
   (*b*) Describe the properties of any two types of hard woods and softwoods used in building construction.
3. Discuss **various properties of timber** that effect its quality as a material of construction.
4. Describe some major **defect of timber** with the help of neat sketches.
5. What do you understand by **"seasoning of timber"** ? Discuss the need of seasoning of wood. Explain briefly the air-seasoning and kiln seasoning giving relative merits of each.
6. Write an Essay on **"Deterioration & Preservation of Timber"**.
7. Write brief notes on :
   (*i*) Ply wood
   (*ii*) Compreg wood
   (*iii*) Annual Rings
   (*iv*) Heartwood and Sapwood
   (*v*) Heart Shake
   (*vi*) Knots
   (*vii*) Slash Cut and Rift Cut
   (*viii*) Preservatives for wood
   (*ix*) Grain of Timber
   (*x*) Equilibrium moisture content
   (*xi*) Hardwood and Softwood.

B. OBJECTIVE TYPE (Tick the most appropriate answer).

1. **Exogenous Trees** are those in which:
   (*i*) Growth takes place by addition of new cells in the form of annual rings around the existing cells.
   (*ii*) Growth is by addition of new cells at the tips at the top of trees.
   (*iii*) Growth is by addition of cells near the roots;
   (*iv*) None of the above.
2. **Annual rings** in a tree describe
   (*i*) The rounded structure of tree trunk
   (*ii*) The rings made up of cells that are added every year by the cell division that takes place beneath the bark

(*iii*) The circular openings made by termite in the tree trunk
(*iv*) None of the above.

3. **Growth in exogenous** timber is fastest in

(*i*) Summer	(*ii*) Autumn
(*iii*) Winter	(*iv*) Spring

4. **Imbibed** (Hygroscopic or bound) waster in a tree is that water which is contained :

(*i*) In the cell cavity.	(*ii*) In the cell walls.
(*iii*) In the cambium	(*iv*) None of the above

5. It is **loss of the water** from — causes shrinkage of wood:

(*i*) Cell walls	(*ii*) Cell cavities
(*iii*) Medullary rays	(*iv*) Bark

6. **Seasoning** is a process of :
(*i*) Felling the trees in a proper season.
(*ii*) Sawing the timber in a proper manner.
(*iii*) Reducing the original moisture content of a tree to an admissible limit.
(*iv*) None of the above.

7. In **Air Seasoning**:
(*i*) Dry air is passed all around the timber.
(*ii*) Timber is stacked in open air and allowed to lose moisture by natural process of evaporation;
(*iii*) Timber is stored in closed chambers and no air is allowed to approach it
(*iv*) None of the above.

8. Water Seasoning signifies
(*i*) Immersing the tree longs in running water parallel to the current to replace sap from within the cells with water.
(*ii*) Treating the timber with water to clean it from molds and fungus.
(*iii*) Applying some water based preservatives to prolong the life of timber.
(*iv*) None of the above.

9. **In' Slash Cut'**, the board is sawn in a direction which is

(*i*) Parallel to the annual rings.	(*ii*) Tangential to the annual rings
(*iii*) At an angle of 45^0 to the rings.	(*iv*) None of the above.

10. **Preservatives** are applied to the wood :
(*i*) To increase its compressive strength.
(*ii*) To enable its beauty.
(*iii*) To make it resistant against fungus and termites.
(*iv*) To improve its workability.

11. **Plywood** is
(*i*) Entirely a synthetic material.
(*ii*) Entirely a natural material.
(*iii*) A material processed and developed from wood as a source.
(*iv*) None of the above.

12. In **laminated wood** and plywood :
(*i*) The grain has the same arrangement.
(*ii*) It is different; being at right angles to the central ply in the side plies in plywood and parallel in all the laminates.

(*iii*) It is different, being parallel in all the laminates.

(*iv*) It is different, being parallel in all the plies and mutually at right angles in the laminates.

ANSWERS : 1. (*i*); **2.** (*ii*); **3.** (*iv*); **4.** (*ii*); **5.** (*i*); **6.** (*iii*); **7.** (*ii*); **8.** (*i*); **9.** (*ii*); **10.** (*iii*); **11.** (*iii*); **12.** (*ii*).

RELEVANT I.S. CODES*

1.	Coniferous sawn timber baulks and scantlings.	IS: 189-1977
2.	Recommendations for maximum possible moisture content of timber used for different purpose.	IS : 287-1973
3.	Classification of commercial timber and their zonal distribution.	IS: 399-1963
4.	Code of Practice for Preservation of Timber.	IS: 401-1967
5.	Glossary of Terms applicable to timber technology.	IS:707-976
6.	Code of Practice for design of structural timber in building.	IS: 883-1970
7.	Code of Practice for seasoning of timber	IS: 1141-1973
8.	Air craft timber (baulks and scantlings).	IS: 1329-1975
9.	Cut sizes of Timber	IS: 1331-1971
10.	Aircraft timber in cut form	IS: 1898-1975
11.	Timber for use in aircraft propeller construction	IS: 2178-1979
12.	Converted timber for lorry bodies	IS: 2179-1979
13.	Code of Practice for finishing of wood and wood products.	IS:2338-1967
14.	Code of Practice for nail jointed timber	IS: 2366-1963
15.	Timber for cooling towers.	IS: 2372-1963
16.	Guide for installation pressure impreg plants for timber.	IS: 2683-1966
17.	Code of Practice for design and construction PILES of TIMBER	IS:2911-PTII-1965
18.	Methods for measurement and evaluation of Defects in timber (PTI & PT II)	IS: 3364-1976
19.	Code of Construction for Timber Floors	IS: 3670-1966
20.	Guide for hand-sawing of timber	IS: 4423-1967
21.	Use of timber in coal mines	IS: 4424-1967
22.	Key for identification of commercial timber	IS:4970-1973
23.	Code of Practice for deign and construction of laminated timber beams	IS: 4983-1968
24.	Coniferous logs(with amendments) Requirement of three grades.	IS: 5246-1969
25.	Teak logs for production of slicked veneers.	IS:5248-1969
26.	Code of Practice for construction of timber ceilings.	IS: 5390-1969
27.	Methods of tests for timber props for mines.	IS: 6346-1971
28.	Guiding Principles for grading and inspection of timber	IS: 6534-1971
29.	Timber species suitable for wooden packaging.	IS:662-1972
30.	Methods of testing natural durability of timber.	IS: 6791-1973
31.	Guidelines for design, installation and testing of timber seasoning kilns	IS: 7315-1974

[**Note:** Some of these codes stand reaffirmed in 1986 to 1994.]

□□□

8

Ferrous Metals

8.1. GENERAL

METALS and their alloys have been a class of indispensable engineering materials. In fact in all types of 'heavy' engineering construction, use of metallic material is taken for granted. These materials also find extensive applications in engineering industry. As such any description of engineering materials without metallic materials will be a practically incomplete effort. We may give a few examples before entering into detailed discussion of these materials.

(*i*) **Ferrous Metals** such as steel and cast iron have been and are being widely used for a variety of structural purposes. Building frames, beams, columns, reinforcement bars etc. and heavy gates and roofing sheets are made almost entirely of ferrous metals.

(*ii*) **Non-Ferrous Metals,** like aluminum and its alloys are fast becoming engineering materials of great importance ranking next only to steel. Aluminium sheets, rods, bars and frames are finding extensive application in non-load and light-loading bearing situations in building construction.

Among the other metals and alloys that are valuable as engineering applications may be mentioned copper, brass, bronze, zinc, lead and nickel.

Metallurgy, the science of metals is a very important subject on its own right. No attempt will be made to discuss the subject here. Our attempt in the following discussion on metallic materials will be restricted only to those aspects which are essential to give an insight into their engineering properties. For detailed discussion on the metallurgy of these materials the readers must refer to the proper texts on each metal.

FERROUS METALS

8.2. INTRODUCTION

The ferrous group of metals includes all types of iron, steel and their alloys. It is typical of this group that **Iron (Fe),** in one form or another, is the principal component of all ferrous materials. At present, the role of ferrous metals in the engineering industries can be easily described as most **dominating**. In all jobs ranging from manufacture of primitive type of agricultural implements to advanced types of aircrafts, ferrous metals and their alloys occupy a prominent position. In the automotive, building and bridge construction, railways, light and heavy machinery, shipping and transportation, and in many other fields of engineering activity ferrous metals and alloys are always there in on form or another. This is explained by a number of reasons.

(*i*) The wide abundance of iron ore in almost all parts of the world.

(*ii*) The economical extraction of iron from its ores.

(*iii*) The flexibility that can be induced in the mechanical properties of iron by combining it with other metals and by heat treatment and such other methods.

The annual global production of ferrous metals has been and remains far in excess than the combined production of all the non-ferrous metals produced in all the countries of the World.

It is the first or basic form in which iron is prepared as a metal from its ores. It is therefore, impure and crude and requires subsequent processing to develop cast iron, wrought iron and steel which are common ferrous metals used in industry and construction.

8.3.1. Manufacture

Pig iron is manufactured in the following stages :

1. Selection of Ore.
2. Dressing of Ore.
3. Calcination, roasting and smelting.

A. Selection of Ore

Iron occurs in nature in combined form as oxide, sulphate, carbonate and silicate etc. Such natural raw sources from which iron can be extracted economically are called iron ores. Following are common iron ores:

1. **Hematite (Fe_2O_3).** It is a rich ore containing 70 per cent iron. It has a dark brown to red colour and is the most common iron ore of our country. It is also called **Red Iron Ore.**
2. **Magnetite (Fe_3O_4).** It is the **black iron ore**, and has the richest percentage (72.4%) of iron. This is the main iron ore in many other countries but not in India.
3. **Siderite ($FeCO_3$).** It is also called the spastic iron ore. It contains 48.2 per cent iron.

Siderite is only rarely used as iron ore in countries where it occur in abundance. Primarily, most of the IRON is produced in the world either from Hematite or from Magnetite.

The selection of the suitable ore is controlled by two major factors: its occurrence in abundance at a suitable place and its quality (purity).

B. Dressing of Ore

The Ore, as it is extracted from the earth, is in big **lumps** containing many other useless or gangue minerals. The size of the ore must be reduced to that within required limits and also the useless associations must be separated. **The combined process of reduction in size and removal of impurities is called ore dressing**. This is achieved by passing the ore through a series of crushers and washing mills. The latter wash away clay and other impurities from the crushed ore.

C. Blast Furnace Treatment

The Blast furnace is a cylindrical, shell –like vessel made of steel. It is 15-30 meters high and 6-8 meters in diameter. It tapers towards the top. The lower part appears as an inverted cone. The interior of the furnace is lined with **refractory bricks**. The furnace is provided with:

(*i*) **hoppers** for loading at the top;
(*ii*) the **gas outlets**, again at the top;
(*iii*) the **tuyers** for injecting hot gases, near the base;
(*iv*) **cooling pipes**, just around the tuyers.

Besides the main furnace, a blast furnace plant requires following additional equipment :

(*a*) **Engines**, for creating and supplying the air blast for the furnace;
(*b*) **Stoves,** for pre-heating the blast of air before it is blown into the furnace;
(*c*) **Coke ovens**, for converting coal to coke by heating the same at 1050^0C or more.
(*d*) **Equipment** for cleaning the blast furnace gas, for storage of raw materials and for receiving the molten iron from the blast furnace.

Operation. The blast furnace operation is a **continuous process** after it is started in the following manner:

(*a*) A **blast** of air is first created by blowing the engines. This blast passes through stoves at 500^0-600^0 C and then is made to enter the furnace through the tuyers in the lower region.

(*b*) Meanwhile, a charge is kept ready at the top in the hopper. The **charge** consists of alternate layers of coke, ore and fluxes (limestone etc.) in pre-determined proportions

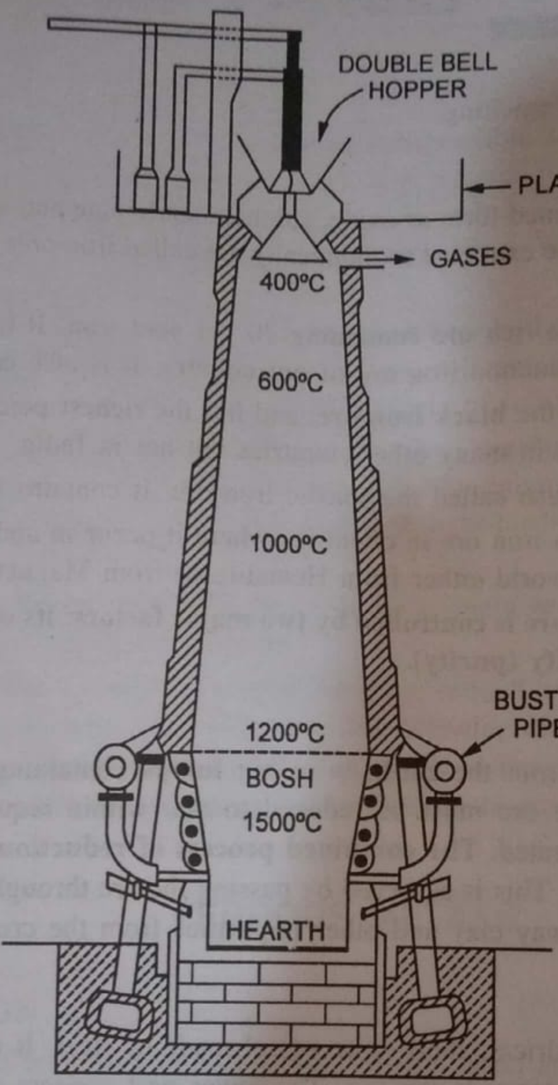


Fig. 8.1. Outline of Blast Furnace.

(*c*) When the hot blast has heated the furnace to a desired extent (this may take some time), the charge is introduced into the furnace by operating the hopper.

(*d*) The hot gases burn the fuel part of the charge thereby creating still higher temperature.

(*e*) The hot molten ore gets reduced by reacting with **carbon monoxide** from the coke; iron (Fe) is produced in the molten form.

(*f*) The molten iron and the impurities (as slag) collect in the lowermost region of the furnace where from they are removed periodically.

(*g*) New batches of charge are introduced at the top.

After the first charge and removal of the first melt of iron, slag, the **operation becomes continuous**; charge is introduced at regular intervals at the top through the hopper and the molten products are drawn of from the lower zone.

Working Zones. Following three **working zones** may be distinguished in a blast furnace.

(*i*) **The Stack Zone.** It is the largest zone and extends from top to the middle of the furnace. The charge coming from above and the hot gases rising from below interact resulting in the dehydration of the ore. Temperature ranges from 400^0-600^0C in this zone.

(*ii*) **The Bosch Zone.** It forms an inverted cone and is the **hottest zone**. It receives the hot air from the blowers through the tuyers, and, the dehydrated charge from the stack zone. It is in the Bosch Zone that reduction of ore take place as per following reactions :

$$\boxed{\begin{aligned} 3Fe_2O_3 + C &= 2Fe_3O_4 + CO \\ 3Fe_2O_3 + 9C &= 6Fe + 9CO \\ Fe_3O_4 + 4CO &= 3Fe + 4CO_2 \end{aligned}}$$

(*iii*) **The Hearth Zone.** It forms the **lowermost** part of the furnace. It serves as a receiving pot for the molten iron and slag. Since the iron and slag have different densities (the slag is much lighter), they form layers, slag floating above the iron melt. These are drawn out from separate holes provided within the blast furnace corresponding to the hearth zone. The pig iron as obtained from the above process is generally impure in composition. It may have iron to the extent of 95 per cent only, rest being carbon, sulphur, silicon, manganese and phosphorus. The slag (called **blast furnace slag**) is an alumino-silicate waste product. Earlier it was always dumped away as a waster material. In recent years, however, it has found applications as a raw material for making many types of cement and concrete and also as a light –weight aggregate.

8.3.2. Types of Pig Iron

Following are a few types of pig iron distinguished on the basis of their properties.

1. Grey Pig Iron. It is distinguished by a **typical grey coloured surface** of iron when broken fresh. It is soft in character and rich in carbon. It is produced when the raw materials are burnt at a very high temperature. It is also called **foundry pig**.

2. White Pig Iron. The broken surface shows **dull white appearance**. This type contains sulphur as the main impurity and hence is considered inferior in grade. It is also called forge pig iron, as it is hard and brittle and can be converted only by using pressure.

3. Bessemer Pig Iron. This type is practically free from sulphur and phosphorous. Therefore, It is used for the manufacture of steel in the Bessemer process.

8.4. CAST IRON

8.4.1. Manufacture

Cast Iron consists essentially of **remelted pig iron.** It contains carbon from 2-4 per cent and small proportions of manganese, silicon and sulphur. The remelting of pig iron is done in a special furnace called **cupola**. A cupola is in essence a small sized blast furnace. It is about 5 m in height, about 1 m in diameter and cylindrical in shape. The cylinder has an inner lining of refractory bricks and is provided with tuyers near the bottom for injecting the supply of air blast.

The working of Cupola is similar to blast furnace except that it can work intermittently. The raw materials - pig iron and steel scrap, fuel and fluxes, are added from the charge door at the top to a previously heated cupola. The air blast is continuously fed through the tuyers. All the impurities of pig iron get oxidized and form a slag that starts floating at the upper layer. The molten cast iron is removed from the lower draw hole and charged directly into moulds of desired shapes. These are called **castings** (of cast iron).

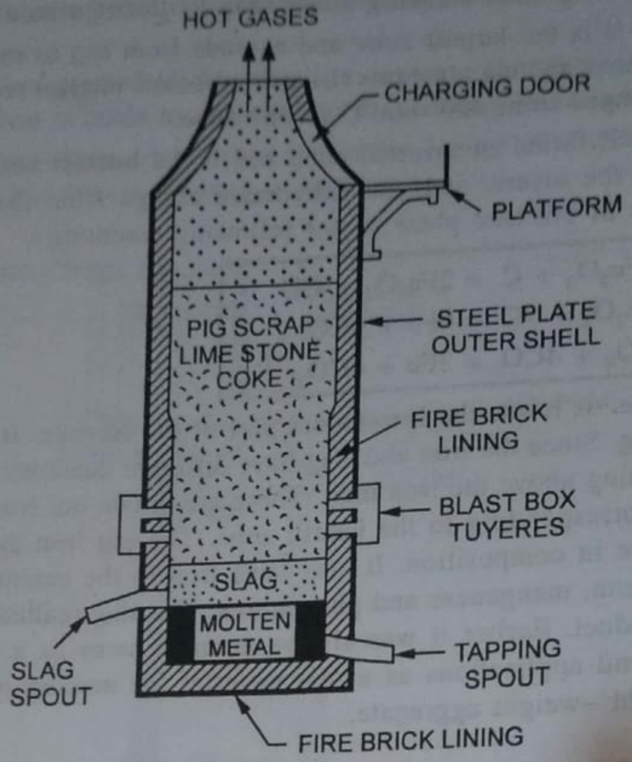


Fig. 8.2. Cupola Furnace.

The role of various impurities that are deliberately kept in the cast iron is broadly as follows:

(*i*) **Phosphorous** - it increases the **fluidity** of the cast iron which is an important property. Its percentage varies between 1-1.5.

(*ii*) **Sulphur** - its presence causes **rapid solidification**. Its content is generally maintained below 0.10 per cent to get the best results.

(*iii*) **Manganese** - gives the cast iron its **hardness**. But its percentage should be below 0.7 percent otherwise the metal will be very brittle.

8.4.2. CLASSIFICATION OF CAST IRON

Following are the common types of cast iron used as engineering materials :

1. Grey Cast Iron. In this type, carbon is present in the flaky, graphite form. It has a typically grayish colour (which is due to graphite). The usual composition of grey cast iron is:

- **Iron** - 92 per cent;
- **Carbon** - 0.5 per cent (combined)
- **Silicon** - 2-3per cent

Grey cast iron is soft and ductile. It finds applications in making castings, dies, moulds, machine frames and pipes etc.

2. White Cast Iron. It is that variety of cast iron in which carbon is present in the **combined form** as iron carbide (FeC) and not as graphite. It has a shining white colour and a bright metallic luster. The metal is very strong, hard and resistant to wear and heat. It is quite brittle as well.

The usual composition of white cast iron is as follows :

- Iron - 94 per cent
- Carbon - 2.5 -3.0 per cent (as iron carbide FeC)
- Silicon - 0.5 – 1.0 per cent

White cast iron is difficult to machine. It is, therefore, first converted to malleable cast iron.

3. Malleable Cast Iron. It is actually "white cast iron" in which property of malleability has been developed by the process of **heat treatment**. The white cast iron is subjected to a process of annealing *i.e.* **heating in an annealing oven at a temperature of 875^0 C for 24-72 hours**. After that, it is cooled gradually to room temperature. Malleable cast iron is tough, ductile, and strong. It has a uniform structure and can easily be machined. It possesses useful properties of both cast iron and mild steels.

The malleable cast iron finds extensive applications in

(*i*) **Automobile industry** for making rear-axle housing, stearing, gear housing, hubs and pedals etc.

(*ii*) **Railway equipment** of a great variety;

(*iii*) **Agricultural machinery** and

(*iv*) **Carpentry tools.**

4. Alloy Cast Iron. This group includes those types of cast iron in which one or more alloying elements have been incorporated with a view of increasing the utility of the metal. The usual alloying elements are nickel and chromium. Nickel is added to effect an increase in the hardness and resistance to wear. Chromium makes the cast iron extremely tough, strong and ductile.

Ductile cast iron, inoculated cast iron, controlled cast iron and chilled cast iron are some other varieties of cast iron specially prepared for specific applications.

8.4.3. PROPERTIES OF CAST IRON

No generalization of the properties of cast iron is possible. This is because the ultimate properties of cast iron depend on three factors, namely

(*a*) The composition of cast iron,

(*b*) The rate of cooling,

(*c*) The nature of heat treatment.

Following is a general account of the properties that depend on composition.

1. Carbon. The amount of carbon and the nature in which carbon is present in the cast iron greatly effect the properties of cast iron. Thus,

(*i*) When most of carbon is present as graphite (free carbon), cast iron is soft and weak (e.g. grey cast iron). But when carbon is present as cementite (fixed as Fe carbide), the metal is hard and strong. Thus, cast iron can be both hard and strong and soft and weak.

(*ii*) The tensile strength decreases with an increase in the graphite content.

2. Alloying Elements. The most important elements often added to cast iron and their effects are:

(*a*) **Nickel.** It may be added in amounts varying between 0.5 to 20 per cent. The common types of nickel-alloyed cast iron are:

- **Nickel cast iron.** It contains nickel between 0.5 and 3 per cent. It is uniform in machinability.
- **Chilled cast iron**. Nickel proportion is kept between 3-5 per cent. This type is very resistant to abrasion.
- **High Nickel cast iron.** In this nickel content may be increased to 20 per cent. This variety is resistant to corrosion (chemical attack).

(*b*) **Chromium.** It is also added in small proportion to cast iron. Addition of chromium increases hardness and tensile strength of cast iron. Generally chromium and nickel are added together.

(*c*) **Molybdenum.** This alloying element is added to increase the hardness of cast iron.

3. Heat Treatment. This type of treatment changes the properties of cast iron to a great extent. Thus, white cast iron when subjected to annealing becomes a soft, very ductile and easily machineable variety called the malleable cast iron. This type of treatment effects the nature of carbon present in the metal. The combined carbon of cast iron gets converted to free particles of carbon.

4. Impurities. As discussed earlier, the influence of certain common impurities like phosphorous, sulphur, silicon and manganese is quite pronounced

8.5. WROUGHT IRON

8.5.1. Manufacture

It is the purest form of IRON containing all impurities below a limit of 0.5 per cent. Carbon is included in these impurities, its proportion being generally less than 0.12 per cent. Besides, wrought iron always contains a small proportion of slag as a silicate component.

The source material for the manufacture of wrought iron is PIG IRON. There are two processes for manufacture of wrought iron: Puddling Process and Aston Process.

1. PUDDLING PROCESS. This consists of heating the pig iron in a small reverberatory furnace called Puddling Furnace. The furnace has lining of iron oxide bricks. The charge is heated to 1200^{0}C. At this temperature, melt is oxidized on coming in contact with iron oxide lining. To ensure that more and more fused metal comes in contact with the oxide lining, the molten charge is regularly stirred or puddled through pudding holes. Hence the name of the process. The impurities form a light slag that is separated from the surface. Carbon is driven off as carbon dioxide. The remaining molten charge, containing some slag, forms the **wrought iron**. It is squeezed to remove any extra slag.

2. ASTON PROCESS. In this process, pig iron is first refined by heating in a Bessemer Converter. All impurities get removed by directing a strong current of air over the molten material. The molten pig iron is cast into moulds.

A mixture of iron oxide and silica in predetermined proportions is heated separately in a furnace to fusing temperatures. This forms slag (iron silicate). It is poured into the ladles.

The refined pig iron is put into the mixing machines where it is first granulated. When still very hot, slag is poured on to it from the slag ladles. The slag is essentially at a lower temperature than the pig iron. The pouring results in abrupt solidification of iron incorporating a good amount of slag. This step of mixing the slag with the iron is called "shooting" and is most important. The iron-slag balls so formed are subjected to pressing machines where the extra quantity of slag is squeezed out of them. The resulting material is **wrought iron**.

8.5.2. Properties and Uses

Following are most important properties of wrought iron :

Strength. It has a tensile strength varying between 2500 to 4000 kg/cm^2. **The strength is greater in longitudinal direction**. The ultimate compressive strength ranges between 1500-2000 Kg/cm^2.

Physical. Wrought iron is **bluish** in colour, has a **silky** lustre and **fibrous** structure. It is malleable, ductile and tough. It is resistant to corrosion.

Density. The metal has a density of 7.8 gm/cc^3 and a melting point of 1500^0 C.

Wrought iron shows good resistance to fatigue and sudden shock. Moreover, it can be welded with ease. Because of the above set of properties, wrought iron is extensively used as a material for making plates, sheets, pipes, tubes etc. It is also used in buildings, railways and marine industries. It is also a material for **general blacksmithy**.

8.6. STEEL

8.6.1. Definition

Steel is essentially a variety of iron containing 0.1 to 1.5 % carbon in the form of cementite (iron carbide, Fe_3C). Besides carbon, many other metals may also be present in addition to iron, giving rise to a great varieties of steel.

If the percentage of carbon exceeds 1.5, the material will become more like cast iron because the carbon will then tend to occur as graphite (free carbon). On the other hand, with decrease in the carbon content (lower than 0.1%), the material would resemble more to wrought iron or the pure iron.

The best thing about steel is that it has the very high compressive strength of cast iron and very high tensile strength of wrought iron. As such it is suited for all types of situation as a structural material.

Steel is a versatile material of modern age. Its properties can be varied over a wide range by varying its composition and by subjecting it to various mechanical and heat treatment processes.

8.6.2. Manufacture of Steel

Steel is at present manufactured by many processes that fall under three broad headings namely, the Bessemer Process, the Open Hearth Process and the Electric Process. In each of these methods, the actual process may be either acidic or basic in principle signifying that the furnace-lining used and the slag maintained in the furnace are either **acidic or basic** in nature, respectively.

1. The Bessemer Process

This method takes its name after the Bessemer Converter which is used for steel making. The converter is an egg or pear shaped vessel supported on trunions in such a way that it can be tilted and even **rotated** about its horizontal axis. The inner walls of the converter are lined with a refractory material. When the **refractory bricks** are made up of clay or silica, the **lining is acidic in character**. The process is then called acidic Bessemer Process. But when the lining is made up of lime of magnesia bricks, it is **basic** in character. The process is then called **basic Bessemer Process.**

The raw material for making steel in the Bessemer Process is **pig iron**. In the acid process, the pig iron must be free from phosphorous and sulphur. In the basic process, however, these impurities are tolerated, and removed by the addition of lime.

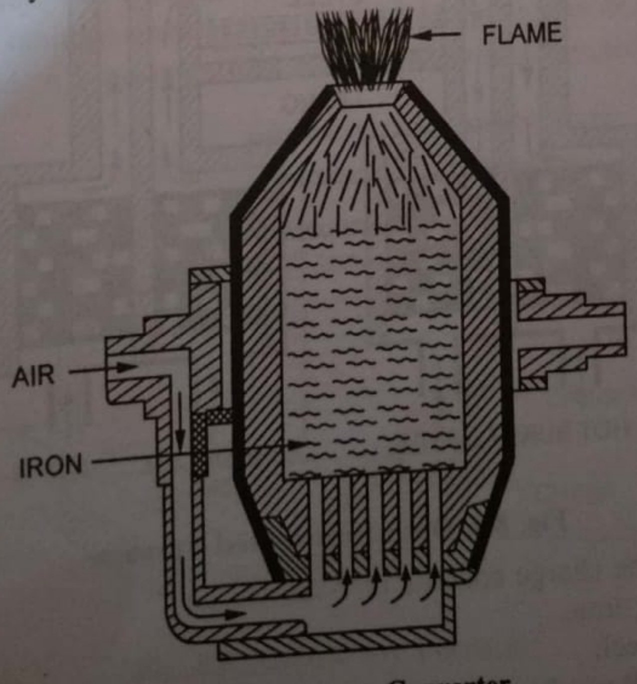


Fig. 8.3. Bessemer Converter.

Following are the main stages in the manufacture of steel in the Bessemer Process.

Stage 1. The Bessemer converter is first tilted to a horizontal position. Molten pig iron is then fed directly from the furnace (either a cupola or even from blast furnace). Air is also simultaneously blown into the converter through the tuyers and the converter is straightened up.

Stage 2. Air is kept blowing continuously through the charge. During this process, most of the impurities of the pig iron like silicon, carbon, manganese, sulphur and phosphorous gets oxidized on reacting with iron oxide formed as a result of reaction of iron and air. These changes may be expressed as follows :

$$\boxed{\begin{aligned} 2FeO + Si &= 2Fe + SiO_2 \\ FeO + Mn &= Fe + MnO \end{aligned}}$$

Stage 3. When oxidation process has progressed sufficiently, predetermined quantities of ferro-manganese or **spiegleisen** are added. This material serves two purposes :

(*i*) It supplies carbon content for the steel;

(*ii*) It deoxidizes any iron oxide left during oxidation of other impurities.

Stage 4. Converter is then tilted into the discharge position and molten metal poured into moulds of special rectangular shapes. The solidified steel is knows as **ingot**, which is the starting material for preparing other steel shapes.

2. *Open Hearth Process*

This is one of the most common processes of steel making. It consists of an elaborate assembly of mechanical and metallurgical devices.

The main part of the plant is known as the **Hearth** which consists of a steel pan lined with a thick layer of refractory material. **The refractory lining may be either acidic or basic in character**. The hearth has varying dimensions and may accommodate steel up to 3000 tons in one charge. The plant is provided with various openings such as charge doors, tapping holes and entry ports for gases.

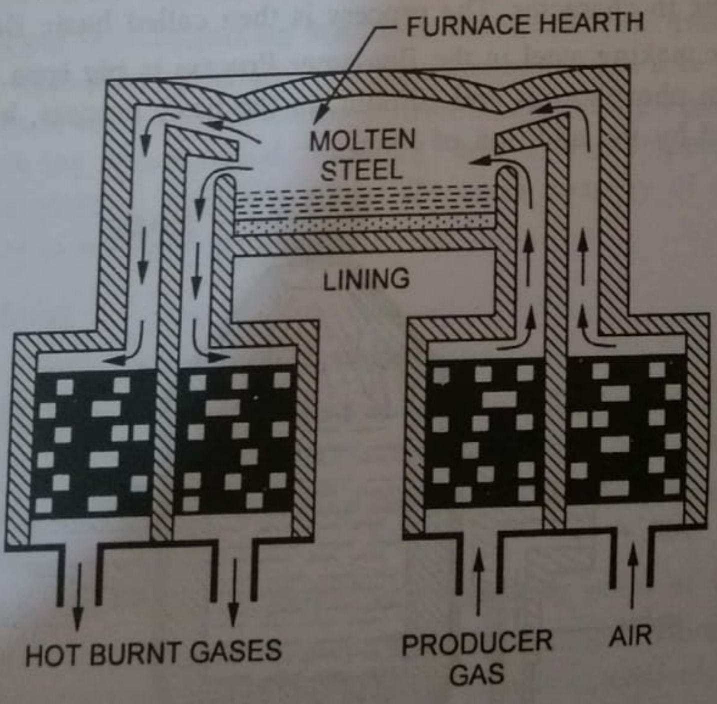


Fig. 8.4. Open Hearth Steel Furnace.

