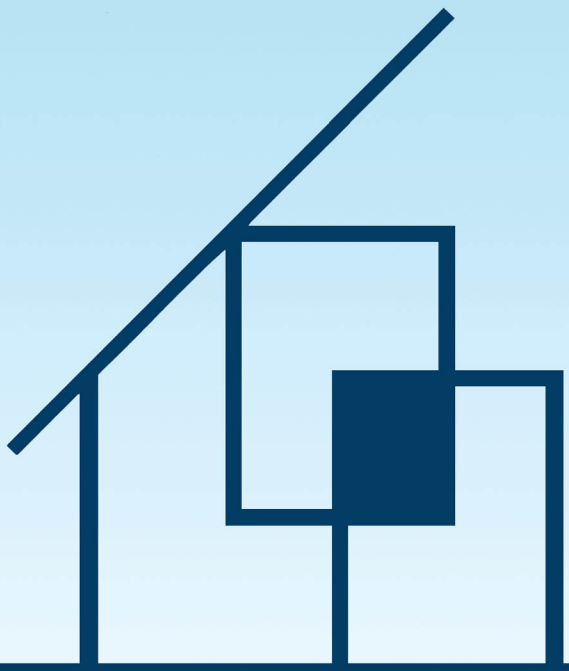
BUILDING MATERIALS

S.K. DUGGAL



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The publisher has gone to great lengths to ensure the quality of this reprint but points out that some imperfections in the original may be apparent

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Preface

The primary purpose of writing this book is to give engineering students up-to-date information on building materials. The book has been prepared after referring to a number of text books, references and standards. S.I. units have been used throughout the text as far as possible.

The author has tried to incorporate essential information concerning manufacture/fabrication of the various building materials; the data covering the more important mechanical and physical properties, influences of various factors on these properties; the causes of defects, their prevention and remedies; testing of materials. An attempt has also been made to present to the reader some of the more general uses and applications of the different materials.

The author gratefully acknowledges the considerable encouragement, splendid help and valuable suggestions received from his colleagues. Appreciation and thanks are also due to those students who went through the preliminary and final scripts. The author is extremely grateful to Dr. S.K. Mallick for reviewing the manuscript and providing his useful suggestions.

Finally thanks are due to my wife Suman and children Swati and Shashank for their tolerance during this trying time. Efforts have been made to keep errors to a minimum. However, they are inevitable. Suggestions are welcomed from all concerned pointing out any oversights.

S.K. DUGGAL

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Chapter

1

PRINCIPAL PROPERTIES OF BUILDING MATERIALS

1.1 INTRODUCTION

Building materials have an important role to play in this modern age of technology. Although their most important use is in construction activities, no field of engineering is conceivable without their use. Also, the building materials industry is an important contributor in our national economy as its output governs both the rate and the quality of construction work.

There are certain general factors which affect the choice of materials for a particular scheme. Perhaps the most important of these is the *climatic background.* Obviously, different materials and forms of construction have developed in different parts of the world as a result of climatic differences. Another factor is the *economic aspect* of the choice of materials. The rapid advance of constructional methods, the increasing introduction of mechanical tools and plants, and changes in the organisation of the building industry may appreciably influence the choice of materials.

Due to the great diversity in the usage of buildings and installations and the various processes of production, a great variety of requirements are placed upon building materials calling for a very wide range of their properties : strength at low and high temperatures, resistance to ordinary water and sea water, acids and alkalis etc. Also, materials for interior decoration of residential and public buildings, gardens and parks, etc. should be, by their very purpose, pleasant to the eye, durable and strong. Specific properties of building materials serve as a basis for subdividing them into separate groups. For example, mineral binding materials are subdivided into air and hydraulic-setting varieties. The principal properties of building

materials predetermine their applications. Only a comprehensive knowledge of the properties of materials allows a rational choice of materials for specific service conditions.

The importance of standardisation cannot be overemphasised. It requires the quality of materials and manufactured items to be not below a specific standard level. However, the importance of standardisation is not limited to this factor alone, since each revised standard places higher requirements upon the products than the preceding one, with the effect that the industry concerned has to keep up with the standards and improved production techniques. Thus, the industry of building materials gains both in quantity and quality, so that new, more efficient products are manufactured and the output of conventional materials is increased.

To develop products of greater economic efficiency, it is important to compare the performance of similar kinds of materials under specific service conditions. Expenditures for running an installation can be minimised by improving the quality of building materials and products. Building industry economists are thus required to have a good working knowledge, first, of the building materials, second, of their optimum applications on the basis of their principal properties, and, third, of their manufacturing techniques, in order that the buildings and installations may have optimum engineering, economic performance and efficiency. Having acquired adequate knowledge, an economist specialising in construction becomes an active participant in the development of the building industry and the manufacture of building materials.

1.2 PHYSICAL PROPERTIES

Density Defined as the mass of a unit volume of homogeneous material denoted by

$$\rho = \frac{M}{V} \text{ g/mm}^3$$

where M = mass (g)

V = volume (mm^3)

Density of some building materials is as follows (g/mm^3) :

Brick	2.5-2.8
Granite	2.6-2.9
Portland Cement	2.9-3.1
Wood	1.5-1.6
Steel	7.8-7.9

Bulk Density is the mass of a unit volume of material in its natural state calculated as

$$\rho_b = \frac{M}{V} \text{ g/mm}^3$$

where M = mass of specimen (g)

V = volume of specimen in its natural state (mm^3)

For most materials, bulk density is less than density but for liquids and materials like glass and dense stone materials, these parameters are practically the same. Properties like strength and heat conductivity are greatly affected by their bulk density. Bulk densities of some building materials are as follows (g/mm^3):

Brick	1.60 - 1.80
Granite	2.50 - 2.70
Sand	1.45 - 1.65
Pine Wood	0.50 - 0.60
Steel	7.85

Density Index is the ratio

$$d_0 = \frac{\text{bulk density}}{\text{density}}$$

$$= \frac{\rho_b}{\rho}$$

It indicates the degree to which the volume of a material is filled with solid matter. For almost all building materials d_0 is less than 1.0 because there are no absolutely dense bodies in nature.

Porosity is defined as the degree to which volume of the material is interspersed with pores. It is expressed as a ratio of the volume of pores to that of the specimen. Porosity is indicative of other major properties of material, such as bulk density, heat conductivity, durability, etc. Dense materials, which have low porosity, are used for constructions requiring high mechanical strength on the other hand, walls of buildings are commonly built of materials, featuring considerable porosity.

Hygroscopicity is the property of a material to absorb water vapour from air. It is influenced by air-temperature and relative humidity; pores — their types, number and size, and by the nature of substance involved.

Water Absorption denotes the ability of the material to absorb and retain water. It is expressed as percentage in weight or of the volume of dry material:

$$W_w = \frac{M_1 - M}{M} \times 100 \qquad W_v = \frac{M_1 - M}{V} \times 100$$

where M_1= mass of saturated material (g)

M = mass of dry material (g)

V = volume of material including the pores (mm^3)

Water absorption by volume is always less than 100 per cent, whereas that by weight of porous material may exceed 100 per cent.

The properties of building materials are greatly influenced when saturated. The ratio of compressive strength of material saturated with water to that in dry state is known as *coefficient of softening*. For materials like clay which soak readily it is zero, whereas for materials like glass it is one. Materials with coefficient of softening less than 0.8 should not be recommended in the situations permanently exposed to the action of moisture.

Weathering Resistance is the ability to endure alternate wet and dry conditions for a long period without considerable deformation and loss of mechanical strength.

Water Permeability is the capacity to allow water to penetrate under pressure. Materials like glass, steel and bitumen are impervious.

Frost Resistance denotes the ability of a water-saturated material to endure repeated freezing and thawing with considerable decrease of mechanical strength. Under such conditions the water contained by the pores increases in volume even up to 9 per cent on freezing. Thus the walls of the pores experience considerable stresses and may even fail.

Heat Conductivity is the ability of a material to conduct heat. It is influenced by nature of material, its structure, porosity, character of pores and mean temperature at which heat exchange takes place. Materials with large size pores have high heat conductivity because the air inside the pores enhances heat transfer. Moist materials have a higher heat conductivity than drier ones. This property is of major concern for materials used in the walls of heated buildings since it will affect dwelling houses.

Thermal Capacity is the property of a material to absorb heat described by its specific heat. Thermal capacity is of concern in the calculation of thermal stability of walls of heated buildings and heating of a material, e.g. for concrete laying in winter.

Fire Resistance is the ability of a material to resist the action of high temperature without any appreciable deformation and substantial loss of strength. Fire resistive materials are those which char, smoulder, and ignite with difficulty when subjected to fire or high temperatures for long period but continue to burn or smoulder only in the presence of flame, e.g. wood impregnated with fire proofing chemicals. Non-combustible materials neither smoulder nor char under the action of temperature. Some of the materials neither crack nor lose shape such as clay bricks, whereas some others like steel suffer considerable deformation under the action of high temperature.

Refractoriness denotes the ability to withstand prolonged action of high temperature without melting or losing shape. Materials resisting prolonged

temperatures of 1580°C or more are known as refractory.

High-melting materials can withstand temperature from 1350-1580°C, whereas low-melting materials withstand temperature below 1350°C.

Chemical Resistance is the ability to withstand the action of acids, alkalis, sea water and gases. Natural stone materials, e.g. limestone, marble and dolomite are eroded even by weak acids, wood has low resistance to acids and alkalis, bitumen disintegrates under the action of alkali liquors.

Durability is the ability to resist the combined effects of atmospheric and other factors.

1.3 MECHANICAL PROPERTIES

The important mechanical properties considered for building materials are strength — compressive, tensile, bending, impact, etc. hardness, plasticity, elasticity and abrasion resistance.

Strength is the ability of the material to resist failure under the action of stresses caused by loads, the most common being compression, tension, bending and impact. The importance of studying the various strengths will be highlighted from the fact that materials such as stones and concrete have high compressive strength but a low (1/5 to 1/50) tensile, bending and impact strengths.

Compressive Strength is found from tests on standard cylinders, prisms and cubes — smaller for homogeneous materials and larger for less homogeneous ones. Prisms and cylinders have lower resistance than cubes of the same cross-sectional area, on the other hand prisms with heights smaller than their sides have greater strength than cubes. This is due to the fact that when a specimen is compressed the plattens press tight the bases of the specimen and the resultant friction forces prevent the expansion of the adjoining faces, while the central lateral parts of the specimen undergoes transversal expansion. The only force to counteract this expansion is the adhesive force between the particles of the material. That is why a section away from the press plates fails early.

The test specimens of metals for tensile strength are round bars or strips and that of binding materials are of the shape of figure eight.

Bending Strength tests are performed on small bars supported at their ends and subjected to one or two concentrated loads which are gradually increased until failure takes place.

Hardness is the ability of a material to resist penetration by a harder body. Mohs scale is used to find the hardness of materials. It is a list of ten minerals arranged in the order of increasing hardness (Table 3.1). Hardness of metals and plastics is found by indentation of a steel ball.

Elasticity is the ability of the material to restore its initial form and dimensions after the load is removed. Within the limits of elasticity of solid bodies, the deformation is proportional to the stress. Ratio of unit stress to unit deformation is termed as *modulus of elasticity*. A large value of it represents a material with very small deformation.

Plasticity is the ability of material to change its shape under load without cracking and to retain this shape after the load is removed. Some of the examples of plastic materials are steel, copper and hot bitumen.

1.4 CHARACTERISTIC BEHAVIOUR UNDER STRESS

The common characteristics of building materials under stress are ductility, brittleness, stiffness, flexibility, toughness, malleability and hardness.

The *ductile* materials can be drawn out without necking down, the examples being copper and wrought iron. *Brittle* materials have little or no plasticity. They fail suddenly without warning. Cast iron, stone, brick and concrete are comparatively brittle materials having a considerable amount of plasticity. *Stiff* materials have a high modulus of elasticity permitting small deformation for a given load. *Flexible* materials on the other hand have low modulus of elasticity and bend considerably without breakdown. *Tough* materials withstand heavy shocks. Toughness depends upon strength and flexibility. *Malleable* materials can be hammered into sheets without rupture. It depends upon ductility and softness of material. Copper is the most malleable material. *Hard* materials resist scratching and denting, for example cast iron and chrome steel. Materials resistant to abrasion such as manganese are also known as hard materials.

EXERCISES

Q.1 (a) Why is it important to study the properties of building materials?
(b) List and define the physical properties of building materials.

Q.2 (a) What are the factors influencing the choice of a building material?
(b) Why is it important to make standards for building materials?

Q.3 Define the following:
(a) Density (b) Bulk density
(c) Density index (d) Porosity

Q.4 Write short notes on the following:
(a) Refractoriness
(b) Heat conductivity
(c) Selection of building materials
(d) Fire resistive materials

Chapter

2

STRUCTURAL CLAY PRODUCTS

2.1 INTRODUCTION

Clay products are one of the most important classes of structural materials. The raw materials used in their manufacture are clay blended with quartz, sand, chamatte

(refractory clay burned at 1000-1400°C and crushed), slag, sawdust and pulverized coal. Structural clay products or building ceramics* are basically fabricated by moulding, drying and burning a clay mass. According to the method of manufacture and structure, bricks, tiles, pipes, terracotta, earthenwares, stonewares, porcelain, and majolica are well recognized and employed in building construction. Clay bricks have pleasing appearance, strength and durability whereas clay tiles used for light-weight partition walls and floors possess high strength and resistance to fire. Clay pipes on account of their durability, strength, lightness and cheapness are successfully used in sewers, drains and conduits.

2.2 BRICKS

One of the oldest building material brick continues to be a most popular and leading construction material because of being cheap, durable and easy to handle and work with. Clay bricks are used for building-up exterior and interior walls, partitions, piers, footings and other load bearing structures.

A brick is rectangular in shape and of size that can be conveniently handled with one hand. Brick may be made of burnt clay or mixture of sand and lime or of Portland cement concrete. Clay bricks are commonly used since these are economical and easily available. The length, width and height of a brick are interrelated as below:

Length of brick = 2 × width of brick + thickness of mortar

Height of brick = width of brick

Size of a standard brick should be 19 × 9 × 9 cm and 19 × 9 × 4 cm. When placed in masonry the 19 × 9 × 9 cm brick with mortar becomes 20 × 10 × 10 cm. Weight of such a brick is 3.0 kg. An indent called frog, 1-2 cm deep, as shown in Fig. 2.1, is provided for 9 cm high bricks. Frog is not provided in 4 cm high bricks and extruded bricks. The size of frog should be 10 × 4 × 1 cm. The purpose of providing frog is to form a key for holding the mortar and therefore, the bricks are laid with frogs on top.

Clay and its Classifications

Clay is the most important raw material used for making bricks. It is an earthen mineral mass or fragmentary rock capable of mixing with water and forming a

**Polycrystalline materials and products formed by baking natural clays and mineral admixtures at a high temperature and also by sintering the oxides of various metals and other high melting-point inorganic substances.*

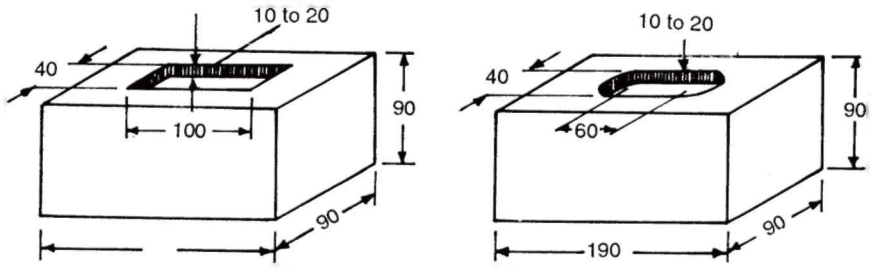


Fig. 2.1 Bricks with Frog.

plastic viscous mass which has a property of retaining its shape when moulded and dried. When such masses are heated to redness, they acquire hardness and strength. This is a result of micro-structural changes in clay and as such is a chemical property. Purest clays consist mainly of kaolinite ($2SiO_2 \cdot Al_2O_3\ 2H_2O$) with small quantities of minerals such as quartz, mica, felspar, calcite, magnesite, etc. By their origin, clays are subdivided as residual and transported clays. Residual clays, known as Kaolin or China clay, are formed from the decay of underlying rocks and are used for making pottery. The transported or sedimentary clays result from the action of weathering agencies. These are more disperse, contain impurities, and free from large particles of mother rocks.

On the basis of resistance to high temperatures (more than 1580°C), clays are classified as refractory, high melting and low melting clays. The refractory clays are highly disperse and very plastic. These have high content of alumina and low content of impurities, such as Fe_2O_3, tending to lower the refractoriness. High melting clays have high refractoriness (1350-1580°C) and contain small amount of impurities such as quartz, felspar, mica, calcium carbonate and magnesium carbonate. These are used for manufacturing facing bricks, floor tiles, sewer pipes, etc. Low melting clays have refractoriness less than 1350°C and have varying compositions. These are used to manufacture bricks, blocks, tiles, etc.

Admixtures are added to clay to improve its properties, if desired. Highly plastic clays which require mixing water up to 28 per cent, give high drying and burning shrinkage, call for addition of lean admixtures or non-plastic substances such as quartz sand, chamottee, ash, etc. Items of lower bulk density and high porosity are obtained by addition of admixture that burn out. The examples of burning out admixtures are sawdust, coal fines, pulverized coal, etc. Acid resistance items and facing tiles are manufactured from clay by addition of water-glass or alkalis.

Burning temperature of clay items can be reduced by blending clay with fluxes

such as felspar, iron bearing ores, etc. Plasticity of moulding mass may be increased by adding surfactants such as sulphite-sodium vinasse (0.1-0.3%).

2.3 CLASSIFICATION OF BRICKS

On Field Practice

Clay bricks are classified as first class, second class, third class and fourth class as per prevalent practice.

First Class Bricks

1. These are thoroughly burnt with deep red, cherry or copper colours.
2. The surface should be smooth and rectangular, with parallel, sharp and straight edges and square corners.
3. They should be free from flaws, cracks and stones.
4. They should have uniform texture.
5. No impression should be left on the brick when a scratch is made by a finger nail.
6. Water absorption should be 12-15% of its dry weight when immersed in cold water for 24 hours.
7. The fractured surface of the brick should not show lumps of lime.
8. A metallic or ringing sound should come when two bricks are struck against each other.
9. The crushing strength of the brick should not be less than 10.5 N/mm^2.

Uses: First class bricks are recommended for pointing, exposed face work in masonry structures, flooring and reinforced brick (R.B.) work.

Second Class Bricks are supposed to have the same requirements as the first class ones except that

1. Small cracks and distortions are permitted.
2. A little higher water absorption of about 16-20% of its dry weight is allowed.
3. The crushing strength should not be less than 7 N/mm^2.

Uses: Second class bricks are recommended for all important or unimportant hidden masonry works and centering of reinforced brick and reinforced cement concrete (R.C.C.) structures.

Third Class Bricks are underburnt. They are soft and light-coloured producing a dull sound when struck against each other. Water absorption is about 25 per cent of dry weight.

Uses : It is used for building temporary structures.

Fourth Class Bricks are overburnt and badly distorted in shape and size and are brittle in nature.

Uses: The ballast of such bricks is used for foundation and floors in lime concrete and road metal.

On Strength

The classification of bricks on the basis of compressive strength is given in Table 2.1.

Table 2.1 Classification of Bricks based on Compressive Strength

Class	Average compressive strength not less than (N/mm^2)
350	35.0
300	30.0
250	25.0
200	20.0
175	17.5
150	15.0
125	12.5
100	10.0
75	7.5
50	5.0
35	3.5

Notes: (i) The burnt clay bricks having compressive strength more than 40.0 N/mm^2 are known as heavy duty bricks and are used for heavy duty structures such as bridges, foundations for industrial buildings, multistory buildings, etc.

(ii) Each class of bricks as specified above is further divided into sub classes A and B based on tolerances and shape. Subclass-A bricks should have smooth rectangular faces with sharp corners and uniform colour. Subclass-B bricks may have slightly distorted and round edges.

	Subclass-A		Subclass-B	
	Dimension (cm)	Tolerance (mm)	Dimension (cm)	Tolerance (mm)
Length	380	± 12	380	± 30
Width	180	± 6	180	± 15
Height				
(i) 9 cm	180	± 6	180	± 15
(ii) 4 cm	80	± 3	80	± 6

On the Basis of Use

Common Brick is a general multi-purpose unit manufactured economically without special reference to appearance. These may vary greatly in strength and durability and are used for filling, backing and in walls where appearance is of no consequence.

Facing Bricks are made primarily with a view to have good appearance, either of colour or texture or both. These are durable under severe exposure and are used in fronts of building walls for which a pleasing appearance is desired.

Engineering Bricks are strong, impermeable, smooth and hard.

On the Basis of Finish

Sand-faced Brick has textured surface manufactured by sprinkling sand on the inner surfaces of the mould.

Rustic Brick has mechanically textured finish, varying in pattern.

On the Basis of Manufacture

Hand-made These bricks are hand moulded.

Machine-made Depending upon mechanical arrangement, bricks are known as wire-cut bricks — bricks cut from clay extruded in a column and cut off into brick sizes by wires; pressed-bricks — when bricks are manufactured from stiff plastic or semi-dry clay and pressed into moulds; moulded bricks -– when bricks are moulded by machines imitating hand mixing.

On the Basis of Burning

Pale Bricks are underburnt.

Body Bricks are well burnt bricks occupying central portion of the kiln.

Arch Bricks are overburnt also known as clinker bricks.

2.4 CHARACTERISTICS OF GOOD BRICK

Size and Shape The bricks should have uniform size and plane, rectangular surfaces with parallel sides and sharp straight edges. The surfaces should not be too smooth to cause slipping of mortar.

Colour The brick should have a uniform deep red or cherry colour as indicative of uniformity in chemical composition and thoroughness in the burning of the brick.

Texture and Compactness The brick should have precompact and uniform texture. A fractured surface should not show fissures, holes grits or lumps of lime.

Hardness and Soundness The brick should be so hard that when scratched by a finger nail no impression is made. When two bricks are struck together, a metallic sound should be produced.

Water Absorption should not exceed 20 per cent of its dry weight when kept immersed in water for 24 hours.

Crushing Strength should not be less than 10.5 N/mm^2.

Brick Earth should be free from stones, kankars, organic matter, saltpeter, etc.

2.5 INGREDIENTS OF GOOD BRICK EARTH

For the preparation of bricks, clay or other suitable earth is moulded to the desired shape after subjecting it to several processes. After drying, it should not shrink and no crack should develop. The clay used for brick making consists mainly of silica and alumina mixed in such a proportion that the clay becomes plastic when water is added to it. It also consists of small proportions of lime, iron, manganese, sulphur, etc. The proportions of various ingredients are as follows :

Silica	50-60%	
Alumina	20-30%	
Lime	10%	
Magnesia	< 1%	Less than 20%
Ferric oxide	< 7%	
Alkalis	< 10%	
Carbon dioxide		Very small percentage
Sulphur trioxide		
Waters		

Functions of Various Ingredients

Silica It enables the brick to retain its shape and imparts durability, prevents shrinkage and warping. Excess of silica makes the brick brittle and weak on burning. A large percentage of sand or uncombined silica in clay is undesirable. However, it is added to decrease shrinkage in burning and to increase the refractoriness of low alumina clays.

Alumina absorbs water and renders the clay plastic. If alumina is present in excess of the specified quantity, it produces cracks in brick on drying. Clays having exceedingly high alumina content are likely to be very refractory.

Lime normally constitutes less than 10 per cent of clay. Lime in brick clay has the following effects:

1. Reduces the shrinkage on drying.
2. Causes silica in clay to melt on burning and thus helps to bind it.
3. In carbonated form, lime lowers the fusion point.
4. Excess of lime causes the brick to melt and the brick looses its shape.
5. Red bricks are obtained on burning at considerably high temperature (more

than 800°C) and buff-burning bricks are made by increasing the lime content.

Magnesia rarely exceeding 1 per cent, affects the colour and makes the brick yellow. In burning; it causes the clay to soften at slower rate than in most case is lime and reduces warping.

Iron Iron oxide constituting less than 7 per cent of clay, imparts the following properties:

1. Gives red colour on burning when excess of oxygen is available and dark brown or even black colour when oxygen available is insufficient, however, excess of ferric oxide makes the brick dark blue,
2. Improves impermeability and durability,
3. Tends to lower the fusion point of the clay, especially if present as ferrous oxide,
4. Gives strength and hardness.

2.6 HARMFUL SUBSTANCES IN BRICK EARTH

Lime When a desirable amount of lime is present in the clay, it results in good bricks, but if in excess, it changes the colour of the brick from red to yellow. When lime is present in lumps, it absorbs moisture, swells and causes disintegration of the bricks. Therefore, lime should be present in finely divided state and lumps, if any, should be removed in the beginning itself.

Pebbles, Gravels, Grits do not allow the clay to be mixed thoroughly and spoil the appearance of the brick. Bricks with pebbles and gravels may crack while working.

Iron Pyrites tend to oxidise and decompose the brick during burning. The brick may split into pieces. Pyrites discolourises the bricks.

Alkalis forming less than 10 per cent of the raw clay, are of great value as fluxes, especially when combined with silicates of alumina. However, when present in excess, alkali makes the clay unsuitable for bricks. They melt the clay on burning and make the bricks unsymmetrical. When bricks come in contact with moisture, water is absorbed and the alkalis crystalise. On drying, the moisture evaporates, leaving behind grey or white powder deposits on the brick which spoil the appearance. This phenomenon is called *efflorescence*.

Organic Matter On burning green bricks, the organic matter gets charred and leave pores making the bricks porous; the water absorption is increased and the strength is reduced.

Carbonaceous Materials in the form of bituminous matter or carbon greatly affects the colour of raw clay. Unless proper precaution is taken to effect complete

removal of such matter by oxidation, the brick is likely to have a black core.

Sulphur is usually found in clay as the sulphate of calcium, magnesium, sodium, potassium or iron, or as iron sulphide. Generally, the proportion is small. If, however, there is carbon in the clay and insufficient time is given during burning for proper oxidation of carbon and sulphur, the latter will cause the formation of a spongy, swollen structure in the brick and the brick will be decoloured by white blotches.

Water A large proportion of free water generally causes clay to shrink considerably during drying, whereas combined water causes shrinkage during burning. The use of water containing small quantities of magnesium or calcium carbonates, together with a sulphurous fuel often causes similar effects as those by sulphur.

2.7 MANUFACTURING OF BRICKS

Additives in the Manufacture of Bricks

Certain additives such as fly ash, sandy loam, rice husk ash, basalt stone dust, etc. are often required not only to modify the shaping, drying and firing behaviour of clay mass, but also to help conserve agricultural land and utilise waste materials available in large quantities. These additives should, however, have a desirable level of physical and chemical characteristics so as to modify the behaviour of clay mass within the optimum range without any adverse effect on the performance and durability. Some of the basic physio-chemical requirements of conventional additives are as under:

Fly Ash A waste material available in large quantities from thermal power plants can be added to alluvial, red, black, marine clays, etc. The fly ash contains amorphous glassy material, mullite, haematite, magnetite, etc. and shows a chemical composition similar to brick earths. These silicates also help towards strength development in clay bodies on firing, when mixed in optimum proportion depending on the physio-chemical and plastic properties of soils to be used for brick making. The proportion of fly ash mixed as an additive to the brick earth should be optimum to reduce drying shrinkage, check drying losses and to develop strength on firing without bloating or black coring in fired product. The crystallites present in the fly ash should comply with the resultant high temperature phases in the finished product.

The desirable characteristics of fly ash which could be used as an additive to the soil mass are given in Table 2.2.

Sandy Loam Addition of sandy loam is often found effective in controlling the drying behaviour of highly plastic soil mass containing expanding group of clay minerals. Sandy loam should preferably have a mechanical composition as

Table 2.2 Desirabe Characteristics of Fly Ash for Use as an Admixture with Brick Earths

S.No.	Characteristics	Desired level
1.	Texture	Fineness, 200 to 300 m^2/kg
2.	Maximum coarse material (+ 1 mm)	0.5%
3.	Maximum unburnt carbon per cent by mass	15%
4.	Maximum water soluble per cent by mass	0.1%

specified below. The material should, however, meet the other requirement as well.

Clay	(< 2 micron)	8-10%
Silt	(2-20 micron)	30-50%
Sand	(> 20 micron)	40-60%

Rice Husk Ash The ash should preferably have unburnt carbon content in the range of 3-5% and should be free from extraneous material. It can be used with plastic black red soils showing excessive shrinkage.

Basalt Stone Dust Basalt stone occurs underneath the black cotton soil and its dust is a waste product available in large quantity from basalt stone crushing units. The finer fraction from basalt stone units is mixed with soil mass to modify the shaping, drying and firing behaviour of bricks. The dust recommended for use as an additive with brick earth should be fine (passing 1 mm sieve), free from coarse materials or mica flakes and should be of non-calcitic or dolomitic origin.

The operations involved in the manufacture of clay bricks are represented diagrammatically in Fig. 2.2.

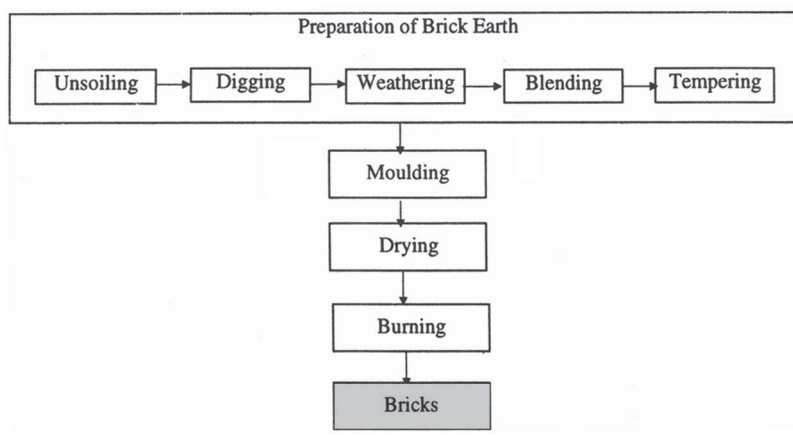


Fig. 2.2 Operations Involved in Manufacturing of Clay Bricks

Preparation of Brick Earth

It consists of the following operations.

Unsoiling The soil used for making building bricks should be processed so as to be free of gravel, coarse sand (practical size more than 2 mm), lime and kankar particles, organic matter, etc. About 20 cm of the top layer of the earth, normally containing stones, pebbles, gravel, roots, etc. is removed after clearing the trees and vegetation.

Digging After removing the top layer of the earth, proportions of additives such as fly ash, sandy loam, rice husk ash, stone dust, etc. should be spread over the plane ground surface on volume basis. The soil mass is then manually excavated, puddled, watered and left over for weathering and subsequent processing. The digging operation should be done before rains.

Weathering Stones, gravels, pebbles, roots, etc. are removed from the dug earth and the soil is heaped on level ground in layers of 60-120 cm. The soil is left in heaps and exposed to weather for at least one month in cases where such weathering is considered necessary for the soil. This is done to develop homogeneity in the mass of soil, particularly if they are from different sources, and also to eliminate the impurities which get oxidized. Soluble salts in the clay would also be eroded by rain to some extent, which otherwise could have caused scumming at the time of burning of the bricks in the kiln. The soil should be turned over at least twice and it should be ensured that the entire soil is wet throughout the period of weathering. In order to keep it wet, water may be sprayed as often as necessary. The plasticity and strength of the clay are improved by exposing the clay to weather.

Blending The earth is then mixed with sandy-earth and calcarious-earth in suitable proportions to modify the composition of soil. Moderate amount of water is mixed so as to obtain the right consistency for moulding. The mass is then mixed uniformly with spades. Addition of water to the soil at the dumps is necessary for the easy mixing and workability, but the addition of water should be controlled in such a way that it may not create a problem in moulding and drying. Excessive moisture content may effect the size and shape of the finished brick.

Tempering Tempering consists of kneading the earth with feet so as to make the mass stiff and plastics (by plasticity, we mean the property which wet clay has of being permanently deformed without cracking). It should preferably be carried out by storing the soil in a cool place in layers of about 30 cm thickness for not less than 36 hours. This will ensure homogeneity in the mass of clay for subsequent processing. For manufacturing good brick, tempering is done in pug mills and the operation is called *pugging*.

Pug mill consists of a conical iron tube as shown in Fig. 2.3. The mill is sunk 60 cm into the earth. A vertical shaft, with a number of horizontal arms fitted with

knives, is provided at the centre of the tube. This central shaft is rotated with the help of bullocks yoked at the end of long arms. However; steam, diesel or electric power may be used for this purpose. Blended earth along with required water, is fed into the pug mill from the top. The knives cut through the clay and break all the clods or lump-clays when the shaft rotates. The thoroughly pugged clay is then taken out from opening provided in the side near the bottom. The yield from a pug mill is about 15000 bricks.

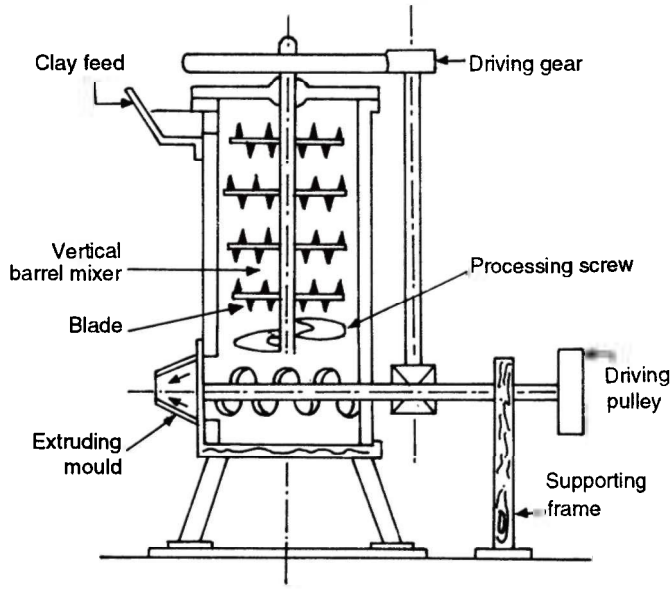


Fig. 2.3 Pug Mill

Moulding

It is a process of giving a required shape to the brick from the prepared brick earth. Moulding may be carried out by hand or by machines. The process of moulding of bricks may be the soft-mud, the stiff-mud or the dry-press process. Fire-brick is made by the soft mud process. Roofing, floor and wall tiles are made by dry-press method. However, the stiff-mud process is used for making all the structural clay products.

Hand Moulding A typical mould is shown in Fig. 2.4. Hand moulding is further classified as ground moulding and table moulding.

Ground Moulding In this process, the ground is levelled and sand is sprinkled on it. The moulded bricks are left on the ground for drying. Such bricks do not have frog and the lower brick surface becomes too rough. To overcome these defects, moulding blocks or boards are used at the base of the mould. The process consists of

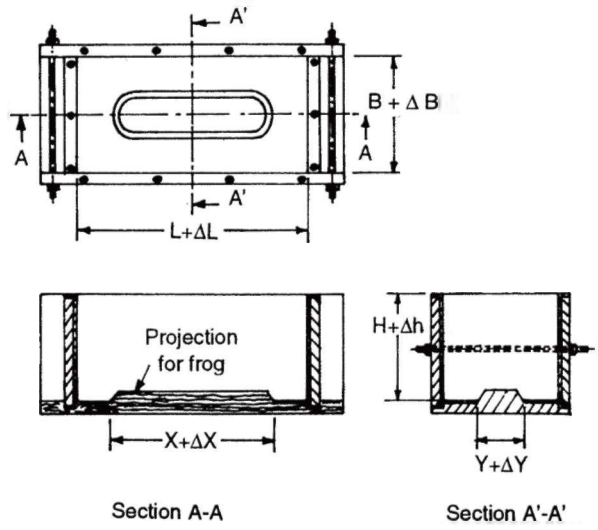


Fig. 2.4 Details of Mould

shaping in hands a lump of well pugged earth, slightly more than that of the brick volume. It is then rolled into the sand and with a jerk it is dashed into the mould. The moulder then gives blows with his fists and presses the earth properly in the corners of the mould with his thumb. The surplus clay on the top surface is removed with a sharp edge metal plate called *strike* (Fig. 2.5) or with a thin wire stretched over the mould. After this the mould is given a gentle slope and is lifted leaving the brick on the ground to dry.

Notes : (i) This method is adopted when a large and level land is available.

(ii) To prevent the moulded bricks from sticking to the side of the mould, sand is sprinkled on the inner sides of the mould, or the mould may be dipped in water every time before moulding is done. The bricks so produced are respectively called sand moulded and slop moulded bricks, the former being better since they provide sufficient rough surface necessary for achieving a good bond between bricks and mortar.

Fig. 2.5 Strikes

Table Moulding The bricks are moulded on stock boards nailed on the moulding table (Fig. 2.6). Stock boards have the projection for forming the frog. The process of filling clay in the mould is the same as explained above. After this, a thin board called *pallet* is placed over the mould. The mould containing the brick is then smartly lifted off the stock board and inverted so that the moulded clay along with the mould rests on the pallet. The mould is then removed as explained before and the brick is carried to the drying site.

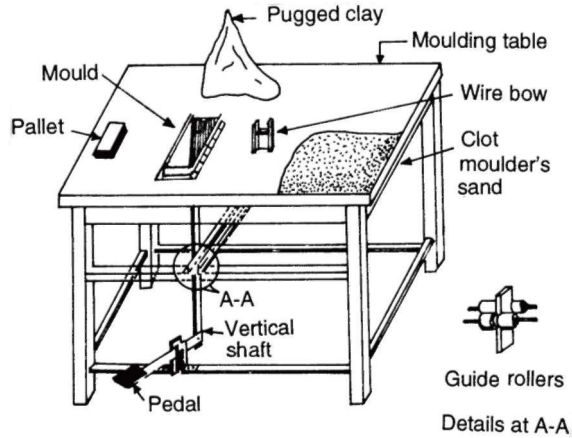


Fig. 2.6(a) Brick Moulding Table

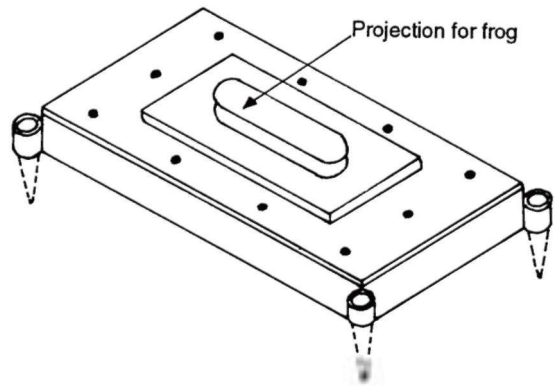


Fig. 2.6(b) Stock Board

Machine Moulding can be done by either of the following processes:

Plastic Method The pugged, stiffer clay is forced through a rectangular opening of brick size by means of an auger. Clay comes out of the opening in the

form of a bar. The bricks are cut from the bar by a frame consisting of several wires at a distance of brick size as shown in Fig. 2.7. This is a quick and economical process.

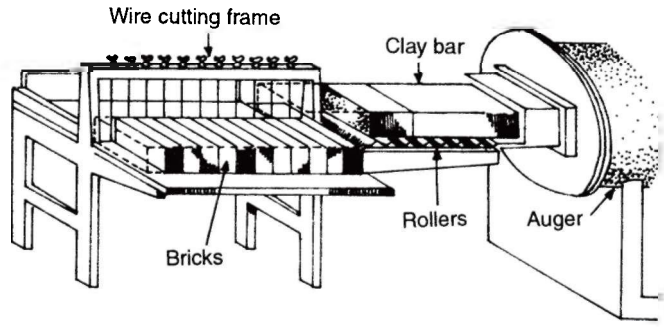


Fig. 2.7 Plastic Moulding

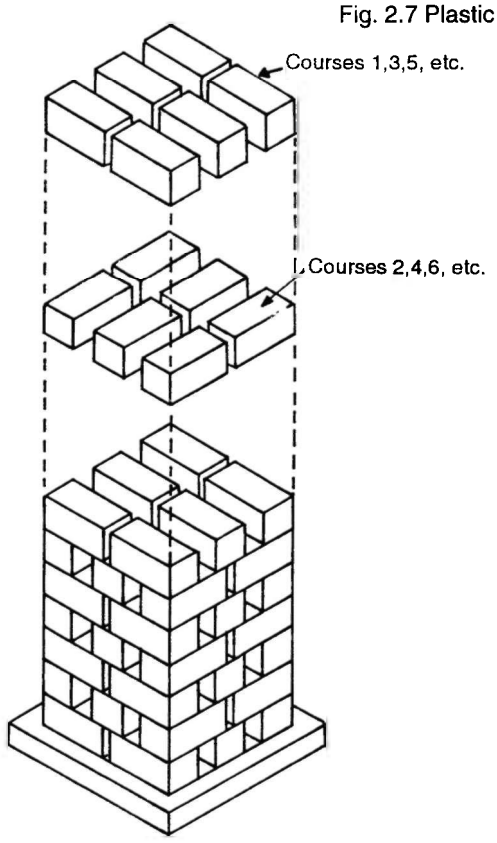


Fig. 2.8 Method of Drying Bricks

Dry-press Method The moist, powdered clay is fed into the mould on a mechanically operated press, where it is subjected to high pressure and the clay in the mould takes the shape of bricks. Such pressed bricks are more dense, smooth and uniform than ordinary bricks. These are burnt carefully as they are likely to crack.

Drying

Green bricks contain about 7-30% moisture depending upon the method of manufacture. The object of drying is to remove the moisture to control the shrinkage and save fuel and time during burning. The drying shrinkage is dependent upon pore spaces within the clay and the mixing water. The addition of sand or ground burnt clay reduces shrinkage, increases porosity and facilitates drying. The moisture content is brought down to about 3 per cent under exposed conditions within three to four days. Thus, the strength

of the green bricks is increased and the bricks can be handled safely.

Clay products can be dried in open air driers or in artificial driers. The artificial driers are of two types, the hot floor drier and the tunnel drier. In the former, heat is applied by a furnance placed at one end of the drier or by exhaust steam from the engine used to furnish power and is used for fire bricks, clay pipes and terracotta. Tunnel driers are heated by fuels underneath, by steam pipes, or by hot air from cooling kilns. They are more economical than floor driers. In artificial driers, temperature rarely exceeds 120°C. The time varies from one to three days. In developing countries, bricks are normally dried in natural open air driers (Fig. 2.8). They are stacked on raised ground and are protected from bad weather and direct sunlight. A gap of about 1.0 m is left in the adjacent layers of the stacks so as to allow free movement for the workers.

Burning

The burning of clay may be divided into three main stages.

Dehydration (400-650°C) This is also known as water smoking stage. During dehydration, (1) the water which has been retained in the pores of the clay after drying is driven off and the clay loses its plasticity, (2) some of the carbonaceous matter is burnt, (3) a portion of sulphur is distilled from pyrites, (4) hydrous minerals like ferric hydroxide are dehydrated, and (5) the carbonate minerals are more or less decarbonated. Too rapid heating causes cracking or bursting of the bricks. On the other hand, if alkali is contained in the clay or sulphur is present in large amount in the coal, too slow heating of clay produces a scum on the surface of the bricks.

Oxidation Period (650-900°C) During the oxidation period, (1) remainder of carbon is eliminated and, (2) the ferrous iron is oxidized to the ferric form. The removal of sulphur is completed only after the carbon has been eliminated. Sulphur on account of its affinity for oxygen, also holds back the oxidation of iron. Consequently, in order to avoid black or spongy cores, oxidation must proceed at such a rate which will allow these changes to occur before the heat becomes sufficient to soften the clay and close its pore. Sand is often added to the raw clay to produce a more open structure and thus provide escape of gases generated in burning.

Vitrification — To convert the mass into glass like substance — the temperature ranges from 900-1100°C for low melting clay and 1000-1250°C for high melting clay. Great care is required in cooling the bricks below the cherry red heat in order to avoid checking and cracking. Vitrification period may further be divided into (a) incipient vitrification, at which the clay has softened sufficiently to cause adherence but not enough to close the pores or cause loss of space — on cooling the material cannot be scratched by the knife; (b) complete vitrification, more or less well-marked

by maximum shrinkage; (c) viscous vitrification, produced by a further increase in temperature which results in a soft molten mass, a gradual loss in shape, and a glassy structure after cooling. Generally, clay products are vitrified to the point of viscosity. However, paving bricks are burnt to the stage of complete vitrification to achieve maximum hardness as well as toughness.

Burning of bricks is done in a clamp or kiln. A clamp is a temporary structure whereas kiln is a permanent one.

Burning in Clamp or Pazawah A typical clamp is shown in Fig. 2.9. The bricks and fuel are placed in alternate layers. The amount of fuel is reduced successively in the top layers. Each brick tier consists of 4-5 layers of bricks. Some space is left between bricks for free circulation of hot gasses. After 30 per cent loading of the clamp, the fuel in the lowest layer is fired and the remaining loading of bricks and fuel is carried out hurriedly. The top and sides of the clamp are plastered with mud. Then a coat of cowdung is given, which prevents the escape of heat. The production of bricks is 2-3 lacs and the process is completed in six months. This process yields about 60 per cent first class bricks.

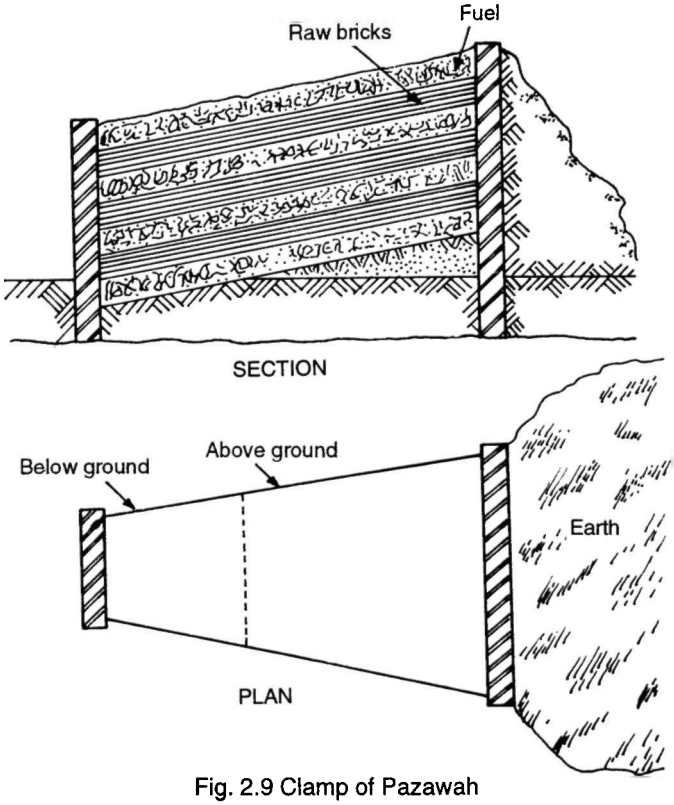


Fig. 2.9 Clamp of Pazawah

Kiln Burning The kiln used for burning bricks may be underground, e.g. Bull's trench kiln or overground, e.g. Hoffman's kiln. These may be rectangular, circular or oval in shape. When the process of burning bricks is continuous, the kiln is known as continuous kiln, e.g. Bull's trench and Hoffman's kilns. On the other hand if the process of burning bricks is discontinuous, the kiln is known as intermittent kiln.

Intermittent Kiln The example of this type of an over ground, rectangular kiln is shown in Fig. 2.10. After loading the kiln, it is fired, cooled and unloaded and then the next loading is done. Since the walls and sides get cooled during reloading

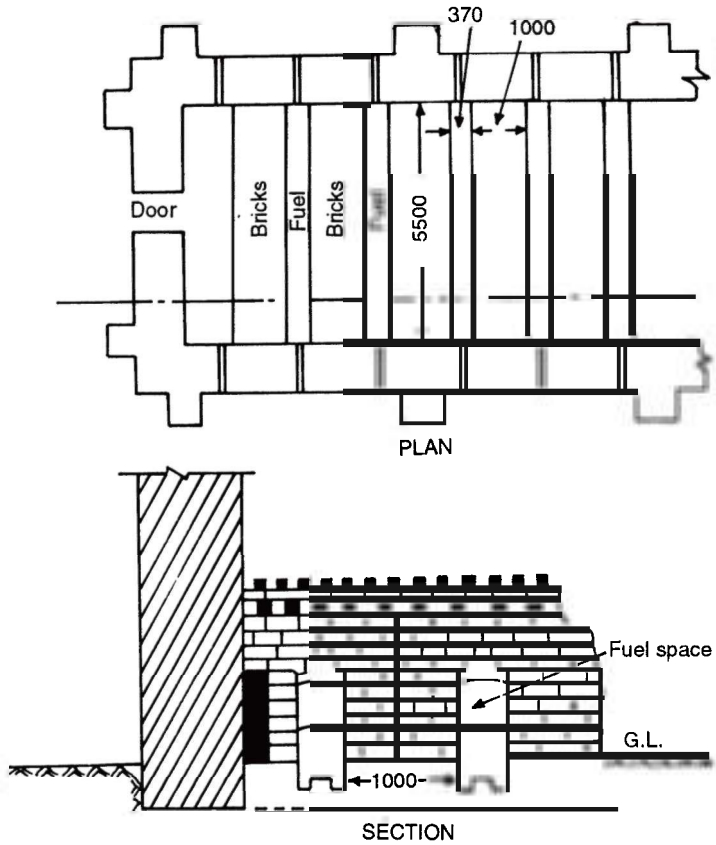


Fig. 2.10 Intermittent Kiln

and are to be heated again during next firing, there is wastage of fuel.

Continuous Kiln : Hoffman's kiln (Fig. 2.11) and Bull's trench kiln (Fig. 2.12). In a continuous kiln, bricks are stacked in various chambers wherein the

bricks undergo different treatments at the same time. When the bricks in one of the chambers is fired, the bricks in the next set of chambers are dried and preheated while bricks in the other set of chambers are loaded and in the last are cooled.

Note : In the areas where black cotton soil occur, a more elaborate method of processing is followed. The clay, which may be black or a mixture of black and yellow, is first washed free of the lime kankar in the 'GHOL' tanks. The slurry is then run off to the setting tanks. After 3-4 days when the clay has settled down, the supernatant water is bucketed off. Opening material like powdered grog of fine coal ash (passing 2.00 mm sieve), which opens up the texture of clay mass, is then added in predetermined proportions. This is usually 30 to 40 per cent of the mass of clay. A solution of 0.5 per cent sodium chloride may also be added at this stage to prevent lime bursting. The clay is then thoroughly mixed with the opening materials added and allowed to dry further for a period of 3-4 days till the mix attains the correct moulding consistency. Grog is prepared by lightly calcining

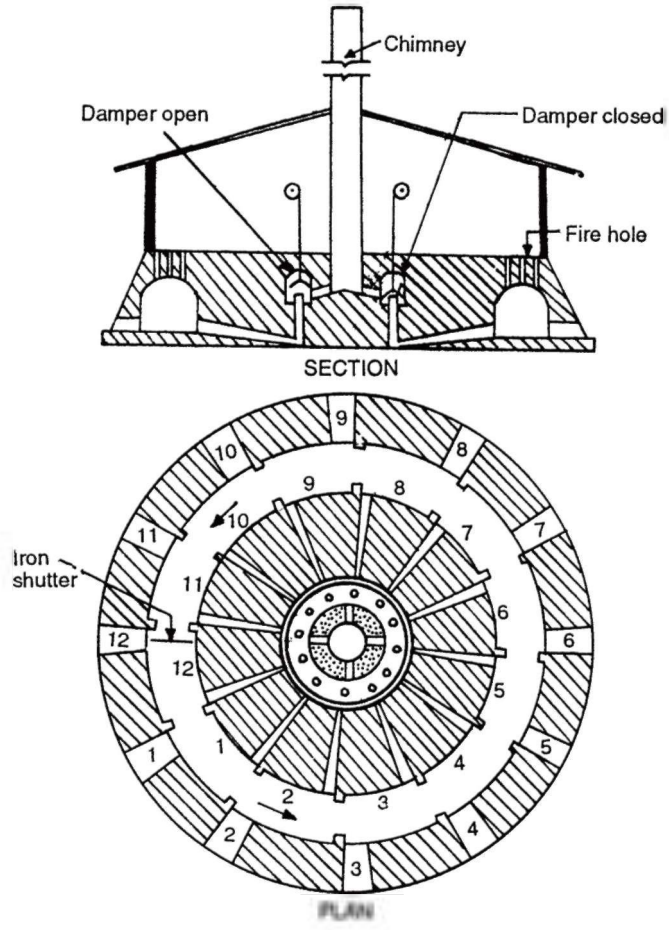


Fig. 2.11 Hoffman's Continuous Kiln

lumps of black cotton soil (about 10 to 15 cm dia.) in a clamp at about 700° to 750°C. Coal ash, fire wood, brambles, etc. may be used as fuel. The fuel and clay lumps are arranged in alternate layers in the clamp. After calcination the clay is pulverized in a machine, such as disintegrator, a hammer mill or a pan-mill to a fineness of less than 2.0 mm.

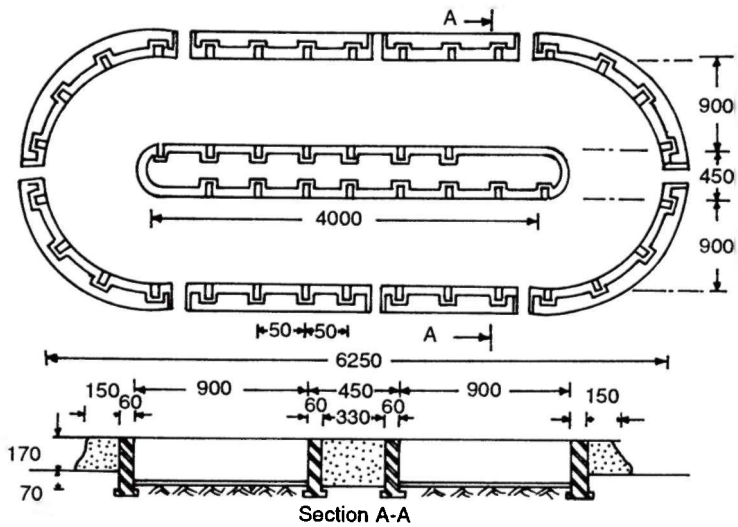


Fig. 2.12 Bull's Trench Kiln

2.8 DIFFERENT FORMS OF BRICKS

Some of the common type of bricks, depending upon the places of use, are shown in Fig. 2.13. Round ended and bull nosed bricks (Fig. 2.13 (a, f)) are used to construct open drains. For door and window jambs, cant brick, also called splay brick, shown in Fig. 2.13 (b, c), are most suitable. The double cant brick shown in Fig. 2.13 (c) is used for octagonal pillars. Cornice brick shown in Fig. 2.13 (d) is used from architectural point of view. Fig. 2.13 (e) shows a compass brick — tapering in both directions along its length — used to construct furnances. Perforated brick (Fig. 2.13 (g)) is well burned brick, but is not sound proof. Figure 2.13 (h) shows hollow bricks. These are about 1/3rd the weight of normal bricks and are sound and heat proof, but are not suitable where concentrated loads are expected. Top most bricks course of parapets is made with coping bricks shown in Fig. 2.13 (i). These drain off the water from the parapets. Brick shown in Fig. 2.13 (j) is used at plinth level and for door and window jambs. Split bricks are shown in Fig. 2.13 (k, l). When the brick is cut along the length, it is called queen closer and when cut at one end by half header and half stretcher, it is known as king closer.

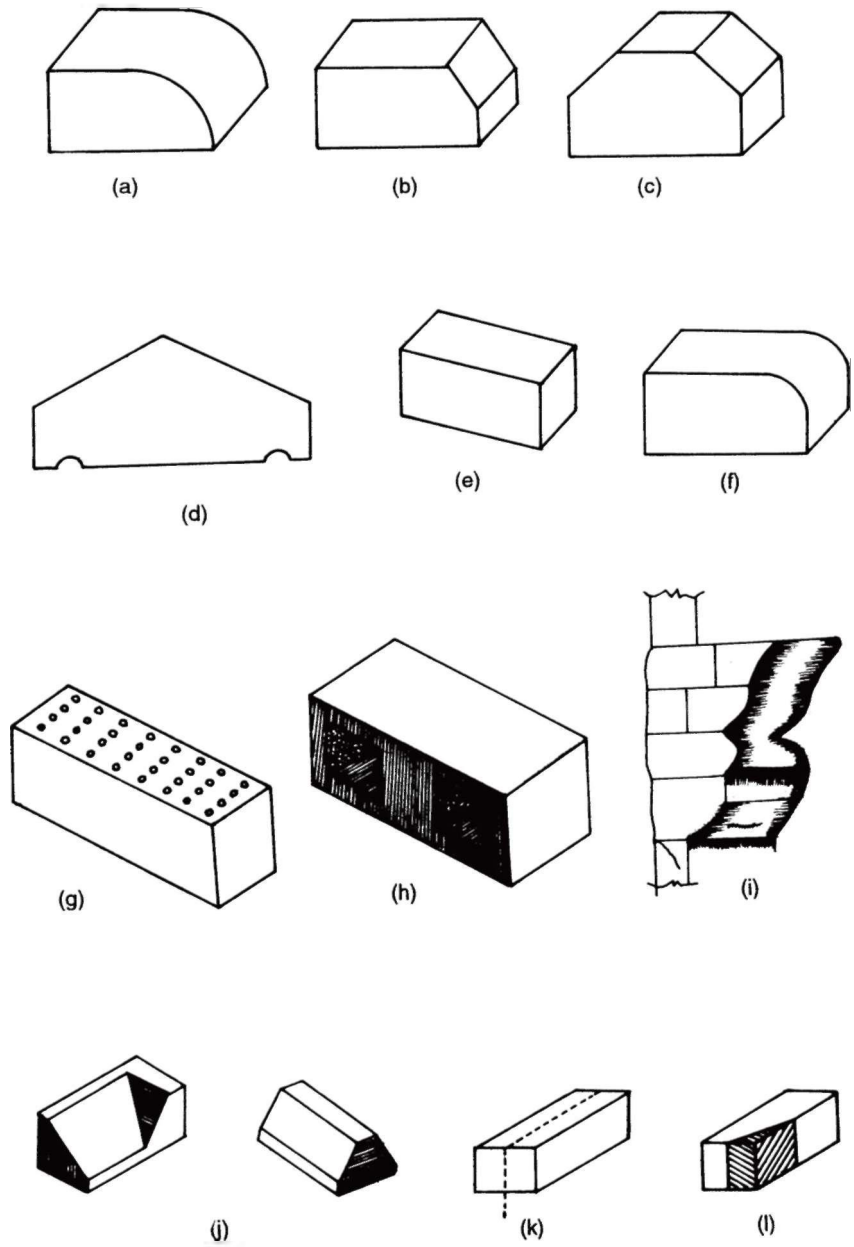


Fig. 2.13 Forms of Bricks

2.9 TESTING OF BRICKS

About fifty pieces of bricks are taken at random from different parts of the stack to perform various tests.

Dimension Test 20 pieces out of selected 50 pieces are taken and are laid flat as shown in Fig. 2.14. The cumulative dimensions of the bricks should be as discussed in Sec. 1.3.

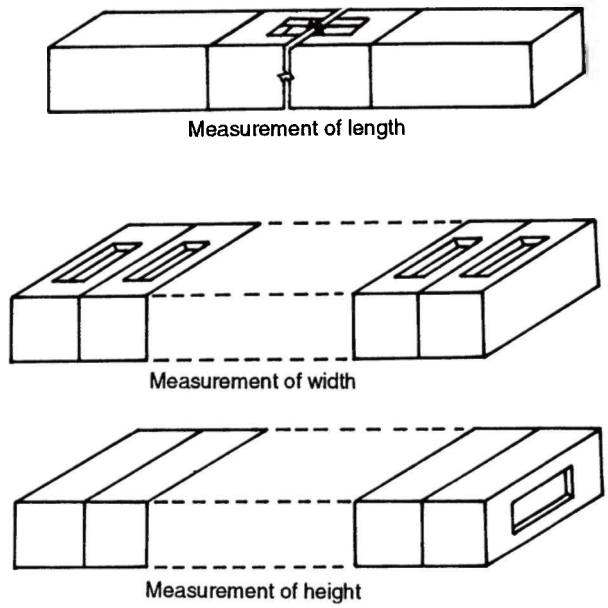


Fig. 2.14 Measurement of Tolerances of Common Building Bricks

Absorption Test The percentage of water absorption is a very valuable indication of the degree of burning. Any of the following tests may be performed.

24 Hours Immersion Cold Water Test Dry bricks are put in an oven at a temperature of 105°± 5°C till these attain constant mass. The weight (W_1) of the bricks is recorded after cooling them to room temperature. The bricks are then immersed in water at a temperature of 27°± 2°C for 24 hours. The specimens are then taken out of water and wiped with a damp cloth. Thereafter it is weighed again and recorded as W_2.

$$\text{The water absorption in \%} = \frac{W_2 - W_1}{W_1} \times 100$$

Five Hours Boiling Water Test The weight of the oven dried bricks (W_1) is

recorded as above. Then the specimen is immersed in the water and boiled for five hours, followed by cooling down to 27°± 2°C by natural loss of heat within 16-19 hours. The specimen is taken out of water and wiped with a damp cloth and the weight is recorded as W_3.

$$\text{The water absorption in } \% = \frac{W_3 - W_1}{W_1} \times 100$$

Compressive Strength Test The crushing affords a basis for comparing the quality of bricks but is of little value in determining the strength of a masonry wall, since the latter depends primarily on the strength of mortar. As a criterion of structural strength for brick, the transverse failure in a wall or pavement is likely to occur on account of improper bedment. For testing bricks for compressive strength from a sample the two bed faces of bricks are ground to provide smooth, even and parallel faces. The bricks are then immersed in water at room temperature for 24 hours. These are then taken out of water and surplus water on the surfaces is wiped off with cotton or a moist cloth. The frog of the brick is flushed level with cement mortar and the brick is stored under damp jute bags for 24 hours followed by its immersion in water at room temperature for three days. The specimen is placed in the compression testing machine with flat faces horizontal and mortar filled face being upwards. Load is applied at a uniform rate of 14 N/mm^2 per minute till failure. The maximum load at failure divided by the average area of bed face gives the compressive strength.

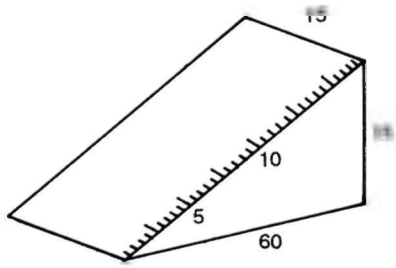


Fig. 2.15 Measuring Wedge

Warping Test Warpage of the brick is measured with the help of a flat steel or glass surface and measuring ruler or wedge of steel (Fig. 2.15). For warpage test, the sample consists of 10 bricks from a lot.

Concave Warpage The flat surface of the brick is placed along the surface to be measured selecting the location that gives the greatest deviation from straightness. The greatest distance of brick surface from the edge of straightness is measured by a steel ruler or wedge.

Convex warpage The brick is placed on the plane surface with the convex surface in contact with the flat surface and the distances of four corners of brick are measured from the flat surface. The largest distance is reported as warpage.

Efflorescence Test The ends of the brick are kept in a 150 mm diameter

porcelain or glass dish containing 25 mm depth of water at room temperature (20°-30°C) till the entire water is absorbed or evaporated. The water is again filled to 25 mm depth in the dish and allowed to be absorbed by the brick or evaporated. Presence of efflorescence is classified as below.

1. Nil — When the deposit of efflorescence is imperceptible.
2. Slight — When the deposit of efflorescence does not cover more than 10 per cent of the exposed area of the brick.
3. Moderate — When the deposit of efflorescence is more than 10 per cent but less than 50% of the exposed area of the brick.
4. Heavy — When the deposit of efflorescence is more than 50 per cent but the deposits do not powder or flake away the brick surface.
5. Serious — When the deposits are heavy and powder or flake away the brick surface.

Some of the specifications limit the efflorescence to not more than moderate (10-50%) up to class 125 and not more than slight (< 10 per cent) for higher classes.

2.10 DEFECTS OF BRICKS

Over-burning of Bricks Bricks should be burned at temperatures at which incipient, complete and viscous vitrification occur. However, if the bricks are overburnt, a soft molten mass is produced and the bricks loose their shape. Such bricks are not used for construction works.

Under-burning of Bricks When bricks are not brunt to cause complete vitrification, the clay is not softened because of insufficient heat and the pores are not closed. This results in higher degree of water absorption and less compressive strength. Such bricks are not recommended for construction works.

Bloating This defect observed as spongy swollen mass over the surface of burned bricks is caused due to the presence of excess carbonaceous matter and sulphur in brick-clay.

Black Core When brick-clay contains bituminous matter or carbon and they are not completely removed by oxidation, the brick results in black core mainly because of improper burning.

Remedial Measures

1. Proper clay materials should be used for brick manufacturing.
2. Moisture should be prevented to come in contact with masonry. This can be done by providing waterproof coping and by using water repellent materials in mortar.
3. By providing damp proof course.

Chuffs The deformation of the shape of bricks caused by the rain water falling on hot bricks is known as chuffs.

Checks or Cracks This defect may be because of lumps of lime or excess of water. In case of the former, when bricks come in contact with water, the absorbed water reacts with lime nodules causing expansion and a consequent disintegration of bricks, whereas shrinkage and burning cracks result when excess of water is added during brick manufacturing.

Spots Iron sulphide, if present in the brick clay, results in dark surface spots on the brick surfaces. Such bricks though not harmful are unsuitable for exposed masonry work.

Blisters Broken blisters are generally caused on the surface of sewer pipes and drain tiles due to air imprisoned during their moulding.

Laminations These are caused by the entrapped air in the voids of clay. Laminations produce thin lamina on the brick faces which weather out on exposure. Such bricks are weak in structure.

2.11 HEAVY DUTY BURNT CLAY BRICKS

These are similar to burnt clay bricks and of the same size but with high compressive strength.

Classification

Class 400 : compressive strength not less than 40.0 N/mm^2 but less than 45.0 N/mm^2.

Class 450 : compressive strength not less than 45.0 N/mm^2.

These are further subdivided as subclasses A and B based on tolerance.

Tolerance

Dimensions (mm)	Tolerances (mm)	
	Subclass A	Subclass B
9	± 3	± 7
19	± 6	± 15

Water absorption should not be more than 10 per cent after 24 hours immersion in water.

Efflorescence should be nil.

Bulk density should be less than 250 N/mm^3.

2.12 BURNT CLAY PERFORATED BRICKS

Perforated Bricks have high compressive strength and less water absorption. The direction of perforations can be vertical or horizontal. These are used in building walls and partitions. The area of perforations should not exceed 30 to 45% of the area of face. In case of rectangular perforations, larger dimensions should be parallel to longer side of the brick.

Dimensions

These are available in the following sizes.

i) 19 × 9 × 9 cm.

ii) 29 × 9 × 9 cm.

Tolerance

Dimensions (cm)	Tolerances (mm)
9	± 4
19	± 7
29	± 10

Perforations

i) Dimension of perforation parallel to short side should not be more than 20 mm in case of rectangular projection and 25 mm in case of circular projection.

ii) Area of each perforation should not exceed 500 mm^2.

Compressive strength should not be less than 7.0 N/mm^2.

Water absorption should not be more than 15 per cent.

Efflorescence should not be more than slight.

Warpage should not exceed 3 per cent.

2.13 BURNT CLAY PAVING BRICKS

The iron content is more than that in the ordinary clay bricks. Excessive iron causes vitrification of bricks while burning, gives natural glaze to the brick, making it more resistant to abrasion. Paving bricks can be manufactured from surface clays, impure fire-clays or shale. However, shales are the best raw material for paving bricks. These are generally burned in continuous kiln for seven to ten days.

Dimensions The available sizes are:

i) 19.5 × 9.5 × 9 cm

ii) 19.5 × 9.5 × 4 cm

Tolerances

Dimensions (cm)	Tolerances (mm)
19.5	± 6
9.5	± 3
9	± 3
4	± 1.5

Compressive strength should not be less than 40.0 N/mm^2.

Water absorption should not be more than 5 per cent by weight after immersion for about 24 hours.

2.14 BURNT CLAY SOLING BRICKS

These are used for soling of roads.

Dimensions

i) 19 × 9 × 9 cm

ii) 19 × 9 × 4 cm

Tolerances Overall dimensions of 20 bricks (selected) should be within following limits.

Length		350-410 cm
Width		165-195 cm
Height		
	9 cm bricks	165-195 cm
	4 cm bricks	74-86 cm

Compressive strength should not be less than 5.0 N/mm^2.

Water Absorption should not be more than 20 per cent by weight after immersion for about 24 hours in cold water.

Efflorescence Rating should not be more than slight.

2.15 BURNT CLAY HOLLOW BLOCKS

Hollow blocks are manufactured from a thoroughly ground, lump free, well mixed clay mass of medium plasticity to allow moulding. The process of manufacture is similar to that of stiff-mud bricks. These are used to reduce the dead weight of the masonry and for exterior as well as partition walls.

Types

Type A — Blocks with both faces keyed for plastering or rendering.

Type B — Blocks with both faces smooth for use without plastering or rendering on either side.

Type C — Blocks with one face keyed and one face smooth.

Dimensions

Length (cm)	Breadth (cm)	Height (cm)
19	19	9
29	9	9
29	14	9

Tolerances

Dimensions (cm)	9	14	19	29
Tolerances (mm)	± 4	± 5	± 7	± 10

Crushing Strength Minimum average value should be 3.5 N/mm^2. Strength of individual block should not fall below the average value by more than 20 per cent.

Water absorption should not be more than 20 per cent.

2.16 BURNT CLAY JALLIS

These are normally used for providing a screen on verandah and construction of parapet or boundary walls. Total void area should not exceed 40 per cent. Keys for bonding with mortar should be 10 mm wide and 3 mm deep. These are generally hand moulded but superior qualities can be produced by machines.

Dimensions

19 × 19 × 10 cm, 19 × 19 × 5 cm,19 × 14 × 10 cm,19 × 14 × 5 cm,14 × 14 × 10 cm,14 × 14 × 5 cm,14 × 9 × 5 cm, 9 × 9 × 5 cm.