The raw materials or the charge consists of

(*i*) Molten or cold pig iron;

(*ii*) Scrap of iron or steel;

(*iii*) Limestone (in the Basic Process only)

Manufacture for steel in this process involves following main stages.

Stage I. The molten charge of the raw material is loaded into the hearth.

Stage II. A mixture of hot air and coal gas is blown in and made to pass over the charge. The gas mixture starts burning and raises the temperature of the molten charge further to boiling. The charge is allowed to remain in this boiling period for some time. **It is during this period that all the impurities get removed from the charge by oxidation.**

Stage III. This is the **finishing stage** or final stage during which predetermined quantities of ferro-manganese are added. Some coke is also added to accelerate the process of deoxidization.

Stage IV. Molten steel is drained into special rectangular moulds to give the cold steel the typical shape of **ingots.**

The refining principle in the open Hearth Process is again of oxidation of impurities, such as silicon, manganese, carbon and phosphorous. In the acid process phosphorous cannot be easily removed. As such, the pig iron should be free from this impurity; otherwise, basic process has to be adopted.

3. *The Electric Process*

Now a days steel is manufactured in great quantities using electric furnaces, especially where power is available at cheap rates. This process ensures best and pure steel, because conditions of temperature and chemical environment can be kept under perfect control.

Electric furnace methods are of two general types: the **Arc Furnace** and the **Induction Furnace.**

The Arc Furnace Process. It consists of following steps :

(*a*) The charge, consisting of steel scrap or ordinary impure steel which requires refining, is placed in the furnace in molten form. **It forms the bath.**

(*b*) A set of current electrodes are brought down into the bath.

(*c*) Arc current is made to pass from the positive to negative electrodes. This action heats up the bath to very high temperatures in very short time. The impurities are all quickly oxidized and expelled (Fig 8.5).

The Induction Furnace Process differs from Arc Process only in the manner in which current is supplied to the bath. **It is also called high frequency furnace method**. The plant consists of a series of refractory crucibles. These crucibles are surrounded by copper turnings that act as primary conductors for current of high frequency. The charge is placed in the refractory crucibles. As soon as current is passed through the copper tubings, great heat is induced to the charge. It becomes greatly heated up and in process gets purified. All the impurities escape on getting intensely heated up.

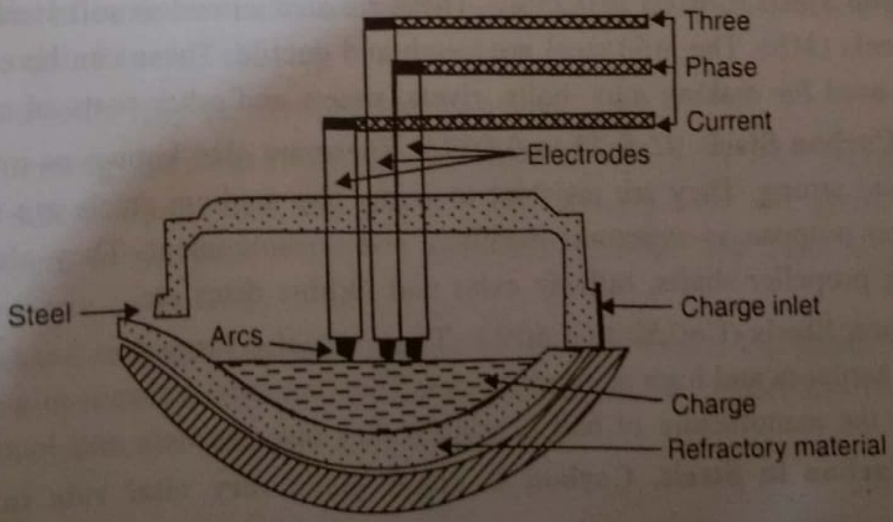


Fig. 8.5. Electric Arc Furnace.

4. Linz-Donawitz Process

This is a modification of the Bessemer Process. In the L-D process, a blast of OXYGEN (and not air, as in the case of Bessemer Process) is blown into the converter containing the heated charge of pig iron and scrap. This oxygen blast is capable of oxidizing even the smallest quantities of the common impurities like silicon, carbon, phosphorus and sulphur very effectively. During the operation of this process, a zone of high reactivity is created in the lower region of the converter where oxygen blast enters the converter. Most of the molten scrap iron being confined in this zone ensures its thorough conversion to a very pure **low-carbon steel**. The L-D process is specially suitable for making **pure steels** from ores rich in phosphorus and sulphur. It has been applied successfully at Rourkela Steel Plant in India.

5. Duplex Process

It is **double-stage process** using essential features of Acid Bessember Process and Basic Open Hearth Process. The main object is to remove all the impurities in the charge of pig iron to convert it into a **pure steel**. The charge of pig iron is first treated as usual in an acid-lined Bessember Converter. This process ensures removal of three main impurities: silica, manganese and carbon. The molten charge so obtained is then treated in the Basic Open Hearth Furnace, which is lined with bricks of lime and magnesia (basic refractories). During this treatment, the other two major impurities like phosphorus and sulphur get removed. For any further refining of the steel as obtained from Duplex Process, we may resort to **electrical refining**.

8.6.3. Classification of Steels

Steels have been classified in many ways such as on the basis of method used in their manufacture, on their carbon content, according to the use for which they are best suited and also on the basis of steel castings.

It is, however, the classification on the basis of their **chemical composition** that is very commonly adopted. Two major groups of steels recognized on this basis are:

- The Plain Carbon Steels and
- The Alloy Steels.

(A) The Plain Carbon Steels. This is the first major group of steels. In them carbon is the only controlling component besides iron. They are further sub-divided into three sub-types.

(*i*) **Low Carbon Steels** (C=0.05 to 0.25%). These are also termed as soft steels or very commonly as mild steels (MS). The mild steel are tough and ductile. These can be easily welded. These steels are used for making nuts, bolts, rivets, sheets and other parts of common utility.

(*ii*) **Medium Carbon Steels** (C=0.25 to 0.50%). These are also known as medium steels. These are hard and strong. They are resistant to wear. The medium steels are used commonly for construction purpose as structural members and reinforcement. They also find applications for making propeller shafts, railway axles and turbine discs etc.

(*iii*) **High Carbon Steels** (C=0.50 to 1.50%). These are also termed as hard steels. They posses very great hardness and high strength values. They are very resistant to wear. The hard steels find use in the manufacture of ball bearing roller, saw, crushers and locomotive tyres.

Function of Carbon in Steels. Carbon in steels plays very vital role in controlling their properties, Thus,

(*i*) The **tensile strength** of steel increases with an increase in the carbon content till its proportion reaches 0.83 per cent. Any increase in carbon content beyond this limit will effect the tensile strength of steels adversely.

(*ii*) The **ductility** of steels decreases with an increase in the carbon content.

(*iii*) The hardness of steels increases with the increase in carbon content. So is the case with regard to heat treatment. High carbon steels give better results on heat treatment compared with the low carbon steels.

As said earlier, the highest carbon content in steels is limited to only 1.5 per cent. When carbon content goes beyond this limit, the material does not remain a steel. It becomes a variety of cast iron.

Usual Impurities. In the plain carbon steels, despite all the care at the manufacturing stage, some impurities like manganese, silicon, phosphorous and sulphur may still be present in minute properties. Their tolerable limits and the effects which they exert on the properties of steel are listed below:

(*i*) **Manganese**. It is generally present between 0.2-0.8%. Within these limits, manganese exerts a beneficial influence on some properties of steel. Thus, it **increases the tensile strength and hardness** of the steel. Further, it neutralizes the excess of sulphur in the steel. But when present above 1 per cent, manganese makes the steel brittle.

(*ii*) **Silicon**. Its presence is generally kept below 0.4 per cent. Within this limit, silicon contributes to increase the hardness. It also acts as a **deoxidizer**, a property which facilitates the hot ingots to be free from blow holes on cooling.

(*iii*) **Phosphorus**. Its proportion must be kept **below 0.1 per cent** in general. In some steels, this limits is fixed at 0.05 per cent. Its increased presence causes the so called "cold short" effect in which the steel becomes **very brittle** and difficult to work at ordinary temperature.

(*iv*) **Sulphur**. It is a **highly undesirable** impurity. Its percentage must be kept below 0.05. Even within this range, it **increases ductility** and decreases the hardness of the steel. When present in higher than above proportions, sulphur makes the steel red short. **Such steel becomes brittle while red hot**.

Summary. Important characters of Plain carbon steel have been tabulated in Table 8.1 for a quick reference.

(B) Alloy Steels. These are steels made **with the addition of a definite proportion of a selected element in addition to carbon at the manufacturing stage**. The alloy steels show some specific properties that are related to the alloying elements.

The alloying elements may be grouped into two categories:

(*i*) **Carbide-forming Elements**. This group includes elements like **manganese, chromium, tungsten, molybdenum and vanadium**. Each element from this group combines with the carbon present in the steel to form a particular carbide. The carbide so formed gives the desired property to the alloy steel.

(*ii*) **Non-Carbide Forming Elements**. This group includes metals like **copper, nickel and silicon.** These are dispersed throughout the body of the steel and impart specific properties without forming any particular compounds.

Table 8.1. Plain Carbon Steels.

S.No	*Class of Steel (Carbon%)*	*Characteristics*	*Important Uses*
1.	**Low Carbon or Mild Steels.**	Steels are soft, ductile and easily machinable in general.	These are used in making of galvanizing sheets. Also used for making wires and nails and in steel bodies of automobiles.
	(*ii*) Carbon less than 0.15 percent.	The steels cannot be heat treated.	
	(*iii*) Carbon between 0.2 to 0.35 per cent.	Can be heat treated. These steels form harder types of steels. The tensile strength of mild steels increases with carbon content.	This sub group of steels is extensively used for making boiler plates, structural shapes, home appliances like refrigerators and air conditioners. It is also used for forging as axles shafts, cylinders, spindles and so on.
2.	**Medium Carbon Steels** (*i*) Carbon between 0.35 - 0.45%.	These steels can be heat treated and thus many desired properties can be developed in them.	These steels are extensively used for making heavy machine parts such as axles for railways and trams, turbine discs etc.
	(*ii*) 0.45 - 0.5%	Very resistant to abrasion and possess very high tensile strength.	Used for making rolling mills, rifle barrels and gun parts, etc.
3.	**High Carbon or "Hard Steels"** Carbon content varying between (*i*) 0.5 - 0.8%	Steels are very "tough" but not very hard.	Used for making handsaws, chisels and for all parts where toughness is requisite quality.
	(*ii*) 0.8 - 1.00%	Hard as well as tough.	For making springs, chisels, dies and drills etc.
	(*iii*) 1.00-1.5%	Very Hard Steels	Specially suited for drills, machine tools, files and razors.

(*iii*) A **third group of elements** like **titanium** and **aluminum** are used to remove some impurities at the manufacture stages acting as 'scavengers'. Such steels are called as **alloy treated steels**.

Benefits of Alloying. Some of major benefits achieved by alloying of steels are :

(*i*) The **tensile strength** of the steel may be increased without effecting its workability.

(*ii*) The **resistance against very high temperature,** abrasion and corrosion may be improved considerably.

(*iii*) The electrical, magnetic and thermal properties may be modified in the desired direction.

The above benefits broaden the field of applications of the steel to a great extent.

Sub-divisions of Alloy Steels. Two main types of alloy steels recognized on the basis of proportion of alloying elements are: low-alloy steels and high-alloy steels.

1. **Low Alloy Steels**. In them, the combined maximum proportion of one or more alloying elements is **limited to 8 per cent only**. Among their major properties may be mentioned: high resistance to corrosion, high machinability and high welding qualities. Such steels find extensive applications in railroad freighters, truck bodies, passenger cars, earth moving equipment and heavy duty plants. Copper, chromium, molybdenum, nickel, manganese and phosphorous are used for making these steels.
2. **High Alloy Steels**. These include steels in which the proportion of alloying elements is **generally kept high** with a view of achieving some special quality in the end product. Such steels include the so-called **tool and die steels**, the stainless steels, the electrical steels and the heat resisting steels. Among the alloying elements used for making these steels are included: tungsten, molybdenum, vanadium, chromium and nickel. The tool and die steels contain the first three elements in varying proportions. The stainless steels are made by additions of chromium up to a proportion of 22 per cent with or without nickel and molybdenum.

8.6.4. A Note on Structural Steels

All those types of steels that may be used in civil engineering construction are some times classified as **structural steels**. They are required to possess a set of properties that make them specifically useful for a particular situation in buildings and other such structure as bridges, railway lines and cable wire projects. We may study them under the following headings: concrete reinforcement, pre-stressing steels, bridge wire steels, cladding steels and railway steels.

Concrete is the most common material of construction. **Plain concrete has very high compressive strength but very low resistance against bending and tensile forces.** This shortcoming of concrete is overcome by incorporation in it steel reinforcement. The resulting product, the reinforced concrete has very high tensile strength and resistance against bending.

The steels used for reinforcement belong to the Mild Steels (low carbon) having a carbon content of 0.25 per cent. These come in plain or indented bars of round or square cross section. These are also supplied in various desired shapes and may be even woven or welded to form mesh. The bond between the reinforcement steels and the concrete is of purely **mechanical** nature *i.e.* without involving any chemical reactions.

Prestressing Steels. This is another use of structural steel. In the process the steel reinforcement is tensioned at the time of placement of concrete. After this, when the equipment for creating tension in the steel member is removed, the steel tends to come to its original shape. But being enclosed within the set concrete it fails to do so. The result is that compressive strength of the concrete and the tensile strength of the steel come to establish a useful balance.

The most important quality required for prestressing steels is their high yield strength in tension. This is important because otherwise the steels may not be able to take high elastic strain. The steels used for Prestressing have a relatively higher carbon content than mild steels: 0.6 to 0.9 per cent. Sometimes manganese steels (alloy steels) are also used for this purpose.

Bridge Wire Steels. In the construction of suspension bridges, use of steel cables of proper qualities is a very important consideration. Such steels should possess following set of properties:

(*i*) high strength: a minimum tensile strength of 1600MN/m^2.

(*ii*) high toughness;

(*iii*) high resistance to fatigue;

(*iv*) high resistance to corrosion.

For this purpose a steel of composition of carbon: 0.55-0.75 per cent and manganese 0.5-0.7 per cent has been found most suitable. These are very commonly heavily galvanized to provide for resistance against corrosion.

Cladding Steels. These are **thin sheets** of proper quality of steel that are used to cover the walls and columns and other structures in a building. The cladding steels are generally from the category of stainless steels with a composition having **chromium** (17-18 per cent), and **nickel** (up to 8 per cent). These may be given attractive finishes by coating with vitreous enamel or polyvinyl chloride.

Railway Steels. Steels find extensive applications in railways; for rails, for construction of bridges, for erecting signal gentries etc. The steel for making rails must be :

(*i*) very strong in compression and bending.

(*ii*) very resistant against wear;

(*iii*) very stable against fatigue;

(*iv*) very stable against shock and impact.

These qualities are met by a steel of the composition :

- Carbon : 0.45-0.6 per cent.
- Manganese: 0.95-12.5 per cent.

8.6.5. A Note on Proceses for Steel Shapes

Iron and steel are made available to the industry in specified shapes like ingots, sheets, plates, wires, pipes, rods, sections and so on. Theses forms are produced in the steel plants using either of the two methods: casting and mechanical working. The essential outline of these processes is given below :

(A) Casting. It is defined as a method by which specified shapes are produced by pouring the molten, metal into specially prepared moulds, where it is allowed to cool. The shapes so obtained are designated as castings.

In fact, in steel, **casting** forms the first step in the process of giving shapes. All the steel is first prepared as 'ingots' which are castings of steels made by pouring the molten steel from the furnace into long rectangular moulds.

In the casting process the moulds are made up of either cast iron or refracting material.

Ingots. These are the basic castings of the metal and are made by the melt pouring from the furnace into rectangular moulds. A single ingot is a rectangular block with a length of 2-3 meters and cross-section between 40-100 cm. Following defects may develop into castings if proper care is not taken at the time of making the ingots.

(*i*) **Blow Holes**. These are small **hole like openings**, continuous or discontinuous, that may develop on the ingots. These are produced when the gases escape from the metal at the time of **cooling** in the mould.

(*ii*) **Segregations**. These are concentrations or localized accumulations of impurities in the interior of an ingot. During the cooling process, the impurities are rejected by the primary metal (iron or steel) from the surface. The cooling proceeds from the surface to the interior. Accordingly, the impurities are gradually brought into the innermost part of the ingot where they cool last of all.

(*iii*) **Ingotism**. It signifies the development of a very **coarse crystalline structure** in the ingot. This structure develops because of a slow rate of cooling of the ingot.

(*iv*) **Pipe**. It is defined as a **central continuous cavity** developing within an ingot. It is considered as a major defect in the ingots. The formation of pipe takes place somewhat in this manner: during the cooling, solidification starts from outside to inside; cooling is always accompanied by contraction; since the sides cool first, material contract (flows) towards the sides, leaving an open space in the central part; the central open space gets widened with further cooling of the ingot and ultimately may take the shape of a cavity running along the center of the ingot.

Control of Defects. Blowholes and Ingotism are cured by mechanical working as described in the following section. As regards development of pipe, it can be prevented by adopting such methods of cooling in which the top portions remain hot till the end so that the pipe is formed in the exterior region of the ingot. It can be then removed by cutting off a thickness of external length of the ingot.

8.6.6. Mechanical Working

All those methods in which desired shape of iron or steel are produced by applying pressure in one way or another are grouped under **mechanical working**. These form the most common methods of producing the steel shapes. Three main processes included under this head are: **Rolling, Forging** and **Pressing**.

1. *Rolling*

Definition. By rolling is understood reduction of iron or steel blocks to the desired dimensions and shapes by passing them through a set of rolls in motion.

The plant where this operation is performed is called a ROLLING MILL. A rolling mill may have numerous set of rolls. These rolls are made of cast iron, high carbon steels or special alloy steels in a great variety of shapes and sizes depending upon the nature of the shape to be produced. The process of rolling is further divided into two classes: **hot** rolling and **cold** rolling depending upon whether the metal to be rolled is in hot condition or in a cold state.

Hot Rolling. It is a very common process for obtaining shapes from metals. It involves subjecting a **preheated metal** (say steel) to a series of rolls. The rolls are provided with projecting collars and grooves according to the shapes desired. When flat smooth surfaces are required, the rollers have a uniform outer shape. Shapes like I, T-Z and H require **grooved rollers**.

Hot rolling is used both in manufacturing semi-finished and finished metallic products. In the semi-finished category are included shapes like billets, blooms and slabs. These form the starting material for other mechanical processes.

The **benefits** of hot rolling of steels are :

(*i*) The process introduces a refinement in the grain size.

(*ii*) It brings about close contact among the constituent grains;

(*iii*) It creates elongation of grains in a direction parallel to rolling.

(*iv*) It reduces the magnitude of the defects like blow-holes etc.

Rails, plates, sheets and stripes are commonly manufactured by hot rolling.

Cold Rolling. It is invariably a finishing process aimed at obtaining shapes of very accurate dimensions that are not possible with hot rolling.

In cold rolling, starting material is commonly a hot-rolled semi-finished product such as a sheet or strip. This material is often heat-treated before subjecting to cold rolling. A common finished product of cold-rolling is Cold Rolled Sheet. Such sheets any be rolled again and again to develop the desired properties. They are often numbered accordingly, the numbers being called as "Temper Numbers", such as T_1, T_2, T_3, T_4 etc. the last number indicates maximum cold rolling.

2. *Forging*

Definition. It is a mechanical process for obtaining the desired shapes of a metal by **giving blows to the metal held within dies**. This is generally achieved by first heating the metal to a specified temperature and then giving blows of definite pressure. Blows are given by hand hammers if the parts to be forged are of small size. For products of bigger dimensions, stream-hammers are used.

In steam-hammer forging, also termed **Drop-Forging**, the metal is given the desired shape with the help of specially designed dies. The hammers are capable of giving 100-300 blows per minute. In such forgings, the dies are of closed type. In these dies, one part of the die is attached to the hammer and the lower part is fixed on the anvil. When hammer is dropped on the anvil, the two parts of the die get closed and form one shape only. With repeated blows, the metals within the die is forced to fill the entire part of the die and take the required shape.

Typical products obtained by forging include tools of all sorts, locomotive axles and wheels and many other complicated shapes which cannot be obtained by rolling methods. In forged products, the grains of the metal develop a strong tendency of flowage during forging in a direction at right angles to the direction of blows. As such, these grains align themselves along the line of the object making it more strong in that direction than across the line.

Forging invariably results in a more dense constitution of the product.

3. *Pressing*

Definition. It is a method of mechanically working the shape of a metal and **involves application of heavy load on the metal placed on an anvil through a hydraulic press**. The presses vary in size and capacity to deliver loads of ten to fifteen thousand tons. During the application of pressure, many original defects of the metal get removed. The structure of the metal also undergoes a change towards a greater crystalline nature.

The method is used for making armour plates, heavy shafting and such other thick parts.

4. *Drawing*

(A) Wire Drawing. This is the main method of shaping metals into wires of various cross-sections. It involves stretching the metal through a series of tapered dies, each die having a hole slightly smaller than the preceding one.

The wires obtained as above are used for making bolts, springs, nails, screws etc.

(B) Tubular Products. The two most common methods of obtaining tubular shape are: welding and seamless drawing.

Welding. Tubular products can be obtained by two methods in the welding process.

- Butt-welding and
- Lap-welding.

In the **Butt-Welding**, the starting material is a **sheet of metal named skelp**. It is first heated and then pulled through a funnel shaped die where it gets curled in such away so that its two edges meet. These edges are welded together continuously as the pipe comes out form the other end. The method is suitable only for preparing tubes of less than 10cm diameter.

In the **Lap Welding**, the ends of the sheet (skelp) are first beveled. These are made to overlap to a shape as desired in the end product. The overlapped ends are then heated to welding temperatures. The so heated tube-like sheet is then subjected to **rolls and mandrel** which weld the overlapping edges.

Seamless Pipe: It consists of pipe which has been obtained without welding. It is carved out of solid metallic billet. Seamless pipes are made by removing the external and internal material from the billet with the help of specially designed rolls and mandrel. The millet from which pipe is to be carved out is first heated to 2200^0F whereby it gets softened. The mandrel can then pierce the billet easily.

5. *Extrusion*

It is a method of shaping the metal by **forcing it out through a die of requisite shape under great pressure applied via ram or plunger**. In this method, shapes can be formed by hot extrusion and cold extrusion, using pre-heated or cold metal. In the hot extrusion, the hot metal must be first heated to a desired temperature.

6. Powder Metallurgy

This method involves converting the metal to a proper grain size as the first step. The **metallic powder is then compacted under pressure to the desired shape**. The shapes so obtained are then heated or sintered very carefully.

The method offers following advantages :

(*i*) Shapes obtained by powder metallurgy require least or no subsequent machining.

(*ii*) It is economical and more shapes can be produced per unit time compared to other methods.

(*iii*) Very **intricate shapes** not possible in other methods can be developed by powder metallurgy.

Its major disadvantages are :

(*i*) The cost of preparing metallic powders may be quite prohibitive.

(*ii*) The ductility and strength of shapes obtained are inferior.

(*iii*) The maximum size of shape is considerably limited.

8.6.7. Heat Treatment

Definition. By heat treatment is understood subjecting the metal (including steels) **to high temperatures** under controlled conditions of environment and then cooling them back to the room temperature in a **perfectly controlled manner**.

Object. It is now well established that a great variety of improvement in the properties of metals (including steels) can be achieved by subjecting them to one or more processes of heat treatment. An increase in hardness, strength and ductility, refinement of grain structure, and removal of the imprisoned gases and internal stresses are some of the objects easily achieved by heat treatment.

Processes. Following four processes are commonly applied under heat treatment :

- Annealing,
- Normalizing,
- Quenching and
- Tempering.

Only a brief note on each will be given below. For detailed study, the reader should refer to books on metallurgy.

1. Annealing. In this method of heat treatment, the metal **is first heated to a temperature** in a particular manner and **then cooled back to normal temperature**. There are many variations of the process of which the following are important.

Full Annealing. The steel (or other metal) is first heated to temperature above the critical temperature. It is then **kept at that temperature for sufficient time**. Subsequently, it is allowed to cool gradually to the room temperature. In this process an intimate solution of the carbon and alloying elements of steel takes place during the period of high temperature. The net result is an **increase in ductility** which makes the steel easily machinable.

Process Annealing. In this process the steel is heated to sufficiently high temperatures (550-650^{0}C) and then **cooled gradually**. The net effect is grain **recrystallization. The heating temperatures in the process are always kept below the critical range.**

Isothermal Annealing. This process involves heating the material above the critical temperature and keeping it at that for a definite time-as is done in the case of full annealing. The cooling is, however, achieved differently: the metal is first cooled **rapidly** to a temperature lower than critical temperature and from there onwards it is allowed to cool **gradually** to the room temperature. The main effect is similar to full annealing but time taken is less in this case.

2. Normalizing. It is defined as a process of heat treatment aimed mainly at refining the grain structure of a metal. In this method as used for steel, the metal **is heated to a definite temperature**

above the critical temperature and then allowed to **cool gradually in air.** Sometimes normalizing is done as a preparatory step for other heat-treatment processes. For instance, tempering.

3. Quenghing. It is another process of heat treatment by which a steel product can be sufficiently hardened to a desired thickness. **It consists of heating the steel beyond the critical temperate**. It is then maintained at that temperature for sufficient length of time to allow full reconstitution. Thereafter it is **cooled suddenly** to room temperatures by quenching or **dipping it into water** or brine or oil.

Tempering. By tempering is understood **further heat treatment of hardened steels in order to make them more stable and suitable for specific purposes**.

In tempering, the hardened steels are again heated to temperatures that are below the critical temperature.

The temperature to which **steel is reheated is of great significance** and controls the development of desired properties. Thus,

(*i*) For developing **additional hardness and strength**, temperatures should not exceed 400^0-600^0C.

(*ii*) Any stresses and strains that might have developed during the quenching of these steels are removed during tempering because cooling is also involved in this process.

Case Hardening

It is a specific process of heat treatment in which **only the outer part of a product is made extra-hard** while the inner part may remain soft and coarsely crystalline. It is commonly applied in the products developed from **low carbon steels**, cast iron and wrought iron. The process involves heating the product above the critical temperature for 1 to 8 hours. The product so heated is immediately **plunged into the cold water**, brine or oil. This results in a "hard case" or the hard outer surface although the inner part or the 'core' remains coarsely crystalline and soft.

Case hardening is of two types :

(*i*) **Case Carburizing**. In this process the steel is heated beyond the critical temperature in an **atmosphere of carbon for 1-8 hours** and then suddenly quenched in water or oil. The carbon–bearing atmosphere can be created with the help of carbon monoxide (gas carburizing) or charcoal (pack carburizing). Steel surface absorbs some carbon from such an atmosphere during heating. The surface becomes extra-hard. Such steels are used for making shafts, gears and automobile axles.

(*ii*) **Case Nitriding**. It is that process of case hardening in which steel is heated in the presence of ammonia at temperatures of 500^0-600^0C and then quenched. As a result the surface of the steel gets hardened due to the formation of iron nitrite. This method is used for case hardening in alloy steels. Ball bearings, dies and valves are made from such steels.

TYPICAL QUESTIONS

A. ESSAY TYPE

1. Discuss briefly manufacture and applications of Pig Iron. Give a detailed sketch of a BLAST FURNACE.

2. (*a*) Explain briefly manufacture of Cast Iron.

(*b*) Discuss the variation in properties of Cast Iron with increase in carbon content and due to impurities.

3. Give an outline of various processes for the manufacture of steel. Which process, in your view, is best suited for our country. Give reasons.

4. (*a*) It is said steel is a material that possess best of the properties of cast iron and wrought iron. Discuss the statement.

   (*b*) Give an outline classification of steels.

5. Give an account of different processes available for giving shapes to metals. Discuss their relative merits.

6. "Without heat treatment, steel may be as good a material as pig iron or cast iron". Critically examine the statement and give your comments.

7. Discuss various methods of heat treatment.

8. Write short note on:
   (*i*) Blast Furnace
   (*ii*) Cupola
   (*iii*) Electric Arc Furnace
   (*iv*) Ores of Iron
   (*v*) Case hardening
   (*vi*) Pipe defect
   (*vii*) Blow Holes
   (*viii*) Stainless Steel
   (*ix*) Normalizing
   (*x*) Structural steels
   (*xi*) Ingotism
   (*xii*) Duplex Process

B. OBJECTIVE TYPE

Tick the right answer :

1. Iron is the source of all the other varieties of iron and steel:
   (*i*) Cast
   (*ii*) Wrought
   (*iii*) Pig
   (*iv*) None

2. Blast Furnace is used for the manufacture of:
   (*i*) Wrought Iron
   (*ii*) Pig Iron
   (*iii*) Cast Iron
   (*iv*) Steel

3. Blast Furnace Slag is the name given to:
   (*i*) The molten impure iron obtained from blast furnace.
   (*ii*) A mixture of iron and waste material obtained on cooling of blast furnace.
   (*iii*) The scum formed by oxidation of impurities that floats on molten pig iron in the blast furnace;
   (*iv*) None of the above.

4. Carbon content of cast iron is in the range of :
   (*i*) 0.5 to 1.5 per cent
   (*ii*) 1.5 to 2.0 per cent
   (*iii*) 2.0 to 4.0 per cent
   (*iv*) 4 to 6.0 per cent

5. Carbon is present as cementite (fixed Fe_3 C, iron-carbide), in
   (*i*) Grey Cast iron;
   (*ii*) White Cast iron;
   (*iii*) Malleable Cast iron;
   (*iv*) None of above

6. Carbon is present as free, graphitic carbon in :
   (*i*) Grey Cast iron;
   (*ii*) White cast iron;
   (*iii*) Malleable cast iron
   (*iv*) None of these;

7. An increment in carbon content causes:
   (*i*) An increase in the tensile strength in steel
   (*ii*) A decrease in the tensile strength.
   (*iii*) An increase up to a definite percentage of 0.83 per cent and there after a decrease.
   (*iv*) Has no effect on tensile strength.

8. In low-carbon steels, the carbon content is within the range of

(*i*) 0.15 to 0.35 per cent (*ii*) 0.25 to 0.50 per cent
(*iii*) 0.50 to 0.60 per cent (*iv*) None of the above.

9. In High carbon steels, the percentage of carbon lies between:

(*i*) 1.55 to 2.0 per cent (*ii*) 1.25 to 1.50 per cent
(*iii*) 0.50 to 1.50 per cent (*iv*) None of the above.

10. In Medium carbon steels, the carbon content is:

(*i*) 0.45 -0.50 per cent (*ii*) 0.35-0.50 per cent
(*iii*) 0.25-0.75 per cent (*iv*) None of the above.

11. Mild steels are actually.

(*i*) Medium carbon steels (*ii*) Low carbon steels.
(*iii*) High carbon steels. (*iv*) None of the above

12. The stainless steels are alloy steels in which —— are the most important alloying element:

(*i*) Nickel and chromium (*ii*) Chromium and zinc
(*iii*) Zinc and copper (*iv*) Copper and tin

13. The most important quality for Prestressing steels is their

(*i*) High yield strength (*ii*) High compressive strength
(*iii*) High resistance to corrosion (*iv*) None of the above

14. The name **pipe** is given in an ingot to describe:

(*i*) Its capacity for getting easily rolled into a pipe.
(*ii*) Presence of a central-cavity that results from cooling process proceeding from outward to inward of the ingot causing a shrinkage that leads to the development of the cavity.
(*iii*) A hole found transversely in the ingot due to escape of gases
(*iv*) None of the above

15. Forging is the process in which shapes are given to the steel ingots by

(*i*) Passing them through a set of rolls;
(*ii*) Pressing them under a heavy load;
(*iii*) Giving them repeated hammer blows
(*iv*) None of the above

16. The process of **annealing** in which the metal is heated below the critical temperature and then cooled gradually is called;

(*i*) Full annealing; (*ii*) Process annealing;
(*iii*) Thermal annealing

ANSWERS: **1.** (*iii*); **2.** (*ii*); **3.** (*iii*); **4.** (*iii*); **5.** (*ii*); **6.** (*i*); **7.** (*iii*); **8.** (*i*); **9.** (*iii*); **10.** (*ii*); **11.** (*ii*); **12.** (*ii*); **13.** (*i*); **14.** (*ii*); **15.** (*iii*); **16.** (*ii*).

RELEVANT IS CODES*

(This is only a very selective list; the number of IS codes on ferrous metals runs into many hundreds).