Tolerances ± 3 per cent.

Breaking load average value should not be less than 1.2 N/mm^2.

Water absorption average value should not exceed 15 per cent.

Efflorescence rating should not be more than slight.

Warpage should not exceed 3 per cent.

2.17 CLAY TILES

Tiles are thin slabs of low melting clays used for various purposes in engineering constructions. These give a very pleasing appearance and good service properties. But due to the considerable mass, labour-consuming manufacture, erection and

drainage problems, and appreciable transportation charges, roofing tiles have lost their importance and are recommended locally. The various types of roofing tiles in common use are shown in Fig. 2.16. Floor tiles are extensively used in houses and industrial buildings. These are durable and impervious to water, resist abrasion well and wash easily. These are manufactured from a clay mass with or without admixtures of colouring impurities by moulding and subsequent burning until baked. The clay should be highly plastic with lean admixtures and fusing agents intended to lower the melting point.

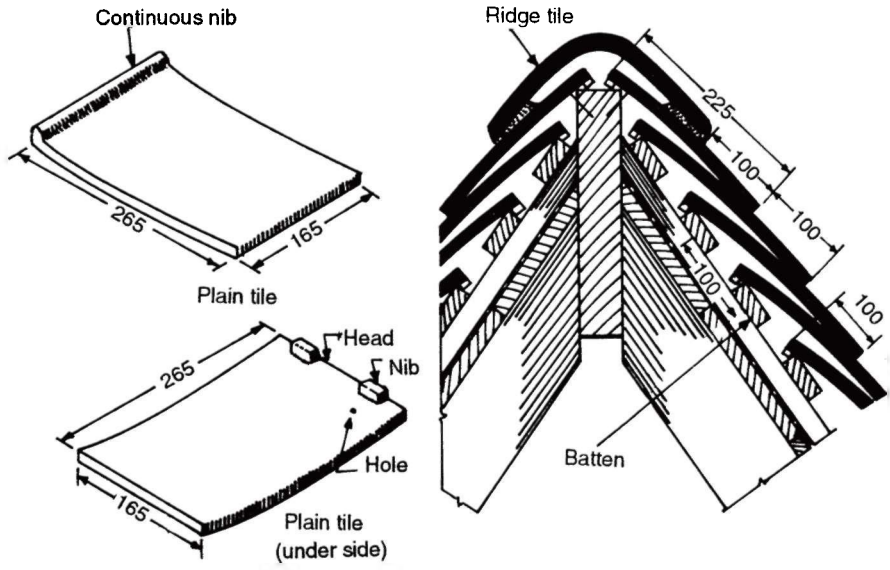


Fig 2.16 (a) Plain Tiling

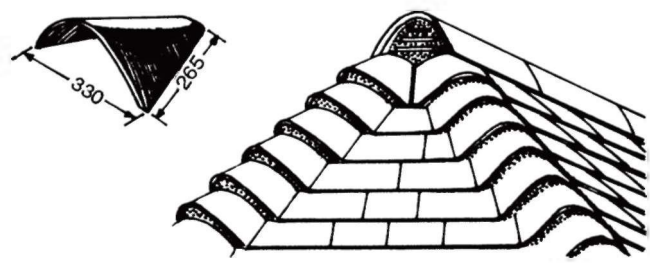
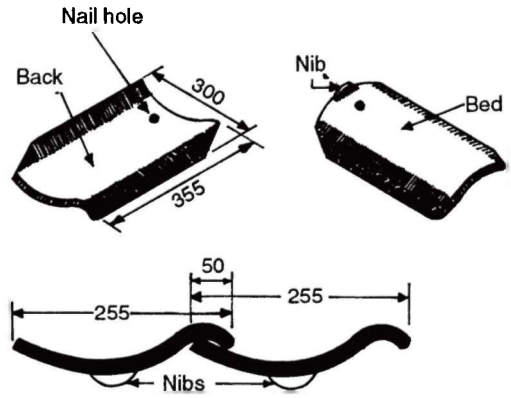


Fig. 2.16 (b) Hip Tiling



SECTION THROUGH TWO PAN TILES

Fig. 2.16 (c) Pan Tiles

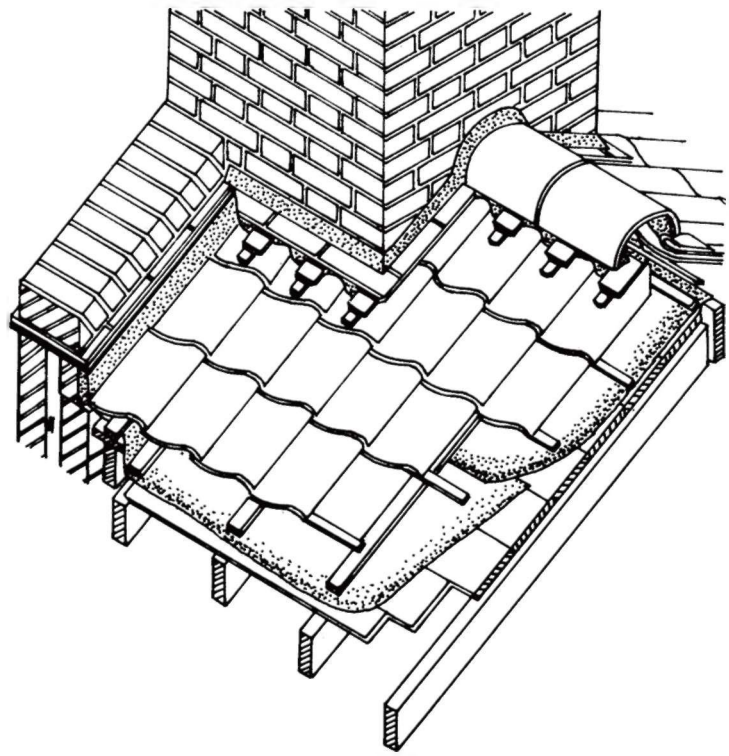


Fig. 2.16 (d) Pan Tiling

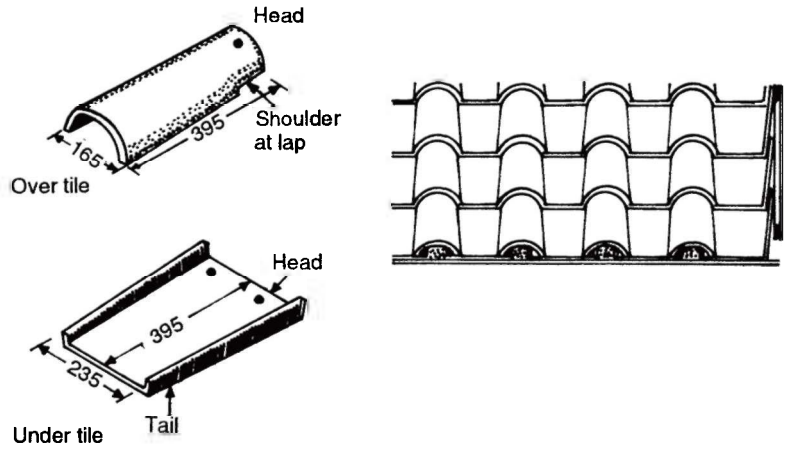


Fig. 2.16 (e) Spanish Tiling

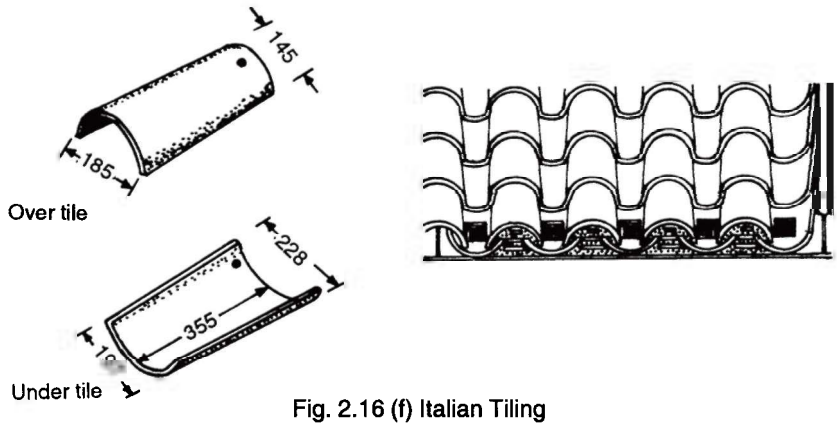


Fig. 2.16 (f) Italian Tiling

Manufacturing

Tiles are made in the same manner as bricks, but are thinner and lighter so require greater care. The burning of tiles is done up to 1300°C.

Characteristics

A good roofing tile should have the following properties:

1. uniform texture.
2. accurate size and shape.
3. free from defects like flaws, cracks and nonuniform burning.
4. water absorption (less than 15 per cent).
5. resistant to atmosphere and dampness.
6. durability.

Uses

They are used as roofing material for low cost houses in big cities and also used to give a pleasing look from architectural point of view.

Testing of Tiles

The plain, clay roofing tiles must comply with two tests — the transverse strength test and the water absorption test.

Transverse Strength Test consists of applying the load along the centre line at right angles to the length of the tile (which has been immersed in water for twenty four hours) supported on the rounded edges of wood bearers. Six tiles are tested and the average breaking load should not be less than 1.5 N/mm^2. Warpage of the tile should not be more than 1-2%.

Water Absorption Test Six tiles are dried in oven at 105± 5°C and cooled at the room temperature. They are then immersed in water for twenty four hours. Thereafter wiped dry and weighed.

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

where, W_1 and W_2 are the respective weights of dry and the immersed specimens.

2.18 FIRE-CLAY OR REFRACTORY CLAY

Fire-clay is a term, loosely applied, to include those sedimentary or residual clays which vitrify at a very high temperature and which, when so burnt, possess great resistance to heat.

These are pure hydrated silicates of alumina and contain a large proportion of silica 55-75%, alumina 20-35%, iron oxide 2-5% with about 1 per cent of lime, magnesia and alkalis. The greater the percentage of alumina, the more refractory the clay will be. Fire clays are capable of resisting very high temperatures up to 1700°C without melting or softening. The presence of a small percentage of lime and magnesia and alkalis help to melt the clay particles more firmly, whereas a large percentage of lime and magnesia tend to melt the clay at low temperatures. Iron oxide or other alkalis reduce refractory qualities of fire clay. The fire clay is used for manufacturing fire bricks used in furnance linings, hollow tiles, and crucibles.

2.19 FIRE-CLAY BRICKS OR REFRACTORY BRICKS

Fire-clay bricks are made from fire-clay. The process of manufacturing is as of an

ordinary brick, burnt at very high temperatures in special kilns (Hoffman's kiln).

Properties

1. The colour is whitish yellow or light brown.
2. The water absorption of fire-clay bricks varies from 4-10 %

Uses These are used for lining blast furnance, ovens, kilns, boilers and chimneys.

The principal varieties of fire-clay bricks are as follows:

Acid Refractory Bricks consist of silica bricks (95-97% silica and 1-2% lime) and ganister bricks (ganister—a hard coloured sand stone containing 10 per cent clay and 2 per cent of lime), used in lining furnaces having acidic slag, steel industry and coke oven.

Basic Refractory Bricks consist of magnesia bricks (magnesia 85 per cent, calcium oxide 25 per cent and silica 5.5 per cent) and bauxite bricks (85 per cent aluminium oxide and 20 per cent clay). These are highly resistant to corrosion and are used for lining furnances having basic slag.

Neutral Refractory Bricks consist of chromite bricks (50 per cent chrome and iron ore containing 30 per cent iron oxide and bauxite containing 15 per cent aluminium and 5 per cent silica), chrome magnesite bricks (Cr_2O_3 18 per cent, MgO 30 per cent), spinel and forsterite bricks. The neutral refractory bricks are suitable at places where acidic and basic linings are to be separated, e.g. for lining copper reverberatory furnance.

2.20 TERRACOTTA

It is an Italian word, *Terra* means clay and *Cotta* means burnt. Terracotta is refractory clay product and is used in ornamental parts of buildings. The clay used for its manufacture should be of superior quality and should have sufficient iron and alkaline matters. By varying iron oxide in clay, desired colour can be obtained. The clay is mixed with powdered glasses, pottery and sand ground to fine powder and pugged several times till it gets uniform and soft for moulding. Terracotta is impervious, hard and cheap. The product is burnt in special kilns (Muffle furnance).

Preparation of Clay The clay is mixed thoroughly with water in a tub. Powdered pottery, glass and white sand are added to it in sufficient proportions. It is then intimately mixed with spades. The intimate mix is then placed in wooden boxes with joints. This allows the surplus water to drain off. Thereafter the mix is passed several times through pug mills.

Moulding and Drying Special porous moulds are made of Plaster of Paris or

of zinc. The pugged clay is pressed into moulds. The dried articles are taken out of the moulds after a few days and then dried slowly.

Burning Terracotta is burned with care to get uniform colour in muffle furnance between 1100-1200°C.

Composition

Dry clay 50-60%	Ground glass 8-10%
Crushed pottery 20%	Clean white sand 10- 20%

Uses

1. Hollow blocks of terracotta are used for masonry.
2. Cornices and arches.
3. Statuettes.
4. Ornamental works.
5. Being fire proof, terracotta is most suitable as casing for steel columns and beams.
6. Porous terracotta is used for sound insulation.

Classification Terracotta is of two types, the porous and the polished (Faience).

Porous Terracotta It is manufactured by mixing sawdust or finely fragmented cork in the clay and has the following characteristics.

1. Light weight.
2. Resistant to weathering action.
3. Fire resistant.
4. Can be nailed and sawn to various shapes.
5. Sound proof.
6. Poor strength — used only for ornamental works.

Polished Terracotta is highly glazed architectural terracotta with relatively coarse body. The polished terracotta is also called *terracotta twice burnt*. The 1st burning is called *biscutting* and is done at 650°C. Then, this product is coated with glazed solution which imparts texture and colour. Thereafter it is dried and fired at 1200°C. The material

1. is hard, strong and durable.
2. can be given different colours.
3. is leak proof (water absorption < 12 per cent) and can be easily cleaned.
4. is resistant to chemical action.
5. is resistant to weathering action of atmosphere.
6. is fire proof.

2.21 PORCELAIN

A high grade ceramic ware having white colour, zero water absorption and glazed

surface which can be soft or hard, consists of finely dispersed clay, kaolin, quartz and felspar, baked at high temperature and covered with a coloured or transparent glaze. The glazing material applied before firing. At high temperatures, the felspar particles fuse and bind the other constituents into a hard, dense, and vitreous mass. High temperature ensures non-porosity and a better product. Because of white colour, it is also called *whiteware* which is of two types:

Soft Porcelain is made from white clay to which flint is added.

Hard Porcelain is made form china clay or kaolin with quartz and felspar are added as filler.

Composition

China clay	50-60%
Ordinary clay	5%
Whiting	< 1%
Felspar	20%

Characteristics

1. Low (zero) water absorption.
2. Hard and glazed.
3. Good refractory material.
4. Good electric insulator.

Uses sanitary wares, containers and crucibles, reactor chambers and electric insulators.

Note : A special type of porcelain known as Ziron Porcelain is used in automobile industry. Its composition is as follows:

Iron	60%
Clay	15-30%

2.22 STONEWARE

A hard ceramic material resembling porcelain with a different colour, usually grey or brownish is made from refractory clay mixed with crushed pottery, stones and sand burned at high temperatures and cooled slowly. The clay used for making stoneware consists of about 75 per cent silica and 25 per cent alumina. Iron oxide is added to give colour.

Characteristics

1. Hard, compact, strong and durable material.
2. Gives ringing sound when struck.
3. Glazed stoneware becomes resistant to chemical and weathering action.

4. Gives good finish and appearance.

Uses

1. Light sanitary wares, e.g. wash basins, water closets, etc.
2. Drain pipes and fittings.
3. Road paving materials.
4. Flooring tiles and wall tiles in toilets and kitchens.

2.23 EARTHENWARE

These are made by burning the ordinary clay at low temperature and cooling slowly. To check shrinkage, sand and crushed pottery are mixed with clay. This also increases the toughness, hardness and strength of the ware.

Characteristics

1. Soft, porous and weak.
2. Glazed earthenware becomes resistant to weathering action.

Uses Earthenware is used for manufacturing drain pipes, lavatory fittings and light weight partition walls.

2.24 MAJOLICA

It is Italian earthenware coated with an opaque white enamel, ornamented with metallic colour. Majolica has a microporous texture.

Uses It is used in doorways, window casings, and facing tiles.

2.25 GLAZING

Bricks, tiles, earthenwares and stonewares are glazed by an impervious film to protect the surface from chemical attack and other weathering agencies. The different types of glazing in use are as to follow.

Transparent Glazing

There are many methods for transparent glazing, but salt glazing is most commonly applied, since this makes the items impermeable. It consists of throwing sodium chloride in the kiln when burning is at peak (1200°-1300°C). The heat of the kiln volatises the salt, which enters into the pores of the burning item and combines with the silica in clay to make soda silicate. The soda silicate so formed combines with alumina, lime and iron in the clay to form a permanent thin, transparent surface coating.

Lead Glazing

Clay and clay items are burned thoroughly. The burned items are then dipped in a solution of lead oxide in admixture with kaolin, felspar and flint. The particles of lead and admixture adhere to the surface of clay items. After this, the articles are returned in potter's kiln where these adhered particles melt and form a thin transparent layer on the outer surface. This method of glazing is used for items of inferior clay which cannot withstand high temperature required for salt glazing.

Opaque Glazing

This is also known as *enamelling*. Borax, kaolin, chalk and colouring matter is fired with total or a part of felspar, flint, and lead oxide. The resulting molten glass is poured into water to give shattered frit. The frit is then ground with remaining materials and water and is made of the consistency of cream known as *slip*. Fully burnt earthenwares known as *biscuits* are dipped in the slip. The biscuits absorb water and form thin layer of glaze on the surfaces. After drying the products, these are once again fired to a lower temperature so as to fuse the glaze.

EXERCISES

Q.1 (a) What are the requirements of soil suitable for burning bricks ?
(b) How can good bricks be made from black cotton soil ?
(c) What are the substances which harm the qualities of good bricks, in their manufacture and as finished product.

Q.2 (a) Enumerate the chief characteristics of clay as material used for manufacture of bricks. Describe its behaviour under varying climatic conditions.

(b) Describe the qualities of first class building bricks and indicate how are they influenced by the
1. nature of clay used
2. process of manufacture
3. manner of firing

Q.3 (a) What are the properties of first class bricks ?
(b) Describe how bricks are classified ?
(c) What are the constituents of good brick-earth ?

Q.4 (a) Describe the common defects in bricks.

(b) What are the factors to be considered while selecting a site for the manufacture of bricks ?

Q.5 (a) What constituents render brick-earth unsuitable for manufacturing bricks?

(b) How does excess of each of the constituents of brick-earth affect the quality of bricks ?

Q.6 Differentiate between
(a) Perforated and hollow bricks.
(b) Acid refractory and basic refractory bricks.
(c) Over-burnt and under-burnt bricks.
(d) Earthenware and stoneware.
(e) Slop-moulded and sand-moulded bricks.

Q.7 (a) Describe the tests performed to check the quality of bricks.
(b) What do you understand by glazing ? How is it done ?

Q.8 Write short notes on:
(a) Clay Jallis (b) Defects in bricks
(c) Clamp burning of bricks (d) Glazing
(e) Efflorescence (f) Heavy duty bricks

Q.9 (a) What is a frog ? State its importance in clay bricks.
(b) What are the characteristics of good bricks ?

Q.10 Describe briefly the tests to which bricks may be put before using them for engineering purposes.

Q.11 What is efflorescence in bricks ? What are its causes and remedies ?

Q.12 (a) What are fire clays ? State there constituents and importance.

(b) Describe the process of manufacturing clay tiles.

Q.13 Write short notes on:

(a) Refractory bricks (b) Earthenware

(c) Majolica (d) Over-burnt bricks

Q.14 Sketch and state the uses of:

(a) Coping brick (b) Bull nose brick

(c) Perforated brick (d) Cornice brick

(e) Hollow brick (f) Queen closer

Q.15 Write short notes on:

(a) Paving bricks (b) Roofing tiles

(c) Terracotta (d) Faience

(e) Porcelain (f) Warpage test of bricks

(g) Majolica

Chapter

3

ROCKS AND STONES

3.1 INTRODUCTION

The history of mankind is supposed to have begun with the stone age marked by the use of implements and weapons made of stone. Prior to that, the difference between animals and homosapiens was largely physical. But once human beings started using stones, the world of both changed entirely.

Stone has been defined as the natural, hard substance formed from minerals and earth material which are present in rocks. Rock may be defined as the portion of the earth's crust having no definite shape and structure. Almost all rocks have a definite chemical composition and are made up of minerals and organic matter. Some of the rock-forming minerals are quartz, felspar, mica, dolomite, etc. The various types of rocks from which building stones are usually derived are granite, basalt, trap, marble, slate, sandstone and limestone.

Use of stone in building construction is traditional in the places where it is produced, although even there its high cost imposes limitations on its use. The

conditions which govern the selection of stone for structural purposes are cost, fashion, ornamental value and durability.

Stone has been used in the construction of most of the important structures since prehistoric age. Most of the forts world over, the Taj Mahal of India, the famous pyramids of Egypt and the great wall of China are but a few examples. Stone has also been extensively used in almost all the elements of building structures, as load carrying units as well as for enhancing the beauty and elegance of the structure. As building material stone has gradually lost importance with the advent of cement and steel. Secondly, the strength of the structural elements built with stones cannot be rationally analysed. Other major factors in overshadowing its use are the difficulties in its transportation and dressing which consume a lot of time resulting in slow pace of construction.

3.2 ROCK-FORMING MINERALS

Being aggregations of minerals, the properties of rocks are dependent upon the character of these constituents, identified by their physical properties such as hardness, cleavage, streak, colour, lustre, specific gravity and shape of crystals.

Some minerals feature great strength, hardness and resistance to chemical attack (quartz); others have poor strength and readily soak in water (gypsum); some minerals display a great tendency to cleavage and split readily along one or several directions (mica), thus decreasing the strength of the rock they make up. Some of the important properties of minerals are as follows:

Hardness is probably the most important property for rapid determination of minerals. It is measured by scratching the mineral with a series of substances of known variation in hardness using the following scale of Mohs:

Talc, easily scratched with the thumb-nail :	1
Gypsum, scratched by the thumb-nail :	2
Calcite, not scratched by thumb-nail but easily cut by knife :	3
Fluorite, can be cut by knife with greater difficulty than calcite :	4
Apatite, can be cut only with difficulty by knife :	5
Orthoclase, can be cut with knife with great difficulty on thin edges :	6
Quartz, not scratched by steel, scratches glass :	7
Topaz :	8
Sapphire :	9
Diamond :	10

If, for example, a given substance is scratched by fluorite and not by calcite its hardness is between 3 and 4.

Cleavage is the measure of the capability of some minerals to split along certain planes parallel to the crystal faces. The various types of cleavage seen in the

minerals are Basal, Prismatic, Cubic, Rhombohedral and Octahedral.

Streak is the colour of the mineral in powder-form. For some minerals, their colour is seen to be entirely different from that of their powder, which makes streak a useful property in the identification of ore-minerals. Streak can be readily observed by scratching it on a streak plate made of unglazed porcelain or roughened glass.

Colour is a valuable characteristic of metallic minerals, but less reliable for non-metallic minerals.

Lustre is shine on the surface of a mineral and its appearance under reflected light classified as vitreous (glassy), greasy, pearly, resinous, dull, silky and metallic.

Crystal The crystal form is of importance when a mineral has had the opportunity to develop its natural shape. This is not the normal condition in rock structure.

The most common mineral constituents of building stones together with their chemical composition and important physical properties are listed in Table 3.1.

3.3 CLASSIFICATION OF ROCKS

The rocks may be classified on the basis of their geological formation, physical characteristics and chemical composition as shown in Fig. 3.1.

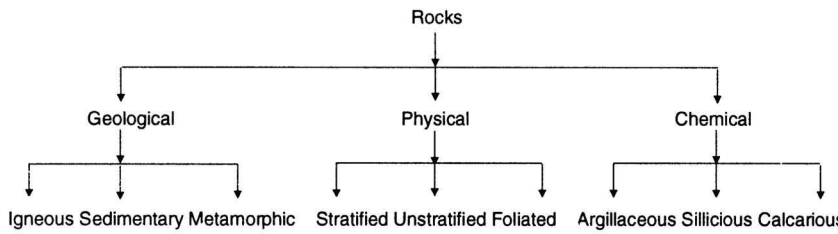


Fig. 3.1 Classification of Rocks

Based on Geological Formation

This classification is based upon the mode of the formation. The rock cycle is shown in Fig. 3.2. On the basis of geological classification, rocks are classified as igneous, sedimentary and metamorphic.

Igneous Rocks also known as *primary*, *unstratified* or *eruptive* rocks are of volcanic origin and are formed as a result of solidification of molten mass lying below or above the earth's surface. The inner layers of the earth are at a very high temperature causing the masses of silicates to melt. This molten mass called *magma* is forced up as volcanic eruptions and spreads over the surface of earth

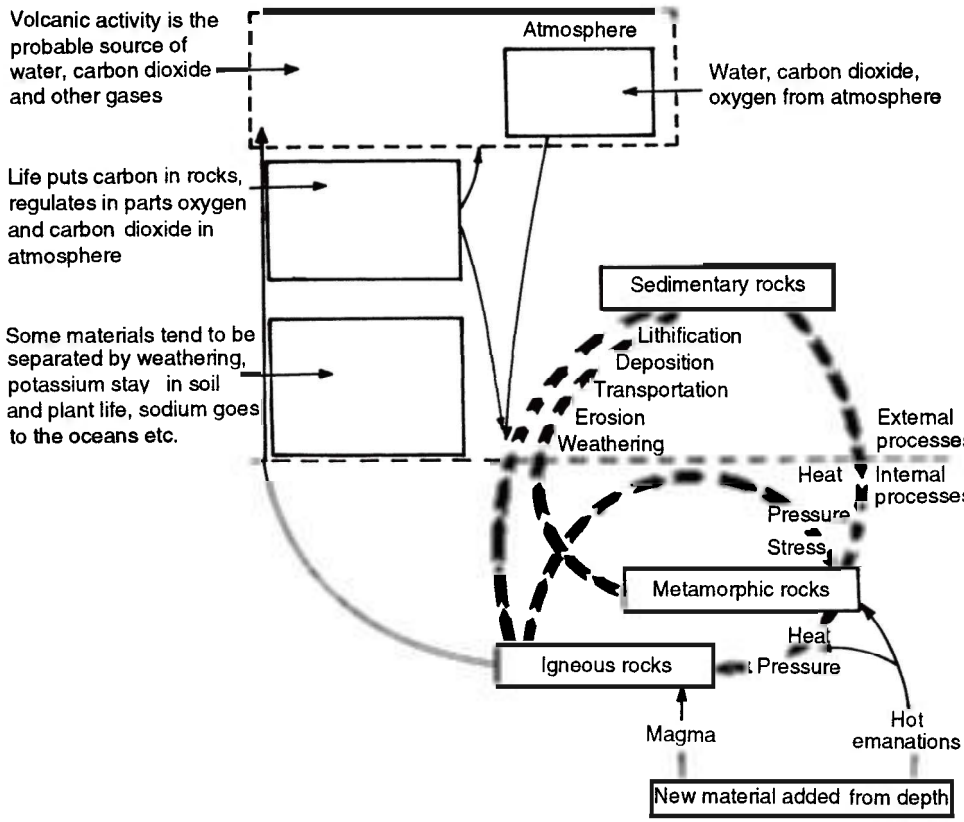


Fig. 3.2 The Rock Cycle

where it solidifies forming basalt and trap. These are known as *effusive* rocks. If the magma solidifies below the earth's surface itself, the solid crystalline rock is termed as *deep-seated plutonic* rock. The examples are granite, syenite, diorite and gabbro. If the magma solidifies at a relatively shallow depth, the resultant rock possesses a finely grained crystalline structure — and is termed as *hypabyssal*. Dolerite is such a rock. The principal constituents of magma are quartz, mica and felspar. The texture of the rock is greatly influenced by the rate of cooling of the

Table 3.1 Chemical Composition and Physical Properties

S.No.	Properties Mineral	Chemical Composition	Hardness (Mohs scale)	Specific Gravity
1.	Quartz	Silicon dioxide (SiO_2)	7	2.60-2.64
2.	Felspar	Alumonio silicates with potas (orthoclase) Example $K_2O \cdot Al_2O_3 \cdot 6SiO_2$	6	2.50-2.60
		Alumino silicates with soda (plagioclase) Examples $Na_2O \cdot Al_2O_3 \cdot 6SiO_2$ $CaO \cdot Al_2O_3 \cdot 2SiO_2$		2.60-2.80
3.	Mica	Silicates of alumina with hydrogen (hydrus alumino silicate) and potash (Muscovite) $KAl_2 (AlSi_3O_{10}) (OH)_2$	2-3	2.70-3.00
		Silicates of alumina with hydrogen (hydrous alumino silicates) iron and magnesia (Biotite) $K (Mg, Fe)_3 (AlSi_3O_{10}) (OH)_2$		2.80-3.10
4.	Amphibole	Silicate of iron, lime, magnesia or alumina (Hornblende) $(Ca\text{-}Na)_{2\text{-}3} (Mg, Fe, Al)_5 Si_6 (SiAl)_2 O_{22} (OH)_2$	5-6	2.9-3.5
		Silicates of lime and magnesia (Tremolite) $CaMg_5Si_8O_{22}(OH)_2$		2.90-3.20
5.	Pyroxene	Silicates of lime, alumina, magnesia and iron (Augite) $X_2Si_2O_6$	5-6	3.20-3.60

Streak	Colour	Lusture	Cleavage	Durability
	Colourless, white to grey, sometimes brown to black	Vitreous	No cleavage (Perfect)	Soluble in hydrofluoric acid, weathers well
White			Straight splitting	
Grey to white	Deep to whitish pink	Vitreous to pearly	Oblique splitting materials	Less durable than quartz
	Colourless or grey to brown	Vitreous to pearly transparent	Can be split along one plane into very thin tough plates	Does not weather well
Colourless to grey	Brown to black	Vitreous to pearly opaque	No cleavage	Does not weather well
	Dark green to black	Vitreous	Perfect on two planes 124°, but do not seperate and flake like mica	Weathers fairly well Weathers poorly
Uncoloured grey or brown	White to grey	Vitreous to silky		
	Green to black		Good on two planes 93° apart	Weathers fairly well

6.	Olivine	Silicate of iron and magnesia $(Mg, Fe)_2 SiO_4$	6-5.7	3.20-3.60
7.	Chlorates	Aluminium silicates with iron and magnesia $(Mg, Fe, Al)_6 (Al, Si)_4 O_{10} (OH)_8$	2-2.5	2.65-2.95
8.	Garnet	Silicates of iron and alumina $X_3Y_2 (SiO_4)_3$	6.5-7.5	3.5-4.3
9.	Serpentine	Hydrous silicate of magnesia $Mg_3Si_2O_5 (OH)_4$	4.00	2.30-2.60
10	Talc	Hydrous silicate of magnesia $Mg_3Si_4O_{10} (OH)_2$	1.5	2.70-2.80
11.	Calcite	Calcium carbonate CaCO3	3	2.70
12	Dolomite	Calcium magnesium carbonate $MgCO_3 CaCO_3$	3.5-4	2.85
13.	Gypsum	Hydrous calcium sulphate $CaSO_4 2H_2O$	2	2.30-2.40
14.	Limonite	Hydrous sesquioxide of iron	5-5.5	3.60-4.00
15.	Magnetite	Ferrous and Feric oxide of iron Fe_3O_4	5.5-6.5	4.40-5.20
16	Pyrite	Iron disulphide FeS_2	6-6.5	4.90-5.20

No streak	Greenish	Vitreous	Indistinct	Weathers poorly
White to green	Greenish	Vitreous to pearly	No cleavage	
No	Red	Viterous	Poor	Renders stone difficult to dress and polish
White	Greenish	Greasy		Soluble in hydrochloric acid and weathers poorly
	White to green	Pearly	Splits into thin brittle plates	Weathering results in serpentine
No streak	White when pure	Vitreous	Perfect in three directions	Effervesces in dilute cold hydrochloric acid, not durable
Pink and white		Vitreous to pearly	Perfect	Effervesces in hot dilute hydrochloric acid, not very durable
White	Colourless white	Vitreous, pearly or silky	Perfect in one plane	Soluble in hydrochloric acid and slightly in water
Yellowish brown	Yellow to dark	Dull		No cleavage soluble in hydrochloric acid
Black	Black	Metallic	Indistinct	Slowly soluble in hydrochloric acid
Green to black	Brassy yellow	Metallic	No cleavage	Oxidises readily when exposed to weather

magma. The classification of igneous rocks on the basis of silica content is as in Table 3.2.

Table 3.2 Classification of Igneous Rocks

Type	% of Silica	Example
Acid rocks	70 - 80	Granite, rhyolite
Intermediate rocks	60 - 70	Syenite, andesite
Basic rocks	45 - 60	Gabbro and some varieties of dolerite
Ultra-basic rocks	30 - 45	Peridotite and some varieties of basalt and dolerite

Notes : (i) When magma cools rapidly, its mass expands under the pressure of intensively evolving gases. Subsequent rapid cooling of swollen lumps of magma gives rise to glassy porous rock known as pumice used as aggregate for light weight concrete, as heat insulating material and as an active mineral admixture to lime and cements.

(ii) During volcanic eruptions, ashes and sands are mixed with molten lava to form tuff lava. Cemented tuff lava is called volcanic tuff. Tuffs have a glassy structure due to rapid cooling and are used as aggregate for light weight concrete and mortar, and as an active admixture to air-setting lime or cement.

Sedimentary Rocks are also known as *aqueous* or *stratified* rocks. The various weathering agencies, e.g. rain, sun, air, frost, etc. break up the surface of earth. Rain water carries down these broken pieces to the rivers. As the rivers descend down to the plains, the velocity decreases gradually and the sediments (disintegrated rock pieces, sand, silt, clay, debris, etc.) in the water settle. Due to the seasonal variation, sedimentation takes place in layers. With time, the sediments get consolidated in horizontal beds due to the pressure exerted by overlying material.

The properties of the sedimentary rocks vary considerably depending upon the nature of the sediment and type of bond between the sediment and grains. Usually, the rocks are well stratified and show well defined bedding planes. The rocks are soft and can be easily split up along the bedding as well as normal planes. The examples of sedimentary rocks resulting from the precipitation of salts in drying water basin (chemical deposits) are gypsum, anhydrite, magnesite, dolomite, lime tufas. Sedimentary rocks resulting from the accumulation of plant or animal remains (organogenous rocks) are limestone, shale, chalk, diatomite and tripoli. The examples of rocks resulting from the deterioration of massive magmatic or sedimentary rocks (fragmental rocks) are sandstone, sand, gravel, carbonate conglomerate and breccia.

Metamorphic Rocks are formed from igneous or sedimentary rocks as a result of the action of the earth movements, temperature changes, liquid pressures, etc. The resultant mass may have a foliated structure, e.g. slate, gneiss, schist and phyallite or non-foliated structure, e.g. marble, quartzite and serpentine. Examples

of transformation of some of the rocks to metamorphic rocks are given in Table 3.3.

Table 3.3 Examples of Transformation of Rocks

S. No.	Original rock	Metamorphic rock
1.	Granite	Gneiss
2.	Syenite	Gneiss
3.	Sandstone	Quartzite
4.	Limestone	Marble, Schist
5.	Marl	Marble
6.	Shale	Slate, schist, phyallite
7.	Mudstone	Slate
8.	Dolomite	Marble
9.	Dolerite, basalt	Schist
10.	Felsite, tuff	Schist, slate
11.	Conglomerate	Gneiss, schist

Based on Physical Characteristics

The rocks may be classified as stratified, unstratified and foliated.

Stratified Rocks show distinct layers along which the rocks can be split. The examples are sandstone, limestone, shale, slate, marble,etc.

Unstratified Rocks do not show any stratification and cannot be easily split into thin layers. The examples of such rocks are granite, basalt, trap, etc.

Foliated Rocks rocks have a tendency to split up only in a definite direction. Most of the metamorphic rocks have a foliated structure, except for quartzite and marble which have granulose structure.

Based on Chemical Characteristics

The rocks may be classified as argillaceous, silicious and calcarious.

Argillaceous The principal constituent is clay (Al_2O_3). The rocks are hard and brittle, e.g. slate, laterite, etc.

Silicious The principal constituent is silica (SiO_2), i.e. sand. The rocks are very hard and durable, e.g. granite, basalt, trap, quartzite, gneiss, syenite, etc.

Calcarious The principal constituent is lime, e.g. limestone, marble, dolomite, etc.

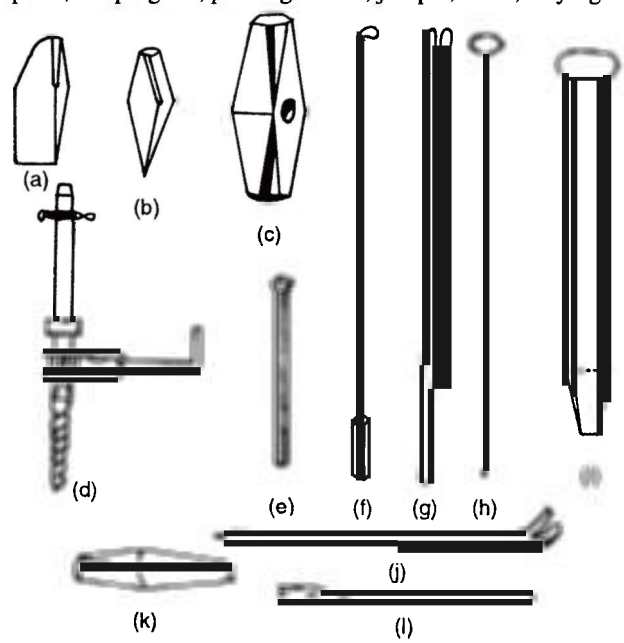
3.4 QUARRYING OF STONES

The only operation involved in the production of natural stone is the quarrying process. The open part of the natural rock from which useful stone is obtained is

known as *quarry*. While selecting a quarry site, the points to be borne in mind are availability of sufficient quantity of the stone of desired quality, proper transportation facilities, cheap local labour, problems associated with drainage of rain water, location of important and permanent structures in the vicinity and site for dumping refuse.

Stone Quarrying Tools

Some of the quarrying tools as shown in Fig. 3.3 are wedge, pin, hammer, dipper or scraping spoon, tamping bar, priming needle, jumper, borer, claying iron, crow bar.



(a) Wedge
(b) Pin
(c) Hammer
(d) Ratchet boring machine
(e) Drill
(f) Dipper
(g) Tamping bar
(h) Priming needle
(i) Jumper
(j) Crow bar
(k) Chisel pointed wedge
(l) Claying iron

Fig. 3.3 Tools for Quarrying Stones

Methods of Quarrying

Rocks suitable for the manufacture of stone materials are called *useful minerals* and the operations involved in obtaining minerals are called *mining*. In the process of mining, voids formed are called *excavations*, and the mined deposits are the

quarries. The purpose of quarrying is to obtain stones for various engineering purposes. A knowledge of various quarrying methods is essential but does not make one very much more competent to choose or specify a stone for building work. Depending upon the nature and surface of rocks and the purpose for which stones are needed, quarrying is done by excavating, wedging, heating or blasting.

Excavating Stones buried in earth or under loose overburden are excavated with pick axes, crow bars, chisels, hammers, etc.

Wedging This method of quarrying is suitable for costly, soft and stratified rocks such as sandstone, limestone, laterite, marble and slate.

About 10 -15 cm deep holes, at around 10 cm spacing, are made vertically in the rock. Steel pins or plugs (conical wedges) and feathers (flat wedges) as shown in Fig. 3.4 are inserted in them. These plugs are then struck simultaneously with sledge hammer. The latter arrangement of plugs and feather is better, since the rock slab splits along the lines of holes. In case of soft rocks, dry wooden pegs are hammered in the holes and water is poured over them. The pegs being wet swell and exert pressure causing the rocks to crack along the line of holes. Then, the

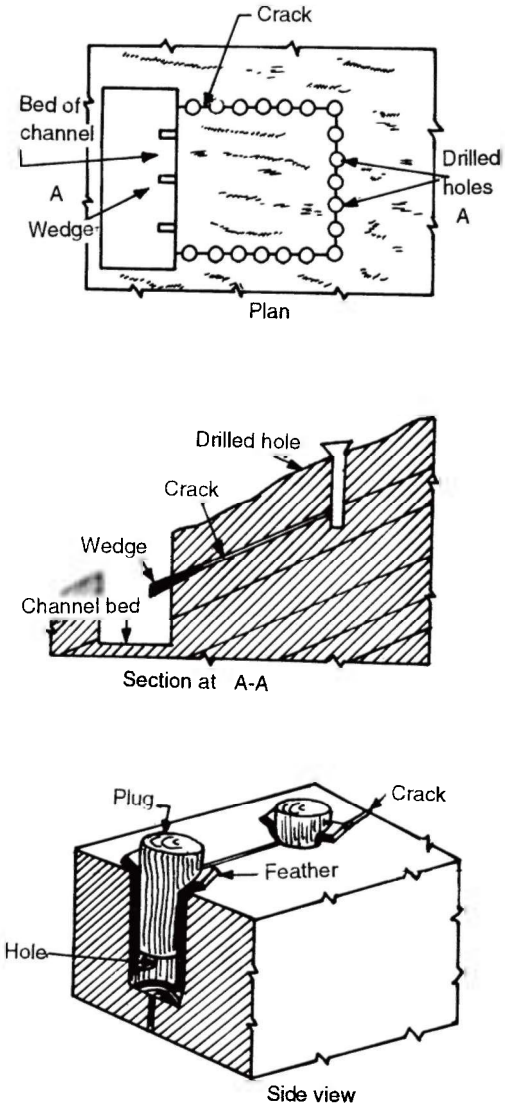


Fig. 3.4 Quarrying by Wedging

wedges are placed on the plane of cleavage (the joint of two layers) on the exposed face of rock and are hammered. The slab is completely detached and taken out with the help of crow bars and rollers. In this method, the wastage is minimum and the slabs of required size and shape can be quarried. This method is used to mine marble.

Heating is most suitable for quarrying small, thin and regular blocks of stones from rocks, such as granite and gneiss. A heap of fuel is piled and fired on the surface of rock in small area. The two consecutive layers of the rock separate because of uneven expansion of the two layers. The loosened rock portions are broken into pieces of desired size and are removed with the help of pick-axes and crow-bars. Stone blocks so obtained are very suitable for coarse rubble masonry. Sometimes, intermediate layers are to be separated from the top and bottom layers. In such a case, the intermediate layer is heated electrically and the expansion separates it from the other two.

Blasting Explosives such as blasting powder, blasting cotton, dynamite and cordite are used. The operations involved are boring, charging, tamping and firing.

Boring Holes are drilled or bored in the rock to be dislodged. For vertical holes, jumper is used whereas for inclined or horizontal holes, boring bars are used. One person holds the jumper exactly in the place where hole is to be made. The other person strikes it up and down and rotates it simultaneously. Water is poured in the hole regularly during the operation to soften the rock and facilitate drilling. The muddy paste generated in the process is removed from holes by scrapping. For hard rocks, machine drilling is employed instead of hand drilling.

Charging The holes are dried completely and the required amount of charge is placed in the holes. For drying the holes, rag is tied in the scrapper and is moved in the hole from where it absorbs the moisture, if any. In case it is found that water is oozing into the hole, water-tightness is ensured inside the hole.

Tamping After placing the charge in the hole, a greased priming needle, projecting a little outside the hole, is placed in the hole which is then filled up with damp clay or stone dust in layers tamped sufficiently with a braced tamping rod. The priming needle should be kept on rotating while tamping is going on. This is done so that the needle remains loose in the hole. The priming needle is then taken out and 60 to 75 per cent of space created by withdrawal of needle is filled with gun powder. A Bickford fuse, a small rope of cotton coated with tar, is placed just touching the needle. The other end of the fuse is kept of sufficient length so that the person igniting it can move away to a safe place. Blasting powder and cordite are ignited by means of a fuse, whereas gun cotton and dynamite are exploded by detonation.

Notes: (i) Detonation is achieved with detonators. These are copper tubes about 5 mm in diameter and 25 mm long containing 5 to 20 grains of fulminate of mercury.

These can be exploded by an ordinary fuse or by an electric current. An electric detonator is shown in Fig. 3.5.

(ii) Tamping should be done very carefully otherwise the explosive fires back in the hole, since the line of least resistance (LLR) is the shortest distance (Fig. 3.6) from the explosive in the hole to the nearest rock face, fissure, crack, fault or plane of cleavage.

Precautions in Blasting Accidents may take place during blasting. Following are some of the points which should be taken note of:

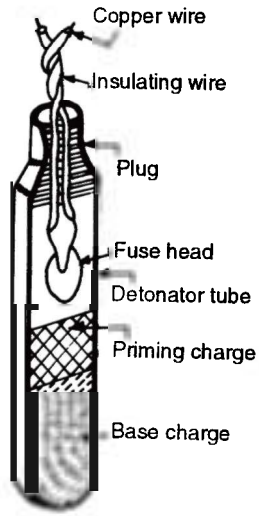


Fig. 3.5 Electrical Detonator

1. Blasting should not be carried out in late evening or early morning hours. The blasting hours should be made public and a siren should warn the workmen and nearby public timely to retire to a safe distance.

2. The danger zone, an area of about 200 m radius, should be marked with red flags.

3. First aid should be available.

4. The number of charges fired, the number of charges exploded and the misfires should be recorded.

5. Explosives should be stored and handled carefully.

6. Detonators and explosives should

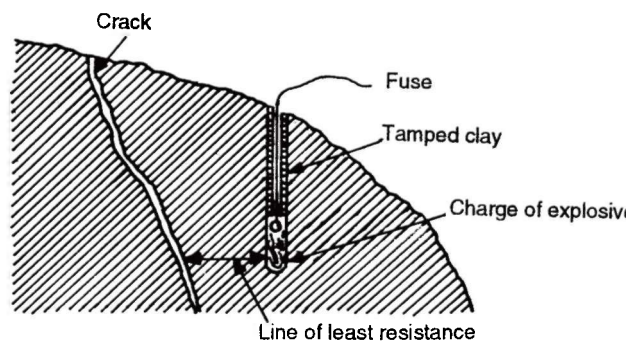


Fig. 3.6 Tamped and Charged Blast Hole

not be kept together.

7. Cartridges should be handled with rubber or polythene gloves.
8. A maximum of 10 bore holes are exploded at a time and that also successively and not simultaneously.

Explosives Used in Quarrying The composition and characteristics of the various blasting-powders and their suitability are given in Table 3.4.

Storage of Explosives The explosives should be stored in a magazine (a special type of building) which should be away from residential areas, petrol depots, etc. The magazine should have ventilators at high levels and should have concealed wiring. It should be protected from lightning. Smoke or fire should not be allowed in the nearby area. Explosives should be protected from extreme heat or cold and also from moisture. They should be handled carefully and gently. The magazine should be surrounded by barbed wire and the entry should be restricted.

Quantity of Explosive Required The quantity of explosive required depends upon several factors such as strength of explosive; method of blasting; number of bore holes—their size, position, etc. and the type and mass of rock to be dislodged. It is very difficult to incorporate all the factors in an expression and obtain the exact amount of explosive required. A rough estimate can be made by:

$$A = \frac{L^2}{0.008}$$

where A = quantity of gunpowder or dynamite (g)

L = length of line of least resistance (m)

3.5 NATURAL BED OF STONE

It is the original bed, plane or position occupied by a stone during its formation in a sedimentary rock. The stones should be so placed that the load line is at right angles to the natural bed. In the case of metamorphic rocks, the plane of foliation or the plane of cleavage is assumed to be its natural bed. It is very difficult to trace the natural bed in the case of igneous rocks and the natural bed is not given due attention. The right placement of stones with regard to the load line is shown in Fig. 3.7 for a few cases.

3.6 SEASONING OF STONE

A freshly cut stone carries some natural moisture known as *quarry sap* making it soft and workable. The quarry sap is a mineral solution and reacts chemically with the mineral constituents when the stone is exposed to atmosphere after quarrying. The stone becomes harder and compact. The process takes about 6 to 12 months

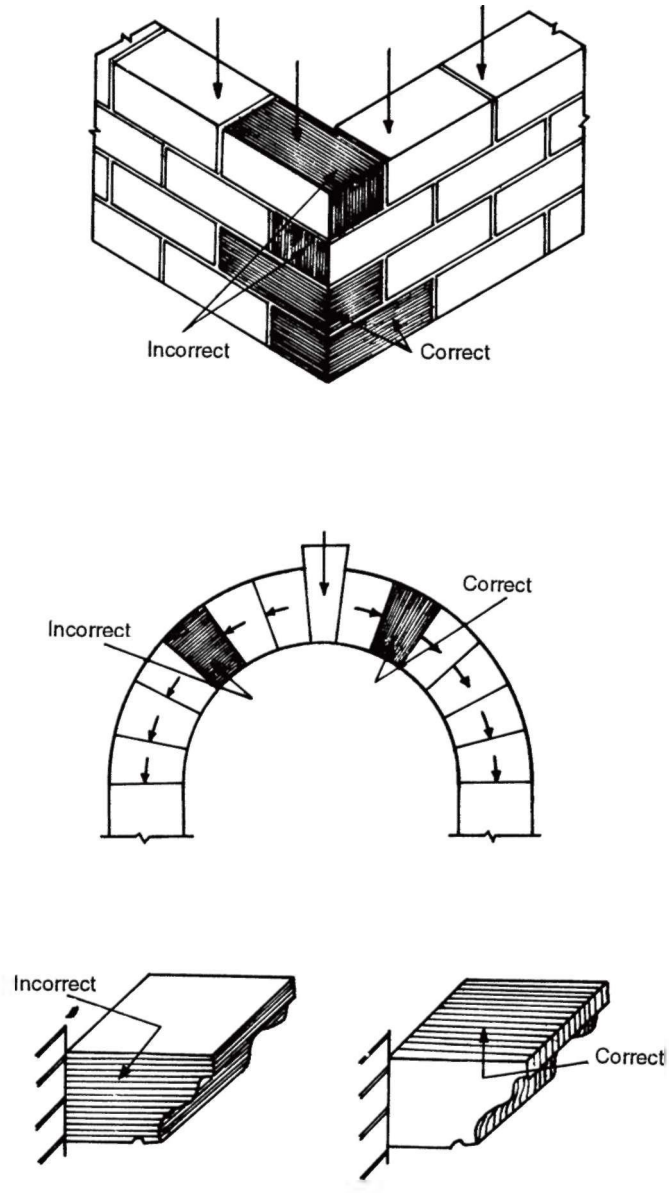


Fig. 3.7 Position of Natural Bed of Stones in Structures

e 3.4 Composition and Characteristic of Explosives

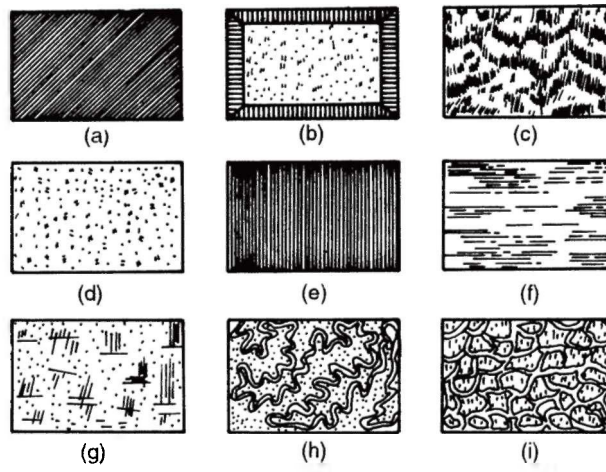
.	Types of explosive	Composition	Characteristics	Suitability
	Blasting powder or gun powder	Saltpetre 65 % Sulphur 15 % Charcoal 20%	1. It has great lifting powder but a little shattering effect. 2. It is easily ignited. 3. It is cheap.	1. In quarrying large blocks.
	Blasting cotton or gun cotton	It is cotton saturated with nitric acid	1. When dry, it is highly inflammable. 2. It can detonate by a shock or even by sun light. 3. It has good shattering effect but no lifting power.	1. Used where demolitions are required.
	Dynamite	It is 75 per cent nitro-glycerine absorbed in 25 per cent sandy earth or solids.	1. It is sensitive to friction and shock. 2. It is the most shattering and powerful explosive. 3. It is unsuitable in cold climates. 4. Specific gravity 1.4.	1. In small bore holes. 2. In small quarries 3. In damp situations, small bore holes.
	Cordite	It is gelatenized combination of nitroglycerine and nitrocellulose.	1. It is smokeless explosive and produces powerful gases. 2. It is similar to dynamite.	1. Under water.
	Gelatine dynamite	It is 80 per cent of blasting gelatine with nitrate of potash and wood pulp.	1. It is tough, rubber textured explosive. 2. It is the most powerful nitroglycerine explosive. 3. Very high water resistance 4. High plasticity 5. Specific gravity 1.5	1. In deep wells 2. Underground works 3. In wet conditions

6.	Gelignite	It is 65 per cent of blasting gelatine and 35 per cent of absorbing powder.	1. It is a powerful explosive. 2. It can be handled more conveniently than dynamite.	1. Under water
7.	Lithofracteor	Nitroglycerine 33 % Nitrate of baryata 16 % Sulphur 26 % Kieselguhr 22% Charcoal 3 %	1. Similar to dynamite but has less power.	1. In tunnels
8.	Rock-a-Rock	Potassium chlorate 79 % Nitrobenzol 21 %	1. High water resistance	1. Most effective under water

for complete seasoning. When the quarry sap evaporates, it leaves a crystalline film on the faces of the stone and makes them weather resistant. The dressing before seasoning improves the weather resistance. As such, the dressing, carving and moulding, etc. should be done as early after quarrying as possible.

3.7 DRESSING OF STONE

A quarried stone has rough surfaces, which are dressed to obtain a definite and regular shape. Dressing of stones is done immediately after quarrying and before seasoning to achieve less weight for transportation, pleasing appearance, proper bedding with good mortar joints, special shapes for arches, copings, pillars, etc. The various types of dressed stones are shown in Fig. 3.8.

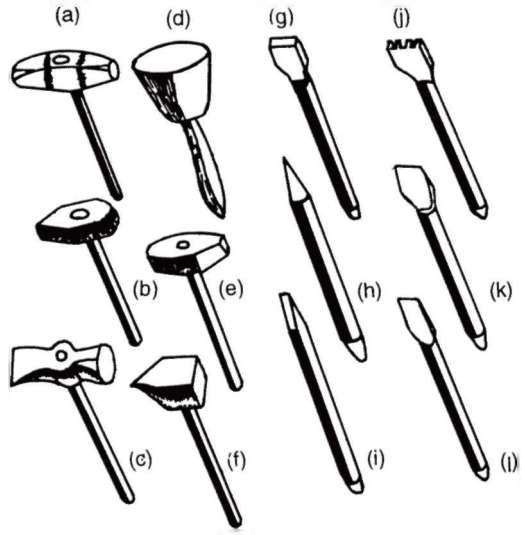


(a) Stroked
(b) Punched
(c) Rock faced
(d) Sparrow picked
(e) Tooled
(f) Sawn
(g) Combed
(h) Vermiculated
(i) Reticulated

Fig. 3.8 Dressed Stone Surfaces

Stone Dressing Tools

The dressing tools are shown in Fig. 3.9. They are wedge, pitching tool, boaster, scabbing hammer, mash hammer, separated pick, punch, scabbing pick, crow bar, axe punch, dressing knife, splitting chisel.



(a) Mash hammer
(b) Face hammer
(c) Mason's hammer
(d) Mallet
(e) Spalling hammer
(f) Scabbling hammer
(g) Drafting chisel
(h) Point chisel
(i) Punch chisel
(j) Crow chisel
(k) Soft stone chisel
(l) Plane chisel

Fig. 3.9 Tools for Cutting and Dressing Stones

3.8 USES OF STONES

Use of stone as building material depends upon the nature of the work, type of the structural element in which it is to be used and its quality, availability and transportation cost. For structural purpose, granite, gneiss, trap, sandstone, limestone, marble, quartzite and slate are most useful.

On the basis of the method of manufacture, items and materials from natural stones are classified as Sawn — obtained either from massive rocks by stone-cutting and stone-splitting machines (large stones) or from semi-product blocks by appropriate working (facing slabs, windows sill slabs, etc.); Split — obtained by splitting and finishing blocks (curb stones, paving blocks, etc.); Roughly split — manufactured by oriented splitting of blocks (bedded stone); Fractured — produced by blasting rocks and separating finer sizes (quarry stone); Crushed — produced by crushing and screening (crushed stone, artificial sand) and; Ground — obtained by grinding rocks (ground mineral powder, stone powder).

Foundation and Wall Items Quarry, split and sawn stones from rocks are used to erect the substructure of buildings. Piece stones sawn and split from limestone, sandstone, dolomite and volcanic tuff are used for walls, piers, abutments, etc.

Facing and Architectural Items Facing slabs and stones, stairs and landings, parapets, etc. are made of slabs sawn or split from semi-finished product blocks with glossy, dull, ground, sawn, pointed, fluted or rock finish. Facing slabs of granite, gabbro, basalt, marble, breccia, limestone, sandstone and volcanic tuff are generally used.

Building Items Elements of stairs, landings, parapets and guard rails are manufactured from granite, marble, limestone, tuff, etc. Pedestal slabs and stones for farming doorways, cornices and window-sill slabs are made from the same material as the facing slabs.

Road Construction Items Curb stones — intended to separate roadways from sidewalks; Paving blocks — used for pavements; Cobble stone — used to reinforce slopes of earth works and banks of water basins; Crushed stone — a mixture of jagged stone fragments (< 70 mm); Gravel — loose agglomeration of rock fragments (70 mm) and Sand — loose mass of mineral and rock particles (0.14-5 mm) obtained from natural stone are used in road construction.

Underground Structures and Bridges are built of slabs and stones from igneous and sedimentary rocks. Tunnels and above-water elements of bridges are built of granite, diorite, gabbro and basalt. Face stones and facing slabs for tunnels and bridges are given rock face, grooved or fluted finishes.

Heat and Chemically Resistant Items are manufactured from non-weathered rocks. For high temperature working conditions, they are made from chromite, basalt, andesite and tuffs. Building elements are protected against acid (except hydrofluoric acid and fluosilicic acids) by using slabs made of granite, syenite, and silicious stones. Limestones, dolomites, marble and magnesite show excellent resistance against alkalis. When high temperature and chemical attack is expected, crushed stone and sand for concrete and mortar are used.

3.9 CHARACTERISTICS OF GOOD BUILDING STONE

A good building stone should have the following qualities.

Appearance For face work it should have fine, compact texture; light-coloured stone is preferred as it is more durable.

Structure A broken stone should not be dull in appearance and should have uniform texture free from cavities, cracks, and patches of loose or soft material. Stratifications should not be visible to naked eye.

Strength A stone should be strong and durable to withstand the disintegrating action of weather.

Weight It is an indication of the porosity and density. For stability of structures such as dams, retaining walls, etc. heavier stones are required, whereas for arches,

vaults, domes, etc. light stones may be the choice.

Hardness This property is important for floors, pavements, aprons of bridges, etc. The hardness is determined by the Mohs scale (Section 3.2).

Toughness The measure of impact that a stone can withstand is defined as toughness. The stone used should be tough when vibratory or moving loads are anticipated.

Porosity and Absorption Porosity depends on the mineral constituents, cooling time and structural formation. A porous stone disintegrates as the absorbed rain water freezes, expands, and causes cracking. Permissible water absorption for some of the stones is given in Table 3.5.

Table 3.5 24 Hours Water Absorption of Stones by Volume

S.No.	Types of stone	Water absorption (% not greater than)
1.	Sandstone	10
2.	Limestone	10
3.	Granite	1
4.	Trap	6
5.	Shale	10
6.	Gneiss	1
7.	Slate	1
8.	Quartzite	3

Seasoning The stone should be well seasoned.

Weathering The resistance of stone against the wear and tear due to natural agencies should be high.

Workability Stone should be workable so that cutting, dressing and bringing it out in the required shape and size may not be uneconomical.

Fire Resistance Stones should be free from calcium corbonate, oxides of iron, and minerals having different coefficients of thermal expansion. Igneous rock show marked disintegration principally because of quartz which disintegrates into small particles at a temperature of about 575°C. Limestone, however, can withstand a little higher temperature; i.e. up to 800°C after which they disintegrate.

Specific Gravity The specific gravity of most of the stones lies between 2.3 to 2.5.

Thermal Movement Thermal movements alone are usually not troublesome. However, joints in coping and parapets open-out inletting the rain water causing trouble. Marble slabs show a distinct distortion when subjected to heat. An exposure of one side of marble slab to heat may cause that side to expand and the slab warps. On cooling, the slab does not go back to its original shape.

3.10 TESTING OF STONES

Building stones are available in large quantity in various parts of the country and to choose and utilize them for their satisfactory performance, it is necessary to test the stone for its strength properties, durability and quality.

Durability Test

Some of the tests to check the durability of stone are as follows.

Smith Test Break off the freshly quarried stone chippings to about the size of a rupee coin and put them in a glass of clean water, one-third full. If the water becomes slightly cloudy, the stone is good and durable. If water becomes dirty, it indicates that the stone contains too much of earthy and mineral matter.

Brard's Test — *for frost resistance* — Few small pieces of freshly quarried stone are immersed in boiling solution of sulphate of soda (Glauber's salt) and are weighed. These are then removed and kept suspended for few days and weighed again. The loss in weight indicates the probable effect of frost.

Acid Test — *to check weather resistance* — confirms the power of stones to withstand the atmospheric conditions. 100 g of stone chips are kept in a 5 per cent solution of H_2SO_4 or HCl for 3 days. Then the chips are taken out and dried. The sharp and firm corners and edges are indication of sound stone.

Crystallisation Test Four 50 mm cubes or cylinders of 50 mm diameter and 50 mm height are dried for 3 days and are weighed. The cubes are suspended in 14 per cent sodium sulphate solution (density 1.055 kg/m^3) for four hours at room temperature (27°± 2°C).The specimens are then taken out of the solution and kept in air for thirty minutes. They are then oven dried at a temperature of 105°C for 24 hours. This process is repeated five times. The specimens are weighed and the difference in weight is found. This test is repeated thirty times and the loss in weight after thirty repetitions is obtained. The change in weight indicates the degree of decay of stone.

Crushing Test

Compressive Strength Test To test stone for compressive strength, specimen pieces in the form of cubes or cylinders are made from samples of rock. The lateral dimension or diameter of test piece should not be less than 40 mm and the ratio of height to diameter or lateral dimension should be 1:1. A minimum of three specimen pieces are tested.

The specimen pieces of diameter or lateral dimension 40 mm are immersed in water at 20 to 30°C for 72 hours and are tested in saturated condition. The specimen pieces are also tested in dry condition by drying them in an oven at 105 ± 5°C for 24 hours and then cooling in a desiccator to 20-30°C. These are tested in universal testing machine. The load is applied gently at a rate of 14 N/mm^2 per minute until

the resistance of the specimen piece to the increasing load breaks down and no greater load is sustained.

The compressive strength of the specimen piece is the maximum load in Newtons supported by it before failure occurs divided by the area of the bearing face of the specimen in mm^2.

When the ratio of height to diameter or lateral dimension differs from unity by 25 per cent or more, the compressive strength is calculated by the following expression.

$$C_c = \frac{C_p}{0.778 + 0.222\,(b/h)}$$

where C_c= compressive strength of standard specimen piece

C_p= compressive strength of the specimen having a height greater than the diameter or lateral dimension

b = diameter or lateral dimension

h = height

The crushing strength of stones varies in the range 15-100 N/mm^2.

Transverse Strength Test To test stone for transverse strength, specimen pieces are made in the form of blocks 200 × 50 × 50 mm. These are tested in saturated and dry conditions similar to as explained in the compressive strength test. Test apparatus used for testing is shown in Fig. 3.10. Each specimen piece is

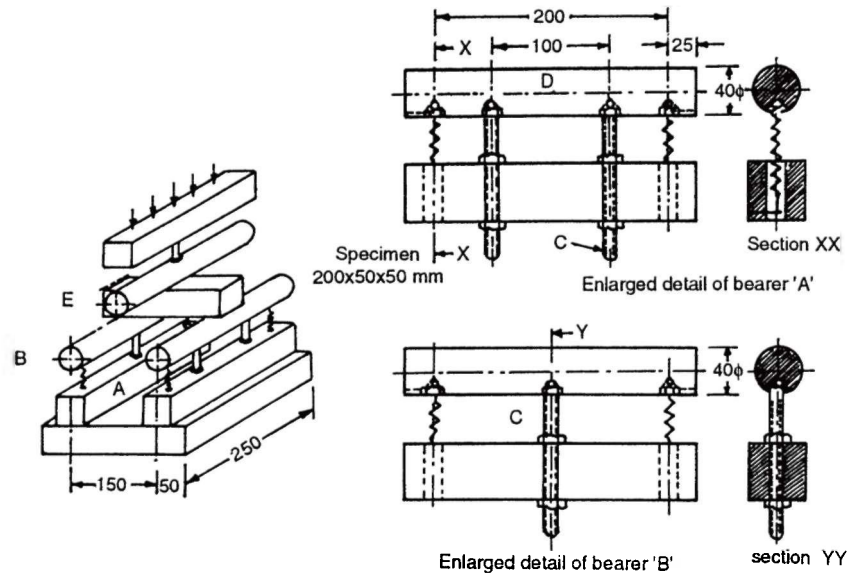


Fig. 3.10 Arrangement for Transverse Strength Test of Stones

supported upon two self-aligning bearers A and B, 40 mm apart, the distance between centres of bearers being 150 mm. Bearer A is supported horizontally on two bearer screws C, which carry hardened steel balls D. Bearer B is supported on one such bearer screw and ball. The load is then applied centrally on the specimen piece at a uniform rate of 2 kN/min through a third bearer E, also 40 mm in diameter, placed midway between the supports upon the upper surface of the specimen S and parallel to the supports.

The transverse strength of the specimen is given by

$$R = \frac{3WL}{2bd^3}$$

where R = transverse strength in N/mm^2

W = central breaking load in N

L = length of span in mm

b = average width in mm of the test piece at the mid section

d = average depth in mm of the test piece at the mid section

Absorption Test — *To test stone for its quality* — 50 g of chippings are oven dried at 105°C for three days and are cooled in a desiccator. The chippings are weighed and recorded as W_1. These are then immersed in distilled water for 3 days and are weighed again, recorded as W_2. The water absorption in per cent is given by

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

In India and some other countries, the degree of water absorption is found from 63 mm cubes. The specimen cube is dried in a desiccator at 110°C and then allowed to cool down slowly. It is weighed and recorded as W_1. The specimen cube is then immersed in water for 24 hours at room temperature, after which it is taken out and wiped off with a rag. It is weighed again and recorded as W_2.

Now, the specimen is immersed in water and temperature is raised at such a rate that water starts boiling in one hour and maintained for 5 hours. Then, the water is cooled and brought down to room temperature in 16 to19 hours. The weight of the specimen in water is found and recorded as W_3. It is then taken out of the water and wiped off with a rag, weighed and recorded as W_4.

$$\text{Per cent moisture absorption by volume after 24 hours} = \frac{W_1 - W_2}{W_4 - W_3} \times 100.$$

Attrition Test — *To check resistance to abrasion* — This test is conducted in Devil's attrition testing machine. A weighed quantity W_1 of 60 mm size broken

stones is put in the drum inclined at 30° to the horizontal, revolving at 2000 r.p.hr. After 5 hours, the material is taken out and sieved through 2 mm sieve. Stone pieces retained on the sieve are weighed and recorded as W_2. The loss in weight indicating the per cent wear is given by

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

It should not exceed 2 per cent.

Hardness This test is performed by scratching a stone with knife on Mohs scale.

Toughness This test is performed by breaking the stone with a hammer. Toughness is indicated by resistance to hammering.

3.11 DETERIORATION OF STONES

The various natural agents such as rain, heat, etc. and chemicals deteriorate the stones with time.

Rain

Rain water acts both physically and chemically on stones. The physical action is due to the erosive and transportation powers and the latter due to the decomposition, oxidation and hydration of the minerals present in the stones.

Physical Action Alternate wetting by rain and drying by sun causes internal stresses in the stones and consequent disintegration.

Chemical Action In industrial areas the acidic rain water reacts with the constituents of stones leading to its deterioration.

Decomposition The disintegration of alkaline silicate of alumina in stones is mainly because of the action of chemically active water. The hydrated silicate and the carbonate forms of the alkaline materials are very soluble in water and are removed in solution leaving behind a hydrated silicate of alumina (Kaolinite). The decomposition of felspar is represented as

$$\underset{\text{(Orthoclase)}}{K_2Al_2O_3 \cdot 6H_2O} + CO_2 + nH_2O = \underset{\text{(Alkaline carbonate)}}{K_2CO_3} + \underset{\text{(Kaolinite)}}{Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O} + \underset{\text{(Hydrated silicate)}}{4SiO_2 \cdot nH_2O}$$

Oxidation and Hydration Rock containing iron compounds in the forms of peroxide, sulphide and carbonate are oxidised and hydrated when acted upon by aciduated rain water. As an example the peroxide — FeO is converted into ferric oxide — Fe_2O_3 which combines with water to form $FeO \cdot nH_2O$. This chemical change is accompanied by an increase in volume and results in a physical change manifested by the liberation of the neighbouring minerals composing the rocks. As another example iron sulphide and siderite readily oxidize to limonite and liberates sulphur, which combines with water and oxygen to form sulphuric acid and finally to sulphates.

Frost

In cold places frost pierces the pores of the stones where it freezes, expands and creates cracks.

Wind

Since wind carries dust particles, the abrasion caused by these deteriorates the stones.

Temperature changes

Expansion and contraction due to frequent temperature changes cause stone to deteriorate especially if a rock is composed of several minerals with different coefficients of linear expansion.