1. Methods of chemical analysis of steels

(PT-I to PT XII
PT-I to III-1972
PT IV to VII -1974
PT VIII-IX- 1975
PT X-XII-1976

(Determination of C, Mn, P, Ni Cr,Mo, Si,S and Mn)

2.	Mild steel and medium tensile steel bars and hard dawn steel wire for concrete reinforcement.	IS : 432 -1966
3.	Rolled steel beam, channel; and angle sections	IS: 808 -1964
4.	Carbon steel castings for general purposes	IS : 1030-1978
5.	Steel doors, windows and ventilators	IS :1038-1975
6.	Hot rolled mild steel, medium tensile steel, and high yield strength steel deformed bars for concrete reinforcements	IS : 1139 : 1966
7.	Methods for Charpy Impact Test (U-notch for metals	IS : 1499-1977
8.	Methods for Brinell Hardness Test for steel	IS : 1499-1977
9.	Method for Vickers hardness tst for steel	IS : 1501: 1968
10.	Method for simple torsion testing for steel wire.	IS : 1717-1971
11.	Plain hard drawn steel wire for prestressed concrete.	IS : 1785-86(2 PTs) 1966,67
12.	Method for Brinell Hardness Test for Cast Iron	IS : 1789-1961
13.	Glossary of terms relating to iron and steel	IS :1956-PT to Pt,VIII, Pt I, II, 1976 Pt.III-IV-1975- Pt.V Pt VIII-1976
14.	Carbon steel forgings for generalengineering purposes	IS : 2004-1978
15.	Method for tensile testing of grey cast iron	IS : 2078-1962
16.	Code for designation of Pig Iron	IS : 2084-1974
17.	High Tensile Steel Castings	IS: 2644-1979
18.	Pig iron for special purpose	IS : 2841-1978
19.	Basic Pig Iron(code) for steel making purpose	IS : 2842-1973
20.	Corrosion resistant alloy steel for general applications	IS:3444-1978
21.	Tool and die steel for hot work	IS : 374801978
22.	Tool and die steel for cold work	IS : 3946-1966
23.	Hot rolled steel channel sections for general engineering purposes	IS : 3954-1966
24.	Alloy and tool steel forgings for industrial use	IS: 4361-1967
25.	Alloy steel billets, blooms and slabs for general engineering purposes.	IS :4368-1967
26.	Case hardening steels	IS : 4432-1967
27.	Heat resistant alloy steel castings	IS : 4522-1979
28.	Hollow steel sections for structural use	IS : 4923 – 1968
29.	Method for axial load fatigue testing of steel	IS-5074-1974
30.	Carburizing steels for use in bearing industry	IS:5489-1975
31.	Stainless steel plate sheet and strip	IS :6911-1972
32.	Code for Practice for fabrication, welding of steel castings.	IS : 6916-1973
33.	Method for spectrographic analysis of plain carbon and low alloy steels.	IS: 8811-1978

[**Note:** Most of these codes stand reaffirmed from 1995 to 1999.]

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9

Non Ferrous Metals

9.1. GENERAL

Although iron and steel are the most commonly used materials in building and engineering industries many non-ferrous metals and alloys have also been used with great advantage in both these fields. In fact, in some cases, they form far-better materials than iron and steel and have replaced them to a great extent. In general, however, the non-ferrous metals are comparatively costlier and are selected for use only when they satisfy certain specific requirements and possess some definite properties.

Following are the **special advantages** of non-ferrous metals (and alloys) over the ferrous metals in some selected areas.

(*a*) **Civil Engineering Construction.** Aluminium and some of its alloys offer a very suitable alternative material to steel in some special engineering construction. Thus, wrought aluminium alloys are

(*i*) Economical;

(*ii*) Resistant to corrosion;

(*iii*) Light in weight

Compared to steels, they have been used in the construction of bridges and roofs in situations where not much strength is required. In these situations they have been found to effect a weight saving of about fifty per cent.

(*b*) **Engineering Industries.** Copper, zinc, nickel and chromium in their pure and alloyed forms have been used as materials in situations where:

(*i*) **High tensile strength** is required at elevated temperatures;

(*ii*) **High ductility** and malleability are required;

(*iii*) **High resistance** to heat is required;

(*iv*) **High electrical** conductivity is the desired property.

In the above fields, steels and other ferrous alloys are no competition to the above non-ferrous metals.

9.2. ALUMINIUM

9.2.1. General

Aluminium is a very common component (about 8 per cent) of the crust of the earth. The most common ore of aluminium is **Bauxite** ($Al_2O_3.nH_2O$). As a metal, aluminium was first recovered only in 1825. Manufacture of aluminium from Bauxite is carried out in two stages.

Stage 1. The ore (bauxite) is first purified from all of its usual impurities as silica, titania and iron and a pure oxide of Aluminium (Al_2O_3) is obtained. There are two major processes to achieve this result. In the BAYERS PROCESS, the powdered ore is treated with sodium hydroxide solution. In the SERPAK'S PROCESS, the powder is **heated with coke at 1800^0 C** in an atmosphere of nitrogen.

Stage 2. From the alumina as obtained above, **metallic aluminium** is prepared by the process of **Electrolysis.**

Electrolysis of alumina is carried out in a huge **electrolytic cell** (called Hall Heroult Cell). The cell is lined with carbon which acts as a cathode. A bath of alumina dissolved in cryolite ($Na_3\ AlF_6$) is put in this cell. This solution acts an **electrolyte**. A set of carbon rods are hung down in the solution. These act as **anode** (Fig. 9.1). This completes the set up for electrolysis.

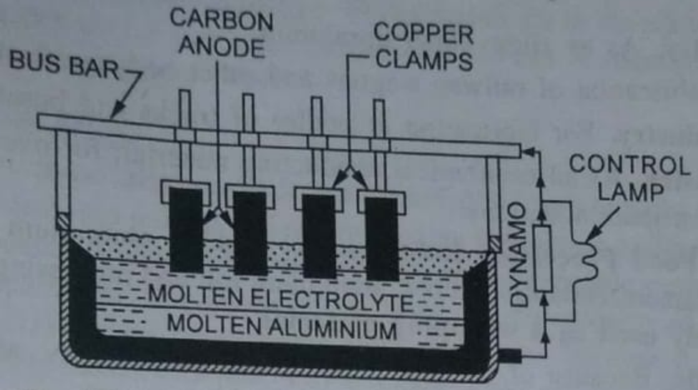


Fig. 9.1. Hall Heroult Cell for reduction of alumina.

An electric current is then passed through the solution. When temperature of around 953^0 C is reached, the solution (electrolyte) breaks into aluminium and oxygen. Aluminium gets deposited in the molten form at the bottom of the tank and is removed from there at **regular intervals**. The impurities get deposited on the anodes as anode mud.

The aluminium as obtained above has a **purity of 99 per cent**. It is put to **further electrolysis** for making aluminium of 100 per cent purity.

9.2.2. Properties

Following are more important properties of this metal :

1. Aluminium is a **white metal** and shows brilliant lustre when fresh.
2. It is the **lightest of all the industrial metals** (except magnesium and beryllium) having a specific gravity of only **2.7.**
3. It has a **low melting point,** 650^0 C, but boiling point is **quite high,** 2057^0 C.
4. Aluminium is known for its **high electrical and thermal conductivities**. Weight for weight, it is a better conductor of electricity even than copper (which is the best conductor). In general, **it has 60 per cent** conductivity of copper for same volume.
5. It has a **tensile strength of about 900 kg/cm^2** in the annealed condition. The same can be improved to 1600 kg/cm^2 by hard-rolling method.
6. It is **very ductile** and can be transformed into any shape by rolling, stamping, extruding, forming, drawing and spinning.
7. Aluminium can also be **cast into any shape** by any method of casting, e.g. die casting, chill casting and sand casting. These (casting) properties of metal are further improved by the addition of an alloying element.
8. Aluminium is **highly resistant to corrosion**. When exposed to moist air, aluminium forms a thin film of **oxide** at the top. This film is impervious to air or moisture and thus saves the metal from further corrosion.
9. The metal is attacked by strong alkalies and weak organic acids.
10. Aluminium forms **excellent alloys with a number of metals** such as copper, magnesium, silicon, zinc, manganese, chromium, copper and nickel.

Aluminium as Engineering material

Because of a combination of very useful properties, aluminium and its alloys find extensive applications as engineering materials in the following industries:

(*i*) **Structural Engineering**. As frames and railing and roofing material;

(*ii*) **Buildings.** As doors and windows, gates and water reservoirs and as ventilating and heating ducts.

(*iii*) **Aircraft industry.** As an alloy: super duralumin.

(*iv*) **Railway.** For fabrication of railway wagons and other body products.

(*v*) **Automobile Industry.** For fabrication of bodies of trucks and buses.

(*vi*) **Electrical Industry.** As an economical conducting material; for overhead transmission from generating to distribution stations.

(*vii*) **Chemical and Food Processing Industry**. For making aluminium tanks, condensers, heat exchangers, containers, collapsible tubes, aluminium foil and processing equipment. **Aluminium foil is extensively used as a wrapping material.**

(*viii*) **Cooking Utensils**. Because of its excellent thermal conductivity, aluminium has become a popular metal for making cooking vessels and cooking ranges.

(*ix*) **Nuclear Energy Projects**. Some aluminium alloys are considerably resistant to nuclear radiation. Hence they have been used as sheathing materials for uranium rods. BORAL, a dispersion of boron carbide in aluminium has been used as a neutron shield

It is claimed that aluminium alloys have been used in some parts of the guided missiles.

9.2.3. Alloys of Aluminium

As said earlier, aluminium makes **very useful alloys** with many metals, such as zinc, nickel, chromium, magnesium, manganese, copper and silicon. The alloys of aluminium are commonly grouped into two classes: Wrought alloys and Casting alloys.

A. *Wrought Aluminium Alloys*

This group includes those alloys which can be given a desired shape by applying pressure techniques such as rolling, hammering, forging, pressing and extruding. The hardness and strength of these alloys is considerably greater than the pure metal. Among the most important examples of wrought aluminium alloys are duralumin, magnesium-aluminium-alloys and magnesium-silicon aluminium alloys.

1. Duralumin. It is an important alloy of aluminium with copper and small amounts of magnesium and manganese, silicon and iron.

Usual composition of duralumin is :

1.	Copper	4.00
2.	Magnesium	0.50
3.	Manganese	0.50
4.	Silicon + Iron	< 1.00
5.	Aluminium	94.00
		100

Duralumin has a **high strength** compared to metal aluminium. Its most important property is, however, **age-hardening**, *i.e.* becoming harder and harder with time in storage.

A special variety of duralumin, called **super duralumin** and containing higher percentage of copper (4.5 per cent) is characterized with a very high tensile strength—5000 Kg/cm^2. Since it is very light in weight, this property has made it very useful in the aircraft industry.

2. Magnesium-Aluminium Alloys. The amount of magnesium varies between 1.8 to 7.5. Among other alloying elements, iron (upto 0.70%), silicon (upto 0.60%), manganese (upto 1.00 per cent) chromium (upto 0.50%) and copper (upto 0.10 per cent) are alloyed in varying proportions.

This group of alloys is available in sheets, plates, tubes, wires and sections (depending upon the compositions). These find uses in ship building, motorcar bodies, and for structures exposed to marine atmosphere.

3. Magnesium—Silicon-Aluminium Alloys. These are similar to the alloys of group 2, but contain silicon varying between 0.3 to 1.3 per cent. Magnesium content is reduced to below 1.5 per cent. These alloys are suitable for structural works.

(B) Casting Aluminium Alloys

This group includes those alloys which are obtained by pouring the metal and the alloying component in a molten form into moulds of required shape. **Copper** and **silicon** are the most important alloying metals. Other metals which are mixed with aluminium include magnesium, zinc and nickel. The main reason for preparing casting alloys is the "poor casting property of aluminium". This means aluminium as a pure metal cannot be cast into intricate shapes because it contracts and cracks on solidification. But when it is mixed with (alloyed) an element like copper and silicon, its CASTABILITY is greatly improved.

The cast alloys of aluminium are sometimes classed as heat-treatable and non-heat treatable. There is a large number of cast alloys of aluminium for different applications. We shall mention below two examples each of heat treatable and non-heat-treatable casting alloys.

Heat Treatable Castings

1. Magnesium Casting Alloy. Its usual compositions is of the following range :

1.	Magnesium	9.50 to 11.0 per cent
2.	Iron	0.35
3.	Silicon	0.25
4.	Manganese	0.10
5.	Nickel	0.10
6.	Copper	0.10
7.	Zinc	0.10
8.	Lead	0.05
9.	Tin	0.0-5
10.	Titanium + Niobium	0.20
11.	Aluminium	reminder

The above alloy is characterized with

(*i*) Very high tensile strength.

(*ii*) Very good corrosion resistance,

(*iii*) Very easy mahinability.

Due to these properties, the alloy finds application in the manufacture of :

(*i*) mining equipment,

(*ii*) aircraft parts,

(*iii*) ship building industry.

Silicon-Casting Alloy. In this alloy, silicon is the dominant alloying element. Usual composition is:

1.	Silicon	3.5-6.0
2.	Iron	0.60% maximum
3.	Manganese	0.5 maximum
4.	Magnesium	0.3 -0.8
5.	Cu, Ni, Zn, Pb, Sn	0.10 Max (each)
6.	Ti +Nb	0.20 max
7.	Aluminium	Reminder

Among the major qualities of this alloy may be mentioned :

(*i*) good resistance against chemical attacks;

(*ii*) good welding characteristics

(*iii*) good machinability

The alloy is used in aircraft, railways, automotive and ship building industries.

Non-Heat Treatable Castings :

Copper–Aluminium Casting. In this type of alloy, copper is the major component from the alloying elements. Other elements are silicon, zinc and manganese. Usual composition is

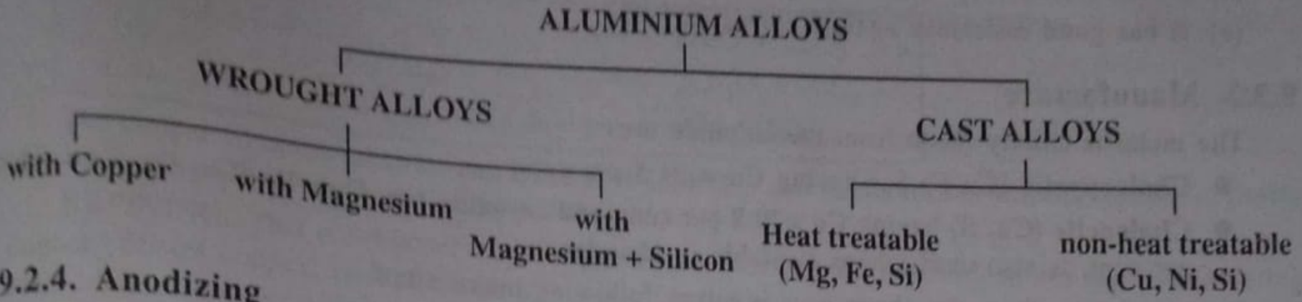
1.	Copper	6.0-8.0%
2.	Silicon	2.0 -4.0%
3.	Zinc	2.0 -4.0%
4.	Iron	1.0 maximum
5.	Manganese	0.60 maximum
6	Nickel	0.50 maximum
7.	Lead	0.30 maximum
8.	Tin	0.20 maximum
9.	Magnesium	0.15 maximum
10.	Aluminium	Reminder

It has excellent casting properties, *i.e.* can be moulded into any intricate shape. It is used for manufacture of machine parts.

Copper-nickel alloy casting. This alloy is specially characterized with good strength at elevated temperatures. It is, therefore, the preferred alloy for **pistons** and **cylinder heads**. Usual composition is:

1.	Copper	3.4 to 4.5 %
2.	Nickel	1.8 to 2.3%
3.	Magnesium	1.2 to 1.7 %
4.	Silicon, Iron	0.60 each maximum
5.	Zinc	0.10 each maximum
6.	Lead, Tin	0.05 maximum
7.	Titanium	0.2 maximum
8.	Aluminium	Reminder

Following chart gives a general idea of Aluminium Alloys.



9.2.4. Anodizing

This is a process for making metallic aluminuim durable by giving a thin oxide coating. This is achieved by making aluminium an anode in an **electroplating cell** (hence the term **anodizing**).

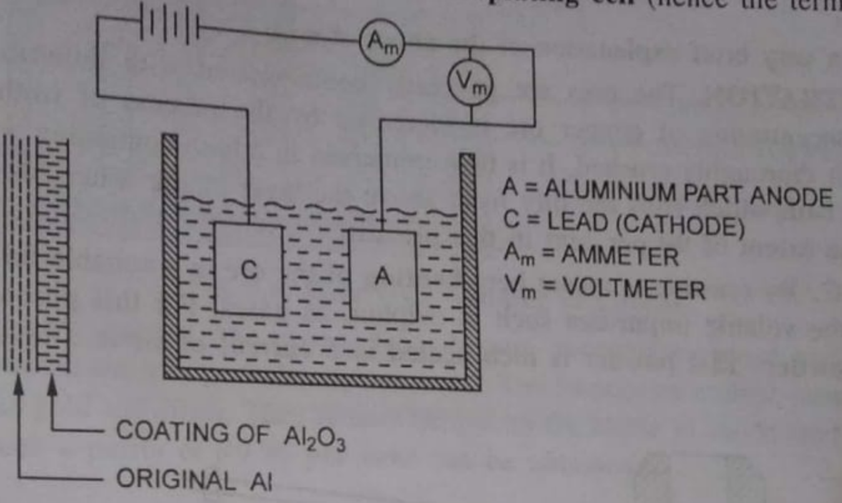


Fig. 9.2. Set for Anodizing.

The process involves converting aluminium part into an anode. Cathode may be made up of lead. The electrolyte consists of dilute sulphuric acid, chromic acid or phosphoric acid with some selected additives. When an electric current is passed (Fig. 9.2) through the circuit, a small thickness of aluminium part gets converted to aluminium oxide (Al_2O_3). This top layer is **exceptionally hard and resistant to corrosion.**

Almost all aluminium alloys can be given a thin (less than 1mm) aluminium oxide coating. But for the formation of relatively thicker layers (called Hard anodizing) some aluminium alloys are not suitable, especially those containing copper and silicon in greater than 3 and 5 per cent proportions respectively.

Anodized coatings are generally porous. For this reason, anodizing is followed by dipping in hot water, with or without dyes to seal these pores for better protective covering.

9.3. COPPER

9.3.1. General

Metallic copper and its various alloys have been used in engineering industries and other activities for many hundred years. This is because of a combination of some very useful properties shown by this metal and its alloy. Among these properties, the following are more important:

(*a*) The metal is **very malleable and ductile** so that it can be given any desired shape;

(*b*) It has **excellent joining properties**, *i.e.* it can be jointed by almost all the common methods: welding, soldering, brazing and riveting.

(*c*) The metal has a very high electrical conductivity.

(*d*) It forms excellent alloys.

(*e*) It has good resistance against corrosion.

9.3.2. Manufacture

The metal is chiefly made from the sulphide ores :

- **Chalcopyrite** (Cu Fe S_2) having Cu = 34.5 per cent;
- **Chalcocite** (Cu_2 S) having Cu =79.8 per cent, and an oxide ore, **Cuprite** (Cu_2 O), Cu = 88.8 per cent, is also used where available in abundance.

Its manufacture from the above ores involves following major steps :

1. Concentration of the ores.
2. Roasting of the ore;
3. Smelting;
4. Converting;
5. Refining.

Following is a very brief explanation of the above steps.

1. CONCENTRATION. The ores are generally contaminated with impurities, called **gangue minerals**. The concentration of copper ore is increased by the process of froth flotation. In this process, ore is first thoroughly crushed. It is then immersed in a bath containing water and oil. Air is then blown in the bath which rises the oily froth above the layer of the water. Most of the copper is concentrated to the extent of 90 per cent in this process.

2. ROASTING. By roasting is meant here **heating** of the ore in a suitable furnace. This process removes most of the volatile impurities such as sulphur, as gases. For this purpose, the ore is first **crushed to fine powder**. This powder is then heated in a current of air in a reverberatory furnace. (Fig. 9.3)

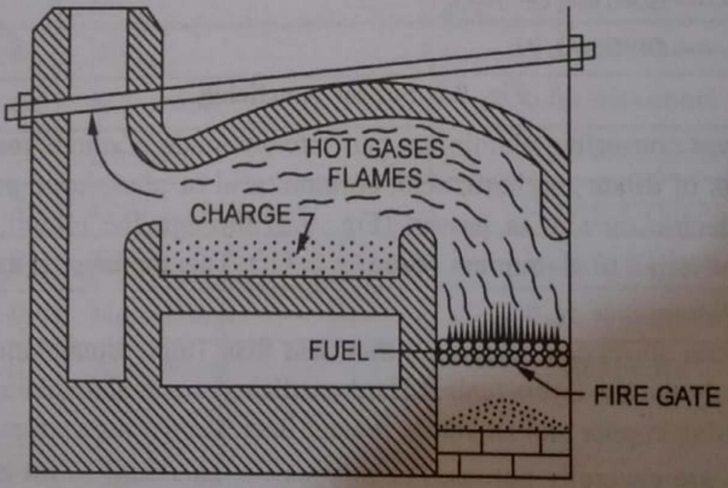


Fig. 9.3. Reverberatory Furnace.

3. SMELTING. It involves heating the roasted ore to very high temperatures-the melting temperatures- in the presence of air, coke and silica. During smelting, iron in the ore combines with silica forming a slag. The copper gets oxidized and sinks below as **matte**. The smelting process is carried out either in reverberatory furnace or in a blast furnace.

4. CONVERTING. This step involves recovery of copper from the **matte**. The matte is treated in **basic-lined Bessemer converter**. Air is blown through this converter which serves to oxidize both the iron and a part of copper of the matte. The iron oxide reacts with silica and forms slag. Copper oxide reacts with copper sulphide thereby liberating metallic copper.

Following reactions take place :

$$\begin{array}{lrcl} (i) & 2FeS + 3O_2 & \longrightarrow & 2FeO + 2SO_2 \\ (ii) & 2Cu_2S + 3O_2 & \longrightarrow & 2Cu_2O + 2SO_2 \\ (iii) & 2Cu_2O + 2Cu_2S & \longrightarrow & 8Cu + SO_2 \end{array}$$

The copper so obtained is termed BLISTER COPPER and needs further refining for better purity. It may contain **silver and gold** as **impurities.**

REFINING. This is achieved most commonly by **Electrolytic Method**. In this method, the crude copper (Blister copper) is first cast into anode plates. Cathode plates are made of pure copper. The tank contains **copper sulphate** solution as electrolyte (Fig 9.4)

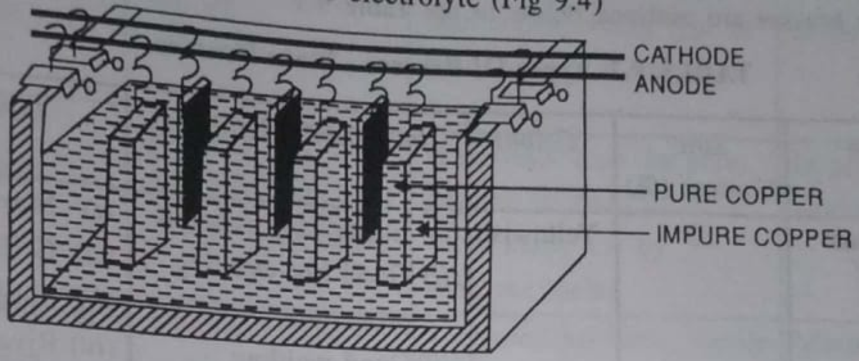


Fig. 9.4. Electrolytic refining of Copper.

On passing electric current, the copper from impure anode is corroded and deposited on pure copper cathode wherefrom it is periodically removed. The impurities consist mostly of fine particles of noble metals like gold and silver. They remain behind on the anode as anode mud. By the **electrolytic** method, copper with a purity of **99.95 per cent** can be obtained.

9.3.3. Properties

Following are important properties of copper metal :

1. It has a **reddish colour** and **bright lustre**.
2. It is highly **malleable** and **ductile.**
3. It has a **melting point of 1083^{0}C** and **boiling point of 2505^{0}C**. Its **specific gravity is 8.93.**
4. Copper has very **high electrical conductivity**, next only to silver. The conductivity is, however, greatly effected by presence of even small percentage of impurities.
5. Copper also has a very high **heat conductivity**.
6. The metal is quite **resistant to corrosion**.
7. Copper is attacked by nitric acid and sulphuric acid in concentrated form. It is stable towards hydrochloric acid and dilute sulphuric acid.

9.3.4. Uses

Most important applications of copper are in the following three areas: electrical industry, chemical industry and in making of alloys.

1. Electrical Industry. As said earlier, copper is characterized with the second highest electrical conductivity. This property makes pure metallic copper eminently suitable as an electrical material. **It is extensively used in the manufacture of generators, motors, switchboards and communication equipment**. Wires drawn from copper are widely used for transmission of sound and electricity.

2. Chemical Industry. Copper is resistant to corrosion. It also has a high thermal conductivity. For these two reasons copper and its alloys find great applications in **chemical plants**. Copper tanks and utensils are also used in food industries, brewing, distilling, milk processing and refining industries.

A good quantity of copper is used for manufacture of many useful copper compounds such as copper sulphate, copper cyanide, cuprous oxide, copper formate and so on. **Copper powder has been used extensively in powder metallurgy.**

3. **Alloys of Copper.** Copper forms very useful alloys with **metallic zinc** and **metallic tin**. These go under the common names of Brasses and Bronzes respectively.

9.3.5. Brasses

These include a group of **copper zinc alloys** in which proportions of zinc range between 5 to 40 per cent. The brasses are stronger and more ductile compared with pure copper. Brasses are further divided into ordinary and special brasses depending on zinc content and the presence of third element. A few of common brasses are outlined below in the Table 9.1

TABLE 9.1. Types Of Brasses - Plain Brasses.

S.No	*Alloy Name*	*Zinc Content (%)*	*Colour*	*Important Character*	*Typical Use*
1.	**Commercial Brass**	10	Yellowish	(*i*) Easily cold worked (*ii*) Good hot-working properties. (*iii*) Good welding	(*i*) Marine hardware. (*ii*) Grill work. (*iii*) Forgings. (*iv*) Rivets. (*v*) Screws. (*vi*) Screen wires.
2.	**Red Brass**	15	Red	Strongly resistant to corrosion in addition to properties of commercial glass.	(*i*) Plumbing pipes. (*ii*) Heat exchanger. (*iii*) Electrical sockets. (*iv*) Hardware
3.	**Low Brass**	20	Gold red	Can be easily soldered, welded and brazed.	Ornamental metal work.
4.	**Cartridge Brass**	30	Typical brassy	Stronger and harder variety of brass.	For automotive radiator cores, ammunition components, springs and lamp fixtures.
5.	**Yellow Brass**	35	Brassy	Strongest of Plain Brasses, resistant to water corrosion.	(*i*) Plumbing accessories. (*ii*) Grill work. (*iii*) Springs, screws and chains.
6.	**"Muntz Metal"**	60	Reddish	(*i*) Can be worked hot only. (*ii*) Stable under non-corroding waters only.	Making of condensers, tubes, architectural work, valve stems.

TABLE 9.2. Types of Brasses - B. Special Brasses.

S.No	Type Name	Composition (In % terms)	Important Characters	Important Uses
1.	**Naval Brass**	Cu: 60 Zn: 39 Tin: 01	Can be worked hot. It is better in resistance to corrosion than Muntz Metal.	(*i*) Marine hardware (*ii*) Motor boat shafting. (*iii*) Condenser tubes.
2.	**Admirability Brass**	Cu: 70 Zn: 29 Tin: 01	Better resistant to corrosion than corresponding type of plain brass, *i.e.* cartidge brass.	It is considered best condenser tube material.
3.	**Lead Brasses**	Copper, Zinc and lead with lead below 5 per cent.	It is softer than the plain brasses so that can be more easily cut by machine tools.	In general plumbing works.
4.	**Aluminium Brasses**	Copper + Zinc + Aluminium up to 5 percent.	Increased hardness, tensile strength, elasticity and ductility.	Machinery castings, rolled bars and forgings.
5.	**Iron Brasses**	Copper + Zinc + iron up to 3 per cent.	Higher strength and better working properties.	In marine construction work.

9.3.6. Bronzes

These **include alloys of copper and tin**. Other metals like aluminium, iron, lead and zinc are also added to make **special types** of Bronzes.

In their general engineering properties, bronzes are stronger and tougher than brasses and hence find application in many engineering industries.

The Ordinary bronzes. These contain **only copper and tin**. The properties of these bronzes depend on tin content which may vary from 4-50 per cent upwards. Tin as alloying element modifies the properties of metallic copper in accordance with its proportion but only up to certain limits. When the tin content is increased beyond this limit, it will either have no effect or exert an adverse effect. This will become clear from the following instances:

(*i*) **Compressive Strength** of bronzes increases with increasing proportions of tin till an alloy of Copper 75 percent and Tin 25 percent is obtained. Alloys having **greater content of tin than 25 percent** will show a **decrease** in compressive strength

(*ii*) **Tensile Strength**. Maximum tensile strength is obtained at a composition of copper **80 percent and Tin 20 percent**. If tin content is increased beyond these limits, the tensile strength of an alloy of that composition will be much lower.

(*iii*) **Ductility**. It is at its maximum at a composition of copper 80 per cent and Tin 20 percent. If tin content is increased beyond these limits, the alloy loses its ductility so much so that **at tin content of 25 per cent**, it may not show any ductility.

The plain bronzes can be heat treated with great benefits. A plain bronze having tin content of 8-11 per cent is regarded a most useful alloy from engineering point of view. It possesses good cold working qualities, high strength and toughness and also sufficient ductility.

Special Bronzes. This group includes alloys of copper and some other metals such as aluminium, manganese, berylliums, antimony, phosphorous, nickel, and lead. In fact, **tin may or may not at all be present in the special bronzes**. A few important special bronzes are mentioned below in outline only.

TABLE 9.3. Special Bronzes.

S.No	*Type Name*	*Composition (In % terms)*	*Important Characters*	*Important Uses*
1.	**Aluminium Bronze**	Copper: 89 Aluminium: 10 Iron; 1 - 2	(*i*) Retains hardness and strength even at elevated temperature. (*ii*) Tensile strength between 4560-5260 kg/cm^2 (*iii*) Fatigue resistance similar to steel. (*iv*) Difficult to weld. (*v*) Excellent resistance to corrosion.	(*i*) It is an excellent antifriction alloy. (*ii*) Ordinary machine construction. (*iii*) Automobile parts construction. (*iv*) Valve-seats for super heated steam and internal combustine engines. (*v*) Pump parts.
2.	**Manganese Bronze**	Copper: 56-60 Manganese: 01 Aluminium: 0.5-1.0 Lead: 0.4 Iron: 0.4-1.0 Zinc: Balance	(*i*) Resistant to sea water (*ii*) Resistant to dilute acids (*iii*) Tensile strength 4500-5000 kg/cm^2.	A very useful low-priced non-ferrous alloy. (*i*) Steam ship propellers. (*ii*) Shafts (*iii*) Axles etc. (*iv*) Castings
3.	**Berylium Bronze**	Berylium 2-2.5% Co: 0.25% + Copper	(*i*) One of the strongest and toughest of copper alloys. (*ii*) Resistant to abrasion. (*iii*) Tensile strength 7000-14000 kg/cm^2. (*iv*) Good endurance under fatigue.	(*i*) Heavy duty switches (*ii*) Cams and bushings. (*iii*) Resistance welding (*iv*) Springs and gears (*v*) Aircraft bearings (*vi*) Non-sparking chisels & hammers.
4.	**GUN METAL (contains both Tin and Zinc)**	Copper = 88% Tin = 8-10% Zinc= 2-4%	(*i*) Can be readily cast. (*ii*) Can be easily machined (*iii*) Has good resistance against seawater. Tensile strength 2800 kg/cm^2.	Used commonly in the past for casting guns (hence the name). Pump castings, water turbine runners, cylinder linings and condenser heads.
5.	**Phosphorous Bronze**	Copper + Tin + Phosphorous upto 1.2 per cent	(*i*) Great strength (*ii*) Resistant to corrosion. (*iii*) Stable under repetition of stresses. (*iv*) Can be rolled and drawn into wires.	In engine parts valve metals; bearing plates in under water fittings.