Vegetable Growth

Roots of trees and weeds that grow in the masonry joints keep the stones damp and also secrete organic and acidic matters which cause the stones to deteriorate. Dust particles of organic or nonorganic origin may also settle on the surface and penetrate into the pores of stones. When these come in contact with moisture or rain water, bacteriological process starts and the resultant micro-organism producing acids which attack stones cause decay.

Mutual Decay

When different types of stones are used together mutual decay takes place. For example when sandstone is used under limestone, the chemicals brought down from limestone by rain water to the sandstone will deteriorate it.

Chemical Agents

Smokes, fumes, acids and acid fumes present in the atmosphere deteriorate the stones. Stones containing $CaCO_3$, $MgCO_3$ are affected badly.

Lichens

These destroy limestone but act as protective coats for other stones. Molluses gradually weaken and ultimately destroy the stone by making a series of parallel vertical holes in limestones and sandstones.

3.12 DURABILITY OF STONES

Quarrying and cutting have a great bearing on the weathering properties of stones. Stone from top ledges of limestone, granite and slate and from the exposed faces of the rock bed is likely to be less hard and durable. Highly absorbent stone should not be quarried in freezing weather since the rock is likely to split. The method of blasting and cutting also influences the strength of the stone and its resistance to

freezing and temperature changes. Small, uniformly distributed charge of blasting powder has a lesser weakening effect than large concentrations of explosives. A porous stone is less durable than a dense stone, since the former is less resistant to freezing. Also, rocks with tortuous pores and tubes are more apt to be injured by freezing than those of equal porosity having straight pores and tubes. Repeated hammering in cutting is likely to injure the stone. Polished stone is more enduring than rough surfaced work, since the rain slides off the former more easily. Stones from stratified rocks should be placed along the natural bed in order to secure maximum weathering resistance. Pyrite, magnetite and iron carbonate oxidize in weathering and cause discolouration of the stone in which they are present. Since oxidation is accompanied by a change in volume, the surrounding structure is weakened.

3.13 PRESERVATION OF STONES

Preservation of stone is essential to prevent its decay. Different types of stones require different treatments. But in general stones should be made dry with the help of blow lamp and then a coating of paraffin, linseed oil, light paint, etc. is applied over the surface. This makes a protective coating over the stone. However, this treatment is periodic and not permanent. When treatment is done with the linseed oil, it is boiled and applied in three coats over the stone. Thereafter, a coat of dilute ammonia in warm water is applied.

The structure to be preserved should be maintained by washing stones frequently with water and steam so that dirt and salts deposited are removed from time to time. The best way is to apply preservatives. Stones are washed with thin solution of silicate of soda or potash. Then, on drying a solution of $CaCl_2$ is applied over it. These two solutions called Szerelmy's liquid, combine to from silicate of lime which fills the pores in stones. The common salt formed in this process is washed afterwards. The silicate of lime forms an insoluble film which helps to protect the stones.

Sometimes lead paint is also used to preserve the stones, but the natural colour of the stone is spoilt. Painting stone with coal tar also helps in the preservation but it spoils the beauty of the stone. Use of chemicals should be avoided as far as possible, especially the caustic alkalis. Although cleaning is easy with chemicals, there is the risk of introducing salts which may subsequently cause damage to the stone.

In industrial towns, stones are preserved by application of solution of baryta, $Ba(OH)_2$ — Barium hydrate. The sulphur dioxide present in acid reacts on the calcium contents of stones to form calcium sulphate. Soot and dust present in the atmosphere adhere to the calcium sulphate and form a hard skin. In due course of

time, the calcium sulphate so formed flakes off and exposes fresh stone surface for further attack. This is known as *sulphate attack*. Baryta reacts with calcium sulphate deposited on the stones and forms insoluble barium sulphate and calcium hydroxide. The calcium hydroxide absorbs carbon dioxide from the air to form calcium carbonate.

$$Ba(OH)_2 + CaSO_4 \longrightarrow \underset{\text{(Barium sulphate)}}{BaSO_4} + \underset{\text{(Calcium hydroxide)}}{Ca(OH)_2}$$

$$Ca(OH)_2 + CO_2 \longrightarrow \underset{\text{(Calcium carbonate)}}{CaCO_3} + H_2O$$

The question whether or not stone preservatives should be used on old and decayed stone is a difficult one. Real evidence of the value of various treatments is most difficult to assess. The treatments, if carefully applied under favourable circumstances, may result in an apparent slowing down of the rate of decay. However, the rate of decay of stone is so slow that a short period experience is of very little value in establishing the effectiveness of the treatment. Also, there is some evidence that treatments which appear to be successful for few years, fail to maintain the improvement. In fact, the value of preservatives is not yet proved, and they may actually be detrimental if judged over a long period.

3.14 SELECTION OF STONES

The conditions which govern the selection of stone for structural purposes are cost, fashion, ornamental value and durability, although the latter property is frequently overlooked or disregarded. Cost is largely influenced by transportation charges, difficulties in quarrying and cutting, the ornamental features, and the durability of stone. The type of dressing of stone may make a difference to the cost, particularly with the stones derived from igneous rocks. When the cost of quarried stone to cost of finished stone is considered, it will be found that the labour cost is far greater than the price of the stone. Thus, a difference in the price between two alternative stones is unimportant and it would be unwise to reject a more durable stone on the grounds that it was costly.

Another factor which should be considered is the suitability of the stone for the type of design, for example, for a highly carved design if, by mistake, a harder stone such as granite is selected the cost will be affected. Colour, arrangement and shape of mineral constituents greatly influence fashion and ornamental value. One of the first factors influencing the selection of stone for a particular work will be colour. It is important that the designer is aware about how the colour is likely to change after long exposure and in particular how it may vary in polluted atmospheres. As an example limestone, being slightly soluble in water, will remain clean in portions facing rain but retain a film of soot in sheltered areas. This results in strong colour

contrast.

Resistance to fire and weathering — factors which are largely influenced by the mineral constitution of the rock — are the most important determinators of durability. It is very important to select a stone according to its exposure conditions. Limestones when used in areas not exposed to rain but acted upon by sulphur gases of polluted atmosphere, form a hard and impermeable surface skin which subsequently blisters and flakes off. It must be noted that flaking of this kind occurs mainly on external work only, although the air inside the building is almost equally polluted, probably due to the damper conditions inside.

Limestones, sandstones and granites all tend to crack and spall when exposed to fire, and there is really little to choose between them in this respect. The type of stones usually selected for specific engineering works are given in Table 3.6.

3.15 COMMON BUILDING STONES

A list of the building stones commonly used along with the classification and characteristics is given in Table 3.7.

3.16 ARTIFICIAL STONES

Where durable natural stone is not available at reasonable cost, artificial stone, also known as *cast stone* becomes the choice. Artificial stone is made with cement and natural aggregates of the crushed stone and sand with desired surface finish. Suitable colouring pigments may be added. However, colouring should not exceed 15 per cent by volume. Cement and aggregates are mixed in proportion of 1:3.

Artificial stone can be moulded into the most intricate forms, cast into any size, reinforced to have higher strength, are most suitable for face work, since grooves, rebates, etc., can be cast easily and are economical. Some of the artificial stones available are as follows:

Concrete Block are cast at site in the construction of piers or cast in moulds for steps, window sills, etc.

Ransom Stone are prepared by mixing soda silicate with cement to provide decorative flooring. These are also known as *chemical stones*. These have compressive strength of about 32 N/mm^2.

Victoria Stone are granite pieces with the surfaces hardened by keeping immersed in soda silicate for about two months.

Bituminous Stone Granite and diorite are impregnated with prepared or refined tar to form bituminous stone. These are used for providing noise, wear and dust resistant stone surfaces.

Table 3.6 Stones for the Specific Uses

S. No.	Type of Work	Recommended Stone Type	Reasons
1.	Heavy engineering works such as bridge, piers, and abutments, break waters, docks and light houses, retaining walls	Granite (of its three varieties, viz biotite-granite, hornblende-granite and tourmaline-granite; biotite-granite is most widely used	It is heavy strong, durable and is capable of resisting large thrust
2.	Building facing the sea	Granite, fine grained sandstone	These are not affected by the weathering action of sand particles blown by wind
3.	Buildings in industrial areas	Granite, compact sandstone	These are acid fumes and smoke proof
4.	Arches	Fine grained sandstone	Strong, durable
5.	Building face work, carved works, ornamental works and stattutes	(a) Marble, close grained sand stone	These are light weight, soft and easy to work and have pleasing colour and appearance
		(b) Fine grained granite	It takes high polish
6.	Fire resisting structure	Compact sandstone	Fireproof
7.	Road metal and aggregate for concrete	Granite, Basalt, quartizite	Hard, tough and has high abrasion resistance
8.	Railway ballast	Coarse grained sandstone, quartizite	These are hard and compact
9.	Electrical switch board	Slate, marble	Poor conductor of electricity

Table 3.7 Classification and Uses of Building Stones

S. No.	Type	Classification	Characteristics	Suitability
1.	Granite	Igneous	1. Sp. gr. 2.63-2.75 2. Water absorption < 1% 3. Compressive strength 77-130 N/mm^2 4. Difficult to work with 5. Fine grained variety takes high polish 6. Colour depends upon colour of felspar 7. Excess of felspar causes early decay	Most suitable for important engineering works such as bridge abutments, piers, dams, sea walls, light houses, etc.
2.	Trap and Basalt (green stone, white stone, blue basalt)	Igneous	1. Sp. gr. 2.6-3 2. Compressive strength 150-190 N/mm^2 3. Not easly to work with	Suitable for road metal and concrete aggregate. Its red and yellow varieties are used for decorative features in structures.
3.	Serpentine	Igneous	1. Compact, but soft and easy to work with 2. Affected by smoke and fumes	Suitable for ornamental works for high quality building works.
4.	Syenite		Similar to granite	Most suitable for road metal.
5.	Sandstone	Sedimentary	1. Sp. gr. 2.65-2.95 2. Compressive strength 65 N/mm^2 3. Weathers well when free from lime and iron	In the form of flag stone for paving, tile stone for roofing, natural stone for ornamental work and grit for heavy engineering works.
6.	Limestone	Sedimentary	1 .Sp. gr. 2.0-2.75 2. Compressive strength 55 N/mm^2 3. Affected by frost and atmosphere 4. Tough but soft enough to be cut	Suitable for flooring, paving and roofing and in the manufacture of lime and cement.

7.	Kankar (impure limestone)	Sedimentary	1. Irregular in shape 2. Porous structure 3. Nodular kankar variety is hard and tough	Black kankar is hard and is used as building material. Nodular kankar is used to produce hydraulic lime.
8.	Mooram (Decomposed Laterite)	Sedimentary	1. Strong and hard	Most suitable for surfacing fancy paths in gardens and bunglows.
9.	Gneiss (Stratified granite)	Metamorphic	1. Strong and durable 2. Can be split into thin slabs for railway tracks.	Suitable for rough stone masonry works, stone pitching and road metal
10.	Laterite (Sandy clay stone)	Metamorphic	1. Porous or cellular structure 2. Soft and easy to work with 3. Affected by the action of water	Suitable for rough stone masonry work. The nodular variety yields road metal
11.	Marble	Metamorphic	1. Specific gravity 2.65 2. Crushing strength 70 N/mm^2 3. Hard and compact 4. Takes fine polish 5. Sufficiently hard and compact	Most suitable for monuments, stattutes flooring, decorative and ornamental works.
12.	Slate	Metamorphic	1. Specific gravity 2.89 2. Compressive strength 77-210 N/mm^2 3. Hard and tough 4. Splits into thin slabs	Most suitable for roof coverings floorings, damp proofing and partitions.

Imperial Stone Finely crushed granite is washed carefully and mixed with Portland cement. The mix is moulded in desired shape and then steam cured for 24 hours. The cured blocks are immersed in silicate tanks for three days. These stones are similar to Victoria stones.

Artificial Marble can be either pre-cast or cast-in-situ. These are made from portland gypsum cement and sand. In the precast variety, the cast-stone is removed after three days. On the fifth day of casting these are treated with a solution, liquid fluorite of magnesia. It is then washed and wrapped in paper for 24 hours and then once again treated with the liquid. After one month the stone is polished by rubbing emery over the surface with a linen rag ball dipped in mixture of lime water and silicate of potash and then the process is repeated without emery. It is used for external works. Cast-in-situ variety is made by laying the mix on canvas, in thickness about 1.5 mm more than the required thickness of the stone. The surface is rubbed over and the airholes are filled with mix. Grinding is done by hand or machine. The surface is then rubbed with a polishing stone. Final rubbing is done with a ball of wool moistened with alum water dipped into a 1:3 mix of hartshorn powder and diatomite.

Garlic stone is produced by moulding a mixture of iron slag and portland cement. These are used as flag stones, surface drains, etc.

EXERCISES

Q.1 What are rock forming minerals? Give a brief account of the physical properties of the felspar, pyrocene, mica and gypsum group of minerals.

Q.2 What is a mineral ? What are their physical properties ?

Q.3 What is meant by 'hardness of a mineral'? How can it be determined? What is Mohs scale of hardness?

Q.4 Give the physical properties of the following minerals: garnet, olivine, felspar, mica and orthoclase.

Q.5 Write short notes on the following:

(a) Lustre (b) Cleavage

(c) Hardness (d) Streak

Q.6 Discuss the three important types of rocks and their formations.

Q.7 What is meant by rock-cycle ? How does it represent the sequence of formation of the three important types of rocks ?

Q.8 Give a brief account of the mode of origin and consolidation of igneous magma. How are igneous rocks classified ?

Q.9 Discuss the formation, mode of occurrence and engineering utility of sedimentary rocks.

Q.10 Describe the important characteristic features and uses of the followings rocks:

Granite, Syenite, basalt, sandstone, marble, gneiss.

Q.11 Write short notes on the following, giving their uses in the civil engineering works:

Granite, sand stone, marble, shale, dolerite.

Q.12 State what do you know about formation, mode of occurrence and engineering utility of sedimentary rocks. What types of them are most common ?

Q.13 Name the three geological classes into which rocks can be divided. Describe the process of their formation. What are the important building stones which are derived from these rocks ?

Q.14 Briefly describe the following:

(a) Dressing of stone

(b) Quarrying

(c) Preservation of stone

Q.15 (a) Describe the principal rock forming minerals.

(b) Describe the properties and uses of any five varieties of stones suitable for construction works.

Q.16 What considerations would guide you in selecting stone for use in the situations mentioned below:

(a) Face work of a building (b) Structure facing sea

(c) Marine structures (d) Dams

(e) Railway ballast (f) Road metal

Q.17 (a) What are the tests to which a stone should be subjected before it is selected for building purposes ?

(b) How would you identify kankar, limestone, sandstone and laterite ?

(c) What are the different methods used in dressing building stones ?

Q.18 Name the stone you will select for the following works. Give a justification for your choice.

(a) Random rubble masonry

(b) Coarse aggregate for reinforced cement concrete

(c) Bed plate for a girder

(d) Building in industrial area

(e) Cornice in a building

(f) Railway goods platform

Q.19 (a) What are the qualities you would look for in good building stone for masonry work ?

(b) What natural features will indicate whether the stone can be quarried by wedges ?

(c) What are the types of explosives generally used in blasting the rocks?

(d) How do you quantify the requirement of explosives in blasting rocks ?

Q.20 (a) What precautions are exercised in storing explosives ?

(b) When is it required to quarry stones by blasting ?

(c) What is the significance of line of least resistance ?

Q.21 Give the characteristics and uses of the following stones:

(a) Granite (b) Sandstone

(c) Marble (d) Slate

Q.22 (a) What are the important considerations which are to be carefully attended before selecting a quarry site.

(b) Describe the process of blasting rocks. State the precautions to be exercised.

Q.23 Describe the various weathering agencies responsible for deterioration of stones. Suggest the precautions to be exercised to reduce the decay of stones caused by these.

Q.24 Distinguish between the following :

(a) Quarry and mine

(b) Stratified rocks and foliated rocks

(c) Plutonic rocks and volcanic rocks

(d) Sillceous rocks and argillaceous rocks.

Q.25 Describe briefly the following :

(a) Qualities of a good building stone

(b) Natural bed of stone

(c) Artificial stone

(d) Quarry dressing of stone

Q.26 (a) Describe briefly the tests you will conduct to assure the quality acceptance of stones.

(b) It has been recommended to provide sandstone tiles on the facia of a multistorey building. The climate in the region is equatorial. If you agree with the selection, justify it or otherwise suggest some other stone with the reasons for the selection.

Q.27 Name the various types of stones which are used for building works and give in brief the specifications for a good building stone.

Q.28 (a) What is the natural bed of stone ? Why is it necessary to set a stone along its natural bed ?

(b) How would you classify the stone for engineering works ?

(c) Discuss the agencies responsible for deterioration of stone. How can stone be preserved ?

Chapter

4

WOOD AND WOOD PRODUCTS

4.1 INTRODUCTION

Wood is a hard and fibrous substance which forms a major part of the trunk and branches of a tree. It can also be defined as a natural polymeric material which practically does not age. Wood as a building material falls in two major classes — natural and man-made. With the advances in science and technology, wood in its natural form as timber, lumber, etc. is being rapidly replaced by composite wood materials in which natural wood is just a basic ingredient of a matrix or a laminate. The latter are found to be more useful and adaptable as they may be treated chemically, thermally or otherwise as per requirements. Some examples are plywood, fibreboards, chipboards, compressed wood, impregnated wood, etc.

Wood has many advantages due to which it is preferred over many other building materials. It is easily available (this won't be true after some years !) and

easy to transport and handle, has more thermal insulation, sound absorption and electrical resistance as compared to steel and concrete. It is the ideal material to be used in sea water. Wood is a good absorber of shocks and so is suitable for construction work in hilly areas which are more prone to earthquakes. Finally, since wood can be easily worked, repairs and alterations to wood work can also be done easily.

Owing to the above mentioned advantages, wood is very widely used in buildings as doors, windows, frames, temporary partition walls, etc. and in roof trusses and ceilings apart from formwork.

4.2 CLASSIFICATION OF TREES

Trees are classified as endogenous and exogenous according to the mode of growth.

Endogenous

Trees grow endwards, e.g. palm, bamboo, etc.

Exogenous

Trees grow outwards and are used for making structural elements. They are further subdivided as conifers and deciduous.

Conifers are evergreen trees having pointed needle like leaves, e.g. deodar, chir, fir, kail, pine and larch. They show distinct annual rings, have straight fibres and are soft with pine as an exception, light in colour, resinous and light weight.

Deciduous trees have flat board leaves, e.g. oak, teak, shishum, poplar and maple. The annual rings are indistinct with exception of poplar and bass wood, they yield hard wood and are non-resinous, dark in colour and heavy weight.

Notes : (i) Conifers, as compared to deciduous, are used predominantly for construction purposes for their long straight trunk and the better quality of wood.

(ii) Characteristic differences between soft woods and hard woods are given in Table 4.1.

4.3 GROWTH OF TREES

In spring the roots of the tree suck sap as food from the soil which reaches the branches and the leaves. Sap contains moisture which gets evaporated. It absorbs carbon from air in presence of sunlight and becomes denser. In autumn, the sap descends and deposits in the form of a layer below the bark. This layer, referred to as the *cambium layer*, hardens and adds a layer of wood to the outside of tree every year in the form of concentric rings. These annual rings furnish valuable information regarding the age of the log, the rapidity and the uniformity of its growth.

Table 4.1 Difference between Soft-wood and Hard-wood

S. No.	Property	Soft wood	Hard wood
1.	Colour	Lighter	Darker
2.	Growth	Faster	Slower
3.	Weight	Lighter	Heavier
4.	Density	Low	High
5.	Annual rings	Distinct	Indistinct
6.	Heart wood and sap wood	Cannot be distinguished	Can be distinguished
7.	Strength	Strong along the grains	Strong along and across the grains
8.	Conversion	Easy	Difficult
9.	Resinous material	Exists in pores	Does not exist
10.	Examples	Chir, fir and others conifers	Teak, sal, sheesham, and other deciduous trees

Generally, the rings are widest at the centre and narrower nearer the bark. Also, the rings are widest at the bottom in young, thrifty trees and near the top in old ones. The cells formed in the cambium layer are primarily cellulose and are commonly referred to as *fibres* because of their needle-like shape. They are cemented into groups by lignin, which gives the strength to wood. The comparative width of annual rings, the direction and the arrangement of the cells and fibres are the causes of the grains of the wood. Rapidly growing trees having wide annual rings produce coarse grained wood, while those of slower growth produce wood with narrow rings or fine grain. The wood is said to be *straight-grained* when the wood elements are straight and run parallel to the pith and *cross-grained* when the elements do not run parallel to the axis. Cross-grain has a pronounced weakening effect on the strength of beams when the slope of the grains is 1:15 or greater.

Timber should be felled as soon as it is matured. The best time is midsummer or midwinter, when the sap is at rest. If it is felled, when the sap is vigorous in movement, the timber decays. If the tree is cut young, it yields soft wood and if it stands too long, the decay starts.

4.4 CLASSIFICATION OF TIMBER

The terms timber and wood are often used synonymously, but they have distinct meanings in the building industry. Wood is the hard, fibrous material that makes up the tree under the bark, whereas timber may be defined as a wood which retains its natural physical structure and chemical composition and is suitable for various engineering works. Timber may be classified as follows.

On the Basis of its Position

Standing Timber implies a living tree.

Rough Timber forms a part of the felled tree.

Converted Timber or Lumber are logs of timber sawn into planks, posts, etc.

On the Basis of Grading

Structural timbers are classified as:

Selected Grade should not contain defects, the estimated effect of which tends to reduce the basic strength of timber by more than 12.5 per cent.

Standard Grade should not contain defects, the estimated effect of which tends to reduce the basic strength of timber by more than 25 per cent.

Common Grade should not contain defects, the estimated effect of which tends to reduce the basic strength of timber by more than 37.5 per cent.

On the Basis of Modulus of Elasticity

The species of timber recommended for constructional purpose are classified as

Group A: Modulus of elasticity in bending above 12.5 kN/mm^2

Group B: Modulus of elasticity in bending above 9.8 kN/mm^2 and below 12.5 kN/mm^2

Group C: Modulus of elasticity in bending above 5.6 kN/mm^2 and below 9.8 kN/mm^2

On the Basis of Availability

According to availability, timber can be of three grades, namely X, Y and Z.

X— Most common, 1415 m^3 or more per year

Y— Common, 355 m^3 to 1415 m^3 per year

Z— Less common, below 355 m^3 per year

This is based upon the figures supplied by the forest departments.

On the Basis of Durability

Test specimens of size 600 × 50 × 50 mm are buried in the ground to half their lengths. The condition of the specimen at various intervals of time are noted and from these observations their average life calculated. Timbers are classified based upon such observations as of:

High durability average life of 120 months and over.

Moderate durability average life of less than 120 months but of 60 months or more.

Low durability average life of less than 60 months.

On the Basis of Seasoning Characteristics

Timbers are classified depending upon their behaviour to cracking and splitting during normal air-seasoning practice under three categories.

Highly refractory (Class A) are slow and difficult to season-free from defects.

Moderately refractory (Class B) may be seasoned free from surface defects, etc. if some protection is given against rapid drying.

Non-refractory (Class C) These can be rapidly seasoned free from defects.

On the Basis of Treatability

This classification is based upon the resistance offered by the heartwood of a species to preservatives under a working pressure of 1.05 N/mm^2 as

(a) Easily treatable.

(b) Treatable but complete preservation not easily obtained.

(c) Only partially treatable.

(d) Refractory to treatment.

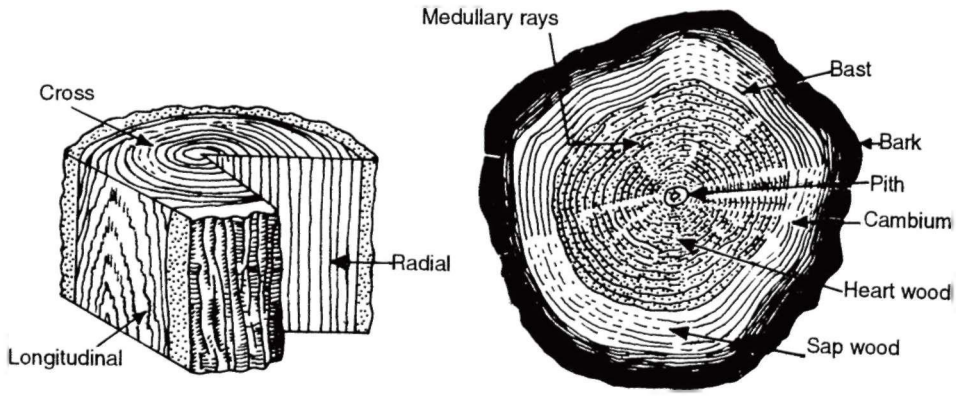
(e) Very refractory to treatment, penetration of preservative being practically nil from the sides and ends.

4.5 STRUCTURE OF TIMBER

A tree can be divided into three portions, crown composed of branches and leaves, trunk, and roots. The trunk accounts for about 80 per cent of the total bulk of wood.

Figure 4.1 shows the structure of well grown timber from trunk of the exogenous tree. The structure of timber visible to naked eye or at a small magnification is called *macro structure*, and that apparent only at great magnifications, the *micro structure*. Macro structure of the timber can be studied by cutting the trunk in three directions (Fig. 4.1 (a)). In the cross-sectional and radial ducts, the following main parts of a tree, e.g. bark, cambium, sap wood, heart wood and pith, become readily apparent (Fig. 4.1(b)). Each of the components has a specific function. The bark protects the wood against mechanical damage. Its inner layer, called bast conveys the nutrients from the crown downwards and stores them. The function of cambium is to grow wood cells on the inside and smaller bast cells on the outside. The sapwood assists in the life process of tree by storing up starch and conducting sap. The cells in the sap wood are active. The heart wood gives a strong and firm support to the tree. With the growth of tree, the cells in the inner older

portion of trunk gradually become inactive and lifeless, but do not decay. This portion of the trunk is called heart wood. At the centre of the cross-section is the pith, a small area occupied by friable tissues consisting of thin walled, loosely connected cells called pith. In a felled tree, it easily crumbles and rots. In the cross-sectional direction, nutrients pass from bast to the heart through groups of cells running at right angles to the cambium layers and are referred to as medullary rays.



(a) Three Main Cuts of a Tree Trunk (b) Cross-section

Fig. 4.1 Cross Section of a Tree

4.6 CHARACTERISTICS OF GOOD TIMBER

1. Narrow annual rings, closer the rings greater is the strength.
2. Compact medullary rays.
3. Dark colour.
4. Uniform texture.
5. Sweet smell and a shining fresh cut surface.
6. When struck sonorous sound is produced.
7. Free from the defects in timber.
8. Heavy weight.
9. No woolliness at fresh cut surface.

4.7 SEASONING OF TIMBER

It is the process of reducing the moisture content of timber in order to prevent the timber from possible fermentation. It can also be defined as the process of drying

the wood to a moisture content approximately equal to the average humidity of the surroundings, where it is to be permanently fixed. Very rapid seasoning after removal of bark should be avoided since it causes case hardening and thus increases resistance to penetration of preservatives. Some of the objects of seasoning wood are as follows:

1. Reduce the shrinkage and warping after placement in structure.
2. Increase strength, durability and workability.
3. Reduce its tendency to split and decay.
4. Make it suitable for painting.
5. Reduce its weight.

Methods of Seasoning

Timber can be seasoned naturally or artificially

Natural or Air Seasoning The log of wood is sawn into planks of convenient sizes and stacked under a covered shed in cross-wise direction in alternate layers (Fig. 4.2) so as to permit free circulation of air. The duration for drying depends upon the type of wood and the size of planks. The rate of drying is however very slow. Air seasoning reduces the moisture content of the wood to 12-15 per cent.

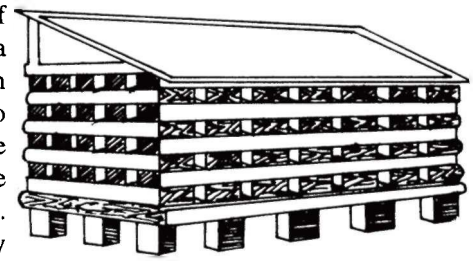


Fig. 4.2 Shed for Air Seasoning of Timber

Artificial Seasoning The prevalent methods are as follws:

Water Seasoning The logs of wood are kept completely immersed in running stream of water, with their larger ends pointing upstream. Consequently the sap, sugar, and gum are leached out and are replaced by water. The log is then kept out in air to dry. It is a quick process but the elastic properties and strength of the wood are reduced.

Boiling in water or exposing to the action of steam spray is a very quick but expensive process.

Kiln Seasoning is adopted for rapid seasoning on large scale to any moisture content. The scantlings are arranged for free circulation of heated air with some moisture or superheated steam. The circulating air takes up moisture required from wood and seasons it. Two types of kilns, the progressive (Fig. 4.3 (a)) and the compartment (Fig. 4.3 (b)) are in use. For most successful kiln-seasoning the timber

should be brought to as high a temperature as it will stand without injury before drying is begun; otherwise the moisture in the hot outer fibers of the wood will tend to flow towards the cooler interior.

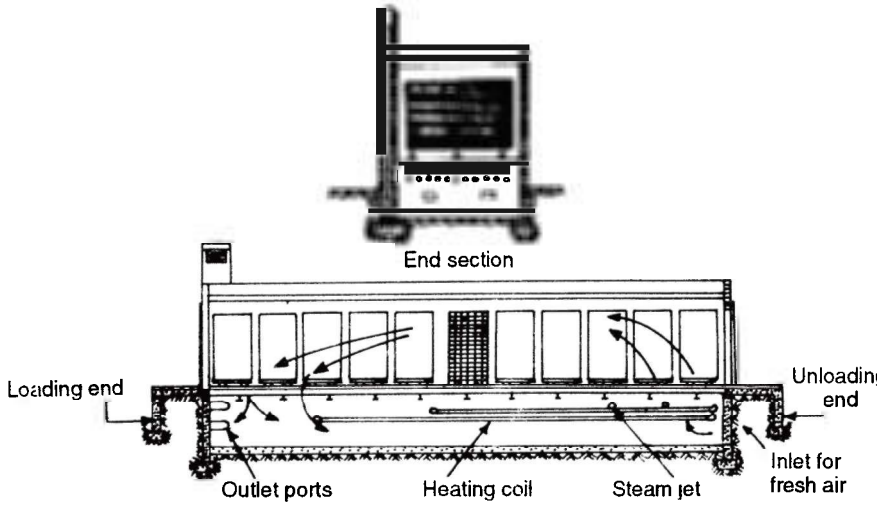


Fig. 4.3(a) Progressive Kiln

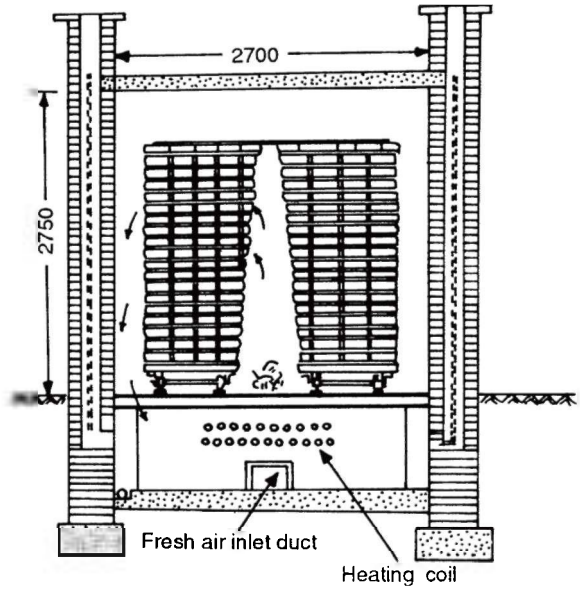


Fig. 4.3(b) Compartment Kiln

Chemical or Salt Seasoning An aqueous solution of certain chemicals have lower vapour pressures than that of pure water. If the outer layers of timber are treated with such chemicals the vapour pressure will reduce and a vapour pressure gradient is setup. The interior of timber, containing no salts, retains its original vapour pressure and, therefore, tends to dry as rapidly as if there had been no treatment. The result is to flatten the moisture gradient curves, to reduce the slope of the curves, and consequently to reduce the internal stresses induced during drying. Since it is these stresses which are responsible for defects such as checks, etc. a chemically treated timber will exhibit fewer defects. Common salt or urea are generally used; the latter is preferred. The corrosive action of common salt is a drawback.

Electric Seasoning The logs are placed in such a way that their two ends touch the electrodes. Current is passed through the setup, being a bad conductor, wood resists the flow of current, generating heat in the process, which results in its drying. The drawback is that the wood may split.

Mc. Neill's Process has no adverse effects; it is the best method although most expensive. The timber is stacked in a chamber with free air space (⅓rd of its capacity) and containing products of combustion of fuels in the fire place. The time required is 15 to 60 days.

4.8 DEFECTS IN TIMBER

The defects in the wood as shown in Fig. 4.4 are due to irregularities in the character of grains. Defects affect the quality, reduce the quantity of useful wood and favour its decay. Following are some of the important defects commonly found in wood.

Shakes are separations in the wood between the annual rings. These lengthwise separations reduce the allowable shear strength without much effect on compressive and tensile values. The separations make the wood undesirable when appearance is important.

Heart Shake occurs due to shrinkage of heart wood, when tree is overmatured. Cracks start from pith and run towards sap wood. These are wider at centre and diminish outwards.

Cup Shake appears as curved split which partly or wholly separates annual rings from one another. It is caused due to excessive frost action on the sap present in the tree, especially when the tree is young.

Star Shake are radial splits or cracks wide at circumference and diminishing towards the centre of the tree. This defect may arise from severe frost and fierce heat of sun. Star shakes appear as the wood dries below the fibre saturation point. It is a serious fault leading to separated log when sawn.

Note: Shakes are most harmful to strength when they follow neutral plane of a beam or run diagonally across the tension side of it. In the first case, they weaken the resistance to horizontal shear, and in the second, they reduce the tensile strength.

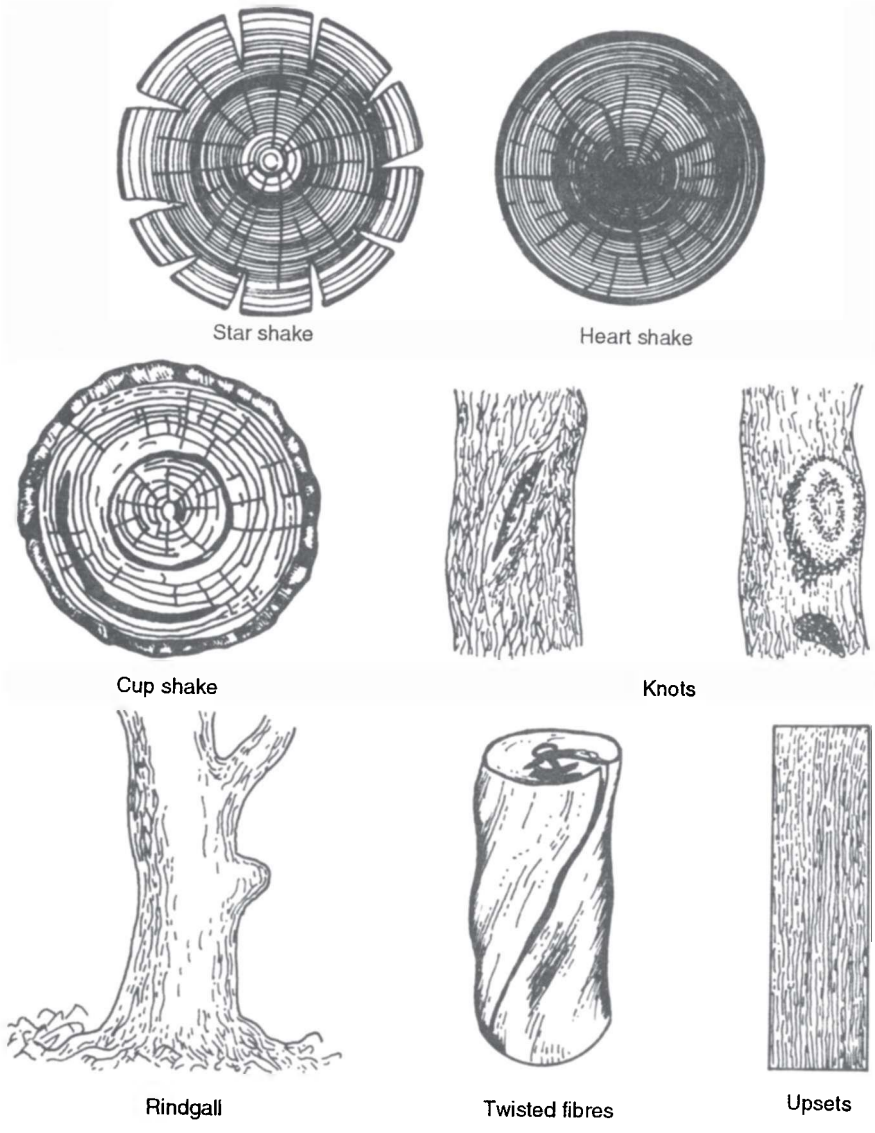


Fig. 4.4 Defects of Timber

Rindgall is characterised by swelling caused by the growth of layers of sapwood over wounds after the branch has been cut off in an irregular manner. The newly

developed layers do not unite properly with the old rot, thereby leaving cavities, from where decay starts.

Knots are bases of twigs or branches buried by cambial activity of the mother branch. The root of the branch is embedded in the stem, with the formation of annual rings at right angles to those of the stem. The knots interrupt the basic grain direction of the wood, resulting in a reduction of its strength. In addition these affect the appearance of the wood. A *dead knot* can be separated from the body of the wood, whereas *live knot* cannot be. Knots reduce the strength of the timber and affect workability and cleavability as fibres get curved. Knots are classified on the basis of size, form, quality and occurrence.

Size Pin knot (under 12 mm), small knot (12-20 mm), medium knot (20-40 mm) and large knot (over 40 mm).

Form Round knot and spike knot (a round knot exposed by sawing lengthwise).

Quality Sound knot — as hard and solid as the surrounding wood, decayed knot — contains advanced decay and is softer than the surrounding wood, encased knot — the annual rings fail to grow into the fibres of the surrounding wood, tight knot — a knot so securely fastened that it holds its position in the finished product.

Occurrence Single knot — when wood fibres deflect around one knot, cluster knot — when wood fibres deflect about two or more knots as a unit and, branch knot — two or more knots radiating from a common centre.

End Splits are caused by greater evaporation of sap takes place at the end grains of log and can be reduced by painting the exposed end grains with a water proof paint or capping the exposed end with hoop iron bandage.

Twisted Fibres are caused by wind constantly turning the trunk of young tree in one direction.

Upsets are caused by the crushing of fibres running transversely during the growth of the tree due to strong winds and unskilled felling consequently resulting in discontinuity of fibres.

Foxiness is a sign of decay appearing in the form of yellow or red tinge or discolouration of overmatured trees.

Rupture is caused due to injury or impact.

4.9 DISEASES OF TIMBER

Dry Rot

It is decomposition of felled timber caused by the action of various fungi. The fungus reduces fibres to fine powder as shown in Fig. 4.5 and the timber looses its

strength. This disease is highly infectious and causes tremendous destruction. It occurs when the timber is imperfectly seasoned and placed in a moist, warm and confined atmosphere having no free access of air. Fungus rapidly dies when exposed to air or sunlight. The best remedy is to cut away the affected part and paint the remaining part.

Note : Fungi that attack growing trees and continue to damage it in structures are known as white or brown rot, white trunk rot, etc.

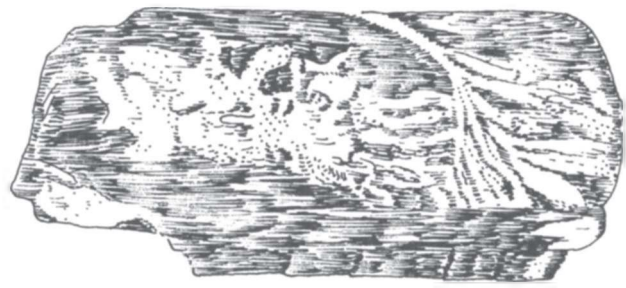


Fig. 4.5 Dry Rot

Wet Rot

When timber is subjected to alternate wet and dry conditions, decomposition of tissues takes place. This is not caused by fungal attack. In a living tree, it is set up by the access of water through wounds in the bark and causes the decomposition of sap and fibres of the tree. This may also occur when timber is seasoned by exposing it to moisture. To avoid wet rot, well seasoned timber is used with preservatives and paints.

4.10 DECAY OF TIMBER

Decay due to Fungal and Bacterial Attack

Wood is essentially an organic substance, made up of a skeleton of cellulose impregnated with lignin. The organic substances are susceptible to attack by both bacteria and fungi. Bacteria are the smallest of living organism and do not cause any serious damage to timber, except for some discolourations. Fungi are a system of plant organism which live in and attack timber causing rot and decay.

The method by which bacteria decompose wood is probably similar in nature to a fungal attack. Fungi reproduce through minute particles called *spores*, millions

of which are produced at the fruiting stage. These spores send out *mycelia*, which in turn destroy the wood tissue by secretions of solvent chemicals and enzymes. After a considerable proportion of the cell wall has been destroyed by mycelia, the wood becomes brittle and weak.

The basic requirements for the existence of fungi are moisture, suitable temperature and food supplies. The wood itself forms the food supply and optimum temperature conditions are in the range of 18°C to 30°C. Some fungi like *Merulius lacrymans* and *Poria incrassata* provide moisture by themselves and seem to thrive even in fairly dry wood leading to what is technically known as *dry rot.* The various symptoms of incipient decay are discolouration, abnormal mottled appearance, roughness of surface and presence of soft spots of intense discolouration.

Control of Fungi and Bacterial Attack One of the prime requirements in the control of fungal attack is the dryness of timber. The timber should not be subjected to alternate wet and dry conditions. When this is unavoidable, a proper preservative treatment should be made. Felled trees should be air-dried as rapidly as possible and sawn timber should be kiln-seasoned properly in accordance with good air-seasoning practice. Thereafter, they should be protected from rain and other sources of moisture. It should be ensured that adequate ventilation is there around the timber to prevent fungal attack. Also, no timber used in a structure should contain sapwood which is more susceptible to fungal attack because of the food supplies stored in its parenchyma.

Damage due to Insects

Termites Termites, or *white ants* as they are inappropriately called, are the most destructive of all insect agencies. They are small, social insects which form vast colonies and possess differentiated casts to carry on specialized functions in the social structure. They completely excavate the wood at the centre leaving the outer shell intact. They also attack furniture and wood work in houses and railway sleepers, etc.

Beetles

Powder post Beetles (Family Lyctidae) attack sapwood of hardwoods with large pores. The eggs are laid in the pores and the larva that comes out eats through the wood, leaving a very fine powder. Even seasoned timber containing sapwood is not immune to attack of these small beetles.

Long-horn Beetles (Cerambycidae) are 6 mm to 20 mm in size. They derive their name from long curved antennae . They normally do not attack seasoned wood and mainly thrive on timber in the forest yard. They can attack any type of wood, though they prefer sapwood. Their bore holes are elliptical in cross-section.

Ambrosia Beetles or Pin hole Borers are very common and attack structural timber, furniture and other wood work in house. They are less than 6 mm in size

and attack both sap wood and heart wood. The larva bores tunnels through the wood which are filled with the characteristic oval-shape pellets.

Furniture Beetles (Anobiidae) are very common and attack structural timber, furniture and other wood works in houses. They are smaller than 6 mm in size and attack both sapwood and heartwood. The larva bores tunnels through the wood which are filled with the characteristic oval-shaped pellets.

Death watch Beetles (Xestobium) are somewhat larger than the previous one and the tunnels made by these are also bigger and filled with bun-shaped pellets. They normally attack timber infested with fungi or otherwise decayed.

Carpenter Ants are usually black in colour and vary in size within the same nest. Unlike termites, they do not eat wood but merely tunnel it out for habitation. Their food is largely nectar, honeydew, and other sweet substances. They normally attack slightly rotted or water-softened wood but may continue into wood which appears perfectly sound. Timbers are often riddled with galleries before the presence of ants is detected. The frass ejected from the workings is quite coarse and shredding.

Control of Insects is much simpler than eradicating fungi. The tunnels made by the insects help in the deep penetration of toxic elements that are used to destroy them. Large scale fumigation is carried out using powerful hydrocyanic acid gas, but this method is not recommended as this gas is highly poisonous and dangerous. The use of creosote is also not desirable because of its odour and undesirable colour. A good insecticide which does not damage the paint or varnish and vapourises easily is yet to be found. The vapours should also not be dangerous to human beings. It is found that no insecticide can fulfill all these requirements in one application and periodic applications are required to be effective. The best alternative is common turpentine mixed with a small quantity of orthodichlorobenzene. This vapour is very deadly to insects and is not poisonous to human beings and animals.

Damage due to Rodents

Although the domestic rodents do not destroy timber in the same sense as the organism so far considered, they are capable of penetrating both wood and concrete. The problem of rodents is more serious in food-handling establishments.

Control of Rodents The guiding principle is to close all openings or passages and making doors and windows capable of closure in a rat-tight manner by fixing metal sheets over the lower parts of doors.

4.11 PRESERVATION OF TIMBER

Timber can easily decay by swelling (when it gets wet), fungi, insects, fire, etc. One of the basic approaches to protect it is to create conditions unfavourable to

fungi. Low humidity, heat and water insulation, etc. help to maintain the timber dry and thus make it insusceptible to damage by fungi. Water absorption, decay and other undesirable effects can be minimized by coating the surface of wood with polymer films or drying oils, oil base paints, varnishes and synthetic enamels. Some of the methods used to poison the food supply to fungus are as below.

Oil Type Preservatives applied over outside of exposed timber, give unpleasant smell and are not suitable when timber is to be painted. The types in use are creosote, carbolinium, solignum etc. with or without admixture with petroleum or suitable oils.

Water Soluble Preservatives are odourless organic or inorganic salts and are adopted for inside locations only. If applied over outside surfaces, the salts can be leached by rain-water. Examples of leachable type of preservatives are zinc chloride, boric acid (borax), etc. Zinc chloride, sodium fluoride and sodium-penta-chloro-phenate are toxic to fungi. These are expensive and odourless (except for sodium-penta-chloro-phenate). Benzene-hexa-chloride is used as spray against borers. Boric acid is used against Lyctus borers and to protect plywood in tea chests. Some of the other water soluble preservatives are fixed type and are as follows.

Copper-chromate-arsenic composition is made of three chemicals.

Arsenic-pentaoxide	$As_2O_5 \cdot 2H2O$	1 part
Copper sulphate	$CuSO_4 \cdot 5H_2O$	3 parts
Sodium or potassium dichromate	$(Na \text{ or } K)_2\ Cr_2O_7$	4 parts

The preservative is in the form of a powder and is used with water. Six parts of this powder is mixed with 100 parts by weight of water. The solution is applied in two coats. The timber is then allowed to dry for six weeks. This treatment renders the timber immune to the attacks of white ants and is known as *AsCu treatment.*

Acid-cupric-chromate composition

Chromic acid	1.7 parts
Copper sulphate	50 parts
Sodium dichromate	48.3 parts

Chromate-zinc chloride composition

Zinc chloride	1 part
Sodium or potassium dichromate	1 part

Copper-chrome-boric composition

Boric acid	1.5 parts
Copper sulphate	3 parts
Sodium or potassium dichromate	4 parts

Zinc-meta-arsenite composition

Arsenious trioxide	3 parts
Zinc oxide	2 parts
Acetic acid	Just to keep the above in solution under operating conditions

Zinc-chrome-boric composition

Boric acid	1 part
Zinc chloride	3 parts
Sodium dichromate	4 parts
Water	100 parts

Solvent Treatment (Preservatives Insoluble in Water) consists of toxic chemical compounds, e.g. pentachlorophenol, benzene-hexa-chloride dichlorodiphenyl trichloro-ethane(D.D.T) and copper naphthenate. These are dissolved in suitable organic solvents like naphtha, or in petroleum products such as kerosene, spirit, etc. The treated timber can be painted, waxed or polished.

Acetic Anhydride Treatment is used for protection of veneers, plywood and light lumbers against decay by acetylation. They are treated with acetic anhydride vapour, which minimises swelling and improves resistance to decay and attack by insects.

Various Treatment Processes

Surface application is done either by spraying, dipping or by brushing the preservative for a short period on thoroughly debarked timber. For the oil type preservatives, the moisture content in timber should not be more than 14 per cent. With water soluble preservatives, a moisture content of 20 to 30 per cent is permissible. At least two coats should be applied. The second and subsequent coats should not be applied until the first one has dried or soaked into the wood. Where possible, the treatment is done hot. Surface treatment is used mostly for treating timber at site and for retreatment of cut surfaces.

Soaking Treatment is submerging debarked timber in the preservative solution for a sufficiently long period until the required absorption of the preservative is obtained.

Hot and Cold Process ensures sterilisation against fungi and insects. The timber is submerged in the preservative solution. Which is then heated to about 90° to 95°C and maintained at this temperature for a suitable period depending on the charge. It is then allowed to cool until the required absorption is obtained. During the heating period, the air in the timber expands and is partially expelled. While cooling, the residual air in the timber contracts and creates a partial vacuum which causes the

preservative to be sucked into the timber. Generally two baths are used, the first containing water where the hot treatment is given and the second the cold bath containing the preservatives into which the timber is transferred immediately after heating. This overcomes the danger of precipitation of chemicals at high temperatures. This arrangement also helps to make the process continuous in case the quantity of timber is large.

Boucherie Process Sap wood of almost all green timbers with the bark on and of bamboos in green condition, soon after felling, can be treated using any of the inorganic water soluble preservatives by this process. The log of wood attached to the hose pipe and connected to the reservoir is shown in Fig. 4.6 containing preservative at a pressure of 0.1-0.2 N/mm^2. Due to hydrostatic pressure, the preservative displaces the sap in the wood. The treatment is stopped when the concentration of preservative at the lower end of the log is the same as that in the reservoir.

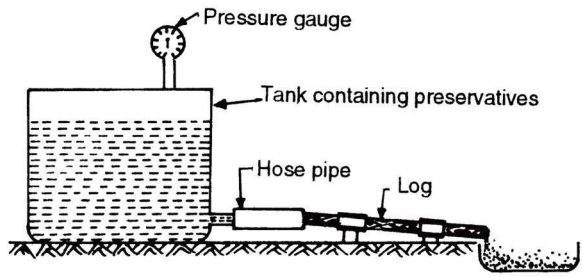


Fig. 4.6 Boucherie Process

Full Cell or Bethel Process is essentially a pressure process and is used when maximum absorption of the preservative is desired. The timber charge is introduced into the cylinder. The door is tightly closed and then a vacuum of at least 560 mm of mercury is created and maintained for half an hour to remove as much air as possible from the wood cells. At the end of the vacuum period, the preservative is introduced into the cylinder, with the vacuum pump working. When the cylinder has been filled with the preservative, the vacuum pump is stopped and the cylinder is subjected to an antiseptic pressure of 0.35 to 1.25 N/mm^2 depending on the species, size, refractory nature of timber, etc. to inject the preservative into the timber. The pressure is held until the desired absorption is obtained. The preservative is then withdrawn from the cylinder and finally a vacuum of 380 to 560 mm of mercury for about 15 minutes is once again applied to free the timber from dripping preservative. Specified retention of toxic chemicals in the timber during the treatment can be had by a proper selection of the concentration of the

toxic material in the treating solution. Desired absorption of the preservative solution is controlled by the duration of pressure and vacuum period.

Empty Cell Processes are also known as *pressure processes* and are aimed at a maximum penetration of the preservative with a minimum net retention. The Lawry process and the Rueping process are commonly used.

Lawry Process: The cylinder is loaded with timber and closed, followed by filling with the preservative. An antiseptic pressure of 0.35 to 1.25 N/mm^2 depending on the timber species, size, etc. is applied until the required absorption is obtained. The pressure is released when a certain part of the preservative injected into the timber is expelled due to the expansion of the entrapped air in the cells. The cylinder is then drained off and finally, a vacuum is applied as described in full cell process.

Rueping Process: In this process, the cylinder is charged with timber and closed. An air pressure of 0.175 to 0.5 N/mm^2 is applied for a specified period depending upon the sap wood content of the timber and is maintained during the subsequent stage of filling up the cylinder with the preservative. When the cylinder is filled, an antiseptic pressure of 0.5 to 1.25 N/mm^2 depending on species, size, etc. is applied until the desired absorption is obtained. This is followed by a vacuum as described under full cell process. In this process, the preservative expelled on the release of the antiseptic pressure is considerable, yielding a low net absorption. This process is specially recommended for treating timber of mixed species and timbers containing sap wood and heart wood.

4.12 FIRE RESISTANCE OF TIMBER

Timber is very inflammable. The fire hazard of timber structures is, however, often overemphasized. When wood burns, the first step is the vapourisation of moisture (118°C) and the next is the volatilisation of extraneous materials (110-165°C). At temperatures (165-220°C) well below the ignition point, destructive distillation or decomposition begins with scorching and evolution of inflammable gases which ignite and form the first flames around the heated wood. As the temperature builds up, the evolution of gases is more rapid and the surface of the timber begins to char. Finally, the point is reached at which the wood itself begins to glow and to ignite (220-390°C). Until this point is reached, the woody portion does not support its own combustion. Quick ignition of inflammable gases and glowing of charcoal occur at about 390-530°C.

Fire proofing makes timber resistant to fire to a degree that it is difficult to ignite and support its own combustion. The fire resistance of wood can be enhanced either by impregnating it with chemicals like phosphates of ammonia, mixture of ammonium phosphate and ammonium sulphate, borax and boric acid, sodium ar-

senate, sodium tetra-borate or by designing wood to provide slow burning construction.

Chemical Methods

These include the impregnation of timber with effective chemicals, or by coating the surface of timber with a layer of noncombustible paint.

Impregnating with Chemicals: As chemicals are water soluble, they are leached out due to rain when applied on exposed structures. Therefore, a second shallow impregnation with a fire-retardant, water-repellent sealer or paints like flamex and bitulac fire-retardant paint is applied which substantially retards leaching. Fire-retardant salts are impregnated by pressure process. Able's process for making wood fire resistant is as follows:

The surface of wood is painted by a weak solution of sodium silicate. Thereafter slaked lime solution of the consistency of a paste is applied followed by the application of concentrated solution of sodium silicate in two coats, the second being applied after 6 hours of the first coat. The composition of the solution is:

Sodium silicate	56 g
Water	50 g
Kaolin	75 g

Surface Coating Method : The most commonly used flame retardant coatings are cement grouts, clay-sulphate paste; paints such as silicate, chloride, phosphate paints and; emulsions like chloro paraffin. Some fire retardants (chemicals) form a film on the surface of wood and decompose under heat yielding non-inflammable gases that dilute the inflammable gases and consequently retard the ignition of the latter. Some of the other fire retardants have low melting point. These melt under heat and form a barrier to the supply of oxygen to the inside.

Structural Method

There is considerable difference between the burning of thin wooden members and that of large timbers. Timber of substantial dimension offers high resistance to fire. Heavy timber on burning form a protective coating of charcoal, which being a heat insulator retards the penetration of heat to the interior. On the contrary, thin members quickly reach the ignition point and burn rapidly. Once the fire is started, flames rise upward in case of wood and hence, wood which is in vertical direction catches fire easily. That is why windows and doors burn more rapidly as compared to beams and floors.

4.13 TESTING OF TIMBER

Specific Gravity

Test specimens 50 × 50 mm in cross-section and 150 mm in length or 20 × 20 mm in cross-section and 60 mm in length are used to determine the sp. gr. of the wood. When rectangular specimens are not obtained, a specimen of about 10 cc volume may be used.

The specimen is weighed and its dimensions are measured. Then, volume is calculated by multiplying all the three dimensions. The volume of irregular specimen is determined by mercury volumeter. The level of mercury in the volumeter is raised to the given mark on the capillary tube and reading is noted. The level is then brought down and specimen is inserted in the volumeter. After raising the level to the given mark, the reading is taken again. Care is taken that no air bubble is entrapped in the volumeter. The difference of the two readings is the volume of the specimen.

Specific gravity is calculated as under:

$$\text{Specific gravity at test} = \frac{W_1}{V_1}$$

$$\text{Adjusted specific gravity} = \frac{W_1}{V_1} \times \frac{100}{100 + m}$$

Where W_1= weight of test specimen

V_1 = volume of test specimen (mm^3)

m = percentage moisture content of the test specimen

Note : If initial condition of the specimen is green (that is, well above the fibre saturation point) adjusted specific gravity is known as standard specific gravity; and if the specimen is dry, the specific gravity is called dry specific gravity.

Volumetric Shrinkage

Volumetric shrinkage is determined on 50 × 50 × 150 mm or 20 × 20 × 60 mm specimen.

The specimen is weighed initially (usually green) and the volume determined. A suitable vessel, half filled with water, is kept on the pan of a weighing balance and weighed. The specimen is then completely dipped in water by means of a needle as shown in Fig. 4.7 and weighed again. The difference of the two readings is volume of the specimen.

The specimen is taken out of the water, wiped with dry cloth, end-coated by immersion in hot paraffin, allowed to air-season under room conditions and weighed periodically until moisture content of about 12 per cent is reached. The volume is determined again. The specimen is then kept in an oven at 103°± 2°C

until an approximately constant weight is reached. After oven-drying, the specimen is again weighed and, while still warm, is immersed in hot paraffin-wax bath, care being taken to remove it quickly to ensure only a thin coating. The volume of the paraffin-coated specimen is determined by immersion as before.

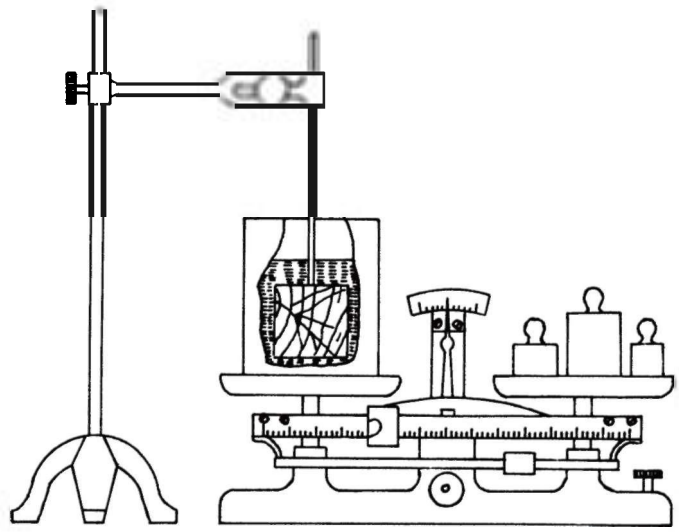


Fig. 4.7 Apparatus for Determination of Volumetric Shrinkage

Volumetric shrinkage form initial condition to required dry condition

$$= \frac{V_1 - V_r}{V_1} \times 100 \text{ per cent of volume in original condition}$$

$$\text{Moisture content, per cent} = \frac{W_r - W_0}{W_0} \times 100$$

The oven dry specific gravity = W_0/V_0

where W_1 and V_1 = weight and volume at initial condition (usually green)

W_r and V_r = weight and volume at the initial required dry condition at r per cent moisture content (usually 12 per cent moisture content or oven dry condition)

W_0 and V_0 = weight and volume at the oven dry condition

Radial and Tangential Shrinkage and Fibre Saturation Point

20 × 20 × 50 mm specimens are cut truly radial or tangential as the case may be in lengthwise direction.

The specimen is weighed initially (usually green) and the length of the specimen is measured by means of a special screw gauge shown in Fig. 4.8. The specimens are allowed to air-season and periodically weighed and measured, until a uniform moisture content of nearly 12 per cent is reached. The specimens are then dried in an oven at 103°+ 2°C until an approximately constant weight is attained. Finally, the specimen is weighed and measured.

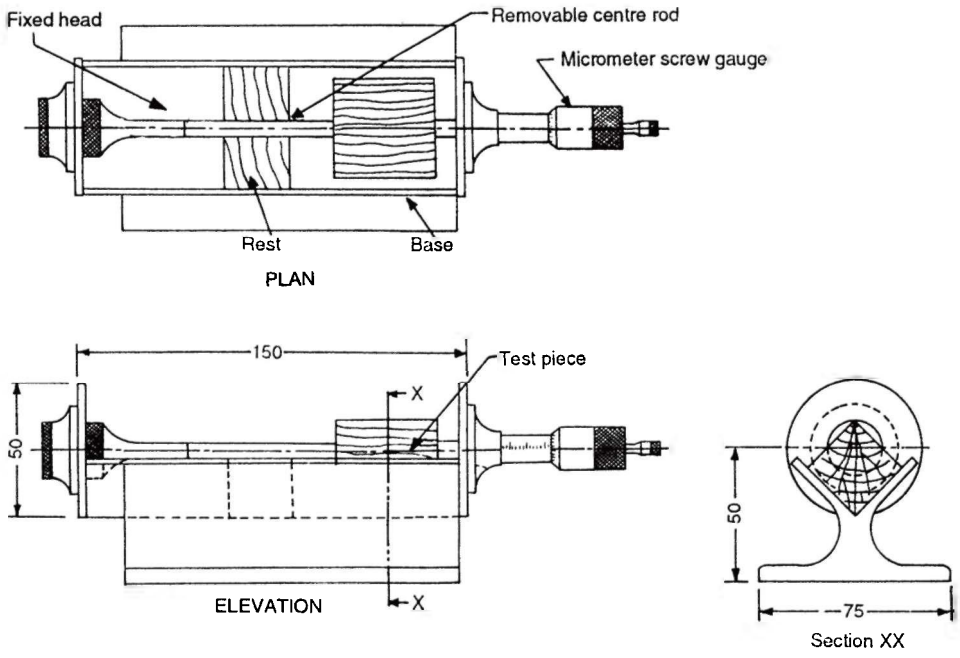


Fig. 4.8 Apparatus for Radial and Tangential Shrinkage

The radial and tangential shrinkage are calculated from the following formulae:

Shrinkage, s, tangential or radial from green to the required dry condition

$$= \frac{l_1 - l_r}{l_1} \times 100 \text{ per cent}$$

$$\text{Moisture content, r, per cent} = \frac{W_r - W_0}{W_0} \times 100 \text{ per cent}$$

where W_1 and l_1 = weight and length in the initial condition (usually green)

W_r and l_r = weight and length at r per cent moisture content

W_0 = weight at oven dry condition

A graph is plotted with r as the ordinate and s as the abscissa. From this graph, the moisture content at which shrinkage commences appreciably is noted. This is known as Y_0 point. The average value of the Y_0 point in the radial and tangential cases is taken as fibre saturation point.

Static Bending Strength

One Point Loading Test The specimen may be 50 × 50 × 750 mm or 20 × 20 × 300 mm. The test specimen is supported on the rig as shown in Fig. 4.9. The load is applied continuously at a constant rate of 2.5 mm per minute in case of 50 × 50 × 750 mm and 1.0 mm per minute in case of 20 × 20 × 300 mm.

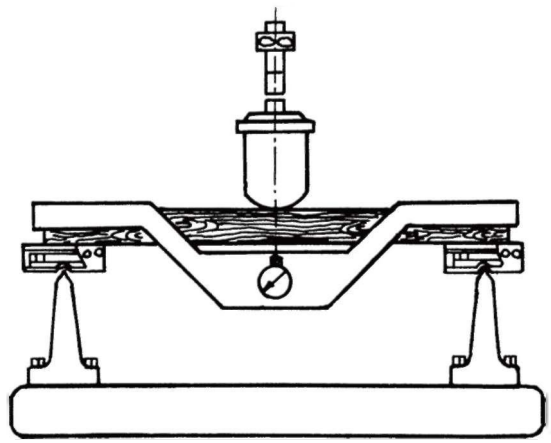


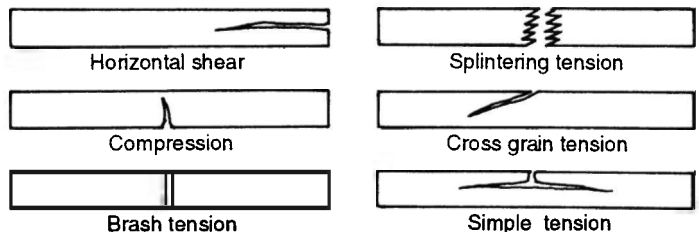
Fig. 4.9 Static Bending Test Equipment

Deflections of the neutral plane at the centre of the length are measured with respect to the points in the neutral plane above the supports. Deflections of the neutral axis are measured at the centre of the beam.

Deflection is measured at suitable load intervals such that about 8-10 readings are available up to limit of proportionality. Beyond the limit of proportionality up to maximum load or beyond maximum load the test is continued until a deflection of 150 mm for 750 mm and 60 mm for 300 mm specimens is reached or the specimen fails to support 1000 N for 50 × 50 × 750 mm or 200 N for 300 mm specimens, whichever is earlier.

The failure of the specimen is recorded according to its appearance and develop-

ment as indicated in Fig. 4.10. The readings of deflections and the loads are recorded and a load-deflection curve is drawn. The various characteristics are determined by the following formulae and from the load-deflection curve. The area is measured by a calibrated planimeter.



4.10 Failure of Timber Specimen Under Static Bending Test

S. No.	*Characteristic*	*Unit*	*Formula*
1.	Fibre stress at limit of proportionality	N/mm^2	$\frac{3Pl}{2bh^2}$
2.	Equivalent fibre stress at maximum load (modulus of rupture)	N/mm^2	$\frac{3Pl}{2bh^2}$
3.	Modulus of elasticity	N/mm^2	$\frac{Pl^3}{4\Delta bh^3}$
4.	Horizontal shear stress on neutral plane at limit of proportionality	N/mm^2	$\frac{3P}{4bh}$
5.	Horizontal shear stress at maximum load	N/mm^2	$\frac{3P'}{4bh}$
6.	Work to limit of proportionality (elastic resilience)	$N\ mm/mm^3$	$\frac{CA}{lbh}$
7.	Work to maximum load	$N\ mm/mm^3$	$\frac{CA'}{lbh}$
8.	Total work	$N\ mm/mm^3$	$\frac{CA''}{lbh}$

where P = load at the limit of proportionality, the point in load-deflection curve at which the graph deviates from the straight line

l, b and h = the length width and height of the test specimen respectively

P′ = maximum load

Δ = deflection at the limit of proportionality

C = area constant

A = area of load-deflection curve up to limit of proportionality

A′ = area up to maximum load

A″ = area up to the final reading when total work is required

Two-point Loading Test The specimen may be 50 × 50 × 100 mm or 20 × 20 × 400 mm. The distance between points of application of the load and the supports (Fig. 4.11) is 150 mm for 50 × 50 mm and 60 mm for 400 mm cross-section. The load is applied at a constant rate of 3 mm per minute and 1.5 mm per minute in the two cases respectively.

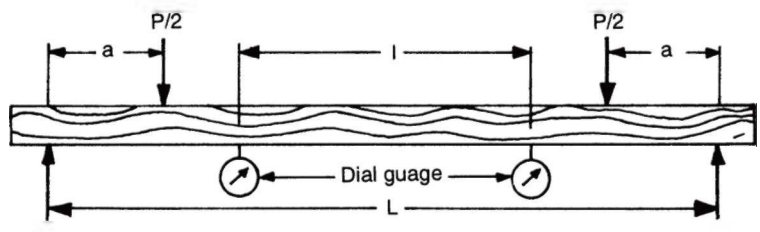


Fig. 4.11 Two Point Load Test

Deflection of neutral axis is measured at the mid span. The distance L between these two points (also called as gauge length) is kept 400 mm and 160 mm for the two specimens respectively. The deflection is measured at suitable load intervals such that 8-10 readings are available up to limit of proportionality and continued up to maximum load. The failure of the specimen is recorded according to its appearance and development as indicated in Fig. 4.10. A graph is plotted with load as ordinate and deflection as abscissa and the limit of proportionality, that is, the point at which the curve deviates from straight line is evaluated. The various characteristics are determined by the following formulae:

S. No.	*Characteristic*	*Unit*	*Formula*
1.	Fibre stress at limit of proportionality	N/mm^2	$\frac{3Pa}{bh^2}$
2.	Equivalent fibre stress at maximum load	N/mm^2	$\frac{3P'a}{bh^2}$
3.	Modulus of elasticity	N/mm^2	$\frac{3Pal_1^2}{4bh^3\Delta}$
4.	Horizontal shear stress on neutral plane at limit of proportionality	N/mm^2	At centre = 0 At ends = $\frac{3P}{4bh}$
5.	Horizontal shear stress at maximum load	N/mm^2	At centre = 0 At ends = $\frac{3P}{4bh}$
6.	Work to limit of proportionality (elastic resilience)	N mm/mm^3	$\frac{P\Delta}{2lbh}$

where l_1 = distance between two fixed points for which deflection is recorded in mm (gauge length)

Impact Bending Strength Test

The specimen for impact bending test is same as that used for static bending strength test. The test is conducted on a suitable impact bending machine. The span is 750 mm in case of 50 × 50 × 750 mm and 280 mm in case of 20 × 20 × 300 mm specimens. The hammer is 25 kg and 1.5 kg for the two sizes respectively.

Static deflection x due to the weight of the hammer is measured at the centre of the specimen. For recording of deflection, a drum is provided which can be brought in contact with a stylus attached to hammer and can be rotated on a vertical axis. On the drum, a paper is fixed by means of sticking tape, under which a carbon paper is placed inverted for recording the impressions. First, a datum line is marked by placing the hammer to rest on the specimen and rotating the drum with stylus touching it. After that, the hammer is dropped from different heights and deflection recorded on the paper fixed on the drum. The first drop of hammer is from a height of 50 mm after which the height of the successive drops is increased by 25 mm until a height of 250 mm is reached, and thereafter increment in height is 50 mm until complete failure occurs or 150 mm or 60 mm deflection is reached for the two sizes respectively. Deflections due to successive drops are recorded. For this purpose, at the drop of the hammer, the drum is to be rotated as the hammer rebounds.