6.	**Nickel Bronze**	Copper + Zinc + Tin + Nickel from 1-10%	(*i*) High Tensile strength (*ii*) Resistant to heat	Pressure tight services
7.	**Cupro-Nickel Bronze**	Copper: 70 Nickel: 30	(*i*) Resistant to corrosion by salt water (*ii*) Resistant to heat (*iii*) Can be cast or cold formed	For making still tubes of heat exchangers.
8.	**Hydraulic Bronze**	Contains Copper, Tin, Zinc and lead. E.g. Copper= 85% Tin= 5% Zinc= 5% Lead= 5%	It is a free machining alloy with pressure tight characters. It can be easily cast into intricate designs.	As a general purpose pressure-tight metal. Used for making condenser heads, valve bodies and pipe fittings.

9.4. LEAD

9.4.1. Manufacture

Lead has been used in one form or another for many centuries in buildings and engineering. The metal is extracted from three chief ore minerals :

(*i*) **Galena**; Lead sulphide (PbS): Lead 77.5 %

(*ii*) **Cerrusite**; Lead carbonate (Pb CO_3): Lead 77.5%

(*iii*) **Anglesite**; lead sulphate (Pb SO_4); Lead 68.3%

Of these, it is **galena** that has been most commonly used. **It is a general characteristic of lead ores that they commonly occur in association with zinc ores**. Further, often these ores contain some parts of silver in them which forms a valuable by-product of lead smelters

Extraction. Lead extraction from the galena (sulphide ore) involves following operations.

(*a*) **Concentration**. The gangue-rich lead ore is concentrated with the usual froth flotation process. The ore particles from a powdered ore **float** in the oily froth and are removed.

(*b*) **Roasting and Sintering**. The concentrated ore is then heated at 450-750^{0}C along with some lime. The lead sulphide gets oxidized:

$$\boxed{2PbS + 3O_2 = 2PbO + 2SO_2}$$

All the impurities like those of iron, copper and zinc also get oxidized at this stage.

(*c*) **Smelting**. Finely powdered and roasted **oxide matte** is then subjected to melting temperatures in a special furnace (Fig 9.5). Lime and coke are also added in adequate proportions. **The oxide is reduced to metallic lead when a blast of hot air is blown through this furnace.** The main reactions taking place in the furnace are:

(*i*) *Reduction of lead oxide :*

$$\boxed{\begin{aligned} Pb\,O + C &= Pb + CO \\ Pb\,O + CO &= Pb + CO_2 \end{aligned}}$$

(*ii*) *Formation of slag :*

$$\boxed{CaO + SiO_2 = CaSiO_3.}$$

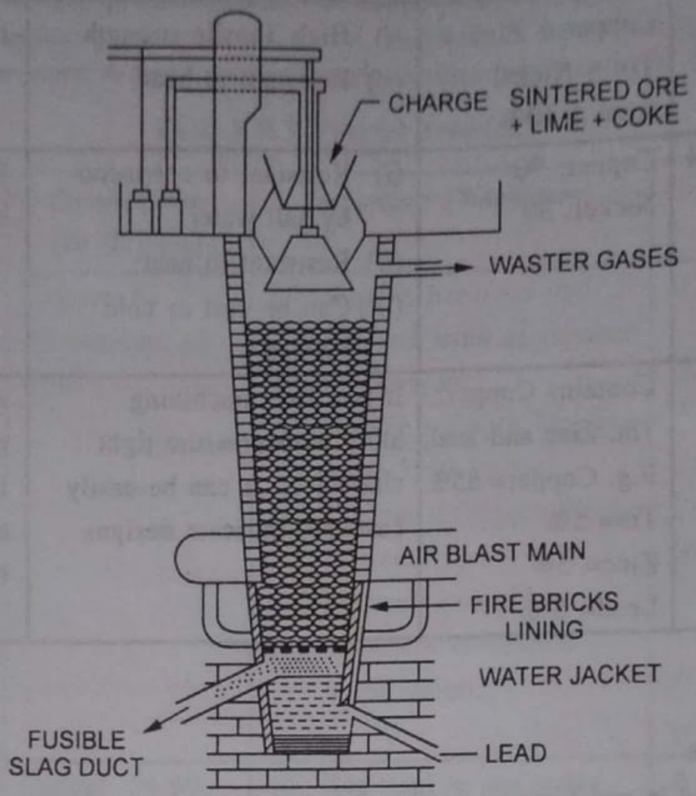


Fig. 9.5. Furnace for Lead Smelting.

(*d*) **Refining**. It is achieved in following three steps:

(*i*) **Removal of metallic impurities**. The impure lead is melted in a reverberatory furnace and air is blown through it. The impurities rise to the surface as an **oxidized scum**.

(*ii*) **Recovery of silver**. This is commonly done by **Parke's Process**. The impure lead containing silver is heated with some metallic zinc. Silver being more soluble in zinc gets dissolved in this metal and rises above molten lead which is heavier. This silver-rich zinc layer is then removed and purified from zinc by distillation process.

(*iii*) **Absolute Refining**. This is achieved only by **electrolysis**. In the Bett's Process, the crude lead is cast into anodes and subjected to electrolysis in a tank containing pure lead sheets as cathode lining. A solution of lead fluosilicate and hydrofluosilicic acid act as **electrolyte**. On passing the current, pure lead from anodes is removed and gets accumulated on cathode sheets. Metallic impurities remain in solution. Noble metals form anode-mud are removed as by –product

9.4.2. Properties

The metallic lead has :

(*i*) bluish grey colour,

(*ii*) typically brilliant lustre,

(*iii*) high density = 11.35 gm/cubic centimeter,

(*iv*) a low melting point of 327^0 C;

(*v*) a high boiling point of 1744^0 C,

(*vi*) very good resistance to corrosion by water, atmospheric gases and many acids.

Lead dissolves in nitric acid. In its mechanical properties, lead is soft and malleable. It can be easily rolled into desired shapes like tubes, rods, wires, ribbons, and pipes. It has a very low tensile strength (210 Kg/cm^2). This strength can be, however, increased by alloying it with 3-12 per cent of antimony.

9.4.3. Uses

Among the many uses of lead as an engineering material, the following are important :

1. **Uses based on Corrosion Resistance.** Lead is characterized with very good corrosion resistance against attack of atmospheric gases, sea water and dilute acids. For this reason it is commonly used in

(*i*) Storage batteries,
(*ii*) Cable covering,
(*iii*) Protective lining in tanks.

Caution. Lead makes poisonous compounds with organic acids. Lead pipes should not be used for drinking water supplies. Further, lead should not be used in any such situation where it is likely to come in contact with food.

2. **Uses based on Chemical Characters.** Lead is used in making quite useful compounds having industrial applications. White lead, red lead and litharge are commonly used for protecting iron and steel from **rusting**. They are also used in ceramic, rubber and glass industries. **Terra ethyl lead** is used in improving the rating of gasoline. Lead-arsenic compounds are important insecticides.

3. **Uses based on Fabrication Characteristics.** Lead melts easily and is highly malleable and ductile. It is possible to roll, extrude or hammer the metal into any desired shape. This makes lead useful in the fabrication of:

(*i*) Lead sheathing of electrical cables;
(*ii*) type metal for the printing industry;
(*iii*) low-melting solders;
(*iv*) biological shielding against gamma radiation.

9.4.4. Alloys of Lead

In general lead does not form many alloys. Its alloying capacity is limited because of its low melting point. Following are more important alloys of lead :

1. **Type Metal.** It is a lead-tin-antimony alloy with a typical composition of :

Lead: 60%; Tin: 10%; Antimony: 30%

The type metal can be remelted and recast into new printing type.

2. **Bearing Metal.** Lead is an important constituent of many bearing alloys. Following are few examples.

(*i*) **Lead Babbitt.** Lead: 63-89%; Tin: 20% Antimony: 10-15%
(*ii*) **Tin Babbitt.** Tin: 60-95%; Lead : up to 20%
(*iii*) Copper lead base alloys, containing lead up to about 20%

3. **Solder.** It is an important alloy of **lead and tin**. Common composition is Lead: 60 per cent and tin 40 per cent. It is used commonly to join metallic surfaces. The tin percentage may be increased up to 50 per cent.

4. **Terne Plate.** It is actually a **steel sheet** coated with a lead solder ailoy having about 20 per cent tin in it. This plate is used for gasoline tanks on automobiles etc.

9.5. ZINC

9.5.1. Manufacture

The chief ore mineral of zinc is a sulphide called **sphalerite** (Zn S : zinc: 67%). **Smithsonite** ($ZnCO_3$), **Zincite** (ZnO) and **Calamine** ($ZnCO_3$) are some other source minerals There are two general methods of manufacture of zinc from its ores: pyro metallurgical and hydro metallurgical.

(A) In the **pyrometallurgical process**, zinc is extracted by the usual stages of concentration, roasting, smelting and refining.

Concentration. The zinc ore is first concentrated by subjecting it to **froth floatation**. The finely powered ore is agitated in a mixture of **pine oil** and **water**. Zinc ore particles come up in the **froth** formed by oil whereas the impurities settle down in water.

Roasting. The concentrated ore is then subjected to roasting (heating) in a hearth furnace in the presence of air. The main purpose of roasting is expulsion of sulphur and conversion of sulphate into oxide.

$$\boxed{2ZnS + 3O_2 = 2ZnO + 2SO_2}$$

The sulphur dioxide so obtained is used in many zinc plants for manufacture of sulphuric acid.

Smelting. It is carried out in special vessels called **retorts** which are provided with condensers. Roasted zinc ore and powdered coal are charged into these retorts. These are placed in a furnace and heated using producers gas at as high temperature as 1450^0C. Zinc is vaporized and is collected in condensers attached to retorts.

$$\boxed{ZnO + C = Zn + CO}$$

The **zinc distillate** is collected. It is solidified to give SPELTER ZINC. It may contain lead and cadmium up to 2 per cent.

Refining. The spelter zinc may be refined to 100 per cent purity by electrolysis or by fractional distillation.

(B) In the **hydrometallurgical process**, the roasted ore is leached with sulphuric acid. The solution is filtered and then treated with lime. This treatment precipitates chief impurities like iron and aluminium. The solution left behind contains mainly zinc sulphate. From this, zinc (pure) is recovered by the method of Electrolysis.

9.5.2. Properties

Following are chief properties of the metal:

(*i*) It is whitish in colour and has bright lustre:

(*ii*) It has a density of 7.4 gm/cc;

(*iii*) Its melting point is 419^0 C and boiling point is only 907^0 C;

(*iv*) It has a tensile strength of 700-1400 Kg/cm^2.

(*v*) In moist air, zinc surface gets covered by a dull basic zinc carbonate;

(*vi*) Commercial zinc (spelter) is easily attacked by acids.

9.5.3. Uses

1. **Galvanizing**. The most common use of zinc is in galvanizing, *i.e.* coating iron and steel with a protective layer of zinc. It is estimated that of the total world production, **40 per cent of zinc is used in galvanizing**.
2. **Die Casting**. Zinc in alloy form is used commonly for die casting. This is due to its low melting point and resistance to shock. The zinc die-casting alloys find great use in automotive industries and electrical industries such as for carburetors, speedometer frames, parts of hydraulic brakes, wind-shield wipers, grills for radiators, in washing machines, vacuum cleaners and motor housing.
3. **Brass Making.** Copper alloyed with zinc forms the well-known group of alloys: **BRASSES.** An estimated **20 per cent** of zinc production is consumed in manufacture of brasses.

9.6. A NOTE ON GALVANIZING

9.6.1. Definition

It is the process of giving iron or steel objects a surface coating of zinc. The zinc coat saves the steel objects from destruction by atmospheric corrosion.

9.6.2. Method

Galvanizing is done by any one of the four methods: hot-dip, electrolytic coating, sherardizing and spraying.

(*a*) **Hot-dip Method.** This is commercially the most commonly used method. A **hot bath** of zinc is prepared in a suitable tank. The iron or steel object is then dipped into this bath. Any surplus zinc from the surface of the object is allowed to drain off. It is essential that the surface of material to be coated is **perfectly clean**. This is often done by treating the surface with hydrochloric acid. The G.I. sheets (galvanized iron sheets used for roofing) are prepared by the hot-dip method.

(*b*) **Electrolytic Plating.** It is also simply known as plating. It is a cold working method. **The object to be galvanized is made to act as cathode**. The anode is of pure metallic zinc. When an electric current is passed through them in the presence of a suitable electrolyte, the zinc from anode dissolves and gets deposited on the cathode article. Springs and such other items are galvanized by this method.

(*c*) **Sherardizing.** In this method, the object to be coated is heated in a **special drum.** The drum contains **zinc dust** and also pure metallic zinc. At high temperatures, a zinc film is deposited over the surface of the object.

(*d*) **Metallic Spraying.** In this method, the object to be covered by zinc coating is first **cleaned and then warmed**. The surface is then brought under an oxyhydrogen or other flame which is fed with zinc in the form of wire or strip. The zinc is sprayed by the flame over the surface of the object.

ACTION. Zinc protects the iron and steel from corrosion by double action.

(*a*) Pure zinc corrodes under atmosphere at a rate of **0.0025 mm per year** compared to rusting of uncoated iron or steel at a rate of **0.8 mm/year**. Hence, the life of steel is increased almost **30 times**.

(*b*) Pure zinc acts **as an anode** to steel and iron and is corroded in preference to steel. Since zinc coating provides a large area, it will be many years before steel is corroded. This is called **galvanic effect** of zinc coating.

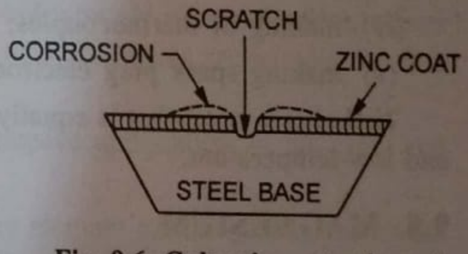


Fig. 9.6. Galvanic protection of zinc coating.

9.7. NICKEL

9.7.1. Manufacture

Nickel was discovered in 1750. It is manufactured from its sulphide ore named pentalandite (NiFe(S)). The ore is first concentrated by **froth floatation process** and then roasted and smelted like other non-ferrous sulphide ores. The matte obtained after smelting contains sulphide of copper also.

The nickel copper sulphide matte so obtained is sometimes used directly to produce the well-known alloy monel metal by first roasting and then treating in a reverberatory furnace. For manufacture of **metallic nickel**, the matte is treated in a blast furnace which gives a nickel concentrate. The concentrate so obtained is refined by electrolysis and cast into ingots.

9.7.2. Properties

Nickel is very close in its properties to **low-carbon steel**. Thus,

(*i*) It is strongest of all the non-ferrous metals. Its tensile strength is in the range of 4200-8400 kg/cm^2 which can be achieved by cold working.

(*ii*) Nickel is **hardest** of the common metals.

(*iii*) Nickel is **highly resistant to many types of corrosion**. Thus it can withstand corrosion by atmospheric gases and moisture, fresh water and salt water, alkalies and alkaline solutions.

(*iv*) Nickel is highly **malleable** and ductile.

(*v*) It has modulus of elasticity, thermal and electrical conductivity **identical to steel.**

(*vi*) Nickel is also **ferromagnetic** like steels.

(*vii*) Its density is 8.9 g/cm^3, and melting point of 1455^0 C

It **cannot replace steel** in its applications mainly because it is a **costly metal**. Its high cost is due to scarcity of its ore and also to a difficult process of manufacture-which may **cost eight to ten times than for steel**.

9.7.3. Uses

The most common use of Nickel is for making alloys with steel. **It is estimated that above 75 per cent of entire nickel produced in the world is used for making nickel-alloyed steels**. In fact a large number of steel varieties are impossible without nickel. Nickel is also used for making alloys with other non-ferrous metals. The Monel-Metal is an alloy primarily of copper and nickel. Nichromes are nickel-chromium alloys and **Incoloys** are Ni-Cr-Fe alloys.

The pure metal nickel is used for **nickel plating** and for the manufacture of coils, springs, hand tools and wire-brushes etc. Some nickel compounds also have important industrial applications. Nickel sulphate, nickel ammonium sulphate and nickel oxide are a few examples.

Metallic nickel is also commonly used as a catalyst in the hydrogenation of oils and fats. Electronic Industry uses nickel in many important products. It is used in.

(*i*) making of permanent magnets;

(*ii*) vacuum electronic tubes, especially cathodes;

(*iii*) photocells and low-power tubes as cathode;

(*iv*) making of thermocouples;

(*v*) making spark plug electrodes.

Nickel is a metal that is equally suited for a great variety of applications both at high-temperature and low-temperature.

9.8. MAGNESIUM

9.8.1. Manufacture

Magnesium forms the **lightest material** used in structural engineering. It has a set of properties that make it suitable as an engineering material.

The main sources of commercial magnesium are :

(*i*) **Magnesium chloride** – A salt obtained from sea water just like sodium chloride.

(*ii*) **Magnesium carbonate** – It occurs in the form of two minerals: magnesite and dolomite.

Magnesium is recovered from sea water through the process of electrolysis. The most commonly used method is **DOW PROCESS**. This involves following two stages.

(*a*) **Concentration of chloride.** Seawater (brine) is pumped into tanks where lime is added to it. The concentrated chloride reacts with lime forming milk of magnesia which settles at the bottom of the tank. It is subsequently filtered and treated with HCl forming magnesium chloride.

(*b*) **Electrolysis.** The magnesium chloride obtained above is dried and charged into the **electrolytic cells**. The cell consists of a steel pot (acting as cathode) and graphite rods (acting as anode).

When heated, magnesium chloride breaks into metallic magnesium and chlorine gas. Pure magnesium collects at the cathode and the gas evolves at anode.

Chemical reduction. Magnesium is recovered from carbonate minerals by first heating them in a furnace. This converts them into oxides. The oxide so formed is reduced by using **Ferro-silicon**, whereby pure metallic magnesium is obtained.

9.8.2. Properties and Uses

Magnesium is a very useful metal both as a pure metal and in alloys. Its main properties are:

(*i*) It is **very light**, with a specific gravity of 1.74.

(*ii*) Its melting point is 650^0 C (1202^0 F), which is similar to that of aluminium.

(*iii*) It has quite **high thermal conductivity** and a high coefficient of thermal expansion.

(*iv*) Magnesium chips can be **ignited readily**.

(*v*) It has a **poor corrosion** resistance.

(*vi*) It has a **better machinability** than any metal.

(*vii*) It forms very **useful alloys** with some metals like aluminium, thorium, zinc, zirconium, and tin and manganese, and also rare earths.

9.8.3. Alloys of Magnesium

It is only in the **alloyed form** that the metal finds uses in industry. The most important uses of **magnesium alloys** are :

(*a*) **In lightweight equipment**. Magnesium alloys have been extensively used in space vehicles, in aircrafts, portable power tools and **moon-rockets**.

(*b*) **In tooling materials**. Magnesium is **light weight**. It can be welded easily. It can be machined easily. This has made magnesium a favourite tooling material in tooling devices such as fixtures and drilling jigs.

Two types of magnesium alloys are produced: casting alloys and wrought alloys. **Casting alloys** are made with aluminium, manganese and zinc. The mutual ratios of these metals are so adjusted that the resulting alloy is suitable for sand and mild castings.

The **wrought alloys** are high strength alloys which find extensive application in air craft and space craft industry.

Magnesium alloys are **named** in a simple manner. The alloying element and its percentage to the nearest whole number are mentioned in a lettered name. Thus 'AZ' is a magnesium alloy containing chiefly aluminium and zinc. Either A or B is used at the end as a serial letter. Examples. AZ 92 A and AZ31B. In the first case the alloy belongs to A serial, it has Aluminium 9 per cent and zinc 2 per cent, rest being magnesium. In the second case, it is an alloy of B serial, containing primarily aluminium (3%) and Zinc (1%)

The very abundant source of magnesium (sea water), coupled with its light weight, its easy machinability and its capacity to form useful alloys make it an **engineering material with great future prospects**.

9.9. TIN

9.9.1. Manufacture

Tin was known to man as far back as 1500 B.C. The most important ore of tin is CASSITERITE (SnO_2). It is also known as tinstone and contains 78.77 per cent tin. Tin is extracted from this ore by the usual process of concentration, roasting, smelting and refining. The ore is concentrated by **gravity method**. Roasting removes volatile impurities like those of sulphur, arsenic and antimony. The roasted ore is then smelted either in reverberatory or in blast furnace. Tin obtained from smelter is invariably **impure**. It is purified by sweating or liquating process

The slag obtained from smelter contains some residual tin. It is therefore, very often treated again for recovering all traces of tin.

9.9.2. Properties and Uses

Tin has a high degree of malleability at low temperatures. Further, it is highly resistant to corrosion. It is, however, a soft material with very low strength.

Most important uses of tin are :

1. **TIN PLATES**. These plates are used for making containers for **food storage.** This is because tin is non-toxic.
2. **TINFOIL**. Tin can be reduced to paper-thin sheets called tin foil. Generally five per cent antimony is mixed with tin for this purpose. Tin foil is extensively used for wrapping food and other articles.
3. **IN ALLOY MAKING**. A large quantity of tin is used in the making of useful alloys with lead, zinc, copper and antimony. Among the well known alloys containing tin may be mentioned Terne Plate, Babbit metal and many brasses and bronzes, already described.
4. **IN TIN PLATING**. Tin is greatly resistant to corrosion by atmosphere and by organic acids. It is, therefore, commonly used for giving a coat on the surface of other metallic articles. This process is called tin **plating**.
5. **IN CHEMICAL INDUSTRY.** Tin compounds are commonly utilized in dyeing, calico printing, white enamels, glasses and glass ware.

9.10. CORROSION OF METALS

9.10.1. Introduction

The phenomenon of corrosion of metals may be defined as a

"Spontaneous chemical reaction between the metal surface and the environment leading to formation of such compounds that are stable in that particular environment. The compounds so formed may be removed from place of their formation creating a metal **composition or structure** or both, different from the original one thereby changing its properties"

From engineering point of view, this process (corrosion) is undesirable. The changes produced during corrosion may be considerably harmful in the service life of the metal.

Corrosion is mostly a matter of **chemical affinity** of a metal with a particular environment. For instance, many metals may remain unaffected in water for many years. Some other metals, however, start getting "eaten up" (destroyed from surface inwards) in a much shorter time. Further, corrosion often indicates a tendency of metal to change to its **original 'ore' composition**. Such refractory substances as silicates and oxides- the ceramics, are least corrosive because these are already nearer to natural composition.

Corrosion is a global phenomenon. Despite all the preventive measures, the corrosion processes destroy metals worth millions of rupees every year. A general estimate puts the metals wasted through this process at 2 per cent of the metal quantity used in a year.

9.10.2. Corrosive Environments

Most common environments in which metals may suffer corrosion are :

- Atmosphere,
- Water,
- Soil,
- Industrial gases, and
- Chemicals.

A. *Atmospheric Corrosion*

Many metals are likely to be unstable in atmosphere. Some of them get quickly oxidized because of their strong **affinity for oxygen**. In others, atmospheric moisture acts as a destructive agent. In industrial areas, atmosphere is polluted with **industrial gases.** These gases react easily with exposed surfaces of many metals—producing undesired compounds

In atmospheric corrosion the metal surface on undergoing a change of temperature on the surface gets oxidized (only at the surface) forming a **thin film of oxide.** Now this film may be:

(*i*) Thin and uniform

(*ii*) Thick and non-uniform

(*iii*) Porous or non-porous.

If it is **non-porous** in nature, it will protect the metal below from further corrosion. If it is of **porous-nature**, oxygen may further penetrate deeper and corrosion may continue. Chromium forms an oxide layer which is thin and non-porous. Similarly aluminium also forms a thin layer of aluminium oxide, Al_2O_3, which is quite strong and non-porous.

Rusting of Iron

This is of **special significance** in engineering practice. In this process of corrosion cells are formed in those areas where there is some difference in composition of iron or steel. In wet environment cells may also form because of unequal concentration of oxygen dissolved in water resting on steel. A large number of ferrous ions pass into solution **at anode** where iron has higher negative electrode potential. Simultaneously at cathode with positive electrode potential hydroxyl ions get formed. These products get diffused into the electrolyte and on coming in contact they react precipitating **ferrous hydroxide**, which may get further hydrated to form a hydrated ferric oxide. The relevant reactions are

$$\boxed{4Fe + 6H_2O + 3O_2 \longrightarrow 4Fe(OH)_3}$$

When the water is removed from ferric hydroxide, there is a change in composition from ferric hydroxide to the red oxide or RUST:

$$\boxed{2Fe(OH)_3 \longrightarrow Fe_2O_3 + 3H_2O}$$

The **rust layer** does not stop further corrosion because it does not take place on the anodes or cathodes. Further, it is quite porous, and can hold water. In fact, **rate of rusting may increase with time for the last reasons.**

B. *Underwater Corrosion*

This type of corrosion results from the attack of water on the surface of the metal for considerable time. This takes place when metal products are required to **remain in contact with water**. For examples, in pipes, in tanks and in submerged parts of ships it has been found that dissolved oxygen is the most important factor in 'eating up' or 'corroding' submerged iron parts.

C. *Corrosion Under Soil*

Many a times metallic structures that have been embedded within soil for long spell of time show considerable erosion. This **under-soil corrosion** is mainly due to a combined action of factors like: acidity of the soil; electrical conductivity of the soil and moisture content in the soil.

D. *Chemical Corrosion*

This may be defined as that type of corrosion where a metal undergoes destruction clearly due to a chemical reaction between the metal and liquids or gases with which it has come in contact. The chemical environment may be dominated by acids, bases, salts, gases and solvents, and behavior of the metal will depend on its affinity for these chemical environments.

9.10.3. Mechanism of Corrosion

Electrolytic Theory. The behavior of a metal in a corrosive environment has been adequately explained by the **Electrolytic theory** which is now generally accepted. According to this theory, when a metal surface comes in contact with a **corrosive environment**, some of the metal is taken into solution as ions *i.e.* electrically charged particles. The theory further envisages that due to certain inherent properties and causes, the surface of the metal gets divided into cathodic and anodic areas. Virtually this means that **the surface of a metal gets covered by numerous small but effective electrolytic cells.**

The various factors that cause the development of anodes and cathodes on the metal surface are:

(*i*) A **difference** in composition (e.g. in bimetal components).

(*ii*) A **variation** in structural homogeneity.

(*iii*) **Difference** in surface finish.

(*iv*) **Unequal** concentration of oxygen in different areas on the surface.

(*v*) **Capacity** of a metal to form films (on reaction) on the surface.

The cells developed may be of the following **two types** :

(*a*) **Concentration cells**. In this type, the cells are caused because of unequal concentration of dissolved oxygen or metal ions on the metal surface. The part with lower concentration of oxygen starts getting corroded. The cells are termed as **oxygen concentration cells** and metal-ion-concentration cells, depending upon the cause of their development.

Galvanic Cells. A galvanic cell is said to have developed when there are two dissimilar metals connected **through an electrolyte**. In practice it happens when two types of metals are used in combination. A familiar example is when brass screws are used on steel sheets. In such a situation one metal become anode and the other a cathode. As soon as the cell becomes active, the anode (metal) starts dissolving. Correspondingly hydrogen or metallic element starts getting deposited at the cathode. **The amount dissolved at the anode and the hydrogen evolved or metal deposited at the cathode are always electro-chemical equivalent.** The electrolytic theory explains the Wet Type of Corrosion. In another type of corrosion, called the Dry Corrosion, presence of an electrolyte is not essential. The corrosion takes place simply because of oxidation-at elevated temperatures.

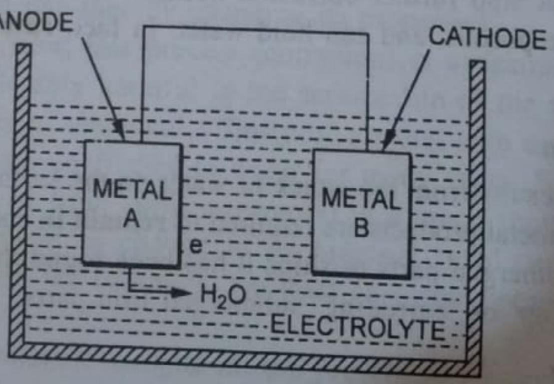


Fig. 9.7. Electrochemical Corrosion of Metals.

Corrosion destroys the metal in a number of ways. Following types of effects are related to corrosive processes under different situations.

1. Uniform Dissolution. When the surface of the metal is uniformly smooth and not covered by any oxide film, electrochemical corrosion may not be possible. On the contrary, the entire surface is uniformly attacked directly by the corrosive agent, e.g. a gas or a liquid in a metal container. The metal may disappear (Fig 9.8). Molybdenum when heated in air may undergo such a corrosion. Similarly, **rusting of iron** surfaces by electro-chemical corrosion is a type of **uniform corrosion.**

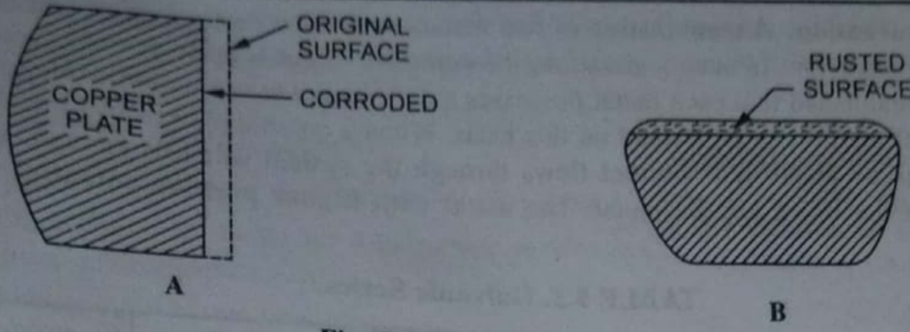


Fig. 9.8. Uniform Corrosion.

2. Pitting. In this case, the metal surface gets damaged by formation of small cavities due to **localized corrosion**. This results in removal of mass of metal on the one hand and unevenness of the surface on the other hand. Both these effects reduce the utility of the metal product. Pitting may be caused due to **chemical nature** of the environment. Certain metals like steel, copper, aluminium and nickel and their alloys are specially prone to pitting. It is believed that pitting is due to electro-chemical corrosion, a pit starting at a nucleus of an inclusion, impurity, discontinuity or a scratch (Fig. 9.9).

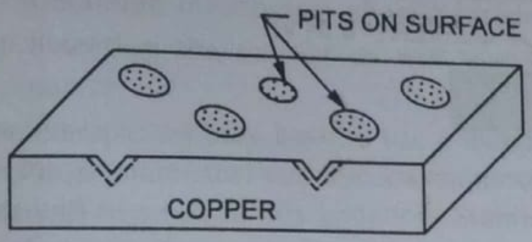


Fig. 9.9. Pitting.

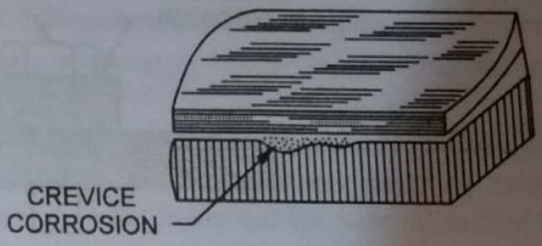


Fig. 9.10. Crevice Corrosion.

3. Crevice corrosion. This type of corrosion is observed at loose contacts between metal parts such as bolts and other attachments especially when these are immersed in a liquid. It is believed that the part of solution that gets held up between the contact space or crevice is responsible directly for corrosive action. This happens because of some changes in liquid properties that are inevitable due to its stagnation. Whatsoever the reasons, the crevice corrosion is of concern.

4. Disturbed granular structure. During corrosion, the metal grains may be attacked either along the boundaries of grains or **across the grains** as well. In the first case, called Intergranular corrosion, the obvious result is loss of cohesion or bond between the grains. The sensitization of stainless steels is an example of inter-granular corrosion. This type of corrosion is also seen in some alloys of aluminium and of copper. In extreme cases, the boundaries may be extensively damaged by corrosion so as to make it spongy in nature. (Fig. 9.11A)

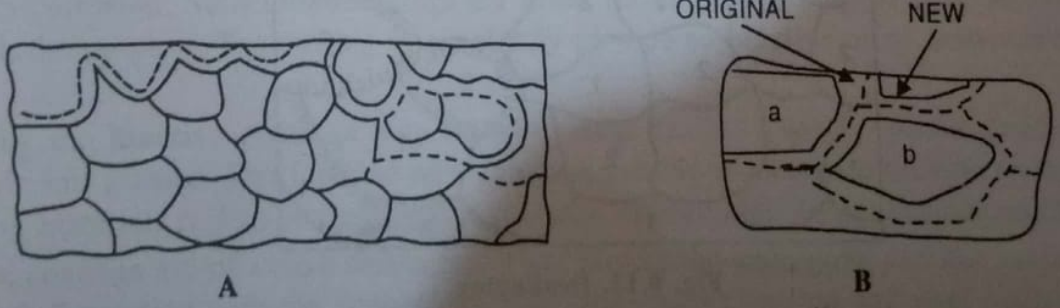


Fig 9.11. (A) Corroded Boundaries (B) Corroded Grains.