From the tracing on the drum, record the actual deflection at each drop (that

is, the distance from the lowest point to the datum line). A graph is then plotted with the exact height of drop plus maximum deflection at that drop H+ (x+ y) as the ordinate and $(y+ x)^2$ as the abscissa. The point at which the curve deviates from a straight line is taken as limit of proportionality. The various characteristics should be determined by the following formulae:

S.No.	*Characteristic*	*Unit*	*Formula*
1.	Maximum height of drop	mm	H
2.	Height of drop at limit of proportionality	mm	H′
3.	Fibre stress at limit of proportionality	N/mm^2	$\frac{3H' Wl}{bh^2\Delta}$
4.	Modulus of elasticity	N/mm^2	$\frac{H' Wl^3}{2bh^3\Delta^2}$
5.	Work to limit of proportionality	$N\ mm/mm^3$	$\frac{H' W}{lbh}$

where H = maximum height of drop under the given weight

H′ = height of drop at the limit of proportionality read from the curve (inclusive of deflection x + y)

W = weight of the hammer

I = span of the test specimen

b = breadth of the test specimen

h = depth of the test specimen

Δ = (y+ x) at limit of proportionality from the curve

Compressive Strength Test

Parallel to Grain The specimen may be 50 × 50 × 200 mm or 20 × 20 × 80 mm. The load is applied continuously during the test at a constant rate of 0.6 mm per minute for both the sizes.

For 200 mm specimen a load of 2.5 kN is initially applied to set the specimen. Deformation under compression is then measured over a central gauge length of 150 mm. Where possible, direct points are obtained on a graph sheet. The reading is continued well beyond the proportional limit. The final reading at the maximum load is recorded. For 80 mm specimen, final reading of the maximum load only is recorded.

Compression failures are recorded according to the appearance of the fractured surface as shown in Fig. 4.12. In case two or more kinds of failures develop, they are described in the order of their occurrence (for example, shearing followed by crushing). The load deformation curves are drawn. Load and deformation at limit

of proportionality are then read accordingly. The various characteristics are determined by the following formulae:

S.No.	*Characteristic*	*Unit*	*Formula*
1.	Compressive stress at limit of proportionality	N/mm^2	P/A
2.	Compressive stress at maximum load	N/mm^2	P′/A
3.	Modulus of elasticity in compression parallel to grain	N/mm^2	$\frac{LP}{\Delta A}$

Perpendicular to Grain The specimen may be 50 × 50 × 150 mm or 20 × 20 × 100 mm. It should be free from defects and faces should approach closely to

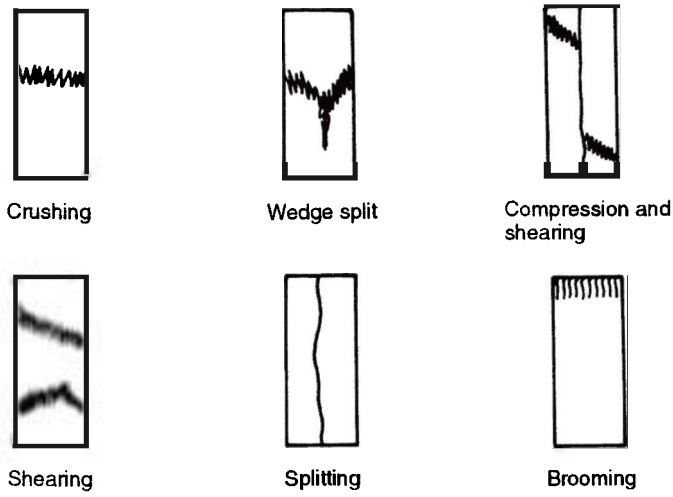


Fig. 4.12 Failure of Timber Specimen Under Compression Parallel to Grain

the true radial and tangential direction.

The load is applied to the radial surface continuously at a constant rate of 0.6 mm per minute for both the sizes.

A small load not more than 500 N on 150 mm and 100 N on 100 mm specimen is initially applied to set the specimen and the deformation is measured to obtain 8 to 10 readings up to limit of proportionality and is continued up to a deformation of 2.5 mm. If maximum load is reached at some lesser value of compressive deformation, the same is recorded along with corresponding deformation. A curve

between load and deformation is plotted. The load and deformation at limit of proportionality is then read. The load at 2.5 mm compression is also recorded. The various characteristics are determined by the following formulae:

S.No.	*Characteristic*	*Unit*	*Formula*
1.	Compressive stress at limit of proportionality	N/mm^2	P/A_1
2.	Compressive stress at compression of 2.5 mm	N/mm^2	P''/A_1
3.	Crushing strength at maximum load	N/mm^2	P_0/A_1
4.	Modulus of elasticity in compression perpendicular to grain	N/mm^2	$\frac{P\,h}{A\Delta}$

where P = load at the limit of proportionality

A = cross-sectional area

P′ = maximum crushing load

L = gauge length between compressometer points

Δ = deformation at the limit of proportionality

A_1 = area of the cross-section normal to the direction of load

P″ = load at 2.5 mm compression

P_0 = maximum load if reached at a compression less than 2.5 mm

h = height of the specimen

Hardness Under Static Indentation Test

The specimens are same as that used in compressive strength test perpendicular to grain. The test is carried out on a suitable testing machine equipped with a special device for penetration into the specimen of a steel bar with hemispherical end or a ball of diameter 11.28 mm to a depth of 5.64 mm that is the projected area of greatest circle is 100 mm^2. The specimen is so placed on the machine that two penetrations are made on the radial face, two on the tangential face and one on each end in case of 50 × 50 × 150 mm size and for 20 × 20 × 100 mm size one penetration is made on tangential and one on radial face. The load is applied continuously at a constant rate of 6 mm per minute for both sizes.

The load required to penetrate the standard steel ball or hemispherical end of the steel bar (11.28 mm dia) to the specified depth of 5.64 mm is recorded for tangential, radial and end surfaces. Where two penetrations on one surface or one penetration on both ends have been made, the average value is taken. The average of radial and tangential hardness is denoted as side hardness.

Shear Strength Test (Parallel to Grain)

The specimen may be 50 × 50 × 60 mm or 20 × 20 × 30 mm. They should be notched on one end as shown in Fig. 4.13 to produce shear failure on 50 × 50 mm or 20 × 20 mm surface in the radial or tangential plane. The test is carried out on a suitable testing machine with the help of a shearing tool in rig. The direction of shearing should be parallel to the longitudinal direction. The load is applied continuously at a constant rate of 0.4 mm per minute. The maximum load required for shearing the area is recorded. The load divided by the area gives the maximum shearing stress in the concerned plane (radial or tangential) for both sizes.

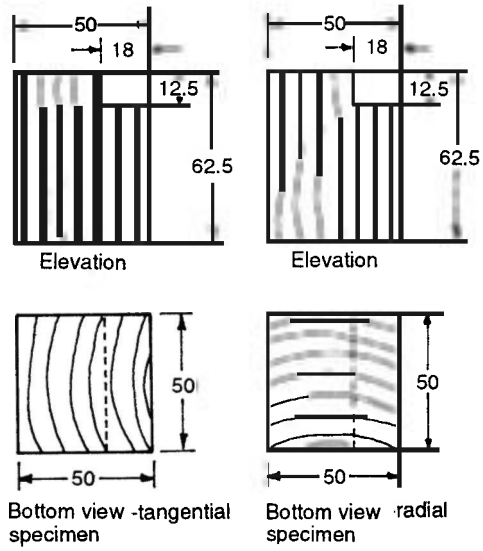


Fig. 4.13 Test Specimen for Shear Parallel to Grain

Tensile Strength Test

Parallel to Grain The test specimen for the two sizes are shown in Fig. 4.14 (a, b). The cross-section of the central portion of the specimen should be 7 × 7 mm or 5 × 5 mm for the specimen in Fig. 4.14 (a) and Fig. 4.14 (b) respectively. The specimen is held firmly in the grips and the suitable elongation measuring device is attached to the gauge length. The load is applied continuously at a constant rate of one millimeter per minute for both sizes. Elongation is measured at suitable load intervals such that 8-10 reading are available up to limit of proportionality. Reading is continued well beyond the proportional limit and final reading of load at failure is recorded.

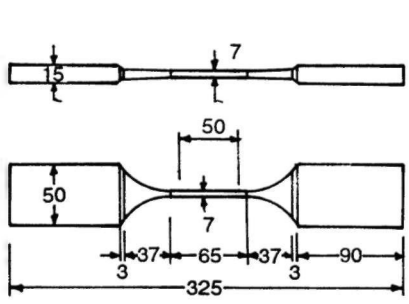


Fig. 4.14(a) Perpendicular to Grain

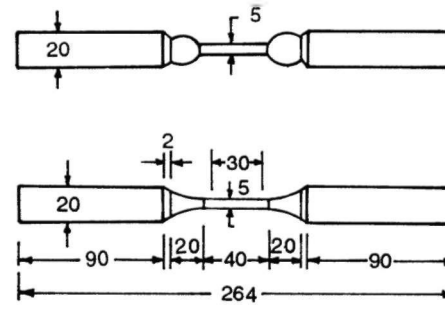


Fig. 4.14(b) Parallel to Grain

Load elongation curves are plotted. The load and elongation at proportional limit are then read. The various characteristics are determined by the following formulae:

S. No.	*Characteristic*	*Unit*	*Formula*
1.	Tensile stress at proportional limits	N/mm^2	$\frac{P}{A}$
2.	Tensile stress at maximum load	N/mm^2	$\frac{P'}{A}$
3.	Modulus of elasticity in tension parallel to grain	N/mm^2	$\frac{LP}{\Delta A}$

where P = load at the limit of proportionality

A = cross-sectional area

P′ = maximum load to cause the failure of the specimen

L = gauge length

Δ = deformation at the limit of proportionality.

Perpendicular To Grain The specimen for the two sizes are shown in Fig. 4.15 (a, b). The notches shown in Fig. 4.15 (a) and 4.15 (b) are so made as to produce a failure on 50 × 20 mm area (Fig. 4.15 (a)) or 20 × 10 mm area (Fig. 4.15 (b)) in the radial or tangential surface as desired. The test is conducted on a testing machine provided with suitable grips to hold the specimen. The load is applied continuously at a constant rate of 2.5 mm per minute until the maximum load is reached for both sizes.

The maximum load required for failure in the case of perpendicular to grain is recorded. The load divided by the area gives the maximum tensile stress perpen-

dicular to grain in the concerned plane (radial or tangential).

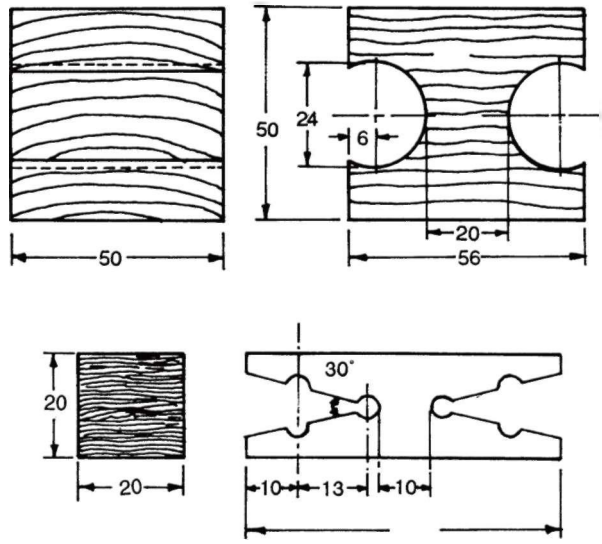


Fig. 4.15 Test Specimen for Tension Perpendicular to Grain

Cleavage Strength Test (Parallel to Grain)

The test specimens for the two sizes are shown in Figs. 4.16(a) and 4.16(b). The

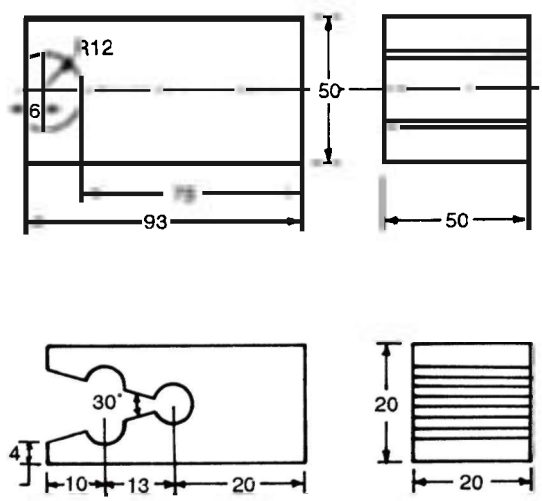


Fig. 4.16 Test Specimen for Cleavage

notches shown in Figs. 4.16 (a) and 4.16 (b) should be such as to fail the specimen in radial or tangential surface as desired. The load is applied continuously at a constant rate of 2.5 mm per minute until the maximum load is reached for both sizes. The maximum load required for failure is recorded. The load divided by the width gives the maximum cleavage resistance N/mm in the concerned plane (radial or tangential).

Brittleness Test

Izod Impact Test The test specimen is 20 × 20 mm in cross-section and 125 mm in length. A saw notch 2 mm in width and 7 mm in depth is made on the radial face of the specimen at a distance of 50 mm from one end so as to produce maximum concentration of impact stress on the cross-section of 20 × 13 mm as shown in Fig. 4.17. The specimen is held vertical tightly clamped as a cantilever in a swinging pendulum machine such that 50 mm length of the specimen is under the clamp. The machine should have a calibrated dial so as to give direct reading of energy absorbed in breaking the specimen in a single blow. The specimen is so clamped that the blow is given in the radial face on the side of notch. The pendulum of the machine is so adjusted that on release from the initial position it may strike the specimen at the lowest point of swing (horizontally) at a distance of 10 mm from the upper end. The impact blow is given by releasing the pendulum and the reading on calibrated dial in N mm is recorded.

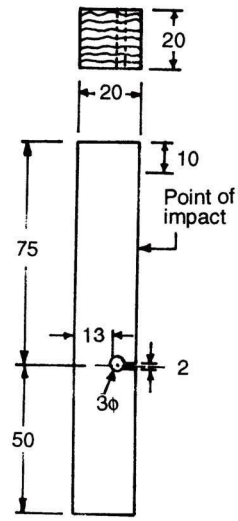


Fig. 4.17 Test Specimen for Brittleness (Izod Impact)

Charpy Impact Test The specimen is 12.5 × 12.5 mm in cross-section and 125 mm in length with the notch at the centre on the radial face. The notch should be *V* type, 2.5 mm in depth and 5 mm in width as shown in Fig. 4.18 so as to produce maximum concentration of impact stress in a cross-section of 12.5 × 10 mm. The specimen is freely supported horizontally with the notch vertical on the base of a swinging pendulum machine up to 10 mm on both ends. The machine should have a calibrated dial so as to give direct reading of energy absorbed in breaking specimen on a single blow. The blow is given on the opposite side of the notch at the centre of specimen. The pendulum of the machine is so arranged that on release from the initial position may strike the specimen at the lowest point of blowing

(horizontally). The impact blow is given by releasing the pendulum and the reading on calibrated dial in N mm is recorded.

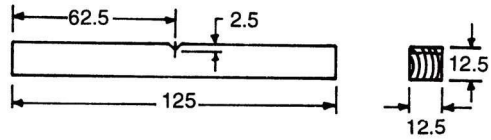


Fig. 4.18 Test Specimen for Brittleness (Charpy Test)

Torsional Strength Test

The dimensions of the cylindrical specimens are shown in Fig. 4.19. The central cylinder should be 220 mm in length for both sizes but the radii should be 25 mm and 12 mm respectively. The end portion for holding the specimen should be 30 mm and 15 mm respectively and 40 mm in length for both the sizes. The test is conducted on a torsion testing machine provided with suitable types of grips to hold the specimen during test firmly on one end and free to rotate at the other end. The specimen is mounted on the machine and the strain (angular twist) measuring device is attached to the specimen at the centre on a gauge length of 150 mm. The torque is applied gradually by turning wheel of the machine at a uniform rate so as to produce a torque of about 5000 N mm per minute. Angular twist is measured in radians or degrees on the specified gauge length 150 mm at regular intervals of

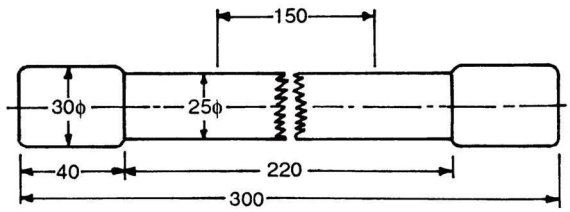


Fig. 4.19 Test Piece for Torsion

torque such that 8 to 10 readings are available upto the limit of proportionality. Readings are continued well beyond the proportional limit and final reading of torque at failure are recorded. The torque-twist curve is drawn. The torque and angular twist at proportional reading limit is read from the curve. The various characteristics are determined by the following formulae:

S.No.	*Characteristic*	*Unit*	*Formula*
1.	Torsion shear stress at proportional limit (TSS at PL)	N/mm^2	$\frac{2M}{\pi r^3}$
2.	Torsion shear stress at maximum torque (TSS at MT)	N/mm^2	$\frac{2M'}{\pi r^3}$
3.	Torsion modulus of rigidity	N/mm^2	$\frac{2ML}{\pi r^4}$

where M = torque at the limit of proportionality

r = radius of the portion of the specimen under gauge

M′ = maximum torque

L = gauge length

π = the angular twist of one end relative to other end at a distance of L

Moisture Content Test

The moisture content of timber and products made of it can be determined by any of the following methods.

Oven-drying Method is most reliable, except for certain timber species containing volatile oils (like deodar) are involved. The method is, however, time consuming and requires cutting of the timber to be tested. Test specimens consisting of a cross-section, 15 to 20 mm long in the direction of the grain, free from all defects, are cut from each sample.

Immediately after each test specimen is cut and loose splinters and saw dust are removed by brushing or scraping, it is weighed. The weighed test specimens are completely ovendried at 103 ± 2°C for 12-18 hours. The oven-dry mass of all the test specimens, is now determined directly after removing from the oven, or after cooling them in desiccators to near room temperature. In case, cutting of specimen from the selected samples is not possible, the moisture content in the whole sample may be determined by collecting borings to a depth of half the thickness of each sample (obtained by means of an auger) in preweighed weighing bottles. The moisture content of each sample is determined by the following formula:

$$M = \frac{W_1 - W_0}{W_0} \times 100$$

The average of moisture content of all the samples from the lot tested is reported correct to the nearest whole number by the following formula for checking confirmity of a lot to the requirements of the relevant specification:

$$\overline{M} = \frac{\sum_{i}^{n} M}{n}$$

where M = moisture content (per cent)

W_1 = initial mass of test specimen

W_0 = oven-dry mass of test specimen

$\overline{M}$ = average moisture content (per cent)

M = moisture content of individual samples (per cent), and n is number of samples selected from the lot

Electrical Moisture Meter Method is a direct, quick, convenient and non-destructive means of determining moisture content of timber and its products. These are of special value in field inspections and for checking of finished timber products. Because of the rapid measurements, and no loss of material by this method, more extensive checking is possible than permitted by the oven-drying method. Resistance type meters with electrode pins of suitable lengths and with species correction and temperature correction charts for the species to be tested are used. The meter readings are taken at three sections along the length in the middle width of each face of every sample. Two sectors are measured at a distance of 450 mm from the ends and the third one at mid length of the sample. If the length of the sample is 1 m or less, readings are made at mid length only on each face. Electrode pins of adequate length are selected for the thickness of timber under test, that is, to probe up to a depth not less than one-fifth the thickness of timber but preferably up to half the thickness. Readings at the various depths into the section are first taken on a few samples to ascertain the presence of large moisture gradients or a wet core (moisture content 20 per cent or above) or a reverse moisture gradient (surface wetter than the core). Moisture gradients are considered to be large if the difference of readings at one-fifth and half the thickness of a sample exceeds four per cent absolute in timber up to 40 mm thick and seven per cent absolute in timber 40 to 65 mm thick. If presence of the condition detailed is confirmed, the meter readings cannot be taken as reliable estimates of the average moisture content in the whole section, but only of the maximum moisture content prevailing within the depth of insertion of pins in case of meters provided with naked pin electrodes, or of the spot moisture content prevailing at the depth of insertion in case of meters provided with insulated pin electrodes. If presence of the conditions detailed is negated, readings at one-fifth thickness are taken as representative of the average in the whole section.

The average moisture content of each sample is calculated as:

$$M = \frac{\sum_{1}^{P} m}{P} \times 100$$

where M = average moisture content of sample (per cent)

m = corrected moisture meter reading in any sector of sample (per cent)

P = number of sector measure

The average of moisture content of all samples tested from a lot is calculated by the formula for checking conformity of a lot to the requirements of the relevant specification:

$$\bar{M} = \frac{\sum_{1}^{n} M}{n} \times 100$$

where $\bar{M}$ = average moisture content (per cent)

M = moisture contents of individual samples (per cent)

n = number of samples selected from the lot

Distillation Method This method is used for species like deodar containing volatile oil or extractives. It is also used for timber impregnated with volatile or non-volatile chemicals that are likely to interfere with the correct determination of moisture content by oven-drying or electrical moisture meter methods.

The apparatus for the test consists of distillation flask with indirect heating arrangement, cold water-cooled condenser of the cold finger type (Fig. 4.20), water trap, scales of accuracy 10 mg, and sealable weighing bottles.

About 50 g of each test sample is distilled till no more water collects in the water trap. Any water condensed elsewhere in the trap is washed down into the trap with the help of a solvent spray. Sufficient time is allowed for a clear separation of water and solvent (xylene or toluene) in the trap. Any bubbles inside the water collected in the trap

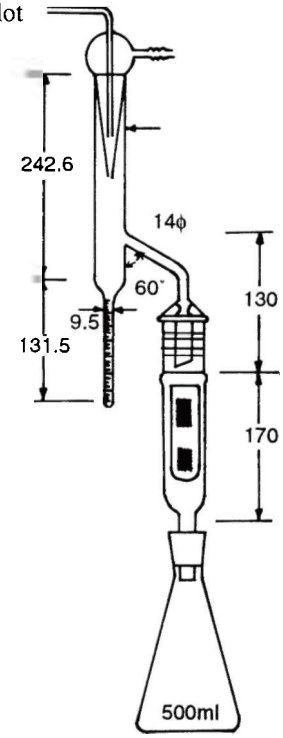


Fig. 4.20 Distillation Apparatus

are removed by tapping it. The moisture content of each sample is calculated by the following formula:

$$M = \frac{M_w}{M_1 - M_w} \times 100$$

where M = moisture content (per cent)

M_1 = mass of test specimen before distillation

M_w = mass of water

4.14 SUITABILITY OF TIMBER FOR SPECIFIC USES

The characteristics and suitability of timbers is given in Table 4.2.

Table 4.2 Characteristics and Uses of Timber from Various Trees

S.No.	Purpose	Requirements	Nature of tree
1.	Agricultural implements	1. Hard and durable 2. Should take good polish	Bel, Arjun, Babul, Black wood
2.	Houses	1. Sufficiently close grained 2. Takes good polish 3. Toughness and durability 4. Pleasing colour 5. Easy to work with	Sisoo, Teak, Ablus, Babul, Haritaki, Jiyal, Kath bel, Mahua, Nirmali, Red wood, Walnut
3.	Bridge	1. Strength, hardness 2. Resistance to salt water action 3. Durability in moist places and under water	Babul, Red cedar, Iron wood, Jarul, Nageshwar, Sal, Satin, Sisoo
4.	Carts and wheels	1. Hardness and durability 2. Close grained	Jiyal, Arjun, Babul, Tamarind
5.	Columns, beams door frames, etc.	1. Hardness and durability 2. Should take good polish 3. Flexibility 4. Light in weight 5. Easy to work 6. Lasts under water	Arjun, Gamhar, Bamboo, Coconut, palm, Jam, Mango, Pial, Palm
6.	Furniture	1. Light, soft and durable 2. Should take good polish 3. Close grains 4. Easy to work with	Teak, Champa, Deodar, Rakta-ghandan, Walnut, Shishum

7.	Fancy goods and toys	1. Easily workable 2. Strength and durability 3. Fairly hard and light weight 4. Scented	Simul, Sandal, Bamboo, Mahogony
8.	Music Instruments	1. Pleasing brick red colour 2. Soft and easy to work 3. Beautiful motteling	Toon, Walnut
9.	Scientific Instruments	1. Moderately hard and tough 2. Light 3. Easy to work with	Guava
10.	Packing boxes	1. Soft and light in weight 2. Lasts under water 3. Cheap	Simul, Palasa, Mango, Deodar
11.	Pegs	1. Hardness and durability 2. Cheap	Arjun, Coconut, Palm, Kher
12.	Piles	1. Strength, hardness and durability 2. Close grains 3. Durable in moist places and under water	Red cedar, Sisoo, Sal, Nageswar, Iron wood
13.	Railway carriage	1. Close grains, hardness and durability 2. Should take good polish	Black wood, Teak, Iron wood, Red wood,
14.	Railway sleepers	1. Hardness, toughness and strength 2. Durability under moist conditions 3. Close grains	Sundari, Red cedar, Sal, Kath bel, Deodar
15.	Scaffolding	1. Strength and durability 2. Flexible 3. Easy to work	Bamboo
16.	Shuttering	1. Hardness and durability 2. Easy to work 3. Durability in moist conditions	Nageshwar, Gamhar, Haritaki
17.	Ships, Boats	1. Hardness, toughness and strength 2. Durability under satly water	Jarul, Babul, Teak, Nageshwar, Bakul, Mahua, Khair
18.	Well curbs	1. Lasts long under water 2. Softness and light weight 3. Easy to work	Red cedar, Palm, Banyan, Babul, Gamhar, Mango
19.	Match Box	1. Moderately hard or soft	Kail, Simul

4.15 PROPERTIES OF WOOD

Physical Properties

Density of wood is approximately equal for all species and averages 1540 kg/m^3

Bulk density depends on the volume of pores and moisture content of the wood. For most wood species, the bulk density is less than unity. Bulk density value is used to determine the quality factor which is the ratio of compressive strength to the bulk density. It is 0.6 for pine and 0.57 for oak.

Moisture movement Timber is liable to shrink or swell with the movement of moisture. This movement is not the same in all the directions. Fig. 4.21 shows two pieces A and B cut from a log. In piece A, the layers producing the annual rings run roughly parallel to the face of the timber, while in piece B, they run roughly at right angles to the face. Movement of the wood due to variations in moisture content is greatest in the plane of the annual rings. The movement a_1 will be greater than movement b. Also, as a_2 is nearer to the condition of b, it will move rather less than a_1. It is clear, therefore, that if a piece of timber is to be used as a board or panel, it will move less if cut like B than like A. It should also be obvious that the slightly varying tendency to movements on the faces of piece may lead to stresses which will cause it to warp. Recommended moisture content for structural elements is 12-20 per cent for doors and 10-16 per cent for windows.

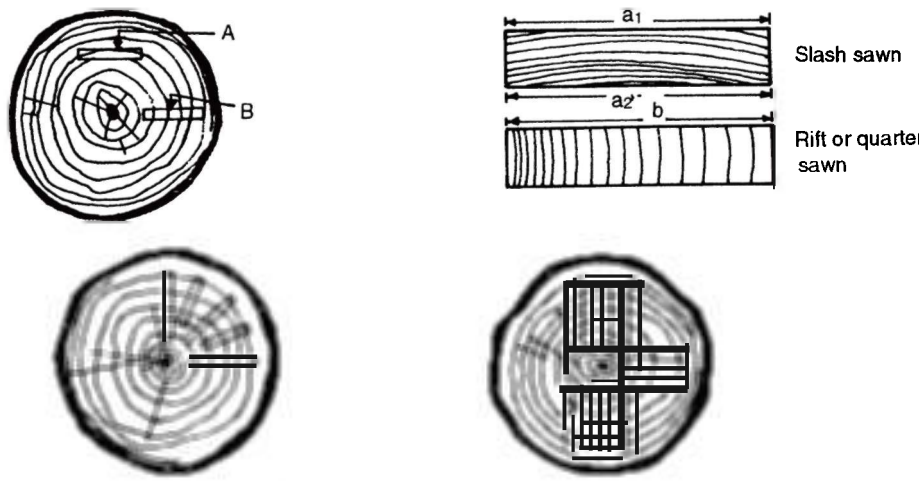


Fig. 4.21 Methods of Converting Timber

Shrinkage is the reduction in linear and volumetric dimensions in drying of wood. Evaporation of capillary water is not accompanied by shrinkage, the latter taking place only when hygroscopic moisture evaporates. Because of structural

non-uniformity, wood shrinks or swells irregularly in various directions. Linear shrinkage along the fibres lies between 0.1 and 0.3 per cent, in radial direction between 3 and 6 per cent and in tangential direction between 7 and 12 per cent. The volume shrinkage factor for various species ranges from 0.2 to 0.75 per cent.

Swelling is the capacity of wood to increase both its linear and volumetric dimensions when it absorbs water. Swelling of wood along the length of fibres ranges from 0.1 to 0.8 per cent, 3 to 5 per cent in the radial direction and 6 to 12 per cent in the tangential direction.

Heat Conductivity is quite low. The coefficient of heat conductivity along the fibres is 1.8 times greater than that across the fibres and averages 0.15 to 0.27 K cal/mh°C. As the bulk density of wood increases and its moisture content decreases, the amount of air entrapped inside cavities decreases, the effect being greater heat conductivity of wood.

Sound Conductivity The velocity of sound in wood is 2 to 17 times greater than in air and as such wood may be considered to have high sound conductivity.

Resistance to Action of Acids and Alkalis Wood is not affected by weak alkali solution but decays in an acid medium (pH< 4).

Mechanical Properties

Wood has three principal axes — longitudinal, radial and tangential — along which properties are fairly constant. Since wood is a nonistropic material, it has three values of modulus of elasticity varying by as much as 150 to 1, three shear moduli varying by 20 to 1 , and six Poisson's ratios varying by 40 to 1. There is no sharply defined elastic limit in wood but there is a proportional limit. However, the stress-strain diagram in any direction is fairly straight over a considerable range before it gradually curves off.

The relative stress-strain curves for direct tension, direct compression and bending stress intensities parallel to the grain in Fig. 4.22 show that in both, direct compression and bending, the proportional limit is in the vicinity of 65 to 75 per

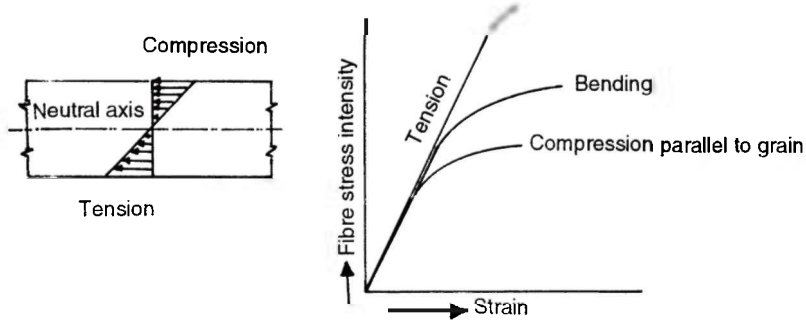


Fig. 4.22 Stress Strain Curves Parallel to the Grain

cent of the ultimate strength. For all practical purposes, there is no proportional limit in direct tension.

Modulus of elasticity of the grain is practically the same in direct tension, direct compression and bending, if shear deformation in bending is eliminated. Because modulus of rigidity of wood is low (approximately 1/15 to 1/20 the modulus of elasticity), the apparent bending modulus of elasticity varies somewhat with the type of loading and span, but in no case it is less than 90 to 95 per cent of the true bending modulus of elasticity.

Compressive strength Compressive strength parallel to fibres, at 15 per cent moisture content, varies from 30.0 to 77.5 N/mm^2. When subjected to compressive force acting parallel to the axis of growth, wood is found to be one of the strongest structural material. However, compressive strength perpendicular to fibres of wood is much lower than that parallel to fibres of wood. Furthermore, a knowledge of the compressive strength is of value in estimating strength in bending, since experiments have demonstrated that the yield point of wooden beams is determined by the compressive strength of the wood.

When wood is subjected to compression parallel to the grain, it may fail through collapsing of the cell walls or through lateral bending of the cells and fibres. In wet wood and in the hardwoods, which are composed of thick-walled fibres and vessels, incipient failure is due to bending of the individual fibres. In cross-grained pieces, the failure is likely to take place through shear parallel to the grain.

The strength of timber compressed across the grain is brought into play whenever a concentrated load is imposed on a beam. Since the compressive strength across the grain is only a small fraction of the compressive strength parallel to the grain, proper allowance for this discrepancy must be provided with a footing to distribute the pressure.

Tensile Strength Parallel to the fibres is of the order 80.0 to 190.0 N/mm^2. However, wooden parts restrained at their ends suffer from shearing stresses and crushing which wood resists poorly, and cannot be extensively used in structures working under tension. Moreover, since the tensile strength parallel to the grain is two to four times the compressive strength, the latter governs the strength of beams. The tensile strength parallel to the grain is influenced to some extent by the nature of the wood elements and their arrangement, but principally by the straightness of the grain and the thickness of the walls of the longitudinal elements. When failure occurs, these elements are ruptured transversely. Knots greatly reduce the tensile strength parallel to the grain. The tensile strength is less affected by moisture than are other mechanical properties.

Across the grain, the tensile strength of wood is low. It is a property closely related to cleavability, and it often determines the strength of a beam which has cross-grain or spiral-grain in its tension fibres. Failure in tension across the grain

occurs through separation of the cells and fibres in longitudinal planes. Knots, shakes, etc. reduce the tensile strength of wood across the grain.

Bending Strength Wood well withstands static bending, owing to which it is widely employed for elements of buildings, e.g. beams, slabs, rafters, trusses, etc. The initial failure of long beams of uniform width is indicated by a wrinkling of the overstressed compression fibres, much like the failures which occur in compression prisms. Final failure of such beams is generally in tension. It is accompanied more or less by snapping as the individual fibres begin to break when the maximum load is reached. Very dry specimens sometimes fail very suddenly in tension before any wrinkling of the compression fibres is noticeable. However, green test pieces fail silently in compression without rupturing of the tensile fibres. Short deep beams fail by horizontal shear suddenly, and this is more common in well seasoned timber of structural sizes than in green timbers or in small beams. Very often shear failures result from defects.

Long narrow beams must be restrained laterally and supported in such manner that the wide sides are vertical. If the first condition is not fulfilled, the member will fail from column action in the compression fibres. Unless the second condition is met, strength of the beam may be very seriously reduced through the inclination of the neutral axis. These requirements are satisfied by diagonal bracing known as *bridging*. The bending strength of some of the timbers is given in Table 4.3.

Shearing Strength Wood has low shearing strength of 6.5-14.5 N/mm^2 along

Table 4.3 Bending Strength of Timbers

S.No.	Trade name	Unit weight N/m^3 at 12% moisture content	Bending strength (N/mm^2) Location		Durability
			Inside	Outside	
1.	Babul	8350	18.2	15.4	Low
2.	Chir	5750	8.4	7.0	Low
3.	Deodar	5600	10.2	8.8	High
4.	Fir	4650	7.8	6.6	Low
5.	Jaman	8500	15.2	12.6	Moderate
6.	Mango	6550	12.4	10.2	Low
7.	Oak	8650	14.8	12.4	Moderate
8.	Sal	8000	16.8	14.0	High
9.	Teak	6250	14.0	11.6	High
10.	Neam	8360			-
11.	Rosewood	7550			High
12.	Shishum	7850			Moderate
13.	Cail	5150			Low

the fibres. Resistance of wood to cutting across the fibres is 3 to 4 times greater than that along the fibres, but pure shear generally does not take place since the fibres are also subjected to crushing and bending.