In the second type of the corrosion, the **body of the grain** also gets damaged by corrosion. This is called **Trans crystalline corrosion**. It results in complete rupture of granular structure of the metal at the surface. (Fig. 9.11B)

5. Galvanic corrosion. A combination of two metals may show destruction of **one of them** only in a given type of corrosion. In such a situation, the corrosive effect is aptly described as galvanic. It has been already established that each metal possesses a definite redox (reduction-oxidation) potential. A galvanic series of metals can be framed on this basis. When a combination of two metals from such a series is placed in an electrolyte, current flows through the system which is enough, with passage of time, to destroy the **more anodic** metal. The metal **with higher positive potential will remain unattacked.**

TABLE 9.5. Galvanic Series.

S.No	*Metal*	*Electrode Potential*	*S.No*	*Metal*	*Electrode Potential*
1.	GOLD	+ 1.5	6.	NICKEL	-0.25
2.	COPPER	+0.34	7.	IRON	-0.44
3.	HYDROGEN	0	8.	ZINC	-0.75
4.	LEAD	-0.13	9.	ALUMINIUM	-1.66
5.	TIN	-0.14	10.	MAGNESIUM	-2.05

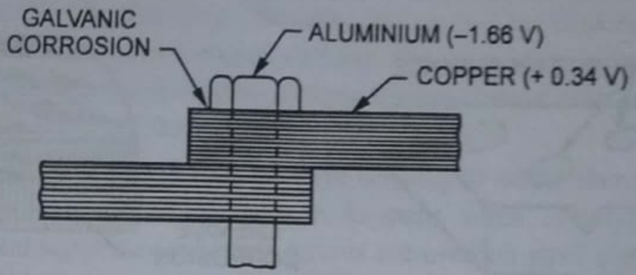


Fig. 9.12. Galvanic attack on aluminium.

Example. A magnesium part in a steel plate or an aluminium bolt in a copper plate form **galvanic cells** leading to excessive corrosion of magnesium or aluminium respectively. (Fig. 9.12)

6. Dealloying. An alloy has two or more metals as inherent constituents. In certain cases, corrosion causes partial or total removal of **one constituent** causing a destruction of microstructure and hence damaging the part made from the alloy. The most noteworthy example in this case is of **Dezincification of Brass**. Removal of chromium from steels during vacuum annealing processes is also an important example. Exact causes of such corrosion are not yet fully established, but the effects can be quite damaging. (Fig. 9.13)

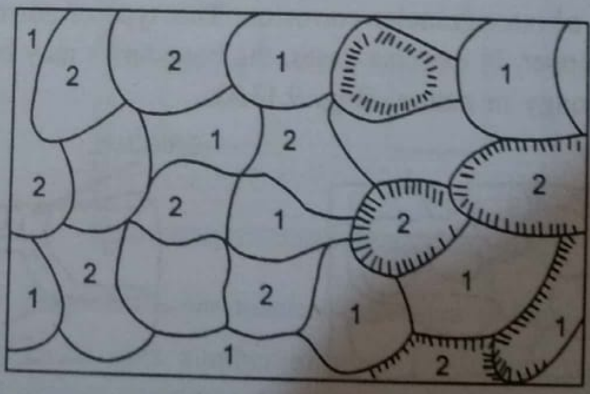


Fig. 9.13. Dealloying.

7. Corrosion fatigue. It may be defined as the **failure of a metal under variable stresses** that have their origin related to corrosion. When the stresses involved are of static nature, the process is then referred as stress **corrosion failure.** The cracking of metals is generally related to the corrosive environment. Exact nature of the causes leading to the development of cracks due to stress corrosions, however, are yet to be clearly established. Steels and alloys of copper, especially some brasses are reported failing under stress corrosion at the **anodic pits**. Development of cracks in the brass parts is sometimes due to stress corrosion.

9.10.4. Prevention of Corrosion

Metals may be saved **from destruction by corrosion** by adopting a three-fold strategy:

(*a*) Proper selection of metal for a particular environment;
(*b*) Keeping environment clean;
(*c*) Providing a protective coating.

(A) *Selection of Metals*

All metals are not stable (with respect to corrosion) in all environments. But some metal or metals may be stable for a particular environment. This fact should be given due consideration while selecting a metal for particular use. There are no set rules for such a selection. The selection of metal becomes useful by :

(*i*) Analyzing the exact **nature of the environment** in which use of a metal is warranted or desired.
(*ii*) Obtaining information about **behaviours of different metals** in that particular environment;
(*iii*) **Selecting the one** which will give the best performance, other things being the same, of course.

For example we may have to use a metal sheeting material in boiler feed water valves. Choice is between iron, plain steel and special stainless steels. The first two metals may be cheap in the initial cost but will rust fast in this situation. Stainless steels may be costly but are best suited for a trouble free surface. Similarly, it is known that aluminium and many of its alloys are quickly destroyed by fresh water or salt-water corrosion. Hence using them as such in **under-water situations** will not be desirable.

(B) *Reducing Corrosiveness of the Environment*

This is another **preventive measure** of importance. Poor drainage of rainwater may be responsible for accelerated corrosion of pipes. Sometimes corrosive nature of an environment can also be corrected. Some **corrosion-reducing chemicals called inhibitors** may be added to boiler-feed waters. This will increase the life of boilers. Similarly suitable treatment may be given to municipal water-supply which is often corrosive to pipes carrying the water.

(C) *Application of Protective Coating*

Metals are often **coated with** either an inorganic or an organic material with a view of protecting them from corrosion. Sometimes coatings are given for decorative purpose only. At other times they serve both the purpose. The coating material may provide an **inactive** or an **active** covering over the metal.

Among the **inactive coatings** may be mentioned: enamel painting, plastic coating, bituminous paints, oils and greases. The function of an inactive coating is merely to provide an insulation to the underlying material. It does not undergo a chemical change after its application on the metal.

Some coatings are of **active character**. They protect the underlying metallic surface by entering into chemical reaction with the atmosphere. The zinc coating on iron and steel (called galvanizing) is the best example from this category. On exposure to atmosphere, metallic zinc forms a thin layer of **zinc carbonate**. This is an **insoluble film** and sticks at the surface making zinc below quite safe from further corrosion. When applied over the iron and steel, zinc coating protects them from atmospheric corrosion for long times. Zinc saves the iron from corrosion in yet another way. It gives iron an electrochemical protection. **Having a higher negative ionic charge than iron**, it acts as an anode and allows iron to act as cathode. In the process, if zinc layer is incomplete or broken on iron product, **it is zinc that gets corroded and not the iron.** This is in fact the third way of protecting metals from corrosion and is sometimes referred as **'cathodic protection'**. Magnesium may also be used with iron and steel in this process.

(D) Methods of Giving Protective Coating

Following methods are commonly used for giving a protective metallic coating: dipping, electroplating, spraying, and cementation.

1. Dipping. This consists of heating the coating metal to its melting point in a dipping tank. The metal **to be protected** is then dipped into this tank whereby a thin layer of the molten material gets deposited over it.

Examples: Galvanizing in which zinc coating is given over iron and steel sheets and other objects. **Tinning**, in which a coat of tin is given over brass and other metals.

2. Electroplating. It is a very common method used for coating delicate products. It involves setting up an **electrolytic cell** in which:

(*i*) The **metal to be deposited is made into an anode**.

(*ii*) The metal which is **to be coated** is made to act as cathode.

(*iii*) The electrolyte contains the metal to be deposited (*i*).

As the electricity is passed through this cell, anode starts dissolving. The material so released from anode gets deposited in the form of a **uniform layer over the metal acting as a cathode**. Common examples of electroplating are: silver –plating, gold plating, nickel plating and chromium plating. In the last mentioned process, chromium is deposited from the electrolyte itself, anode being of a third metal. The surface of the metal to be coated must be thoroughly cleaned before electroplating.

3. Spraying. In this method, the protective coat is applied by spraying it over the metal to be coated. The coating material is first heated to **atomizing temperature** *i.e.* when it is converted to a vapours state. It is then sprayed from a suitable **spray gun** on to a **warmed surface** of the metal. Coatings of zinc, tin, aluminium and copper on other metals are often given by this method.

4. Cementation. It is another sophisticated method for giving protective coating over delicate metal objects. The metal objects are placed in a drum in which the coating is fed in **dust or powder form**. Both materials are heated together for several hours. **Sherardizing** is a process of this group in which zinc coatings are given on iron or steel objects.

5. Cladding. This is a method of covering the metal surface to be protected with a thin sheet of the coating metal. Cladding is achieved by passing both the metal and the protective cover through rollers at high temperatures. **The two are virtually bonded together.**

Example: Alclad. In this **pure aluminium** forms as layer over an aluminium alloy.

6. Anodizing. By anodizing is understood the formation, by artificial means, of an oxide layer over the surface of aluminium metal sheet. This oxide layer acts as a **protective covering** and saves the aluminium underneath from atmospheric corrosion.

TYPICAL QUESTIONS

A. ESSAY TYPE

1. Discuss the important properties and engineering applications of any one of the following metals:

   Copper, Lead, Zinc, Aluminium.

2. (*a*) What are alloys ?
   (*b*) Discuss the alloys of copper.
3. How is aluminium manufactured? Discuss fully applications of aluminium as an engineering material with special reference to its advantages over:
   (*a*) Copper in electrical industry
   (*b*) Steel in construction industry.
4. Discuss alloys of aluminium and their engineering applications.
5. "Had nickel ore been available in abundance, the need for low carbon steel been not there". Discuss the statement critically giving properties of nickel and its alloys that compare well with that of steel.
6. "Corrosion of Metals is a process which causes losses of millions of rupees every year". Give your comments.
7. Discuss the process of "corrosion of metals" in all its aspects explaining the process, its effects and methods useful to check the corrosion.
8. Explain any two of the following :
   (*a*) Electrolytic theory of corrosion
   (*b*) Galvanizing
   (*c*) Effects of corrosion
9. Write short notes on any five :
   (*i*) Anodizing (*ii*) Babbit Metal
   (*iii*) Special Bronzes (*iv*) Galvanic Corrosion
   (*v*) Galvanic (Potential) Series. (*vi*) Preparation of Magnesium
   (*vii*) Gun Metal (*viii*) Antifriction alloys.
   (*ix*) Duralumin.

B. OBJECTIVE TYPE

Tick the Right Answer

1. In the Hall-Heroult process, the solvent for aluminium oxide is
   (*i*) Caustic Soda (*ii*) A mineral called cryolite (Na_3 AlF_6)
   (*iii*) Hydrochloric Acid (*iv*) None of these
2. The melting point and boiling point of aluminium are respectively
   (*i*) 650^0 C and 2057^0 C (*ii*) 690^0 C and 2157^0 C
   (*iii*) 780^0 C and 1957^0 C (*iv*) None of these.
3. Weight for weight, electrical conductivity of aluminium is ——— copper
   (*i*) Greater than (*ii*) Less than
   (*iii*) Equal to (*iv*) Not related
4. **Resistance** of aluminium to atmospheric corrosion is
   (*i*) very poor (*ii*) quite good
   (*iii*) excellent (*iv*) bad
5. **Duralumin** is an alloy of aluminium with - as the main alloying element:
   (*i*) Copper (*ii*) Lead
   (*iii*) Zinc (*iv*) Tin

6. **Anodizing** is a process of
   (*i*) Giving a zinc coat over the surface of steel
   (*ii*) Forming anodes out of a metal for uses in electrolysis.
   (*iii*) Converting the top layer of aluminium to a corrosion resistant aluminium oxide through electrolysis.
   (*iv*) None of these

7. **Brasses** are alloys of copper and
   (*i*) Zinc   (*ii*) Aluminium
   (*iii*) Lead   (*iv*) None of these

8. **In "Muntz Metal"**, an alloy of copper, zinc content is increased to:
   (*i*) 60 per cent   (*ii*) 30 per cent
   (*iii*) 20 per cent   (*iv*) 15 per cent

9. **Aluminium Bronze** is an alloy of:
   (*i*) Copper, aluminium and Iron;   (*ii*) Copper, aluminium and tin;
   (*iii*) Copper, aluminium and zinc;   (*iv*) None of the above.

10. Of the four metals, ________ is poisonous and should not be used for making articles that come in contact with drinking waster or edibles:
   (*i*) Zinc   (*ii*) Lead
   (*iii*) Copper   (*iv*) Tin

11. **Galvanizing** is a process of
   (*i*) Giving a shining paint to a metallic surface
   (*ii*) Giving a coating of zinc over an iron or steel surface to protect it from corrosion.
   (*iii*) Electrode painting of chromium over steel.
   (*iv*) None of the above.

12. **Nickel** is the ________ of all non-ferrous metals
   (*i*) Strongest   (*ii*) Weakest
   (*iii*) Cheapest   (*iv*) Lightest

13. **Magnesium** is the ______ of all the non-ferrous metals;
   (*i*) Strongest   (*ii*) Weakest
   (*iii*) Lightest   (*iv*) Cheapest.

14. **Cassiterite** is the ore of
   (*i*) Tin   (*ii*) Lead
   (*iii*) Zinc   (*iv*) Magnesium

15. "RUSTING of iron" is a process of formation of ______on surface due to atmospheric corrosion:
   (*i*) Ferric hydroxide;   (*ii*) Ferric carbonate;
   (*iii*) Ferric sulphate;   (*iv*) None of the above

16. In **galvanic corrosion**, the metal getting eroded faster acts as a
   (*i*) Cathode   (*ii*) Anode
   (*iii*) Electrolyte   (*iv*) None

ANSWERS: **1.** (*ii*); **2.** (*i*); **3.** (*i*); **4.** (*iii*); **5.** (*i*); **6.** (*iii*); **7.** (*i*); **8.** (*i*); **9.** (*i*); **10.** (*ii*); **11.** (*ii*); **12.** (*i*); **13.** (*iii*); **14.** (*i*); **15.** (*i*); **16.** (*ii*)

RELEVANT I.S. CODES*

ALUMINIUM

1.	Cast Aluminium and Aluminium alloys for manufacture of utensils.	IS: 20-1977
2.	Wrought Aluminium and Aluminium Alloys for manufactures of utensils.	IS: 21-1975
3.	Primary Aluminium notched bars and ingots for Aircraft purposes	IS: 23-1965
4.	Methods for chemical Analysis of Aluminium and alloys.	IS: 504-1963
5.	Aluminium and aluminium alloy ingots and casting for general engineering purpose	IS: 617-1975
6.	Aluminium channels	IS: 3921-1966
7.	Analysis of aluminium, manganese, zinc and silicon	IS: 4354-1967
8.	Glossary of terms for aluminium and its alloys	IS: 5047-1969
9.	Wrought aluminium and aluminium alloys for electrical purpose.	IS: 5082-1969
10.	Classification of bauxite for use in the production of aluminium	IS: 5953-1971
11.	Code of designation for aluminium and its alloys	IS: 6051-1970
12.	Anodized aluminium for automobile use.	IS: 6651-1972
13.	Recommended practice for anodizing aluminium	IS: 7088-1973
14.	Code of Practice for use of aluminium alloys in structures.	IS: 8147-1976
15.	Code of Treatment for heat treatment of aluminium alloys.	IS: 8860-1978

COPPER

1.	Copper (Prescribes specifications of eight grades of copper)	IS: 191-1967
2.	Recommended procedure for inspection of copper base alloy and castings	IS: 1408-1968
3.	Copper plate, sheet and strip for industrial use.	IS: 1972-1977
4.	Dimensions for wrought copper and copper alloy rods and bars for general engineering use.	IS: 2826-1974
5.	Methods of chemical analysis of copper nickel-zinc alloys.	IS: 3187-1965
6.	Glossary of terms for copper and copper alloys	IS: 3288-1973
7.	Nickel-copper alloy castings	IS: 4131-1967
8.	Copper master alloys (15 Alloys)	IS: 5742-1970
9.	Copper Nickel Alloys	IS: 6517-1972

LEAD

1.	Lead pipe (for other than chemical purpose)	IS: 404-1977
2.	Lead sheet and strip (do)	IS: 405 -1977
3.	Lead and lead alloys for electrical sheeting purpose	IS: 1339-1977
4.	Lead antimony alloys	IS: 1654-1978
5.	Electroplated coating alloys	IS: 1992-1979
6.	Methods for sampling lead and lead alloys,	IS: 8439-1977

ZINC

1.	Zinc requirements for virgin zinc	IS: 209-1966
2.	Zinc base alloy die casting	IS: 742-1966
3.	Code of Practice for the manufacture of zinc alloy pressure die castings	IS:1655-1968

4. Zinc anodes for electroplating	IS:2605-1964
5. Hot dip zinc coatings on steel alloys	IS: 4736-1968

BRASS, BRONZES AND GALVANIZING

1. Naval Brass Rods and Sections	IS: 291-1977
2. Brass Ingots and castings	IS: 292-1961
3. Aluminium bronze ingots and castings	IS: 305-1961
4. Tin Bronze ingots and castings	IS: 306-1968
5. High tensile brass rods and sections	IS: 320-1962
6. Cold rolled brass sheets, strip and foil	IS: 410-1977
7. Phosphorous bronze sheet strip etc.	IS: 1385-1968
8. Recommended practice for hot dip galvanizing.	IS: 2629-1966
9. Method of testing uniformity of zinc coating.	IS: 2633-1972
10. Brass wire for cold-heated and machined parts	IS: 2704-1964

MAGNESIUM

1. Materials for use in magnesium ox chloride flooring	IS: 657-1962
2. Magnesium powder for explosives	IS: 2307-1977
3. Magnesium ingots for remelting	IS: 6694
4. Code of practice for preparing metallo graphic specimens.	IS:7729-1977

TIN

1. Tin Bronze ingots and castings	IS : 306-1968
2. Pack rolled tinplate	IS: 597-1978
3. Methods for chemical analysis of tin ingots.	IS: 1993-1974
4. Cold reduced tin plate and black plate refined secondary tin.	IS-4280-1967

NICKEL

1. Fabricated nickel anodes.	IS: 1958-1967
2. Methods of chemical analysis of nickel	IS: 2766-1968
3. Primary Nickel	IS: 2782-1964
4. Methods of analysis of copper zinc nickel alloys	IS: 3187-1965
5. Nickel-copper alloy castings	IS: 4131-1967
6. Electroplating of nickel and chromium on plastics.	IS: 8376-1976

CORROSION

1. Determination of corrosion (electrolytic)	IS: 8516
2. Corrosion of steel reinforcements	IS: 9077
3. Protection of Iron & Steel from corrosion	IS: 3618

Note: Most of these codes stand reaffirmed since 1990.]

10

Paints and Varnishes

10.1. INTRODUCTION

Civil engineering construction of almost all the types is considered incomplete unless it is given a **finishing coat**. It means a lot of things in different constructions. The best designed residential building will be considered unfinished if its properly plastered walls are not covered with a coat of proper distemper in the interior and snowcem on the exterior; or if its doors and windows and cabins and other wood work and metal work is yet glaring in the raw **original form**. Same thing can be said about a steel bridge spanning a mighty river. The steel frame has to be given a finish by painting. The paints and varnishes are, therefore, such materials which give the final appearance to the structure. The paints and varnishes give the aesthetic appeal to the construction on the one hand and also protect the material used against many deteriorating agents thereby increasing their life on the other hand.

10.2. DEFINITIONS

A PAINT is essentially a **coating** or covering material applied on a metallic or non-metallic surface and is defined as a**"dispersion of a pigment in a suitable drying oil in the presence of a solvent called thinner or dilutent"**

Thus, a paint has **three essential ingredients**:

- a **pigment** - which is the real colouring substance.
- a **solvent** - in which the pigment is dissolved and
- a **drier** - which is necessary to quicken the process of evaporation.

There are a number of other surface finishes, which differ from paints in their constitution. Thus,

A VARNISH contains **no** pigment. Instead, it has a resinous substance dissolved in a suitable oil or volatile liquid.

A LACQUER is a finishing material which is a dispersion of resins and cellulose esters in a volatile solvent. It dries quickly by evaporation of solvents.

AN ENAMEL is a blend of a paint with a varnish giving a finish that is strong, durable and brilliant at the same time.

10.3. FUNCTIONS OF A PAINT

Paints are applied on metallic and non-metallic engineering surfaces for two reasons:

(*i*) **Protecting** them against deterioration by atmospheric agencies,

(*ii*) **Developing** a decorative effect.

Most commonly paint may be a protective covering as well as decorative finish.

10.4. CHARACTERISTICS OF AN IDEAL PAINT

Following basic qualities are required in a good paint.

1. **Good hiding power.** An ideal paint should be capable of **covering the existing surface** of a material uniformly and thoroughly.

2. **Permanent colour.** After its use, paint is exposed to atmosphere. It may get moist again and again. It may also be effected by various types of radiation on its surface from sunlight. All these will effect the 'colour' (pigment) of the paint. A good paint must maintain its colour under all these conditions.
3. **Resistance to corrosion.** A paint should be **chemically inert** to the atmosphere. This is essential if a paint has to protect the underlying surface of a metal or non-metal.
4. **Easy application.** Paints may have to be used over wide surface areas. It is therefore, necessary that paint should be of such a nature that it can spread easily, smoothly and uniformly.
5. **Economical in cost.** Since a paint is an additional component on a material its cost should be as low as possible. Materials that make costly paints will not be used in common construction.

10.5. INGREDIENTS OF A PAINT

Paints are prepared by intimately mixing various ingredients in proper proportions. Following are essential ingredients of an ideal paint.

1. **The vehicle.** It is actually an oil which can dry on exposure. Hence it is also called a **drying oil.** Such an oil is unsaturated in composition On exposure to air it gets saturated (and hence dries out). The drying oil or vehicle has the capacity to keep the pigment and other ingredients in solution or suspension. These ingredients get deposited in the film made by the drying oil on the surface of the object. The most commonly used drying oils are: **linseed oil, dehydrated castor oil, tung oil, bleached oil** and **fish oil.**

   DRIERS are those substances which are added to drying oils to **accelerate their rate of drying**. They act as catalysts in the oxidation process of the drying oils. The **linoleats, resonates** and **naphthanates** of metals like lead, magnesium and vanadium are commonly used **driers**.
2. **Bases.** A base is a solid substance that forms the body of the paint. It consists of a **very fine powder** of a suitable material such as white lead, red lead, iron oxide and titanium oxide etc. The base material makes the ultimate paint film harder, stronger, elastic and safe against cracking and moisture. It makes the paint stable against ultra-violet light as well.
3. **The pigment.** It is a colouring material added to the above components in order to impart a desired shade and colour. A pigment is invariably added in a finely powdered state. Following is just an illustrative list of pigments used for obtaining different colours through paints.

TABLE 10.1. Pigments for Colours.

Colour	*Suitable Pigment*
WHITE	**White Lead; Titanium White; Lithophone**
RED	Red Lead, Venetian Red; Chrome Red; Natural Red Oxide of Iron
BROWN	Oxides of Iron
YELLOW	Chrome yellow; zinc chromate; yellow ochres.
BLUE	Pursian Blue; Pairs Blue, Ultramarine; Cobalt Blue.
BLACK	Graphite Lamp black, Carbon Black; Ivory Black.

4. **Solvents and dilutents.** These are such volatile substances that are added to a paint in order to make its application easy, smooth and uniform. The solvents and dilutents must possess the capacity:

   (*i*) for **taking all the other components** into solution or suspension;

   (*ii*) for **evaporating quickly** on exposure to atmosphere.

These are also called **thinners** which reduce the viscosity of the paints to a great extent. **Petroleum, spirits** or **naphthas, turpentine** and **coal tar** hydrocarbons are some of commonly used solvents or dilutents.

5. **Extenders.** These are also called **fillers**. A filler is a substance which can be added to a paint to increase its bulk volume without effecting its useful properties. These materials (fillers) are **necessarily inert** toward other ingredients of a paint. Commonly used extenders are: **chalk, gypsum, barite, silica** and **magnesium silicate.**

10.6. TYPES OF PAINTS

A variety of paints are available in the market. In fact **paint industry** in itself forms a major sector in the industrial world of developed and developing countries. The various types of paints may be discussed under following broad groups :

1. COLD WATER PAINTS. These consist of **mineral pigments** that are carried in water in the presence of a drier. **Soyabean** protein and **caesin** are the common binders. Cold water points get easily washed away. Hence they are suitable only for the interior applications.

2. OIL PAINTS. These are **common paints** quite useful for ordinary use on metal and wood products on a large scale. An oil paint generally has a **low order** shine. It is, however, quite opaque. The oil paints contain an unsaturated oil like linseed oil and their hardening is because of oxidation of the oil on exposure to the atmosphere.

3. ENAMEL PAINTS. These are usually available as **ready made paints** and consist mainly of **white lead or zinc white**, petroleum, resinous matter and **an oil**. An enamel paint forms a hard, impervious enamel like surface on drying. This group includes the most commonly used paints for interior and exterior work in building construction works. The final surface has good appearance and is resistant to chemical attack by acids, alkalies and fumes. Hence these can be applied within the industrial buildings also. The enamel paints are available in all **colours** and **shades.**

4. LACQUERS. A lacquer is defined as a solution (or suspension) of **resins** and cellulose ester in a **volatile solvent**. Cellulose ester, any pigment, a plasticizer and a dilutent are the usual constituents of a lacquer in addition to the solvent.

Cellulose esters used in lacquers are chiefly **cellulose nitrates** and **cellulose acetates**. They give the lacquer the property of forming a film on evaporation of the volatile solvent. The film so formed is **quite hard, impervious** and **durable**. Resins improve the adhesion of the film to the surface. If a pigment has also been used in the lacquer, the paint is then called **cellulose pigment**. More often a lacquer may be without a pigment when it is used only as a finishing material. A mixture of shellac and alcohol forms a common example of rapid-drying lacquer.

Coster oil is often added to lacquers as a **plasticizer**. **Plasticizers are substances which are added to lacquers to improve their general properties like adherence, toughness and resistance to deterioration of the film formed on drying.**

5. EMULSION PAINTS. An emulsion is defined as a **suspension** of one liquid within another liquid. In an emulsion paint, one of these liquids must be the **paint source**. The other liquid may be simply a carrier. Latex paints used for painting wood and cement plaster form the best examples. These contain latex (organic resin in liquid form) emulsion in water. When applied, water phase containing the latex particles thoroughly dispersed in it dries by evaporation. A thin film of latex paint is left behind on the surface of the object. **Butadiene-Styrene** is a very commonly used resin for making an emulsion which gives a **fire-resistant odourless paint**.

6. SYNTHETIC PAINT RESINS. The synthetic paint resins form a group in themselves that has been used extensively for manufacture of **high quality paints**. These are mostly emulsions in which a synthetic resin rather than natural resin has been used along with another liquid. The synthetic resins include the following members :

TABLE 10.2. SYNTHETIC PAINT RESINS.

S.No	*Group*	*Members*	*Field of Application*
1	ALKYD	Amino Phenolic Styrenated	Automotive industrial products
2.	CELLULOSE	Nitrate Butyrate Ethyl	Quick drying finishes (Lacquers)
3.	EPOXY	Amine Phenolic Polymide	Buried steel tanks and pipes
4.	VINYL	Acetate Butyal Chloride	General purpose

7. ALUMINIUM PAINTS. An **aluminium paint** is actually an emulsion of very fine flakes of aluminium in a varnish. The aluminium flakes may be finer than even 100 mesh. On application, the flakes get deposited one above another on the surface along with the vehicle. In one common variety of an aluminium paint, **asphalt-base** varnish is the vehicle. The paint should be thoroughly agitated before application.

Aluminium paints possess **very good hiding powers**. Besides, they are highly reflective and impart a good appearance to the surface. They are impervious to moisture and resist corrosion well.

Aluminium paints are used extensively for metal painting especially for water pipes, oil storage tankers and gas tanks.

8. CEMENT PAINTS. This group includes a variety of paints in which **cement is the main constituent besides a colouring pigment in powdered form**. The finely powdered pigment is thoroughly disbursed in the cement powder making an intimate mixture. These pigments also contain varying proportions of hydrated lime, hygroscopic salts and water-repellent additives like aluminium stearates.

Cement paints are cheap, durable and can be made highly decorative by using selected pigments. Applications of cement paints require techniques necessary for both cementing and painting. The cement part of the paint needs moisture to set and harden and hence the paste of paint must be cured carefully **after application**. Similarly, the **paint part** may require application in two or more coats to give the best decorative and protective results.

Cement paints can be given on both **external** and **internal** portions in buildings. They can be applied even on damp surfaces, which is a **unique advantage**. These are, however, suited only for painting constructions in bricks, stones, and concrete. They cannot be usefully applied on metals and timber.

9. DISTEMPERS. These are finishing coat paints used only on the interior walls in building construction. They consist mainly of **whiting and glue size in water**. The whiting material consists of mainly chalk, whereas glue size is made from animal glues and serves as adhesive. In case a coloured distemper is desired, the required pigment is also added in a finely powdered form.

Distempers are used in building in place of ordinary whitewash. These provide a more durable, smooth and pleasing **final surface**. Distempers are, however, destroyed by moisture and may start pealing off after use during wet seasons.

10. MISCELLANEOUS PAINTS :

Graphite Paint. It is a **black paint** used on iron parts in mines and other underground works as also in industrial plants. The graphite particles spread uniformly over the metal surface and make it resistant to corrosion by a variety of chemicals such as chlorine, ammonia and compounds of sulphur.

Luminous Paint. It is a special purpose paint. It is made by dissolving **calcium sulphide** in Varnish. On application, the paint emits light after the light source is discontinued. As such these paints are used for painting symbols on roads and highways. They prove quite helpful during nights.

Inodorous Paint. Paints containing turpentine emit offensive smells. For obtaining odourless paints, methylated spirit is **used as a solvent**. White lead or zinc white in finely powdered state are dissolved in methylated spirit

Silicate Paint. It is prepared by mixing together finely powdered **calcined silica** and a resinous substance. The paint is resistant to chemical attacks and also against heat. Silicone resins are used in these paints. Silicate paints are used in boilers, ovens and on concreter and masonry. These paints are also resistant against ultraviolet radiations.

10.7. APPLICATION OF A PAINT

A paint cannot and should not be applied on any surface (metallic or wooden) **without preparing the surface in a thorough manner**. Following is a brief account of steps required in application of a paint.

A. On Wood

Products or parts made out of timber require painting in many cases. The operations required for giving an effective paint on wood are:

(*i*) **Cleaning**. This involves clearing off the surface of the wood **thoroughly**. All dust, rough projections and particles of grease or oil or any foreign material should be removed from the wood surface using a suitable method of cleaning. Cloth dusters and cleaning brushes may be used for this purpose. This may be followed by using fine grade sand papers where necessary.

(*ii*) **Knotting**. This simply means treatment of knots. The knots in wood, as we know, are common defects that may be found to some extent in all the timber parts. They are hard, brittle and often resinous. In order to obtain uniform finish of a paint, all the knots on the surface must be covered with a **thick paste of shellac with spirit**. Alternatively, a paste made of **red lead with glue** can also be used during knotting. Any cracks, nail depressions, holes and other grooves may also be filled with the above paste or even with a paste of chalk in linseed oil. Often two or more coats may be required to achieve **complete killing** of the knots.

(*iii*) **Primary treatment.** This is also called **PRIMING**. It is most important step in painting. It involves giving a rough coat on the timber surface with **white lead**, litharge or **red lead** in linseed oil. **The function of the primary coat is to make the timber surface as smooth as possible**. This way the surface will receive the subsequent paint thoroughly and uniformly.

(*iv*) **Stopping.** The surface of object is rubbed with the help of pumice or fine grade glass paper **after first coat** of paint has thoroughly dried. This is called stopping. It is aimed at removing any irregularities that are yet visible after the first coat and to prepare the first coat for receiving the **second coat** of the paint in a better way.

(*v*) **Application of paint.** After the primary coat or priming, the desired paint is applied with the help of a **suitable brush** in two or three more coats. Each subsequent coat is applied only **when the previous coat has completely dried**. The **last coat** is called the finishing coat and is given only when the surface has been made perfectly smooth by way of previous coats and is totally dry.

B. On Metals

Very **elaborate cleaning** is required for metal surfaces before painting because they are most often covered with undesirable matter. The metal surface may be sufficiently cleared only by mechanical methods. Sometimes, however, chemical cleaning may also become necessary. First stage is, therefore, cleaning.

1. CLEANING :

(*a*) **Mechanical cleaning**. A variety of methods are available for cleaning the metal surfaces mechanically. Among these may be mentioned: **sand-blasting, barrel finishing, grinding** and **ultra sonic cleaning.**

In **sand blasting,** called abrasion cleaning, impurities are removed from the surface of a metal by exposing it to **a blast of compressed air** rich in sand or grit. The blast performs a quick rubbing action.

The **barrel finish** method involves placing the metallic objects in a barrel along with a desired abrasive. The barrel is given motion due to which the parts come in contact with the abrasive. Sometime a liquid with **suitable pH value may also be placed in the barrel.** Barrel treatment has proved useful in de-greasing, descaling and fine finishing of many delicate metallic products.

The **Ultrasonic cleaning** method is rather a sophisticated technique. It uses the sound-wave energy to remove the dirt, impurities and scales of earlier paints quickly and effectively. In a specially designed tank holding a suitable bath (liquid) sound waves with frequencies between 20-40 kc are introduced. These **agitate the bath** with great force, generating cavitation pressures. Impurities are virtually **sucked out** from the metal surface in this method. **Acoustic cleaning** has been used for typewriter parts, printed circuit boards and transistors etc.

Steam-cleaning and flame–cleaning are two other methods used for removing deeply settled impurities from the metal surfaces.

(*b*) **Chemical Cleaning**. Some metal surface impurities **may not be easily removed** completely by mechanical cleaning. The surface in those cases may require a **chemical treatment** to remove, for example, mill scale and rust in steel and oxide surface in aluminium.

Chemical cleaning uses either **an alkaline medium** or an **acidic medium**. The decision (for using a particular medium) depends on the **type of metal** to be cleaned. Chemical cleaning may be achieved by applying the cleaner by hand or through **spray guns**. In difficult cases, the metal surface may be exposed to the **vapours** of the cleaning medium (vapour de-greasing) or even by **electro cleaning**.

Sulphuric acid, hydrochloric acid, nitric acid and phosphoric acid are the **acids** that have been commonly used for chemical cleaning. Sodium hydroxide, sodium carbonate, trisodium phosphate and sodium fluoride are some of the alkalies that find use in alkaline cleaning of metals.

2. PRIMING. A **primary coat** is essential in most cases of iron and steel painting. This coat may be of **red lead** dissolved in raw linseed oil or boiled linseed oil. For aluminium surface, however, the priming coat is generally of **zinc chromate**.

3. UNDERCOATS. The metal surface is ready to receive the final paint after the primary coat is completely dried. The surface is then given one or two more coats of the paint that need **not be rich with the pigment**. Purpose of undercoats is to completely hide the surface of the metal under them and offer a base for the final coat of the paint for a **smooth, uniform** and **brilliant result**.

4. FINISHING COAT. This has to be given with great care and caution. The paint for the final coat must have **all the essential ingredients in a perfect blend** to give the best finish to the surface. Application should be done extremely carefully to avoid such defects as formation of dull patches (**blooming**), glassy patches (**flashing**), thickly painted patches (**wrinkling**) and so on. In fact the entire purpose of giving a paint cover may be lost in the careless blending of the final coat or **poor workmanship** in its application.

C. On Cement or Concrete Surface

Paints are also used on cement plastered surfaces and concrete surfaces. Following preparatory steps are essential to get the best results.

(*a*) **Let the surface get completely dry.** Any paint given on a wet surface of plastered wall or floor or ceiling or concrete surface will fail to give the desired result. The moisture from cement will retard evaporation, dilute the paint and may even start chemical reactions if it contains alkalies from the cement. The effort will be a shear waste.

(*b*) **Clean the dry surface.** The cemented surface is likely to have on it molds, fungi and efflorescence patches and lot of dust deposited on it. All these surface imperfections must be thoroughly removed **before** application of paint. This can be done by brushing and spray washing.

(*c*) **Use only right type of paint.** Paints of all compositions cannot be used on all cemented surfaces because of alkaline nature of cement in the plaster or in the concrete.As such, **oil-based** paints are liable to **deteriorate**. In such cases, it is essential that the surface is first covered by a **primer coat** of an alkali-resistant paint.

10.8. VARNISHES

Definition. A varnish may be defined as a "homogeneous liquid containing essentially a resinous substance dissolved in a suitable oil or a volatile liquid". A varnish does not contain a pigment. Moreover, it is always used as a finishing coat.

Functions of a varnish. More commonly a varnish is used over a wooden object as a **decorative** and **protective** covering. The varnish brings out the grain of wood in a brilliant manner when given without a paint. On the painted surface, varnish imparts a delicate brilliance. Moreover, the resinous material dissolved in the varnish forms a thin film on drying which protects the surface below from deterioration to moisture.

Ingredients. The two essential components of a varnish are **a base** or resinous substance and a **solvent**. The resin of a varnish may be natural or artificial, Natural resins used in varnish are: **rosin, copal, shellac, amber** and **dammer**. Synthetic resins include phenyl and **vinyl resins**.

The main solvents used in varnish are: **boiled linseed oil, turpentine** and **methylated spirits**. Water has also been used in some special varnishes.

Types of varnishes. Some common types of varnishes distinguished on the basis of the solvent or constituents are as follows :

1. Oil varnishes. Those varnishes in which linseed oil has been used as a solvent form this group. The base material may be amber or copal. Although they dry slowly, they form a **hard and durable film**. Hence they are popular for use in external finish. They are quite resistant to weather changes.

2. Turpentine varnishes. These are made by dissolving gum, mastic or rosin in turpentine. They have the advantage that **they dry quickly**. At the same time, the film formed is neither much durable nor resistant to moisture. Hence, they are to be used only for interior work.

3. Spirit varnishes. These are commonly used varnishes **for furniture**. They consist of shellac dissolved in methylated spirit. **French Polish** is a varnish belonging to this group. Sometimes a small quantity of a pigment is also added to give a desired shade to the finish. The spirit varnishes are also not much durable. They are **also not** resistant to weather changes. Hence these can be given only on wooden articles protected from rain, gases and light.

4. Japans. These are a class of varnishes that have asphalt as an important ingredient. Asphalt is dissolved in a linseed oil in the presence of a volatile thinner. JAPANS are applied mostly to metal surfaces. The surface is first-given a coat of japans and then heated to baking temperature, at 210^0 C, for a few hours. On cooling, the paint forms a **coating** that is highly resistant to chemical corrosion.

TYPICAL QUESTIONS

1. (*a*) Define Paints and Varnishes?

   (*b*) What are the main functions of a paint and a varnish?

   (*c*) Discuss in details essential constituents of paints. Give examples of some typical paints.

2. Discuss the process of application of paints on different surfaces such as

   (*i*) Plastered walls (*ii*) Metallic structures

   (*iii*) Wooden Furniture

3. Write detailed account of the functions, types and methods of applications of Varnishes.

4. Write short notes on:

   (*i*) A drier in a paint (*ii*) Lacquers

   (*iii*) Aluminium paints (*iv*) Synthetic paint resin

   (*v*) Distempers (*vi*) Knotting

   (*vii*) Japans.

5. Tick the right answer :

   (*a*) In **a paint**, the vehicle is the term indicating

   (*i*) Pigment (*ii*) Drying oil

   (*iii*) Filler material (*iv*) None of these

   (*b*) **Enamel** paints are

   (*i*) Readymade paint

   (*ii*) Made on the job paint

   (*iii*) Partly processed and partly made on the job

   (*iv*) None of these.

   (*c*) **A lacquer** is defined as an **emulsion**

   (*i*) of resins and cellulose ester in a volatile solvent

   (*ii*) of mineral pigment carried in water in te presence of a drier

   (*iii*) paint made with an oil that gives an opaque surface

   (*iv*) None of these.

   (*d*) A **distemper** is actually a

   (*i*) Paint used on wooden parts

   (*ii*) A varnish used in plywood

   (*iii*) A finishing coat paint used on the inner surface of building

   (*iv*) None of these.

   (*e*) In **japans**, the essential components are

   (*i*) Shellac dissolved in methylated spirit

   (*ii*) Gun, rosin and turpentine

   (*iii*) Asphalt dissolved in linseed oil

   (*iv*) None of these.

NSWERS : (*a*)—(*ii*); (*b*)—(*i*); (*c*)—(*i*); (*d*)—(*iii*); (*e*)—(*iii*)

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11

Plastics

11.1. INTRODUCTION

Broadly speaking any material that shows the property of **plasticity**, i.e. the capacity to undergo a change in shape under external pressure and retain the new shape even when the pressure is withdrawn, is called a **Plastic Material**. This is in contrast to an elastic material which also undergoes a change in shape under pressure but regains the original shape as soon as the pressure is released.

In industry, the term **PLASTICS** refers to a **vast group of materials** that are derived mostly from **organic resins** and possess the property of **plasticity** by virtue of which many intricate components, units and parts can be made from them through industrial processes involving heat and pressure.

Plastic have found very **wide applications** in every major industry and in the manufacture of many items of engineering importance.

11.2. GENERAL PROPERTIES

Plastics are a group of materials which possess many useful properties which have made them most popular engineering materials in certain fields. Among such applications following need special mention.

1. **Light weight**. Plastics are undoubtedly the **lightest** of engineering materials, their density varying between 1.1 g/cc to 1.6 g/cc compared to 1.75 of magnesium, the lightest of metals.

2. **High resistivity** to corrosion and also to electric current makes them ideal materials **as insulators**.

3. **Low thermal conductivity** makes them suitable materials for use as **thermal** insulators.

4. **Easy formability**. Many **intricate** shapes and complicated designs can be given to Plastics with considerable ease and at economical cost. Hence, these offer unlimited choice in **product design**.

5. **Appeasing colour and finish**. Plastics are amenable to acquiring any desired colour besides taking the desired shape and smooth excellent surface finish.

6. **Low cost**. Compared to similar products made from other materials, plastics are generally very economical in cost.

11.3. CLASSIFICATION

All the plastics are grouped under two main classes depending upon their behavior towards heat: thermoplastics and thermosetting plastics..

11.3.1. Thermoplastics

All those varieties of **plastics which become soft on heat**, so much so that they can be remoulded again and again are classed as **thermoplastics**. These plastics harden on cooling (and soften on heating). **Their hardness is, therefore, a temporary property subject** to change on heating. Examples: **acrylic plastics, celluloid plastics, polyethylene, polystyrene** and **asphalt.**

11.3.2. Thermosetting Plastics

This group of plastics **hardens on heating and curing at a particular range of temperatures.** Once 'cured' or set, **they do not become soft by any further heating.** Their set and **hardness** is, therefore, a **permanent property** that does not change on heating again. They may get destroyed but do not become soft on reheating. Examples **bakelite, epoxy** and **silicones** provide the best examples of thermosets.

11.4. CONSTITUTION OF PLASTICS

Plastics are sometimes called "organic polymers". The polymers are made by combining or 'uniting' the building units of smaller organic compounds called **monomers**. The process of **combining** these monomers to make polymers is called **polymerization.**

There are three methods available for polymerization:

1. **Addition** polymerization;
2. **Condensation** polymerization;
3. **Copolymerization**.

(*a*) **Addition Polymerization**. In this method, a polymer is obtained by **adding** one monomer to another : a **dimmer** is obtained. To this dimmer, addition of another monomer converts it to a **trimmer**. The process can be repeated till a desired polymer is obtained. Thus, monomers of ethylene, CH_2, added one after another make **polyethylene**, which is a common thermoplastic. In fact, **all the plastics of thermoplastic group are made by addition polymerization.**

(*b*) **Condensation Polymerizastion.** It is a process involving **chemical reactions** between:

(*i*) a **compound** with itself;

(*ii*) a **compound** with another compound;

In this chemical reaction, some simple compound is eliminated at the formation of a polymer. An example may make this phenomenon clear. **Phenol monomer and Formaldehyde monomer** when condensed together will result in Bakelite, which is plastic material. In this reaction, **water molecules** are released and eliminated.

$$\boxed{\text{PHENOL + FORMALDEHYDE = PHENOL – FORMALDEHYDE (Backelite) + WATER}}$$

Both thermosetting plastics and thermoplastics may be made by condensation polymerization.

(*c*) **Copolymerization.** It is, in fact, an addition polymerization **but with a difference**. Here monomers from two or more types are **added** together. This is because some monomers cannot be added to themselves. They respond to addition with monomers of other compounds favourably. The best example of a copolymer plastic is: **butadiene-styrene**. It is the **rubber** used for tyres.

11.5. MANUFACTURE OF PLASTICS

This topic is better studied in two subheads: the raw materials used in Plastic Manufacture and the Processes of Fabrication of Plastics.

A. Raw Materials

There are at least four basic raw materials for manufacture of plastics: **resins** or **binders; fillers** or **extenders;** and **plasticizers** and **pigments.** These are discussed below in outline..

1. **RESINS (BINDERS).** These are the starting materials in the plastics industry. They are natural or synthetic products of **organic constitution**. The more common types of resins belongs to two groups: thermoplastic resins and thermosetting resins.

(*a*) **The Thermoplastic Resins.** These are either of **cellulose** type or of non-cellulose type.

The CELLULOSE RESINS are derived from cellulose materials like esters and ethers. Among them those used for plastics are: Cellulose nitrate (celluloid), ethyl cellulose, benzyl cellulose and cellulose acetate. The cellulose nitrate was the material used for the **first plastic products**. These resins have been used to manufacture plastics of wide ranging properties, such as those possessing

(*i*) **perfect** transparency,
(*ii*) **great** toughness,
(*iii*) **excellent** machinability,
(*iv*) **excellent** electrical properties;
(*v*) **high** colour adaptability

These plastic are, however, **weak towards strong acids** and **moisture.**

The NON CELLULOSE RESINS include vinyl resins and polyamide resins.

VINYL RESINS. It is a group of colourless, transparent and non-toxic resins. Most commonly used members are: polymers of vinyl chloride, vinyl acetate, methyl methacrylate and acrylics.

Some of them (like styrene and methyl methacrylate) are included among the **lightest binders.** They possess such useful properties as low electrical conductivity which makes them eminently suitable for insulation at radio frequencies. Others like **vinyl chloride** are better suited as coatings for wires and cables. This is because they have a **better resistance to deterioration**. They are highly flexible

Similarly, **NYLON** which is a **polyamide plastic**, is characterized with the property of orientation and high softening point. **NYLON** yarn possesses very **high tensile strength** and finds wide use in **textile industry**.

(*b*) **The Thermosetting Resins**. These include the following common types :

(*i*) **Phenolic Resins**. They are made by condensation of **phenol** and formaldehyde. In fact, phenol-formaldehyde plastic with the trade name of Bakelite was the first from the group of thermosets to be manufactured in 1932. When a suitable type of filler is combined with these resins, a plastic material of desired quality can be obtained. The phenolic resins are characterized with:

  (*i*) **high dielectric** strength,
  (*ii*) **high mechanical** strength,
  (*iii*) **high resistance** to chemicals
  (*iv*) **high resistance** to water.

  These resins have been widely used as important components in a wide range of products such as electric toggles, electric motor starters, radio cabinets and other parts and in toilets utilities.

(*ii*) **Urea-Formaldehyde** resins are specially suited for making electrical and mechanical products. These resins have a high resistance to oil, water, weak acids and alkalies. They can be **given any colour** because urea is basically light coloured.

(*iii*) **Melamine Formaldehyde.** They make the tableware plastics. This group is characterized with **high impact strength** and **durability**.

(*iv*) **Furfuryl Resins**. These are dark coloured resins. They are slightly better than phenolic resins and can be used in place of them. These resins harden or **set at a uniform rate**. The source materials for furfurly are **oat shells**, sugarcane refuse and husk of rice.

(*v*) **Shellac.** It is also a thermosetting binder. It is used extensively in manufacturing **insulating plastics**.

2. FILLERS. These include a number of materials that are used in the manufacture of plastics with a view of **increasing their bulk weight without interfering adversely** in their properties. Wood pulp, corn, husks, cotton, fibers, asbestos, micas, clays, lead and zinc oxide, metal powders and glass fibers are some commonly used fillers. These materials impart useful properties of shock resistance and strength against fracturing to plastics.

3. PLASTICIZERS. These are substances which are added to **obtain improvement in certain properties** in which the resins may be lacking. Such properties like shock-resistance, toughness, flexibility and non-inflammability can be greatly improved by addition of plasticizers to resins.

Plasticizers are an essential constituent of thermoplastics. In the thermosets, they are **seldom used**. Chemical compounds like dibutyl phthalate, tricresyl phosphate, butyl cleate and camphor are some commonly used plasticizers.

4. PIGMENTS. Pigments are added to the plastics at the time of manufacture to impart them a **desired colour**. Zinc oxide, barites and other metallic pigments may be used in proper proportions. It is essential that the type of pigment selected should be durable and **inert towards plastic resins.**

Besides the above materials certain other substances may also be required in the manufacture of **some varieties** of plastics. Their purpose is to give some special property in the ultimate product or to make the process (of manufacture) easy and economical. These include substances that act as catalysts, lubricants and solvents.

B. Fabrication of Plastics

Casting and moulding are two main processes commonly used to fabricate end products from plastic resins. The selection of method depends on the **type** of plastic resin being used and the **design** of the end product.

CASTING. In this method, desired objected are made by

(*i*) **heating** the resins to their melting points to make **hot liquid** melts from them;

(*ii*) **pouring** the hot liquid into the moulds of desired shape and design;

(*iii*) **curing** the product in the mould itself for a definite time.

The **curing** may require much time ranging from **few hours** to few weeks. It is an expensive method but products obtained are quite strong and hard.

MOULDING. It is a very **common method** in plastic industry. It involves shaping the material under high pressure or temperature or both factors operating **simultaneously**. Following are more important processes of moulding plastics.

1. Compression Moulding. This is the **most prevalent moulding** method. In this the plastic is pressed into the mould in a heated state. Thus both pressure and temperature are required. The object is **kept hot** while being pressed till its all the contours are fully developed. Pressures ranging from 35-40 Kg/cm^2 and temperatures of 38-76^{0}C (100^0-200^{0}F) or even more are commonly reached during compression moulding.

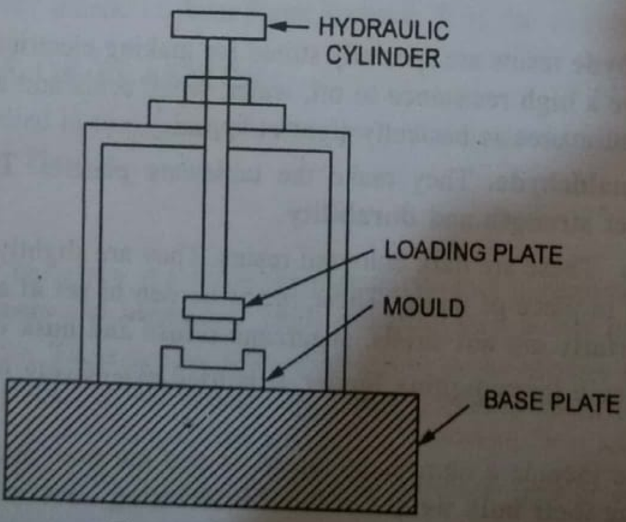

Fig 11.1. Compression Moulding.

2. Injection Moulding. In this method, the plastic material is first heated in a chamber. When it is sufficiently hot, it is then **forced into the mould** (that is kept cold) through a duct under requisite pressure. It is a common process for producing shapes from thermoplastic materials (Fig. 11.2).

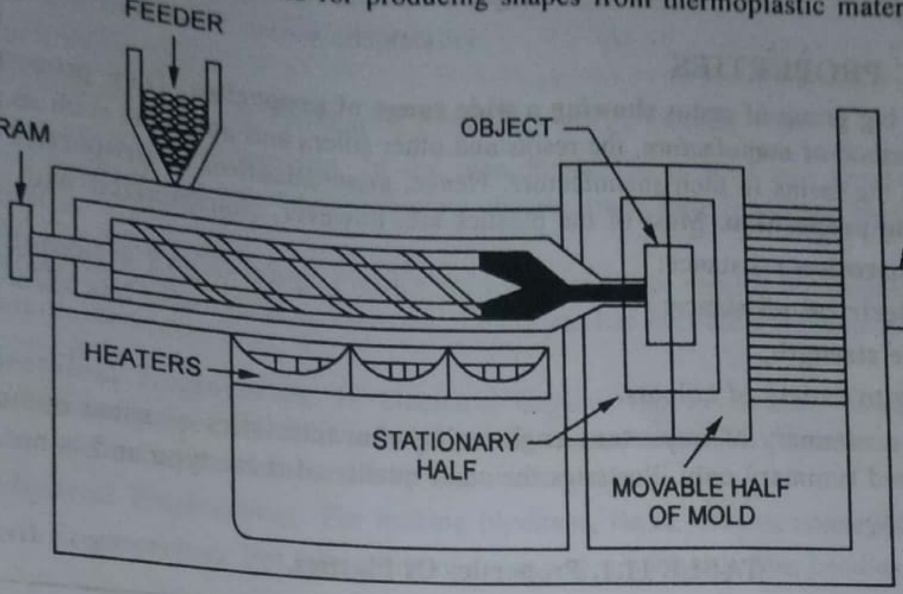

Fig. 11.2. Unit for Injection Moulding.

3. Transfer Moulding. It is a special type of moulding process applicable only to thermosetting plastics. It combines principles of both the compressive and injection moulding.

The material is first heated in a heating chamber. It is then forced into (injected into) a mould which is kept hot. **In the mould**, the plastic is pressed hard till it confirms to the final shape of the product. **The product is cured under pressure and in a hot state.**

4. Extrusion. This is an **exclusive process for thermoplastic materials** and is similar to injection moulding in principle. Hot material is extruded though a die of a requisite shape. Thus, there is a die in place of a mould in the extrusion process. Plastic conducts, rods, bars tubes and sheet materials are obtained by extrusion.

5. Cold Moulding. In this process, shapes are obtained by applying pressure on the selected type of resin. The product, however, may be cured by baking in an oven. The process has limited applications and is used in phenol-formaldehyde resins.

6. Calendering. It is a process of converting thermo plastic material into a thin sheet of a desired thickness. A heated mixture of the resin and plasticizers is passed through, a series of heated rolls. The gap between the two rolls gives the thickness to the sheet (Fig 11.3).

7. Laminating. This is a process of obtaining **plastic impregnated laminates** of wood, cloth, glass fibers and paper. Exact technique will differ from material to material. Commonly, the materials to be laminated is first soaked in the desired **plastic resin liquid**. It is then squeezed through a set of rolls and dried. The product is then **cured under controlled conditions of temperature and pressure**.

Besides the above methods used for shaping the plastics, these can be converted to foams, films, fibers

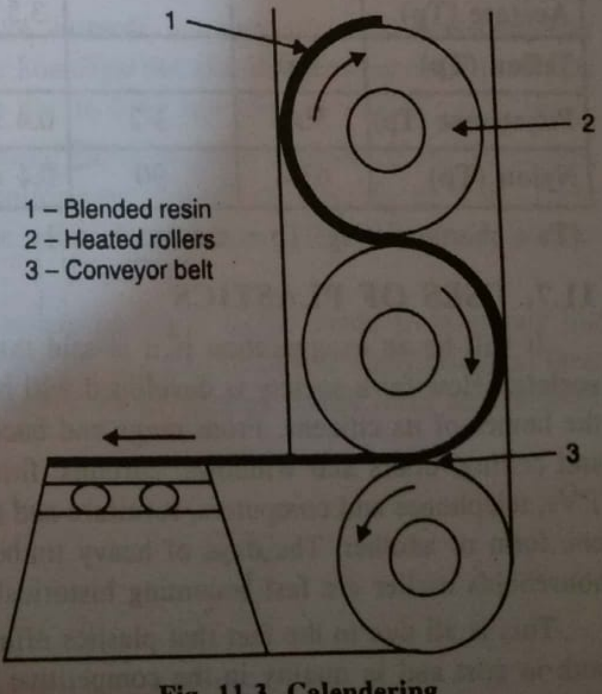

Fig. 11.3. Calendering.

and variety of other shapes by specific methods. A discussion of all of these methods is beyond the scope of this book. Readers interested in further studies on plastics are referred to standard books on Plastics Technology.

11.6. SPECIFIC PROPERTIES

Plastics form a big group of resins **showing a wide range of properties**. Their properties depend on the grade, the method of manufacture, the resins and other fillers and additives such as plasticizers etc.used along with the resins in their manufacture. Hence, **generalization of properties of plastics will be a misleading preposition**. Most of the plastics are, however, characterized with

(*i*) **excellent corrosion** resistance;
(*ii*) **excellent electrical** resistance;
(*iii*) **good tensile strength**;
(*iv*) **amenability** to variety of colours.

Given below is a summary of **important engineering characteristics** of some commonly used plastics. The tabulated summary only illustrates the chief quality of these type and is not exhaustive at all.

TABLE 11.1. Properties Of Plastics.

Type of Plastic	*Tensile Strength (kg/cm^2)*	*Elongation %*	*Modulus of Elasticity*	*Diaelect. Constant*	*Resistance ohm/cm*	*Specific Gravity*	*Temp. Limit (0^0C)*
Phenol Formaldehyde (Ts)	500-700	0.5-1.5	1×10^6	5-6.0	10^{11}	1.3	120^0
Epoxy (Cast) Ts	800-850		0.4×10^6	3.5	10^{16}	1.2	150^0
Polyester (Ts)	300-700		1.5×10^6	6.0	10^{14}	2.0	150^0
Cellulose Acetate (Tp)	450	15-50	0.8×10^6 to 3.5×10^6	5.5	10^{12}	1.3	90^0
Teflon (Tp)	300			2.0	10^{15}	2.2	260^0
Polystyrene (Tp)	500	1-2	0.4×10^6	2.5	10^{19}	1.05	90^0
Nylon (Tp)	630	90	0.4×10^6	3.5	10^{13}	1.1	120^0

[Ts = thermosetting; Tp = thermoplastic]

11.7. USES OF PLASTICS

It will be an exaggeration if it is said that **plastics form an index of the progress of modern society.** How far a society is developed will be easily determined form the use of plastic products in the homes of its citizens. From mugs and buckets to complete bathroom fittings to flooring, walling and ceiling, doors and windows, curtains, fittings, bodies and parts of electronic gadgets including T.Vs, telephones and computers, furniture and the conveyance used, plastics find use in all of them on one form or another. The days of heavy timber and heavier cotton, woolens, iron and steel used in households earlier are fast becoming historical phenomena.

This is all due to the fact that plastics offer some definite advantages over all the other materials both in cost and in quality in the competitive market. A few advantages of plastics are:

(*i*) Excellent combination of mechanical and electrical properties.
(*ii*) Light weight combined with adequate strength characteristics.
(*iii*) Easy fabrication into most intricate designs.
(*iv*) Uniform finish and colour adaptability.
(*v*) Much lower cost.

Most significant fields of application of plastics are as follows.

(*a*) **Aeronautical Engineering**. In the manufacture of control and navigational instruments, pipelines and fuselage. As reinforced fiberglass plastics, these have found use in aerospace engineering for space crafts.

(*b*) **Automotive Engineering.** Plastics are widely used for making windshield, instrument panels, tail–light lenses and other such accessories. Fiberglass has become a popular material for motor car bodies.

(*c*) **Electrical Engineering.** In electrical engineering insulation, power transmission and communication equipment. Also, in parts of generators, motors, switchboards, condensers, fluorescent light fixtures and cabinets of most of the electronic gadgets.

(*d*) **Industrial Engineering.** For making pipelines, tanks, towers, conveyors etc.

(*e*) **Civil Engineering.** For fabrication of doors and windows, knobs, handles and other ornamental structures.

11.8. PLASTICS IN CIVIL ENGINEERING

The inherent qualities of plastics such as their capacity to be moulded in any shape, design, colour and appearance coupled with resistance to corrosion and insulation against thermal and electrical shocks have made them popular materials in many parts of a building. The trend is on the increase. Only a few typical uses will be mentioned:

(*a*) **Flooring and wall tiles**. In many new modern construction tiles made up one or other type of plastics are used as a matter of choice because these:

(*i*) are resistant to many types of chemicals;
(*ii*) are easy to clean and maintain;
(*iii*) keep the original beautiful appearance till end, and
(*iv*) are light in weight and easily replaceable.

(*b*) **Water storage and conducting**. Plastics tanks, cisterns, tubing and connections are fast replacing cast iron, steel and concrete materials in the housings and dwellings because of their low weight, better adaptability and appealing looks as also due to their low cost.

(*c*) **Plastics sheeting and pannels**. Resin impregnated paper or glass or cloth or any other type of fiber marketed as laminated plastics find many applications in civil engineering as well. These mixed–plastics (composites) are lightweight and can be used for roofing purposes. Similarly, plastics mixed with craft paper form good cladding material.

Door and window handles, grips, rods and such accessory items earlier made from metals like aluminium, iron and copper etc. are easily available in plastics and find extensive applications as these require **no further surface treatment** for giving a desired finish. **Copal resins** form an important constituent of paints, varnishes and lacquers.

TYPICAL QUESTIONS

1. (*i*) What do you understand by the term Plastics?
   (*ii*) How they are classified? Give examples.
   (*iii*) Write a general note on properties and civil engineering uses of plastics.
2. Give a brief account of processes of manufacture of plastics commonly applied in industry.
3. Write short notes on :
   (*i*) Thermoplastics (*ii*) Thermosetting plastics
   (*iii*) Plasticizers (*iv*) Calendering
   (*v*) Injection moulding.
4. Tick the right answer.
   (*a*) Specific gravity of plastic is as compared to magnesium
   (*i*) Lower (*ii*) Higher
   (*iii*) Same
   (*b*) The tensile strength of Phenol formaldehyde lies in the range of
   (*i*) 300-700 kg/cm^2 (*ii*) 300-500 kg/cm^2
   (*iii*) 500-700 kg/cm^2 (*iv*) none of these
   (*c*) The electric resistance of epoxy is of the order of
   (*i*) 1010 ohm/cm (*ii*) 1012 ohm/cm
   (*iii*) 1014 ohm/cm (*iv*) 1016 ohm/cm

ANSWERS : (*a*)—(*i*); (*b*)—(*iii*); (*c*)—(*iv*).

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12

Miscellaneous Engineering Materials

12.1. INTRODUCTION

The subject of engineering materials is so vast that a mere introduction to it would require many books. In a text book type of discussion only the **most important** materials used in bulk can be taken for study in outline. Yet, it cannot mean that many other materials that are **not used in bulk** are less important and may be ignored easily. It is not so. In the civil engineering practice, for instance, bricks, stones, timber, cement, concrete, metals and plastics will not make complete houses and buildings. Host of other materials are also needed while raising the construction and then using it for a better life. The list of such materials, shall remain endless as the material-making industry has become highly innovative.

We are discussing below, in mere outline, some other materials used beneficially in engineering industry in one way or another.

12.1.1. Abrasives

An abrasive may be defined as a hard resistant material that can be used for smoothening, wearing away, grinding or polishing the surface of other materials. Some abrasives are had enough to **cut through** many other materials.

The essential characters of an abrasive are its **hardness** and brittleness. It must be very hard. Most important **natural** abrasive is diamond. It is the hardest substance known.

12.1.2. Types

There are **two classes** of abrasives: natural and synthetic. The **natural** abrasives occur as minerals or rocks in the crust of the earth. Diamond, garnet, corundum and quartz are some examples of natural abrasives. The **artificial** or **synthetic** abrasive group includes a number of materials possessing very high hardness, Carborundum, aluminium oxide and glass fall in this group.

12.1.3. Forms

Abrasives are used both in **block** form and **powdered** form. The **abrasive blocks** are pieces cut in suitable shapes from the abrasive material. These are used as grindstones, whetstones, millstones and cutting edges and teeth.

For use in **powdered form**, the material is crushed and ground to different grades and sizes. This powder is used as such and also after bonding it on cloth or paper, for example, emery paper, emery cloth etc.

12.1.4. Applications

Abrasives are used in numerous engineering fields. These are **necessary for polishing, grinding and finishing surfaces of metals, leather, wood and stone.** Some of them form an **integral part** of cutting, boring and drilling tools, e.g. diamond and carborundum.

12.1.5. Important Abrasives

Most of the abrasives used in industry in good volume belong to synthetic group, diamond being an exception.

1. **Diamond.** It is a **natural abrasive** and purest form of carbon (C). It has the greatest hardness (H=10). In the gem variety, diamond is perfectly colourless. Coloured and **imperfect crystals and grains are used as industrial abrasives.** Being the hardest substance, it has a very long life as an abrasive compared to any other materials. It gets destroyed only by impacts.

Diamond abrasives are used as core drilling stones, in rock and metal cutters, wire-drawing dies and gear grindstones.

India has some reserves of diamond in Madhya Pradesh- in the Panna Diamond mines. African countries dominate in the world production. Belgian Congo, South Africa, Congo, Angola, Sierra Lone, Brazil and Venezuela are few diamond producing states.

2. **Carborundum (carbosil, carbolon).** It is an artificial (synthetic) abrasive. Its hardness is next only to diamond. In composition it is silicon carbide and is manufactured by fusing a mixture of high purity sand, coke and saw dust. It was first manufactured in 1888 in an attempt to produce artificial diamonds. At present it is manufactured by using a very high current through an electric are at 2482 ^{0}C (4500 ^{0}F). **Silicon carbide** is formed at the centre of the mixture.

Common applications of carborundum include in the making of grinding wheels, abrasive papers, abrasive cloths and tool sharpening blocks.

3. **Boron carbide.** It is manufactured by heating together **boric oxide and coke at 2600^{0}C**. It is almost of same hardness as carborundum and is used chiefly as a **powdered abrasive.**

4. **Corundum (H=9) $A1_2O_3$ Natural.** This mineral occurs in nature in many varieties. Its perfect, flaw-less **crystals are gems of high value**. Examples: **ruby, sapphire**. The imperfect varieties are used as abrasives. Corundum is **also** manufactured **synthetically.**

For use as an abrasive corundum is required to possess

(*i*) bright lustre

(*ii*) uneven fracture

(*iii*) freedom from inclusions, and

(*iv*) purity in composition.

Varieties. Following varieties are available :

(*i*) **Synthetic Corundum**. It is manufactured by fusing bauxite ($A1_2O_3$ nH_20) in an electric are furnace. Bauxite used for making synthetic corundum should be free form iron and silica. **Alundum** is trade name of synthetic corundum.

(*ii*) **Emery**. It is natural abrasive consisting chiefly of grains of corundum and another mineral , **magnetite**. It finds wide applications in giving finish to cutlery products. It is also used in **glass ware** industry.

(*iii*) **Industrial Sapphire**. It is in fact another name for a rather pure type of corundum. In nature, it is of transparent crystalline structure. The mineral is also produced artificially.

Corundum deposits of various grades are found in many Indian States. Important deposits are in Sonaphar (Assam) and Pipra (M.P.)

5. **Quartz (H=7). Natural**. It is one of the **most common** natural minerals. When pure, it is silicon dioxide (SiO_2). Quartz is also the most commonly applied abrasive in many fields. It may be used as pure quartz in blocks and also as quartz sands, sandstone, quartzite, flint, chert and pumice, all of which are various forms of silica in nature.

India has vast reserves of industrial grade quartz - occurring in almost all parts of the country.

6. Garnet (H=6-7) Natural. Garnet is a **group name** for minerals which are silicates of magnesium, calcium, aluminium and chromium. Of this group, varieties named as **Almandine** and **Grossularite** are commonly used as abrasives.

Powdered garnet is used for making coated papers, cloth and discs. Garnet coated paper and cloth are used extensively in wood, plastics, rubber, leather and metal industries.

India has got good reserves of abrasive grade garnet in Tamil Nadu, Rajasthan, Madhya Pradesh and Andhra Pradesh States.

12.2. ADHESIVES

12.2.1. Definition

Any substance that is capable of **joining materials by attachment of their surfaces can be grouped as an Adhesive.** The process of joining the materials using adhesives is called Adhesive Bonding, and is a class in itself, like welding, soldering and fastening.

12.2.2. Classification

Many natural and artificial products possess adhesive qualities. **Five groups** of adhesives recognized in industry are as follows :

(*i*) **Glues** from animal and vegetable sources;
(*ii*) **Thermoplastic** adhesives;
(*iii*) **Thermosetting** adhesives,
(*iv*) **Elastomer** adhesives
(*v*) **Ceramic** adhesives

Among the **glues**, the animal glues are extracted from the bones and hides of the animals by heating them in water tanks. The **Vegetable glues** are obtained from seeds, corns, stems and other parts of plants. Common examples of organic glues are: hide glue, bone glue, casein glue, zein glue and starch glue.

The resin adhesives form important groups of adhesives. They are indispensable for high –grade bonding. These may be natural or synthetic in nature. The list of natural resins include shellac, asphalt and rosin.

The synthetic resins include two main groups: thermosetting and thermoplastic.

The thermosetting resin adhesives form **heat-resistant** and **insoluble** compounds after their application. They form useful adhesives where high strength, stability at elevated temperature and resistance to moisture are the required qualities. Examples of this group include the Phenolic Adhesive. It is used extensively for the bonding of **plywood and other boards, metal and glass surface**. Other examples are: Urea-formaldehyde, melamine formaldehyde and phenol-resorcinol.

The Thermoplastic resin adhesives are **general purpose** adhesive used for common type of bonding stable at ordinary temperatures **only** and in dry conditions. Moisture and heat will break the bond developed by these types of adhesives. Polyvinyl alcohol is the best example from this category; **cellulose nitrate, cellulose acetate, poly vinyl acetate** and **polystyrene** are other examples.

The Elastomer adhesives are derived from rubber. They have many useful properties and find extensive applications in wood, glass and leather industries. Sometimes they are referred as **rubber cements**. Among the important qualities of these adhesives is their capacity to **bind together materials having different thermal expansion**. These adhesives are **not good** for joining metals.

12.2.3. Uses

Adhesives find very widespread applications in industry ranging from **aircraft to match box** making industries. It is agreed that in each aircraft, automobile, house and articles of common use one or another adhesive **has been** definitely used. The following listing of applications of adhesives is only **indicative** rather than exhaustive:

1. **Aircraft** and rocket construction: for wing flaps, floor panels, bonding skin to fuselage etc.
2. **Paper and packaging** industries: corrugated cardboard making;
3. **Plywood** and fiberboard industries;
4. **Laminated paper**, wood and board;
5. **Bookbinding**, envelopes, stamps;
6. **Sand paper**, emery paper and abrasive cloth making;
7. **Tobacco** industry – in cigarettes.
8. **As the mastic in floor and wall tiles**, linoleum and other furnishings;
9. **Shoe** industry;
10. In automobile industry.

12.2.4. Advantages

The adhesives offer following advantages over other joining methods and processes :

1. **By and large**, they offer a bond allowing **uniform** stress distribution over a large area. This is different than in rivets and bolts which cause stress concentration at the place of application.
2. Materials of **different nature** and composition may be bonded together: rubber to glass, metal to wood, metal to glass and so on.
3. **Size and shape** are no limitation for bonding. Blocks, grains and powder, all can be **bonded together** or on any other material. These are the best materials for achieving bonds of thin sheets.
4. The adhesive joints provide **good resistance to fatigue** and moisture transfer.
5. Many adhesives can provide **electrical insulation.**

12.2.5. Disadvantages

Despite a number of advantages, there are certain disadvantages also in the application of adhesives.

1. A long time is **often** required before the bond is obtained after application. All adhesives require **some time** to cure and become hard; hardness development is not **instantaneous.**
2. Curing may require, in many cases, **heat or pressure** or both. Hence, the process will involve additional labour, equipment, coat and time.
3. In almost all cases, the surfaces to be bonded together require **thorough preparation** (very smooth finish). In some cases it may prove quite ardous.
4. Most common adhesives have service temperature limitations; they are stable only up to certain temperatures.

12.3. ASBESTOS

12.3.1. General

This name implies a group of **naturally occurring minerals** which have a conspicuous **fibrous** structure. Some forms of asbestos possess quite useful engineering properties such as :

(*i*) The **flexibility** and **strength** of the individual fibers is such that these can be spun into yarn, woven into cloth or felted into sheets.

(*ii*) The **high resistance** to **electricity** and **sound** that can be used for insulation against them:

(*iii*) **Low conductivity of heat**: so that asbestos can be used for heat insulation as well.

12.3.2. Types

There are **two** types of asbestos recognized on the basis of mineral composition :

1. **Serpentine Asbestos.** It is also termed Chrysotile asbestos. In composition it is a hydrated magnesium silicate: 3 MgO. $SiO_2.H_2O$.
2. **Amphibole Asbestos.** They are complex silicates of calcium, magnesium and iron. In nature, asbestos occurs in fissures or bands passing through other rocks. It is termed **cross-fibre** when occurring transverse to the veins and **slip fibre** when occurring parallel. The first type is considered better.

12.3.3. Use

Asbestos has found applications as an **insulating material** in a wide variety of situations. It has been used as raw asbestos or in mixed forms:

(*a*) **Heat Insulation:** Asbestos paper and asbestos mill board are manufactured by compounding **asbestos** (80% or more) with **china clay** (20%) with the help of a suitable binder such as sodium silicate. Pure asbestos heat insulators are made by binding together rough fibers. This is used for heat insulation of boilers and bulkhead lining in tanks whereas millboard is used in the manufacture of gaskets and washers.

(*b*) **Sound Insulation.** Small length fibers have been used for sound insulation by converting them into lightweight boards and blocks.

(*c*) **Electrical Insulation**. Asbestos paper is used as a cover for electric wires in electric motors and coils. For electrical insulation, asbestos of long-fibred variety and that which does not contain any iron in it is **only** used.

12.3.4. Asbestos-cement–Products

Short-fibred asbestos has been used for mixing with cement and making tiles, sheets and pipes of very useful properties. These asbestos –cement products are;

(*i*) light in weight

(*ii*) resistant to corrosion

Such asbestos-cement products are specially recommended in buildings for roofs, walls and drainage systems.

ASBESTOS FABRIC. "Asbestos Fabric" is woven from such varieties of asbestos that have long fibers of high strength and flexibility. From such asbestos fabric tapes, ropes, cloth, lining, gaskets and other shapes can be easily cut or made for specific uses. Asbestos fabrics find use in making fire proof dresses, conveyor belts and boiler insulation etc.

Besides the above main uses, asbestos has applications as

(*i*) a **filler** material,

(*ii*) a **matrix** material in thermosetting plastics,

(*iii*) a **component** of high-temperature resistant drilling fluid.

12.3.5. Indian Deposits

Workable deposits of good quality asbestos occur in Cuddapah and Kurmool districts of Andhra Pradesh. These are of **chrysotile type.**

The **amphibole** type asbestos have been found in many states such as: Madhya Pradesh, Tamil Nadu, Maharastara, Rajasthan, Orissa and Uttar Pradesh.

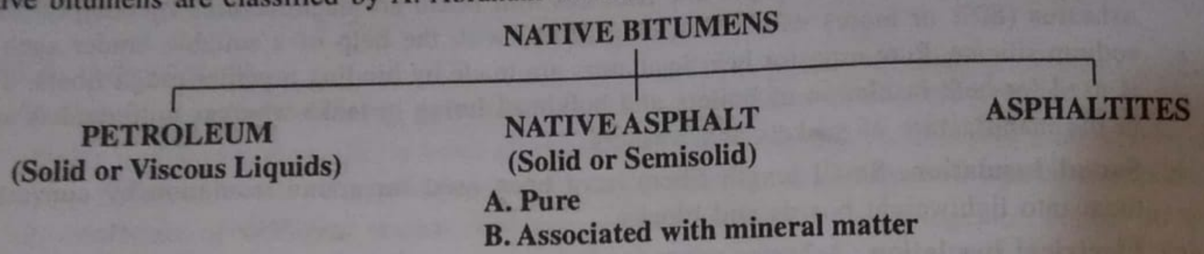
12.4. ASPHALTS AND BITUMENS

12.4.1. General

Asphalt and bitumen form an **inter-related group** of materials that have wide applications in construction engineering. The term asphalt is used somewhat differently in different countries. Thus, in USA, by Asphalt is understood a **solid or semisolid product in which the dominating constituents are the bitumens.** This definition covers both the natural **asphalt rock** and the by-product of similar composition obtained during refining of crude petroleum.

In Europe and elsewhere, however, the term **asphalt is generally restricted to a naturally occurring rock which contains bitumens in good abundance.** It is not used for artificial mixtures or products.

The term **bitumen**, however, is universally regarded as a **complex mixture of hydrocarbons.** The native bitumens are classified by A. Abraham as follows:



12.4.2. Types

1. Native asphalt. Pure asphalt occurs in nature in the form of solid or semi-solid deposits in certain parts of the world. The best known are the Lake Asphalt deposits of Venezuela. Sometime the asphalt rock may contain other mineral impurities.

2. Asphalt rock. It is a type of limestone converted-to-asphalt rock. This has happened at places where natural bitumens have entered the crevices of limestone rock and changed it to an **asphaltic composition**. The asphalt rock is used at places of occurrence for road paving and road making.

3. Asphaltites. These are actually asphalt like in composition and have low softening points (1000°C). Some asphaltites are used considerably in electrical storage batteries, thermo-plastic moulded goods, mastic flooring and pipeline coatings.

Countries producing natural asphalt and asphalt rock are: Trinidad, Albama, France, Germany, Italy, United States of America, Iraq and Syria.

4. Cutback asphalt. This term is used for an asphalt/bitumen with suitable volatile solvent. The liquid type of asphalt is used in repair works in roofs and floors.

5. Asphaltic emulsions. These are made by mixing asphaltic/bituminous material with 50-60 percent water and a very little quantity (about 1%) of an emulsifying agent. Such emulsions have been found useful in water proofing (damp proofing) layers.

12.4.3. Uses

Asphalts are used generally in combination with other materials in many engineering fields. Some examples are given below :

1. Electrical uses. High grade asphalts are used in electrical industry on mixing with wood tar, pitch, rubber and resin. The **battery containers** are best example.

2. Roadway construction. Asphaltic bitumens are characterized with a set of useful properties such as: resistance to weather, water proofness, binding capacity and ability to provide a flexible surface. For these qualities, they are **used extensively in highway construction** both in the road **foundations** and as **surface materials.**

Three types of asphaltic mixture used in roads are :

(*i*) **Rolled Asphalts**
(*ii*) **Mastic Asphalt**
(*iii*) **Compressed Rock Asphalt**

The rolled asphalt is used for paving only. The mastic asphalt is rich in bitumens. It is used mixed with aggregates when it forms a water proof and plastic material which can be given desired shape while hot.

3. **Asphaltic paints.** Bituminous asphalts are used as essential ingredients in certain paints. Such paints are specially useful for damp walls and over concreter structures.

4. **Asphalt concrete.** Some asphalt is refined to specifications that give it **excellent binding properties**. It is called asphalt cement and when mixed with fine and coarse aggregates, it gives asphalt concrete. It is in this form that the asphalt is generally used in highway and airport paving, where it gives the pavement desired flexibility and strength at the same time.

12.5. COMPOSITE MATERIALS

12.5.1. Introduction

It is a **group of materials** made up by combining together materials of different characteristics in such a way that the new material has the best qualities of the **materials combined together**. Numerous such composite materials specifically manufactured for different engineering applications are already available in the market. The list is being enlarged every year by vigorous research and development in this direction. Among some commonly known composite materials may be mentioned fibre glass, metal fibre composites, graphite composites, rubberized coating and so on.

12.5.2. Composition

The composites consist of **one of the material** as a basic or matrix substance and the other as fibres, filaments, whiskers or even as fabric. Thus, in fibre glass, the matrix consists of a **plastic polyester** in which are contained brittle but very hard thin fibres of **glass**. The resulting material is both **hard** and **strong** and plastic in character. Among the materials commonly used as fibres or whiskers following may be mentioned only as typical examples.

(*i*) **Glasses.** These are extensively used in manufacture of composites suitable for heat, sound and electrical insulation. The matrix may consist of fabric, polyesters and rubber.

(*ii*) **Metals.** Fibres and whiskers made from many metals have been used with great advantage for producing highly useful composite materials. Metals like copper, steel, graphite and tungsten and compounds like silicon carbide are best examples. They impart increase in strength per unit weight of the base metal. Coraphite fibres impart excellent wear resistance.

(*iii*) **Organic fibres.** Aromatic polyamides are used for making fibres which impart excellent properties to the composites such as fatigue resistance, impact resistance and thermal stability.

12.5.3. Applications

Different composite materials find applications in aircraft industry, pressure vessels, electrical industry, chemical industry and in components of building construction as replacement of timber, steel and other metals.

12.6. GLASS

12.6.1. Definition

The term **glass** signifies an **amorphous solid substance that has been formed by supercooling a liquid solution containing chiefly silica and some other selected components**. In general usage, glasses are defined simply as super cooled liquids.

12.6.2. Manufacture

The basic raw material for the manufacture of good quality glass is SILICA, which in nature occurs as **quartz (SiO_2)**. This material melts at 1700°C and is cooled rapidly without allowing it to undergo recrystallization. Quartz and other desired components (to give different types of glass) are heated in special **glass melting furnaces**. The molten glass comes out, rather flows, from these furnaces continuously. Various glass shapes are obtained from this molten glass by any one of the following process:

1. **Pressing.** Moulds of the required shapes are filled with the molten glass. It is then cooled while under desired pressure. Sheets of glass are made by this method.
2. **Blowing.** Air is blown in a controlled manner through the molten glass in proper containers. This air pressure drags the glass-liquid to a desired shape.
3. **Drawing.** In this process, stream of molten glass is made to pass through moving rolls. It comes out from the other side in the desired drawn form on cooling.

12.6.3. Properties

1. Glass has **quite high tensile strength**. In very fine wires drawn from melts glass may show tensile strength as high 7.0×10^5 kg/cm^2. The ordinary glass threads possess tensile strength of 700 to 1400 Kg/cm^2. The modulus of elasticity of glass is also very high. Both these properties, however, show great variations depending upon the composition of the glass and method of manufacture
2. Glasses have **low ductility, low conductivity and low coefficient of thermal expansion.**
3. Glasses are **resistant to acids** and many other chemicals. Hence they are ideal materials for storage of chemicals.
4. Glasses are **very good electrical insulators**.
5. They have **very high** softening point and can be used at high temperature.

12.6.4. Types of Glass

Many varieties of glass are made by adding special compounds in the silicon dioxide at the time of fusion. Following are some commonly used types of commercial glass.

1. **Silica glass.** It is pure silica SiO_2, **without any additives**. Its use is restricted to high-temperature applications. It has a high softening temperature.
2. **Soda lime glass.** This is the most common type of glass-used extensively for domestic purpose: window panes, plate glass, light bulbs and containers. A typical composition of soda lime glass is as follows :

   SiO_2: 71-74 per cent; Na_2O: 13-17 per cent; CaO :05-14 per cent;
3. **Leaded glass.** This glass has a high refractive index. This property is induced into the glass by adding **lead oxide** with silica during the manufacturing stage. A usual composition of leaded glass is:

   SiO_2 : 67-73 per cent PbO : 15-30 per cent
   K_2O : 4-7 per cent Na_2O : 9-12 per cent

   The leaded glass has special applications such as

   (*i*) in making shields for protection **against gamma radiation**;
   (*ii*) in the manufacture of **optical instruments**;
   (*iii*) for making **neon signs**.
4. **Borosilicate glass (pyrex).** It is a special type of glass made by adding **Boron oxide** as the chief additive with silica at the time of manufacture. This addition of born on oxide gives the

special property of increasing its melting point and resistance against thermal shock. The glass can be heated and cooled again and again without any risk of damage. This is because its **coefficient of expansion** gets reduced considerably by the addition of boron oxide. Alumina and sodium oxide are other additives in this glass.

Borosilicate glass is used extensively in high-temperature conditions, such as,

(*i*) making of laboratory wares for experiments;

(*ii*) Cooking utensils.

It is also used for telescopes and glass piping.

PYREX is a trade name for a borosilicate glass. A typical composition of Pyrex is: SiO_2-81%, Al_2O_3 = 2%, Na_2O-4%; B_2O_3-12%

12.6.5. Industrial Forms of Glass

Glass is used in industry in a variety of forms. Some common forms are as follows :

1. Pressed glass. This is prepared by moulding the fused glass (of any composition) into sheets and other shapes under pressure. These sheets are the starting material, for making glassware and structural blocks.

2. Glass building blocks. These are manufactured from pressed glass by fusing two or more sheets in such a way that a partial vacuum is caused in the interior of the blocks. These blocks are subsequently annealed to induce in them **structural qualities**. These blocks are used in **masonry construction** for permitting transmission of light without being transparent and without bearing any loads.

3. Glass fibres. It has been found that very thin fibers of glass possess very high tensile strength. **The thinner the fiber, the higher the strength**. This property has resulted in a separate industry of considerable importance: the glass fiber industry. Fibers of glass are made in a special manner: The molten glass is forced out through numerous minute openings in the form of thin streams. Upon these streams is **impinged** a blast of air or steam under a precalculated pressure. **The streams solidify into thin fibers.**

Glass fibers have become an important reinforcement material for plastics resins and even concrete. The glass-reinforced plastic is commonly known as FIBRE GLASS and has acquired a place of its own as a composite engineering material. It is used in manufacture of shock proof headgears (helmets), car bodies, boats and a variety of other components.

4. Laminated glass. These are made by bounding together two or more plates of glass. Sometimes, layers of a third material like asphalt, rubber or resin are also made a part of the laminated glass. The laminated glass is characterized with:

(*a*) **Shattering-resistance** *i.e.* its pieces do not fly away in all directions on its getting suddenly broken under impact. This makes laminated glass an ideal material for use as a safety glass in automobiles and aircraft.

(*b*) **Shock resistance** *i.e.* it can bear safely sudden impacts up to desired value. This property also plays a great role in laminated glass being used as a safety glass.

BULLET RESISTANT GLASS. This is specially useful in vehicles and other automobiles used for security reasons. It is in fact a variety of laminated glass which is made by pressing together several layers of glass and vinyl resins in alternating manner. Thickness of such glass ordinarily varies from about 12 mm to 75 mm or more.

12.6.6. Uses of Glass

Glass has a very wide field of industrial applications. Thus:

(*i*) **For an Architect** - glass is an indispensable architectural material. In all the modern buildings including the **high-rise buildings**, glass curtain walls make the skyline.

(*ii*) **For a civil engineer** - it is one of the most important materials for construction which cannot be avoided.

(*iii*) **For an electrical engineer**, glass is a useful insulating material in many situations, and is also an essential material for making tubes and valves.

(*iv*) **For a mechanical engineer**, glass alone or in a composite material is an integral part in automobiles and other locomotives including railway wagons.

(*v*) **To a chemical engineer**, it is packaging material without any easy alternative.

Glass finds applications from the kitchen of a poor man to most advanced scientific devices and in palatial buildings and cabinet rooms. It can be made in varieties possessing a combination of mechanical, electrical, optical and chemical resistant properties that make them ideal industrial materials for very diverse applications.

12.7. INDUSTRIAL FUELS

12.7.1. General

A fuel may be defined as any material that on combustion yields heat energy. The fuel may be solid, liquid or a gas. In general, the **release of heat energy** is due to oxidation at a sufficiently rapid rate. In radioactive materials, it is due to atomic disintegration.

Fuels form single most important group of materials in engineering industry. It is inconceivable to fabricate, manufacture, develop or produce any other engineering material without using fuel of one type or another.

All fuels may be classed into **three** main groups; solid fuels, liquid fuels and gaseous fuels. Many of them are of natural occurrence; others are manufactured. Table 10.1 shows their broad classification.

TABLE 12.1. Classification of Fuels.

Origin	*Solid*	*Liquid*	*Gaseous*
Natural	(*a*) WOOD (*b*) COALS (*i*) Peat (*ii*) Lignite (*iii*) Bituminous coal (*iv*) Anthracite (*c*) ATOMIC FUELS	(*a*) CRUDE OIL (*b*) NATURAL GASOLINE	Natural Gas
Manufactured	COKE	TAR PETROLEUM DISTILLATES Gasoline Diesel Kerosene	PRODUCERS GAS WATER GAS COKE OVEN GAS LPG

A. COAL

12.7.2. Definition

Coal is principally a highly carbonaceous matter. In all cases coal has been formed in nature as a result of alteration of wood (plants) under favourable conditions of temperature, pressure and chemical decomposition and dissociatioin. It is composed chiefly of carbon, hydrogen, nitrogen and oxygen, **carbon being the single most important constituent**. Moisture, volatile matter and mineral matter are the other important constituents of coal.

12.7.3. Types

Various types of coal are recognized commonly on the basis of **degree of alteration** (called coalification) from the parent material. These are: **peat, lignite, bituminous coal** and **anthracite.**

In the chemical analysis of these varieties, percentage of following four components is given great importance:

1. Moisture
2. Volatile Matter
3. Fixed carbon
4. Ash

Following is only a brief account of chief types of coal.

1. Peat. It is the **least converted variety** of coal. Often vegetable structure is visible to the naked eye. It represents the first stage of conversion of wood to coal.

Peat is highly rich in moisture containing 80-90 per cent of water. It has to be air dried after which it forms a good source of energy. In India peat deposits occur in Niligiri hills of south India.

2. Lignite (brown coal). It is the **coal of lowest rank**. Lignite has as **brown** appearance. The decomposition of woody tissue in lignite is of a higher order than peat. Vegetable matter is **not visible** any more. The coal is compact and woody in texture.

In general, lignite has carbon **below** 70 per cent, oxygen **above** 20 per cent and moisture between 20-45 per cent. Lignites have low heating power that may range between 6,000-11,000 B.Th.U (British Thermal Units). Its most important use is in the manufacture of produces gas.

In India, Lignite deposits occur in Assam, Kashmir, Rajasthan and Tamil Nadu.

3. Bituminous coal (common coal). Under this group are included a **group of coals that are pitch black to** dark grey in colour. They are all laminated (layered) in structure and show a very high degree of coalification. The bituminous coals are often classified into following three types on the basis of **their carbon content**; sub-bituminous, bituminous and semi-bituminous.

The **sub-bituminous coals** are richest in moisture content and volatile matter. They show no caking power.

The bituminous coals show a typically **banded appearance**. Their carbon content ranges between **70-90 per cent**. The volatile matter also ranges between 20-30 per cent. Their calorific value is quite high: 11000-15000 B.Th.U. These are used for **producing steam** and for manufacture of **coke.**

The semi-bituminous coals are of still higher order and may contain carbon between 90-93 per cent. They are quite poor in volatile matter. Such coals are also used for steam raising and for coke manufacture.

In India, most of the coals extracted from the coal fields of Bihar, Bengal and Madhya Pradesh are of Bituminous group. They are also referred as Gondwana Coals.

4. Anthracite. It is the coal of the highest rank in which all the vegetable matter has been completely converted to coal. Anthracites are richest in fixed carbon containing up to 98 per cent, the range being 92-98%. They contain very little volatile matter and also only a small percentage of moisture. Anthracite, therefore, **burns without smoke**. They do not have any caking power. Their most common use is in **steam raising**.

India has good reserves of anthracite in Jammu & Kashmir and Assam. They are also called **Tertiary coals**. Their reserves in the country are estimated at about 1000 million tonnes.

We have referred above **about caking power of coals**. This is described as a property of coals by virtue of which they become **soft and plastic on burning** and fuse to make a cake. These are termed as caking coals. Some of them are used for the manufacture of coke which is an **improved version of coals**. Many bituminous coals show caking power. Those coals which do not soften on burning and yield only a powdery residue are termed non-coking or **free burning coals**. Anthracites are examples of non-coking coals.

12.7.4. A Short Note on Coke

COKE may be defined as a product of destructive distillation of coal in an environment **practically free from air**. Coke is also produced in the destructive distillation of petroleum when it is known as petroleum coke. **Most of the volatile compounds of coal are expelled during this distillation.** What is left behind is a hard, porous mass composed mostly of carbon. This is coke. The process of converting coal into coke is termed **carbonization.** It is carried out at temperatures ranging from 590-1180^{0}C on bituminous and semi-bituminous coals.

Coke is used as **domestic fuel**. It is also a very commonly used metallurgical fuel. Coke is used in metallurgical operations both as a fuel and as a reducing agent. Coals suitable for coke manufacture should be free from sulphur and **should not have more than 17 per cent ash content.**

Although India possesses huge reserves of bituminous coals, they are not suited for manufacture of coke because :

(*i*) their ash content is high, as much as 30 per cent;

(*ii*) they are not amenable to washing.

Their non-washability is considered a drawback because washing can remove good amount of mineral matter.

B. PETROLEUM

12.7.5. Definition

Petroleum literally means rock oil but its scope has now been widened to include **naturally occurring hydrocarbons as obtained from below the earth as solids, liquids and gases**. The following discussion is, however, limited to liquid hydrocarbons.

12.7.6. Composition

Crude oil is chiefly a **complex mixture of a variety of hydrocarbons which occur in an isomeric (inter-related) combination**. The chief constituents are: paraffins, napthanes and aromatic hydrocarbons. Besides, small quantities of compounds of sulphur, nitrogen and oxygen are also always present in crude.

Origin. Many theories have been proposed to explain the origin of petroleum. The one generally accepted suggests that petroleum is formed from an essentially organic source. The transformation of micro-organism to oil takes place through a series of complex processes of the source material under very suitable bio-chemical environment, bacterial and chemical processes of decomposition. As regards the exact **organic source**, it is suggested that marine life of **low order** is the chief contributor.

12.7.7. Properties and Uses

Crude oil is a viscous liquid. It ranges in colour from light yellow through brownish, greenish shades to even a black appearance. It exhibits property of fluorescence. Its specific gravity varies from 0.76 to 0.98.

Crude oil as obtained from the earth is subjected to refining in big plants called **refineries.** The crude oil is first heated and then fed into distillation chambers., The products of distillation are

collected at different levels where they get concentrated in accordance with their volatility. Thus, when the **non-volatile** matter collects at the bottom in the distilleries, the **volatile** compound will be found in the **upper chambers**, the most volatile being collected at the top.

The most important fuel products obtained from crude oil are: gasoline, diesel, aviation fuel, kerosene and residual oil.

12.7.8. Indian Occurrences

India is an **oil importing country**. Even then during last three decades it has made great progress in increasing output from the existing oil fields and also in locating new oil fields. Presently, oil is produced in India from three major oil fields: Assam, Gujarat and Bombay. The Digboi oil field lies in the Brahamputra valley and first well was made in 1953. Another oil field in Brahamputra valley is Moran Oil field.

In Gujarat, oil has been tapped from two oil fields, namely the Cambay and Ankleshwar oil fields. The Bombay High Oil basins are off the Port located in the sea and are productive since 1978.

Other areas where oil potential is being explored are located in West Bengal, Ganges Valley, Himachal Pradesh, Orissa, Andhra Pradesh, Tamil Nadu, Karnataka and Jammu & Kashmir but not much success has yet been made in terms of actual oil production..

12.7.9. Natural Gas

This gas commonly occurs associated with petroleum. In composition, it is mainly **methane**. It contains small proportions of other heavier hydrocarbons such as ethane and propane, as also some nitrogen, hydrogen, sulphide, and rarer gases. It has to be first purified of sulphur and other hydrocarbons before supplying for use as fuel. India has huge reserves of natural gas.

12.7.10. Producer Gas

It is an **artificial fuel** that is manufactured by passing air and steam through a heated layer of coal or coke. **The process is carried out in special chambers to which coal is fed from the top whereas air and steam are charged from the bottom**. The gas is made to escape from one side of the chamber near the top. It is transported to the desired destination for use.

Chemically, producer gas contains nitrogen (55%), carbon monoxide (25%) hydrogen (15%) and carbon dioxide (5%) respectively.

12.7.11. Water Gas

It is also a **manufactured fuel** that is made by passing steam over a layer of coal or coke that is periodically heated up by blowing a blast of air through it. The chemical reaction is as follows :

$$C + H_2O \longrightarrow CO + H_2$$

Water gas is thus a mixture of carbon monoxide and hydrogen.

12.8. INSULATING MATERIALS

12.8.1. General

All those materials **that retard or stop the flow of heat or electricity or sound through them may be broadly defined as insulators or insulating materials**. The same material may not be insulator against all the three types of energy waves; it may be insulator against heat or electricity or sound or more than one of the two transmissions.

The importance of insulating materials cannot be overemphasized in engineering practice. Since heat and electricity are the main sources of energy in many important operations, a safe handling of these sources may be impossible without insulators. The insulators may be studied under three general headings: thermal insulators, electrical insulators and sound insulators,

12.8.2. Thermal Insulators

The main function of a **thermal insulator** is to act as a partial or total **barrier** in the passage of heat. A thermal insulator, therefore, should possess following properties :

(*a*) It should have **very low** thermal conductivity;

(*b*) It should have a **very high** softening point.

(*c*) It should be **stable** to thermal shocks, *i.e.* should not break on repeated heating and cooling.

(*d*) It should be **stable chemically** and physically at high temperatures for prolonged periods at a stretch.

(*e*) It should be resistant to moisture and vibrations and have good strength too.

The situations where a thermal insulator may be required are varied. A few may arise where :

(*i*) the **flow of heat** has to be stopped from a working place to the outside environment, such as a furnace to outside;

(*ii*) the flow of heat has to be stopped **from an outside** source to a place, for instance in special rooms where equipment is to be worked at low temperatures or comfort has to be insured in a hot climate for inside living.

Types of Heat Insulators

Following are some common heat insulating materials used in engineering industries :

1. **Magnesia plastic**. This consists of thoroughly blended mixture of hydrated magnesium carbonate (85%) and asbestos (15%). It is applied as a plastic mass cover over the surface from which escape of heat is to be controlled e.g. in steam raising plants. It is also called **magnesia-asbestos cement.**

2. **Alfoils.** These are essentially thin sheets made from **aluminium and its alloys.** When wrapped over steam pipes and other such appliances, it serves as a good insulating material.

3. **Asbestos**. It is one of the best heat insulating materials for big and small applications alike. Insulating sheets made from asbestos mixing some clay in the presence of a suitable **binder** are used for insulating boilers and also for bulk head lining in ships. **Asbestos is also good sound insulator.**

4. **Cork**. It is lightweight external tissue or bark of the oak tree. It has been found to be a good **heat insulator** and is used much for the same purpose. Sheets, boards and other shapes are prepared from cork by heating it under pressure. These sheets are **used as a lining** in steam pipes and also in refrigeration and other cold storage insulation.

5. **Cellular rubber**. It is a special variety of rubber made **extra porous** during manufacture. This rubber is used as an insulator in **cold storage** and refrigeration lining.

6. **Mineral wool**. It is also called Rock Wool. This material is obtained commercially from impure limestones. The rock is first heated to melting temperatures. Jet of **air or water** is made to fall on streams of this molten rock which solidifies into wool like structure. **Clay and dolomite are also used for making mineral wool.**

Mineral wools sell under different trader names like "cordonite" and "rocksill". Besides being good heat insulator, the wool is also a good electrical insulator.

7. **Vermiculites**. These are group of mica-like **foliated minerals**. Some varieties of vermiculites are processed for manufacture of heat insulators that are specially useful for furnace insulations.

12.8.3. Electrical Insulators

Following are the requisite qualities for an electrical insulator :

(*a*) A very poor electrical conductivity *i.e.* a very high electrical resistively.

(*b*) Resistance to deterioration on heating;

(*c*) Very low thermal expansion;

(*d*) Non-inflammable;

(*e*) Chemical stability at high temperatures.

(*f*) High Strength, hardness and resistance to abrasion.

Following are some commonly used insulating materials in electrical industry.

1. Mica. The name indicates a **group of natural minerals** having a sheet like structure by virtue of which they can be separated into thin **elastic sheets.** Of this group, two members named **Muscovite** (white mica) and **Phlogopite** are used extensively as electrical insulators. These minerals have very low thermal conductivity, high electrical strength, great toughness, flexibility and resilience-a unique combination for an **ideal insulator**. Muscovite can be used for electrical insulation up to 550° C whereas the best grade phlogopites have a range up to 1000° C. Mica in different forms is used in a variety of electrical devices such as resistance of electrical heating appliances, in rheostat brush holders, commutations of dynamos and motors, in fuse boxes, air craft spark plugs, radio, radar and television and so on.

2. Asbestos. Highest grade of asbestos which occurs in long fibers and is practically free from iron oxides is a commonly used insulators in many electrical appliances. It is used as a covering for electrical wires, in traction type electric motors and coils. (It has been already described briefly).

3. Rubber. It is one of the very **commonly used** electrical insulators. It has following special properties:

(*i*) **very low** electrical conductivity;

(*ii*) high resistance to moisture and abrasion;

(*iii*) high flexibility (elasticity);

(*iv*) high resilience.

4. Paper. Paper is also classed among very useful insulators for common use. Insulation paper is specially made without addition of fillers. When impregnated with oil, its properties as an insulator get further improved. Such oil-impregnated paper becomes much **resistant to moisture**.

5. Synthetic resins. These artificial materials have occupied a place of **great importance** in the field of electrical insulation. They are available both in solid and liquid form. Among the solids, products of **cellulose esters** and **phenolic vinyles** etc. are important. **Bakelite** is an outstanding example of this group. The liquid resins are used along with oils and varnishes where on solidifying they yield an infusible mass with electrical insulating properties. Alkyl resins, polyvinyl elements and phenolic varnishes are examples from this group.

6. Porcelain. It is a **burnt mixture of clay**, feldspar and quartz. It forms an important group of insulating materials which are characterized with:

(*i*) high stability

(*ii*) sufficient hardness

(*iii*) imperviousness to moisture

These properties make ceramic materials most **suitable for high-voltage insulation**, switch boxes, condensers and other heating elements.

7. Glass. It is also an insulating material having many applications. Among the main qualities of glass may be mentioned: chemical inertness, stability at high temperatures, resistance to moisture and sufficient hardness.

8. Cotton. In the form of cloth, cotton finds extensive use as an insulating cover. Its properties are also improved by impregnating it with oils and coating with varnishes.

12.8.4. Sound (Accoustic) Insulators

High noise is fast becoming an **acute problem** in many cities and towns. Insulation against noise is as important an engineering problem as against heat. In fact in cosmopolitan cities **"noise pollution"** is one of the biggest challenges for the citizens. Hence, with the passage of time and with industrial progress, **acoustic insulation** has to be given due consideration. The importance of sound insulating materials has acquired good impetus in insulating industry. Following materials are used at present as acoustic insulators:

1. **Cellular concrete.** It is a variety of concrete in which **voids are created** during manufacturing stages. Generally it is made by adding powdered aluminium and water to a cement used for making concrete.

2. **Acoustic plaster.** This is made by mixing together magnesium oxychloride granulated slag and some gelatin. The plaster is applied directly to walls where it forms porous covering which serves as a barrier against transmission of sound waves.

3. **Acoustic boards.** These are made by bonding together fibrous materials like wood and vegetable fibers in a matrix of plaster. They are light in weight and can be cut and joined on the ceiling and in the partition walls.

Acoustic boards are also made by using **Vermiculite** and **Perlite**. The former is a naturally occurring flaky mineral and when mixed with gypsum makes a board of **good heating and sound insulating properties**. Perlites are made by burning clays which become **light in weight, porous in character** and **insulating in nature**.

12.9. LUBRICANTS

12.9.1. Definition

A **lubricant** is a substance which is **applied between solid surfaces** moving with respect to each other with a view of

(*i*) **Overcoming** any type of friction arising due to motion.

(*ii*) **Facilitating** smooth motion of the parts.

(*iii*) **Protecting** them from mutual wear.

A lubricant may be a **liquid** or a **solid.**

10.9.2. Functions

It is known that a lot of **heat and friction** is likely to be generated between any two solid parts of a device **during motion** in contact with each other. This friction can create three main problems:

(*a*) It will increase the wear of the parts and thus decrease the life of the machine.

(*b*) It will increase the power required to move the parts with passage of time. The power may be manual, animal or electrical. Such increased requirements would involve extra costs.

(*c*) The efficiency of machine **gets reduced considerably** even after additional power inputs.

All these factors may cooperate making the **running costs** and maintenance of the machine a difficult affair.

When a lubricant is used, its main function is **to reduce this friction between the two parts that move in contact with each other to as lower limit as possible.** Actually, a lubricant virtually acts as a separating medium between the surfaces in motion. In fact, it acts as a **third substance** in between the two parts and may itself get consumed while protecting the two parts from wearing out.

12.9.3. Properties of a Lubricant

A lubricant should possess most of the following properties to serve the purpose :

1. **Viscosity.** It must have **proper viscosity** to match its required applications. Lubricants for a sewing machine, for example, require low viscosity, whereas those to be used in automobiles may need highly viscous substances. The speed of the machine and the load under which it is to run are

two factors that define the proper viscosity of the lubricant. The lubricity of lube oil is its capacity to form a uniform lubricating surface.

2. Flash point and fire point. These refer to temperatures at which a liquid forms vapors that catch fire. If the flame formed is **not continuous,** (*i.e.* vapor formation is not continuous) the temperature is termed **flash point.** But if the vapor-formation is continuous so that it burns with a **continuous flame,** the temperature is termed **fire point. Principally these points define a resistance to oxidation.** Since the lubricants have to be used in situation where some heat is inevitable during motion of the parts, it is essential that **these should have high flash points and fire points** to avoid the risk of their burning during use.

Pour point is a related property and of **great importance in** low temperature applications of lubrications. It signifies the **low temperature** at which a liquid lubricant will stop flowing *i.e.* it will freeze. Obviously, if pour point is high, the liquid lubricant between the parts will freeze and not act as a lubricant.

3. Carbon residue. The lubricant on consumption between the parts should not leave any carbon residue.

4. Cost. A lubricant is a consumable material. Hence **it must be low in cost.**

12.9.4. Types of Lubricants

A. *Liquid Lubricants*

1. Mineral oils. These are derived from petroleum. They are characterized with high stability of their viscosity over wide range of temperatures. They are available at economical costs.

2. Greases. These are mineral oil products derived from petroleum which have been thickened by the addition of fatty acid soaps. A soap, as we know, is produced by a chemical combination of a metal hydroxide with a fatty acid or even a fat. **The soap serves a specific function in the grease**: it holds the oil ready for use at the surface for application. It does not allow the oil to drip away. The greases are described as **sodium, barium, calcium** and **lithium** greases depending upon which "hydroxide" has been used for the making of soap. Each of these greases has a **specific range of stability**. Thus, calcium greases are stable only up to 100^0 C. At higher temperatures most of greases become unstable.

3. Other oils. Oils derived from vegetables (e.g. olive oil, castor oil, palm oil) also may be used as lubricants. Their cost is, however, prohibitive in most cases. Similarly, oils derived from animal sources such as whale oil, lord oil and fat oils were used in the past as lubricants. Now they have been replaced by the mineral oils.

B. *Solid Lubricants*

A solid that has least **co-efficient of friction** and high durability at elevated temperatures may also prove a good lubricant in specific situations such as at very high temperatures and where oil cannot reach easily. Among such solid lubricants graphite, mica and soapstone have been used with good results.

Graphite (Also known as **plumbago** and **black lead**) is pure carbon in composition. It occurs as a natural mineral. It has a specific gravity of 2.1 - 2.3, and hardness of 1 in Mohs' scale of hardness. It has an **excellent quality of adhering to metal surface in very thin films and flakes**. It can fill all the spaces and pores available in between the contact surfaces. As such the friction between the parts is considerably reduced. Graphite is used both as a **"dry" lubricant** and in a **mixed state** with the greases.

12.10. REFRACTORIES

12.10.1. Definition

A **Refractory** material may be defined **"as a non-metallic material suitable for the construction of lining of furnaces operated at high temperatures."**

Such a material must be chemically and physically stable at high temperature. This is considered as the single **most important requirement**.

12.10.2. Properties

A refractory material is required to meet the following situations while in use :

(*i*) **It has to withstand** high pressure, **which may be due to the weight of the furnace walls and from the furnace contents.**

(*ii*) It has to **resist repeated thermal shocks**, due to repeated heating and cooling of the furnace contents.

(*iii*) It has to bear **internal stresses** resulting from temperature changes.

(*iv*) It has to resist **against rubbing action** which may be due to repeated movement of contents of the furnace against the refractory lining.

(*v*) It has to **face chemical attack** by hot liquids, solids and gases and fumes.

It is, therefore, necessary that a refractory material must possess properties to satisfy the **above service conditions**. Based on these requirements, following are important qualities of refractories that are generally tested :

1. Fusion temperture. It is defined as that **temperature at which refractory starts softening before it actually melts**. The softening temperature is tested by the **Pyrometric Cone Test.**

In this test use is made of a standard set of small test pyramids each having its own **softening temperature**. The pyramids also called **SEGER CONES** are made of specific composition. Their softening points lie between 600^0 -2000^0C. Usually the softening point of one cone is higher by 20^0C than the preceding cone. Thus, first pyramid (cone) will be softening at 620^0 C, second at 640^0C, third at 660^0C and so on. The refractory material **to be tested** is also given the shape of the standard cones in a specific manner. These cones (standard as well as that of material to be tested.) are **heated simultaneously in a furnace**, By comparing the softening of the new cones with standard cones, their softening points can be established.

It is essential that a given refractory material should have **a much higher softening** point than the temperature of the furnace in which it is indeed to be used.

2. Chemical composition. A refractory substance is required to behave as a **chemically inactive material towards the environment in which it is to used**. Chemically speaking, the environment in most furnaces is either acidic or basic. Hence a refractory must be either of acidic composition or of basic composition. If it is neutral towards the two environments, it may be used in either case.

An **acidic refractory** is an **acidic oxide** in its composition and hence is stable in acidic environment furnaces; **silca, silicon carbide** and **alumina** type are acidic refractories.

The **basic refractories** are oxides of **some bases**. They can easily withstand attack of basic slags and basic melts. Examples are: **Magnesia, lime and dolomite.**

The **neutral refractories** are of such composition that neither acidic nor basic environment of furnace pose any danger to their stability at high temperature. Hence they can be used safely in both the types of furnaces for lining. Examples: Fire clays.

3. Strength. Refractories used for lining for furnaces have to bear with loads from the walls and from the contents of the furnace. It is, therefore, essential that refractory substances must also possess high mechanical strength at elevated temperature.

To test this quality, the test material is first cast into a **specific shape**. It is then heated to very high temperatures under different pressures. The amount of deformation in its original shape will give the measure of strength of the material being tested. Obviously, weaker materials will deform considerably at lower temperatures under lower loads.

4. Thermal conductivity. In industrial operations, refractory materials of both **high thermal** conductivity and **low thermal** conductivity may be required in different cases. For example, refractories of high conductivity are required in coke oven batteries and muffle furnace retorts. In many other furnaces, however, it is desirable to prevent heat loss to the maximum possible extent . In these cases, low conductivity is the required quality.

Fire clays and chrome bricks are "low conductivity" materials whereas magnetite and silica fall in the category of high conductivity refractories.

5. Porosity. Porosity may be defined as "volume of the pores in a substance expressed in percentage terms of its total volume". Porosity affects many other properties of a refractory material like its strength, thermal conductivity and even chemical stability. Higher porosity **decreases** the strength. But it reduces the chances of spalling or peeling off of the refractory at high temperature.

6. Spalling. By spalling is understood **breaking, cracking or peeling off** of a refractory material when used for considerable time at **high temperature**. Spalling is more commonly developed during rapid changes in temperature which create internal stresses in the material. Resistance to spalling depends on:

(*i*) coefficient of thermal expansion;

(*ii*) thermal conductivity;

(*iii*) porosity.

High porosity, **good** thermal conductivity and **low** coefficient of thermal expansion give a **better resistance** to spalling. Refractories with high alumina content and also clay materials show good resistance to spalling.

7. Thermal expansion. It is essential that a refractory material should expand as little as possible while in use. This is explained by two reasons. Firstly, on expanding the refractories will occupy more space in the furnace thereby reducing its total capacity. Secondly, repeated expansion and contraction will induce internal stresses in the body of refractory contributing towards its rapid breakdown.

12.10.3. Classification

Refractories are generally classified on the basis of their chemical composition into three groups as **Acid Refractories, Basic Refractories and Neutral Refractories**. Since this has already been described, we shall give below chief characters of some common refractory materials failing in these groups.

1. Silica refractories. Silica (SiO_2) is known to maintain its strength at high temperatures. It forms excellent ACID refractories for use in roofs of metal–melting furnaces. They have very low porosity and high thermal conductivity. Silica refractories have tendency to spall when temperature falls below 650°C. Hence, they should be used only where continuous operations **at high temperature** are necessary in the process.

2. Fireclay bricks. These are **neutral class** of refractories. Fireclay refractories are manufactured from suitable types of clays with composition of about 60 per cent silica and 40 per cent alumina. The fire clay refractories have a high resistance to spalling, high strength at elevated temperatures and low coefficient of thermal expansion. They are, however, **not recommended for metal –melting furnace.** But in most other operations, fire clays are the commonly used refractories. In glass making furnaces, in reverberatory furnaces and even in steel making, fireclays are extensively used.

3. Magnesite bricks. These are basic refractories made by heating the source rock magnesite ($MgCO_3$) at 1700°C. The sintered product is mixed with some clay for moulding. Magnesite refractories are characterized by high strength but are generally poor towards thermal shocks and spalling. These are used extensively in the metallurgy of iron and steel.

4. High alumina (bauxite) refractoires. They are so named because they contain more than 50% of Alumina (Al_2O_3). They have very high softening temperatures. These refractories have Bauxite (AL_2O_3) as their main constituent. The alumina content ranges between 50 percent to 99 per cent. High alumina refractories are resistant to spalling and also have high crushing strength at elevated temperatures.

They are also stable to many slags and fumes. These find **extensive use in cement making kilns**, oil fired furnaces and glass furnaces..

5. Chromite refractories. These are classed as neutral refractories. They are manufactured from a natural mineral CHROMITE. Bricks made from chromite possess a **high** thermal conductivity, **low** porosity and **high** resistance to slags of both acidic and basic character. They are, however, **poor towards spalling**.

Chromite refractories are used for lining the furnaces for steel making and in copper metallurgy.

6. Graphite. It is classed among **excellent refractories** for some special uses. Graphite may be best suited in conditions where refractory material is **not exposed** to oxidation. It can withstand temperature as high as 2500^{0}C and above without spalling. It possesses quite **high strength** which increases with temperature.

7. Silicon carbide. This material has very good refractory properties. The thermal conductivity of silicon carbide is of the order of 25 Btu/cm, which is ten times more than that of fireclay bricks. It also possesses very high strength and durability. But because of its high cost, silicon carbide is used only as a **special purpose refractory material.**

8. Zirconia. Zirconium is a yellow coloured refractory with **excellent resistance against alkaline fluxes**. It finds application in high quality **glass making**.

12.11 RUBBER

12.11.1. Introduction

Rubber is essentially an **elastic material**, that is, a material which undergoes volumetric changes under pressure but regains original dimensions on the release of the pressure. Rubber is obtained both as a natural product and as a synthetic product. Natural rubber is obtained from the **milky sap** (called latex) of trees. One variety called **heva brassiliensis** contains 30-40 per cent of latex. Synthetic rubber is made like plastics and consists of monomers derived from petroleum, **coal and coke**. The synthetic rubber molecules are termed as elastomer (rather than polymers.)

The most important property of rubbers is that in them elastic strain is not proportional to stress. Further, there is a definite time-lag between stress and corresponding strain. Many rubbers show strains of several hundred per cent..

12.11.2. Production

The **crude latex** obtained from rubber plantation is coagulated by adding some chemicals like **acetic acid** or by heating. The **coagulated rubber** is then subjected to a number of refinements and treatments to obtain the **final product** for industrial applications. The treatment is important because natural rubber becomes **too soft** on heating and **too brittle** at low temperatures.

Compouding. This is an important step in the preparation of rubber for industrial uses. It means **addition of some selected compounds like sulphur, magnesia, carbon black, antimony suphide, silica and lithophone etc with natural raw rubber**. Each compound improves particular properties of rubber. Following examples will explain this :

(*a*) Rubber is **not stable** at high and also at very **low temperature**. This defect can be removed by the addition of **sulphur or lime or magnesia**.

(*b*) Raw rubber **deteriorates easily** when exposed to atmosphere. This weakness can be removed with the help of certain chemicals grouped as antioxidants which are **organic compounds**.

(*c*) Raw rubber is **quite light in weight**, In order to make it bulky, hard and strong, certain materials are added which are called fillers. The fillers **do not effect** the main properties of rubber. They make it cheaper. **Carbon black** is a very common filler.

(*d*) Pigments are also added to obtain **different colours and shades**. Dyes and pigments like lithophone, litharge and zinc sulphide etc. are some examples.

Vulcanizing. It is the most important example of the compounding process. It involves adding some definite quantity of **sulphur** with the raw rubber before it is marketed. In this process, the rubber is first heated to specified high temperatures and then made to mix with sulphur chemically. Vulcanizing makes the rubbers

(*i*) resistant to heat;

(*ii*) strong against wear and tear, and

(*iii*) stable against organic acids.

12.11.3. Types of Rubber

1. Natural rubber. This is the rubber obtained by coagulating and compounding the latex derived form rubber plantations. In chemical structure, natural rubber may be considered as an **addition polymer of isoprene**. The positive qualities of such a rubber are:

(*i*) **Low hystresis**, which means, it liberates only a small amount of heat when it is flexed again and again.

(*ii*) **High strength.** It has been observed that strength of natural rubber still remains greater after prolonged use than those obtained in the synthetic rubber.

The negative quality of natural rubber is that it is **easily attacked by many gases** in the atmosphere, especially ozone. Its use in industry has largely been replaced now-a-days by the synthetic rubbers. In structure, natural rubber may be considered an addition polymer of **isoprene.**

2. Synthetic rubbers. A large variety of rubbers have been synthesized from following few monomers:

(*i*) isoprene
(*ii*) styrene
(*iii*) isobutylene
(*iv*) butadiene
(*v*) chloroprene
(*vi*) acrylonitrile

These monomers are polymerized generally by the process of **addition polymerization and copolymerization**. They are also **cross-linked** with sulphur.

The following are more important types of synthetic rubbers :

1. **SBR (Styrene-Butadiene Rubber).** It is one of the strongest and most durable of synthetic rubbers. The tensile strength of SBR may be anywhere between 175-235kg/cm^2. Its elongation is of the order of 500-600 per cent. The SB rubber is used for car tyres, tubing and conveyor belts.
2. **EPR (Ethylene-Propylene-Rubber).** It is a **light weight** rubber with some exclusive properties. This rubber is stable against ozone and hence can be used in the open. It is also resistant against chemicals. EPR has **good electrical** resistance.
3. **Neoprene (polychlroprene) rubber.** This rubber is a multiuse rubber because of its resistance to atmospheric gases, especially ozone, abrasion and oils. It is a preferred material for cable covering in electrical industry. It has also been used for making rubber garments (aprons and gloves). Neoprene has also been used for manufacturing conveyor belts, bearing pads and gaskets for engines.

4. **Butyl rubber.** This is a **low strength**, low density rubber prepared by adding monomers of butadiene.
5. **Thiokol (polysuphide rubber).** It is a variety of rubber which is **specially resistant to gases** and **solvents**. For this reason, this rubber finds applications in some special situations in fuel tanks of aircrafts and rockets. It is also used for gaskets and caulking material.
6. **Silicone rubbers.** It is a group of rubbers having additives like fluorine, nitrides, or of phenyl groups. Silicone rubbers are strongest at elevated temperatures compared with other rubbers. Further, they are resistant to ozone and many other solvents. The vulcanized silicone rubbers are used for tooling materials.
7. **Reclaimed rubber.** This is like any new rubber which has been made by using **scrap rubber** as the raw material. The waste product is first treated with alkalies to destroy chords or fabrics. The refined raw materials are then heated and coagulated as usual. Reclaimed rubber is **in no way** inferior to freshly made rubber.

12.11.4. Uses of Rubber

Rubber is an **indispensable material** in certain areas such as for tyres and tubes for automobile and aviation industries. This, however, is not the only major sector for use of rubber. In recent years, natural ands synthetic rubber have found wide application in civil, mechanical, electrical and chemical engineering fields. Following is only an outline of such applications.

Civil Engineering. Adhesives, apparel, belt conveyors, expansion joints, gaskets, hose –pipes, rubber floor tiles and seals.

Mechanical Engineering. Adhesives, conveyor belts, engine mounts, tyres and tubes, upholstery and vibration damping devices.

Electrical Engineering. Wide scale **insulating covering** for wires and cables.

Chemical Engineering. For corrosion resisting applications as linings, coating, rubber containers and pipes.

12.12. WIRE ROPE

12.12.1. Definition

Wire ropes are **rope like strands made from iron and steel wires**. They are required for hauling or hoisting or supporting loads in cable projects and other situations. A typical **Wire Rope** is made by **helically twisting** a number of wires to make strands of them. Then, a number of strands are helically **twisted** to make a rope. Twisting is generally done around a **hemp or wire core.**

12.12.2. Types

Different types of wire ropes are generally designated by figures indicating.

(*i*) the number of **strands** in each rope, and

(*ii*) the number of **wires** in each strand.

For instance, the wire rope No. 6x7 indicates that there are **six strands** in all, and that each strand has been made by twisting together **seven wires**. Few other types of wire ropes are: 6x19, 8x19, 6x39 and so on.

Ropes are also distinguished on the basis of **method of twisting**.

(*a*) **Regular lay.** In this type, wires in a strand are twisted in **one direction** (say clock wise), whereas strands themselves are twisted in the opposite direction (*i.e.* anticlockwise in this case.).

(*b*) **Lang lay.** This is the more common type of laying in which wires and strands are twisted in the **same direction** (both clockwise or anticlockwise) to form a wire rope.

12.12.3. Properties

Since wires are made mostly from **steel**, their properties will depend largely on the **type of steel** used in the wire ropes. They will also depend on

(*i*) the diameter of an individual wire,
(*ii*) the number of wires in each strand,
(*iii*) the number of strands in each rope,
(*iv*) the **manner** of laying or twisting.

Strength of a standard wire rope will be controlled by the composition of the steel wire in it. Wires made from a steel containing carbon from **0.05 to 0.15%** are **soft** and of **low** strength. They make only weak ropes.

The **plow–steel-rope** is made from high carbon (0.65 to 0.80%) steels. The improved **plow steel wires** are made from steel containing as much as 0.85% or more carbon.

Hardness or resistance to abrasion of a wire rope also increases with an increased carbon content in the original wires used in the rope.

12.12.4. Uses

Wire ropes are finding increasing applications within and outside the industry. They are used in elevators, in cable car traction, in suspension bridges, in automobiles used for recovery purpose and for scrapping, dredging and digging.

TYPICAL QUESTIONS

A. ESSAY TYPE

1. Discuss any two of the following:
   (*a*) Use of Abrasives in engineering industries.
   (*b*) Advantages and disadvantages of ADHESIVES as engineering materials.
   (*c*) Natural and synthetic abrasives.
2. "No engineering activity worth any importance would be possible without use of industrial fuels." How far this statement is correct? Explain, giving examples, use of various types of solid, liquid and gaseous fuels in engineering activities.

   Or

   Explain the classification and properties of **coals.**
3. Explain the difference between :
   (*i*) Corundum and garnet.
   (*ii*) Leaded glass and boro-glass.
   (*iii*) Anthracite and bituminous coals.
   (*iv*) Coke and coal.
   (*v*) Thermal insulators and electrical insulators.
   (*vi*) Acid Refractory and neutral refractory.
   (*vii*) Regular lay and Lang lay wire ropes.
4. Give an account of manufacture, types and uses of Glass.
5. Write short notes :
   (*i*) SBR
   (*ii*) Vulcanizing
   (*iii*) Spalling
   (*iv*) Asbestos
   (*v*) Fireclay
   (*vi*) Asphalt

(*vii*) Solid Lubricants
(*viii*) Mica
(*ix*) Laminated Glass
(*x*) Bullet proof Glass

B. OBJECTIVE TYPE

Tick the correct statement/answer :

1. The hardest **abrasive** known and used in the industry is
   - (*i*) Tungsten carbide
   - (*ii*) Alundum.
   - (*iii*) Diamond.
   - (*iv*) Carbonumdum.
2. **Asbestos fabric** is the name given to a fabric woven form the thin fibers made of:
   - (*i*) long and flexible fabrics of a fibrous variety of amphiboles and serpentines.
   - (*ii*) thermosetting resins such as phenolic formaldehyde.
   - (*iii*) thermosetting plastics and glass fibers.
   - (*iv*) none of the above.
3. **Glass threads** have a tensile strength which may be:
   - (*i*) As high as 108 × 7 kg/cm^2
   - (*ii*) As low as 100 kg/cm^2
   - (*iii*) Varying between 700 kg – 7000 kg/cm^2
   - (*iv*) None of the above
4. **Coke** is
   - (*i*) Simply a variety of COAL like lignite
   - (*ii*) Always a product derived from petroleum
   - (*iii*) obtained form both coal and petroleum by their destructive distillation
   - (*iv*) obtained by burning wood in the absence of air.
5. **Flash point** in a lubricant is:
   - (*i*) that temperature at which a liquid on heating gives a continuous yield of vapours.
   - (*ii*) that temperature at which a liquid on heating gives discontinuous vapours.
   - (*iii*) that temperature at which a liquid get converted totally and abruptly into vapours.
   - (*iv*) None of the above.
6. **Thermoplastics** are those resins
   - (*i*) which can be heated and cooled again and again and a new shape can be given to them on heating.
   - (*ii*) Which can be given a desired shape only once and do not soften on heating subsequently;
   - (*iii*) on which heat has no effect;
   - (*iv*) which are natural and which cannot be manufactured artificially.
7. **Spalling** is the term used to express:
   - (*i*) Decay and disintegration of refractories on repeated use.
   - (*ii*) Mixing of sulphur with rubber to improve its properties.
   - (*iii*) Method of twisting the strands in a wire rope.
   - (*iv*) Cleaning the surface of wood before applying paint.

ANSWERS : **1.** (*iii*); **2.** (*i*); **3.** (*iii*); **4.** (*iii*); **5.** (*ii*); **6.** (*i*); **7.** (*i*)

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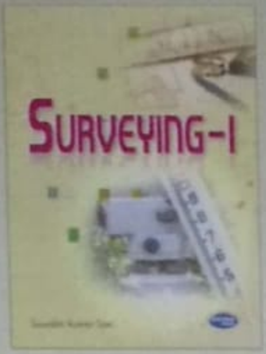

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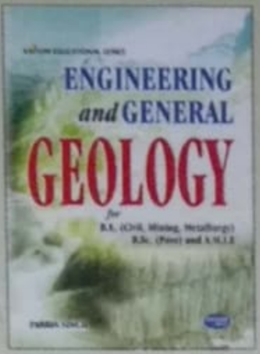

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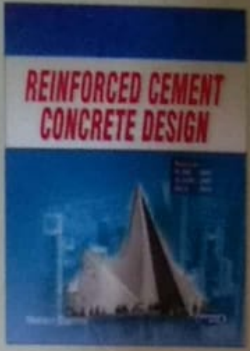

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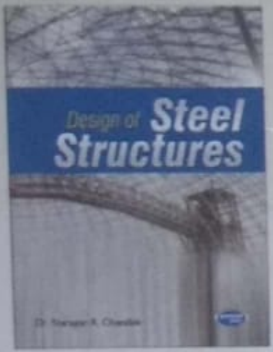

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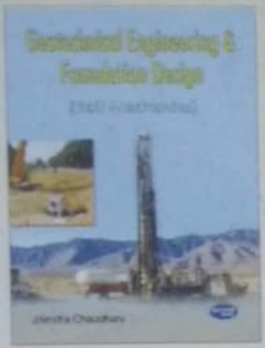

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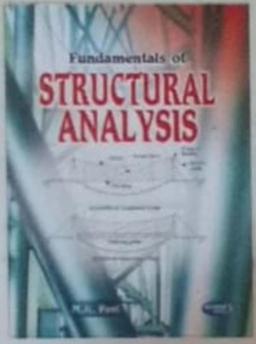

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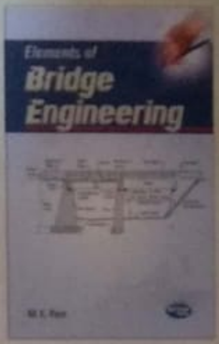

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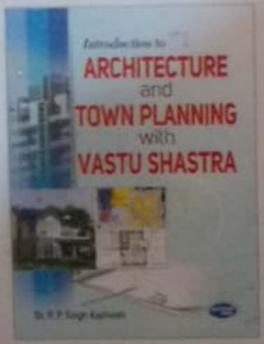

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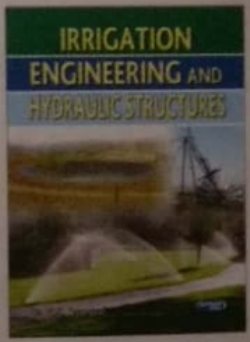

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