Stiffness In general, denser woods are more stiff. A green timber is less stiff than when seasoned. The structural sizes of timber are about as stiff as the clear small sticks.

Toughness A wood which has a large capacity to resist shock or blows is called tough. Hard wood as a class excels in toughness. Long leaf pine is the only one of the conifers possessing much toughness. In general, green wood is tougher than seasoned wood.

Cleavability is the measure of the ease with which wood may split. Most hard woods split more easily along radial planes than along tangential surfaces. Among the conifers, with an exception of longleaf pine, the difference in cleavage strength in the two directions is not great.

Hardness is defined and measured as resistance to indentation and resistance to scratching. Both are important properties in woods used for finishing and for furniture. These properties, together with the ability to wear without splintering, determine the wearing resistance of wood for floors and pavements.

Effect of Moisture on Mechanical Properties of Wood

Variations in the moisture content of the cell walls are accompanied by large changes in the strength and stiffness of wood. After years of seasoning, large timbers may lose enough water to effect an increase in tensile and compressive strength and in stiffness, but defects arising from shrinkage stresses often decrease the resistance to horizontal shear stresses. In kiln-seasoning, the normal increase in strength due to loss of moisture is often nullified by case-hardening, a condition which prevents complete drying of the piece and produces internal stresses.

The mechanical properties of wood are not materially affected by a reduction of the moisture content until the point of fibre-saturation is reached. Further drying causes a large, proportionate increase in strength and stiffness.

Effect of Temperature on Strength of Wood

The effects of temperature on wood are dependent upon the moisture content. Dry wood expands slightly when heated, while wet wood shrinks owing to evaporation of moisture. Very high temperatures, such as those used in vulcanizing, slightly weaken dry wood. Freezing somewhat increases both the strength and stiffness of wood. If wood is kept moist during the heating process, it is rendered very pliable and is weakened.

4.16 WOOD PRODUCTS

Many wood based products have been developed to economise on the use of timber.

Veneers

The primary process in the manufacture of wood based products is veneering which produces thin sheets of wood known as *veneers*. The thickness of veneers varies from 0.4 to 0.6 mm. The most suitable wood for this purpose is walnut. However, other species like teak, sissoo, rose wood, etc. are also used. The logs to be used for this purpose are kept in wet storage to avoid end splitting and are softened by heating with hot water or steam and the bark is removed. The log is then cut to veneers. Depending on the cutting process, the veneers are classified as rotary veneers (Fig. 4.23) and sliced veneers (Fig. 4.24). These are used in the manufacture of plywood and other laminated boards.

Plywood

A wood panel glued under pressure from an odd number (usually 3 to 13) of layers/piles of veneers is known as plywood (Fig. 4.25). The outer most veneer sheets in a plywood panel are called *faces*. The interior ply/plies which have their

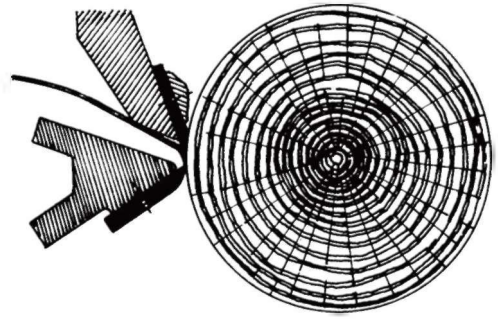


Fig. 4.23 Rotary Cutting

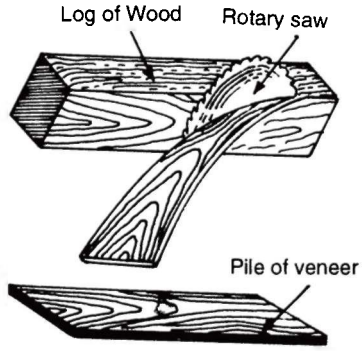


Fig. 4.24 Sliced Veneer

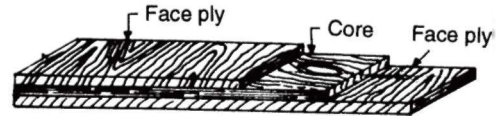


Fig. 4.25 Plywood

grain directions parallel to that of the faces are termed as *core/centre*. Other piles which have grain directions perpendicular to that in the face are termed as *cross bands*.

Plywood may be classified upon direction of grains in the plies and on the type of adhesive used. Normally the alternate plies are oriented at 30° or 60° in *star* plywood. The faces are arranged with the grain at 45° to that of the centres in *diagonal* plywood. When the plies are bonded together with water-soluble glues such as casein glue, *interior grade* plywood is obtained and when bonded with phenol formaldehyde adhesive it is identified as *exterior grade* plywood which is completely water proof.

Plywood Grades Plywood is graded as boiling water proof (BWP) grade, boiling water resistant (BWR) grade, warm water resistant (WWR) grade and, cold water resistant (CWR) grade, depending upon the type of adhesive used for bonding of the veneers. These are further classified as AA, AB, AC, BB, BC and CC based on the quality of the two faces, each face being of the kind A, B, or C. After pressing, the finished plywood is recommended to a moisture content not less than 8 per cent and not more than 16 per cent.

Advantages

1. It has good strength both along as well as across the grains.

2. The wood shrinks or swells more across the grains. Since plywood has cross-grained construction, the tendency to shrink or swell is reduced.

3. It has better splitting resistance due to the grains in adjacent veneers in cross direction as such nailing can be done very safely even near the edges.

4. Plywood can be curved into desired shapes.

Uses These are extensively used for partitions, ceilings, doors, concrete form work, plywood boards, lamin boards (built-up boards with core strips up to 7 mm wide and 7 mm thick) and block boards (built-up boards) etc.

Fibre Boards

These boards built up of felting from wood or vegetable (wood wastes, waste paper, agricultural wastes, etc.) are classified by the process of their moulding. If the boards are moulded by wet process, the main bond is by the felting of woody fibres and not by added glue. For the boards moulded by dry process, the bond between the predried fibres is improved by adding 4-8% of synthetic resin. For better performance wood preservatives and other admixtures are often added to the pulp. *Insulating boards* are not compressed during manufacture. *Hard boards* have one surface smooth and the other one textured. Some of the trade names of hard boards are Masonite, Celotex, Essex boards, etc.

Classification Hard boards are classified as medium, standard or normal and tempered hard boards depending upon the density. The requirements of hard boards are given in Tables 4.4, 4.5 and 4.6.

Table 4.4 Requirements of Hardboards

Type of Board	Average density (10^3 x Kg/ m^3)	Thickness (mm)	Bending strength (Modulus of rupture) average (MPa)	Maximum water absorption by mass after 24 hrs immersion (%)
			6	
Medium hardboard	Min. 0.35	8	6	40
	Max. 0.80	10		
		12		
Standard hardboard	More than 0.80	3	30	40
		4		
		5		
		6	30	30
		7		
Tempered hardboard	1.2	3		
		4		
		5	50	20
		6		
		9		

Table 4.5 Thickness of Hardboards

Type	Nominal thickness (mm)	Tolerance (mm)
Medium hardboard	6	± 0.5
	8	± 0.7
	10	± 0.7
	12	± 0.9
Standard hardboard	3	
	4	± 0.4
	5	
	6	± 0.5
	9	± 0.7

Table 4.6 Width and Length of Hardboards

Type	Width (m)	Maximum tolerance on Width (mm)	Length (m)	Maximum tolerance on length (mm)
Medium hardboard	1.2		1.2, 1.8, 2.4	
Standard hardboard	1.2	± 3	3.0, 3.6, 4.8	± 5
Tempered hardboard	1.2		and 5.5	

Uses They are widely used for wall and ceiling cladding, partitions, doors, perforated acoustic tiles, railway carriages, bus bodies, etc.

Particle Boards or Chip Boards

They are manufactured from particles of wood or other ligno cellulose materials which are agglomerated, formed and pressed together by the use of an organic binder together in the presence of heat, pressure or moisture. They are manufactured from small timber pieces and wood wastes. The latter is first converted into small chips. The moisture content of chips is reduced to 15 per cent and then some gluing material, usually phenol formaldehyde, is sprayed. The chips are then spread to form a mat and then pressed in a hydraulic press in presence of heat and moisture.

Dimensions and Tolerances The size of particle boards in mm should be as follows :

Length (mm)	4850, 3650, 3000, 2750, 2400, 2100, 1800, 1500, 1200, 1000, 900.
Width (mm)	1850, 1800, 1500, 1200, 1000, 900, 600, 450
Thickness (mm)	6, 9,12, 15, 19, 22, 15, 27, 30, 35, 40
Tolerances	
Length	± 8 mm
Width	± 8 mm
Thickness	± 2.5%
Above 25 mm	+ 2.5%
Up to 25 mm	± 5%
Density	Mean density of particle boards shall be between 500.0-900.0 Kg/m^3

Uses These are widely used in buildings, partitions, ceilings, floor slabs, doors, furniture, etc.

Block Boards

The core is made up of strips of wood each not exceeding 25 mm in width, forming a slab, glued between at least two surface veneers (Fig. 4.26). The directions of the grains of the core blocks run at right angles to that of the adjacent outer veneers.

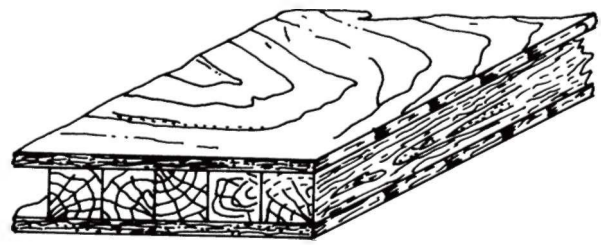


Fig. 4.26 Block Board

The grades and types of block boards are represented as:

ICOM	Interior grade commercial type
IDEC	Interior grade decorative type
XCOM	Exterior grade commercial type
XDEC	Exterior grade decorative type

These are further subgraded as Grade 1 and Grade 2. Grade 1 is *exterior grade* used for bus bodies, railways coaches, prefabricated houses, etc. and Grade 2 is *interior grade* used for furniture, partition, panelling, ceiling, etc.

Uses These are extensively used for construction of railways carriages, bodies of buses, marine and river crafts, partitions, furniture, etc.

Batten Boards have core made up of 80 mm wide wood pieces as shown in Fig. 4.27, forming a slab glued between at least two surface veneers. The directions of the grains of the core block runs at right angles to that of adjacent outer veneers.

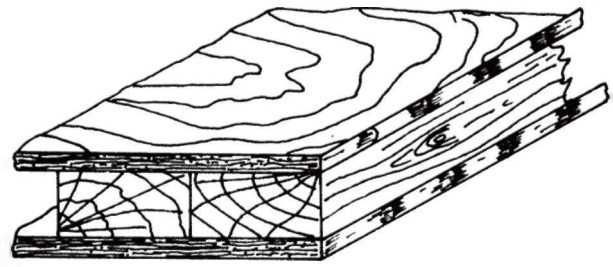


Fig. 4.27 Batten Board

Lamin Boards have a core of strips, each not exceeding 7 mm in thickness as shown in Fig. 4.28, glued together to form a slab which in turn is glued between two or more outer veneers. The directions of the grains of the core block run at right angles to that of the adjacent outer veneers.

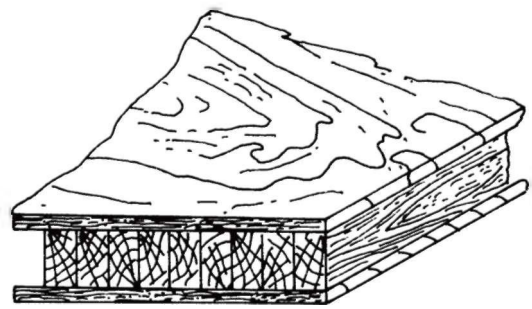


Fig. 4.28 Lamin Board

EXERCISES

Q.1 Draw the cross-section of a matured tree. What is the best season for felling a tree ?

Q.2 What suggestions do you propose for improvement in construction to avoid decay of timber, and what measures are to be taken, when it has occurred ?

Q.3 (a) State the principal causes of decay of timber.
(b) How is seasoning done on a large scale?
(c) Discuss the methods of preserving timbers.

Q.4 (a) What are dry and wet rots ? How are they caused and prevented ?
(b) What is seasoning of timbers and why is it done ?
(c) State the qualities you will consider in selecting timber for construction purposes ?

Q.5 (a) What is the effect of paint on unseasoned timber ?
(b) What are the requirements of good preservatives ? What are the main types ?
(c) Describe various defects in timber ?

Q.6 Explain the following defects of timber.
(a) Shakes (b) Rindgall
(c) Upsets (d) Knots

Q.7 (a) What is the difference between soft wood and hard wood ?
(b) State the characteristics of good timber.
(c) Describe briefly the methods of timber preservation.
(d) What are the diseases of timbers ?

Q.8 Write short notes on the following:
(a) Defects in timber (b) Ply wood
(c) Seasoning of timber (e) Hard board
(d) Preservation of timber (f) Veneers

Q.9 Discuss briefly the following:
(a) Effects of moisture on mechanical properties of wood.
(b) Effect of temperature on strength of wood.
(c) Fire resistance of timber.

Q.10 Describe the physical and mechanical properties of timber.

Q.11 Suggest suitable timber for the following purposes. Give also the reasons for your choice.
(a) Doors (b) Railway sleepers
(c) Piles (d) Scaffolding
(e) Shuttering (f) Pegs
(g) Purlins (h) Well curb
(i) Furniture (j) Agricultural equipments
(k) Packing boxes

Q.12 Write short notes on the following:
(a) AsCu Treatment
(b) Plywood
(c) Hard board
(d) Lamin board
(e) Chip board
(f) Batten board

Q.13 (a) Describe the various processes of application of preservatives.
(b) Define seasoning of timber. How is seasoning done on large scale ?
(c) Why is it necessary to provide odd number of veneers in a plywood ?

Q.14 (a) What is plywood and where is it used with advantage ? State its uses in modern buildings.
(b) What are the principal categories in which the trees can be classified ? Give two examples of each of them along with their uses as building material.

Q.15 Describe the chief characteristics and uses of the following in the construction industry:
(a) Sheeshum
(b) Teak
(c) Deodar
(d) Bamboo
(e) Sal
(f) Plywood

Q.16 Differentiate between:
(a) Exogenous and endogenous trees
(b) Star shake and heart shake
(c) Natural and artificial seasonings
(d) Lamin board and batten board

Q.17 What are the various tests performed to test the suitability of timber ? Describe in detail the tests performed to determine moisture content of timber.

Q.18 Describe the following tests for:
(a) Compressive strength
(b) Impact strength
(c) Cleavability
(d) Tensile strength

Q.19 (a) Explain the damage caused by insects to wood.
(b) Why is preservative treatment necessary for timber ?
(c) Describe briefly the application of preservatives to increase the fire resistance of wood.

Q.20 (a) What are the advantages of wood based products ?
(b) Explain the different ways of classification of timber.
(c) Explain the different methods of veneering.

Chapter

5

MATERIALS FOR MAKING CONCRETE - I CEMENT

5.1 INTRODUCTION

Assyrians and Babylonians were perhaps the first to use clay as cementing material. In ancient monuments, e.g. forts, places of worship and defence structures, stones have been invariably used as a construction material with lime as the binder. Records show that Egyptians have used lime and gypsum as cementing materials in the famous pyramids. Vitruvius, a Roman scientist, is believed to be the first to have the know how about the chemistry of the cementitious lime. One of the most notable examples of Roman work is the Pantheon. It consists of a concrete dome 43.43 m in span. The calcareous cements used by the Romans were either composed of suitable limestones burned in kilns or were mixtures of lime and puzzolanic materials (volcanic ash, tuff) combining into a hard concrete. Vitruvius's work was followed by the researches made by M. Vicat of France. Joseph Aspedin of Yorkshire (U.K.) was the first to introduce Portland cement in 1824 formed by heating a mixture of limestone and finely divided clay in a furnance to a temperature

high enough to drive off the carbonic acid gas. In 1845, Issac C. Johnson invented the cement by increasing the temperature at which the mixture of limestone and clay were burned to form clinker. This cement was the prototype of the modern Portland cement. From then onwards, a gradual improvement in the properties and qualities of cement has been made possible by researchers in U.S.A., U.K., France and Germany.

Cements in a general sense are adhesive and cohesive materials which are capable of bonding together particles of solid matter into a compact durable mass. For civil engineering works, they are restricted to calcareous cements containing compounds of lime as their chief constituent, its primary function being to bind the fine (sand) and coarse (grits) aggregate particles together.

Cements used in construction industry may be classified as hydraulic and non-hydraulic. The latter does not set and harden in water such as non-hydraulic lime or which are unstable in water, e g. Plaster of Paris. The hydraulic cements set and harden in water and give a product which is stable. Portland cement is one such.

Cement can be manufactured either from natural cement stones or artificially by using calcareous and argillaceous materials. The examples of natural cements are Roman cement, Puzzolana cement and Medina cement and those of artificial cement are Portland cement and special cements.

Today cement finds extensive use in all types of construction works; in structures where high strength is required e.g. bridge piers, light houses, lofty towers, and large structures such as bridges, silos, chimneys. And also in structures exposed to the action of water, e.g. reservoirs, dams, dock yards etc. Cement mortar, concrete, reinforced brick work, artificial stones, plastering, pointing and partition walls are routinely used in buildings.

5.2 PORTLAND CEMENT

It is a cementing material resembling a natural stone quarried from Portland in U.K. Portland cement may be defined as a product obtained by finely pulverizing clinker produced by calcining to incipient fusion, an intimate and properly proportioned mixture of argillaceous and calcareous materials. Care must be exercised in proportioning the raw materials so that the clinker of proper constitution may be obtained after burning.

5.3 CHEMICAL COMPOSITION OF RAW MATERIALS

The three constituents of hydraulic cements are lime, silica and alumina. In addition, most cements contain small proportions of iron oxide, magnesia, sulphur

trioxide and alkalis. There has been a change in the composition of Portland cement over the years, mainly reflected in the increase in lime content and in a slight decrease in silica content. An increase in lime content beyond a certain value makes it difficult to combine completely with other compounds. Consequently, free lime will exist in the clinker and will result in an unsound cement. An increase in silica content at the expense of alumina and ferric oxide makes the cement difficult to fuse and form clinker. The approximate limits of chemical composition in cement are given in Table 5.1.

Table 5.1 Chemical Composition of Portland Cement

Oxide	Function	Composition (%)
CaO	Controls strength and soundness. Its deficiency reduces strength and setting time.	60-65
SiO_2	Gives strength. Excess of it causes slow setting.	17-25
Al_2O_3	Responsible for quick setting, if in excess, it lowers the strength.	3-8
Fe_2O_3	Gives colour and helps in fusion of different ingredients	0.5-6
MgO	Imparts colour and hardness. If in excess, it causes cracks in mortar and concrete	0.5-4
Na_2O+K_2O	These are residues, and if in excess cause efflorescence and cracking	0.5-1.3
TiO_2		0.1-0.4
P_2O_5		0.1-0.2
SO_3	Makes cement sound.	1-2

Notes : (i) The rate of setting of cement paste is controlled by regulating the ratio $SiO_2/(Al_2O_3 + Fe_2O_3)$.

(ii) Where development of much heat of hydration is undesirable, the silica content is increased to about 21 per cent, and the alumina and iron oxide contents are limited to 6 per cent each.

(iii) Resistance to the action of sulphate waters is increased by raising further the silica content to 24 per cent and reducing the alumina and iron contents to 4 per cent each.

(iv) Small percentage of iron oxide renders the highly siliceous raw materials easier to burn. However, if these are in excess, a hard clinker, difficult to ground, is produced. When iron oxide combines with lime and alumina to form C_4AF, it neutralizes some of the undesirable properties contributed by alumina when combined with lime alone. When iron oxide combines with lime alone, it promotes instability.

(v) The alkalis accelerate the setting of cement paste.

The oxides in fusion interact with each other to form a series of more complex products and form the cement clinker.

5.4 COMPOSITION OF CEMENT CLINKER

The various constituents combine in burning and form cement clinker. The compounds formed in the burning process have the properties of setting and hardening in the presence of water. They are known as *Bogue compounds* after the name of Bogue who identified them. Le-Chatelier and Tornebohm have referred these compounds as Alite (C_3S), Belite (C_2S), Celite (C_3A) and Felite (C_4AF). The following Bogue compounds are formed during clinkering process.

The principal mineral compounds in Portland cement	Formula	Name	Symbol
1. Tricalcium silicate	$3CaO \cdot SiO_2$	Alite	C_3S
2. Dicalcium silicate	$2CaO \cdot SiO_2$	Belite	C_2S
3. Tricalcium aluminate	$3CaO \cdot Al_2O_3$	Celite	C_3A
4. Tetracalcium alumino ferrite	$4CaO \cdot Al_2O_3 \cdot Fe_2O_3$	Felite	C_4AF

The properties of Portland cement varies markedly with the proportions of the above four compounds, reflecting substantial difference between their individual behaviour.

Tricalcium Silicate is supposed to be the best cementing material and is well burnt cement. It is about 25-50% (normally about 40 per cent) of cement. It hydrates rapidly generating high heat and develops an early hardness and strength. However, raising of C_3S content beyond the specified limits increases the heat of hydration and solubility of cement in water. The hydrolysis of C_3S is mainly responsible for 7 day strength and hardness. The rate of hydrolysis of C_3S and the character of gel developed are the main causes of the hardness and early strength of cement paste. The heat of hydration is 500 J/g.

Dicalcium Silicate is about 25-40% (normally about 32 per cent) of cement. It hydrates and hardens slowly and takes long time to add to the strength. It imparts resistance to chemical attack. Raising of C_2S content renders clinker harder to grind, reduces early strength, decreases resistance to freezing and thawing at early ages and decreases heat of hydration. The hydrolysis of C_2S proceeds slowly. At early ages, less than a month, C_2S has little influence on strength and hardness. While after one year, its contribution to the strength and hardness is proportionately almost equal to C_3S. The heat of hydration is 260 J/g.

Tricalcium Aluminate is about 5-11% (normally about 10.5 per cent) of cement. It rapidly reacts with water and is responsible for flash set of finely grounded clinker. The rapidity of action is regulated by the addition of 2-3% of gypsum at the time of grinding cement. Tricalcium aluminate is responsible for the initial set, nigh heat of hydration and has greater tendency to volume changes causing cracking. Raising the C_3A content reduces the setting time, weakens resistance to sulphate attack and lowers the ultimate strength, heat of hydration and contraction

during air hardening. The heat of hydration is 865 J/g.

Tetracalcium Alumino Ferrite It is about 8-14% (normally about 9 per cent) of cement. It is responsible for flash set but generates less heat. It has poorest cementing value. Raising the C_4AF content slightly reduces the strength. The heat of hydration is 420 J/g.

5.5 HYDRATION

The chemical reaction between cement and water is known as *hydration* of cement. The reaction takes place between the active components of cement (C_4AF, C_3A, C_3S and C_2S) and water. The factors responsible for the physical properties of concrete are the extent of hydration of cement and the resultant microstructure of the hydrated cement.

When the cement comes in contact with water, the hydration products start depositing on the outer periphery of the nucleus of hydrated cement. This reaction proceeds slowly for 2-5 hours and is called *induction* or *dormant period.* As the hydration proceeds, the deposit of hydration products on the original cement grain makes the diffusion of water to unhydrated nucleus more and more difficult, consequently reducing the rate of hydration with time. At any stage of hydration, the cement paste consists of gel (a fine-grained product of hydration having large surface area collectively), the unreacted cement, calcium hydroxide, water and some minor compounds.

The crystals of the various resulting compounds gradually fill the space originally occupied by water, resulting in the stiffening of the mass and subsequent development of the strength. The reactions of the compounds and their products are as follows:

$$C_3S + H_2O \rightarrow C\text{–}S\text{–}H^* + Ca(OH)_2$$
$$C_2S + H_2O \rightarrow C\text{–}S\text{–}H + Ca(OH)_2$$
$$C_3A + H_2O \rightarrow C_3AH_6$$
$$C_3A + H_2O + CaSO_4 \rightarrow CA\cdot C\overline{S}H_{12}$$

Calcium sulpho-aluminate

$[\ H^*$ is H_2O, $\overline{S}$ is $SO_3\ ]$

$$C_4AF + H_2O \rightarrow C_3AH_6 + CFH$$

The product C-S-H gel represents the calcium silicate hydrate also known as *tobermorite gel* which is the gel structure. The hydrated crystals are extremely small, fibrous, platey or tubular in shape varying from less than 2 μm to 10 μm or more. The $Ca(OH)_2$ liberated during the silicate phase crystallizes in the available free space. The gel must be saturated with water if hydration is to continue. The calcium hydroxide crystals formed in the process dissolve in water providing hydroxyl (OH^-) ions, which are important for the protection of reinforcement in

concrete. As hydration proceeds, the two crystal types become more heavily interlocked increasing the strength, though the main cementing action is provided by the gel which occupies two-thirds of the total mass of hydrate.

Notes : (i) It has been found that hydration of C_3S produces lesser calcium silicate hydrate and more $Ca(OH)_2$ as compared to the hydration of C_2S. Since $Ca(OH)_2$ is soluble in water and leaches out making the concrete porous, particularly in hydraulic structure, a cement with small percentage of C_3S and more C_2S is recommended for use in hydraulic structures.

(ii) It is particularly important to note that the setting (the change of cement paste from plastic to stiff solid state) and hardening (gain of strength with hydration) is a chemical reaction, wherein water plays an important role, and is not just a matter of drying out. In fact, setting and hardening stop as soon as the concrete becomes dry.

5.6 RATE OF HYDRATION

The reaction of compound C_3A with water is very fast and is responsible for flash setting of cement (stiffening without strength development) and thus it will prevent the hydration of C_3S and C_2S. However, calcium sulphate ($CaSO_4$) present in the clinker dissolves immediately in water and forms insoluble calcium sulpho-aluminate. It deposits on the surface of C_3A forming a colloidal membrane and consequently retards the hydration of C_3A. The amount of $CaSO_4$ is adjusted to leave a little excess of C_3A to hydrate directly. This membrane in the process breaks because of the pressure of the compounds formed during hydration and then again C_3A becomes active in the reaction.

The hardening of C_3S can be said to be catalyzed by C_3A and C_3S becomes solely responsible for gain of strength up to 28 days by growth and interlocking of C-S-H gel. The increase in strength at later age is due to hydration of C_2S.

Notes : (i) The development of strength of the four principal compounds of cement with age is shown in Fig. 5.1.

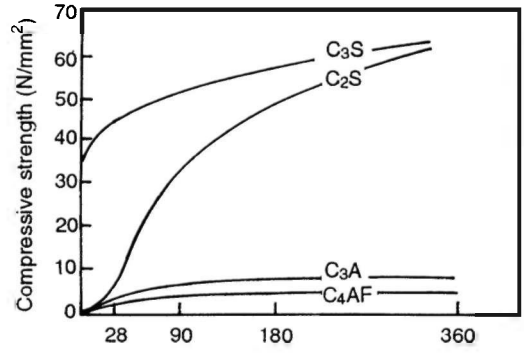


Fig. 5.1 Contribution of Cement Compounds to Strength of Cement

(ii) The rate of heat evolution of the compounds if equal amount of each is considered will be in the following descending order :

C_3A,C_3S, C_4AF, C_2S

(iii) The rate of hydration is increased by an increase in fineness of cement. However, total heat evolved is the same. The rate of hydration of the principal compounds is shown in Fig. 5.2 and will be in the following descending order :

C_4AF, C_3A, C_3S, C_2S

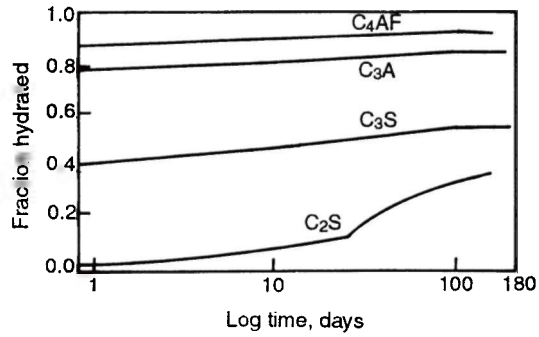


Fig. 5.2 Rate of Hydration of Pure Cement Compounds

5.7 WATER REQUIREMENT FOR HYDRATION

About an average 23 per cent (24 per cent C_3S, 21 per cent C_2S) of water by weight of cement is required for complete hydration of Portland cement. This water combines chemically with the cement compounds and is known as *bound water*. Some quantity of water, about 15 per cent by weight of cement, is required to fill the cement gel pores and is known as *gel water*. Therefore, a total of 38 per cent of water by weight of cement is required to complete the chemical reaction. If excess water is present, it will lead to capillary cavities.

5.8 MANUFACTURE

Calcareous and argillaceous raw materials are used in the manufacture of Portland cement. The calcareous materials used are cement rock, limestone, marl, chalk and marine shell. The argillaceous materials consist of silicates of alumina in the form of clay, shale, slate and blast furnance slag.

From the above materials, others like lime, silica, alumina, iron oxide and small quantities of other chemicals are obtained. Cement can be manufactured either by dry process or wet process.

Dry Process

The dry process is adopted when the raw materials are quite hard. The process is slow and the product is costly. Limestone and clay are ground to fine powder separately and are mixed. Water is added to make a thick paste. The cakes of the paste, which contain about 14 per cent of moisture, are dried and are charged into rotary kilns (Fig. 5.3). The product obtained after calcination in rotary kiln is called *clinker*. The clinker is obtained as a result of incipient fusion and sintering at a

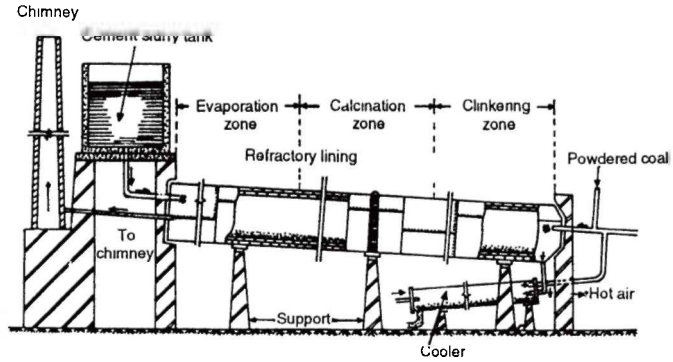


Fig. 5.3 Rotary Kiln

temperature of about 1400°-1500°C. Because ferric oxide has lower melting point than the other oxides, it acts as a flux. Aeration of cement clinker, which is commonly practised to slake free lime, also causes an absorption of some moisture and carbon dioxide. Absorption of moisture tends to decrease the setting whereas that of carbon dioxide accelerates setting. The clinker is cooled rapidly to preserve the metastable compounds and their solid solutions — dispersion of one solid in another — which are made as the clinker is heated. Clinker is then cooled and ground in tube mills (Fig. 5.4), where 2-3% of gypsum is added. Generally, cement is stored in bags of 50 kg. A flow diagram of dry process is shown in Fig. 5.5. The purpose of adding gypsum is to coat the cement particles by interfering with the process of hydration of the cement particles. This retards the setting of cement.

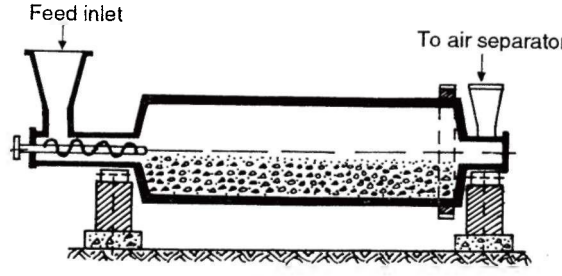


Fig. 5.4 Tube Mill

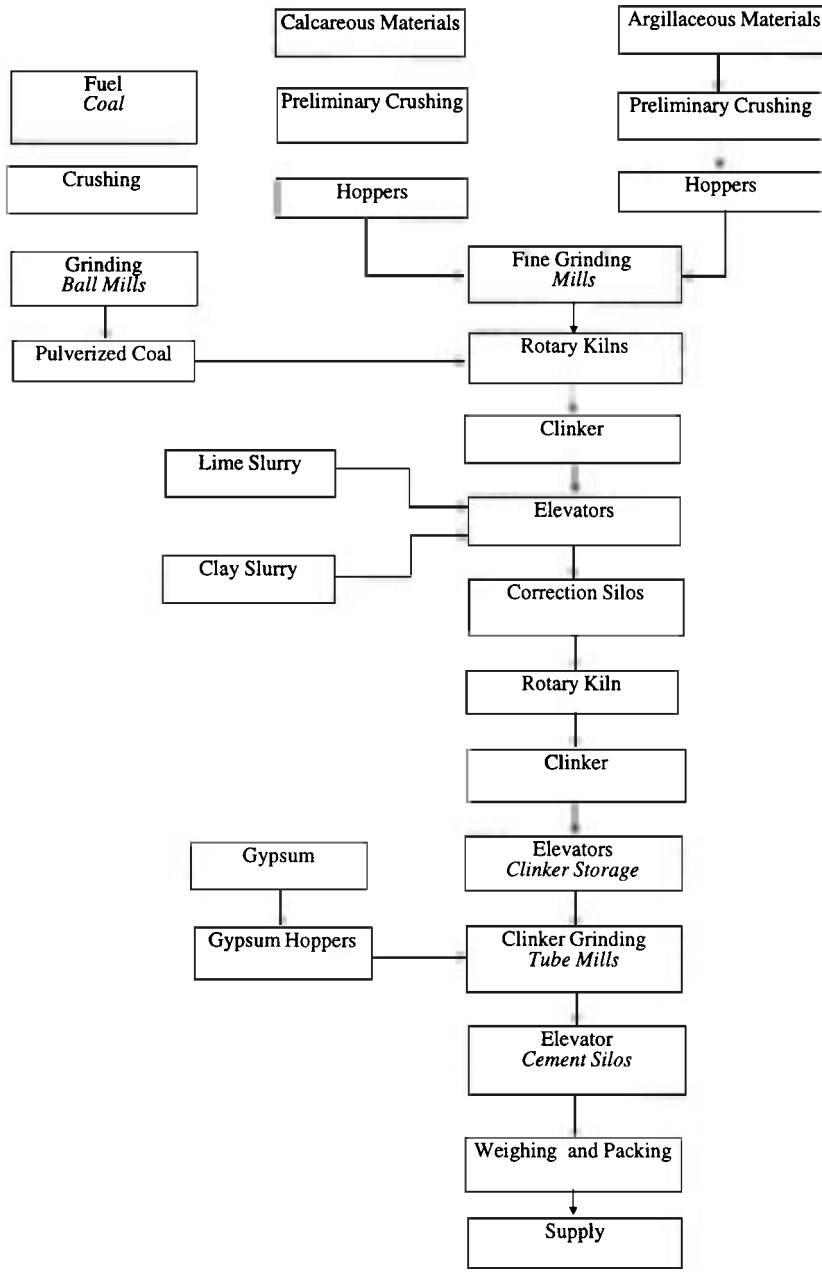


Fig. 5.5 Flow Diagram of Cement Manufacture — Dry Process

Wet Process

The operations are mixing, burning and grinding. The crushed raw materials are fed into ball mill (Fig. 5.6) and a little water is added. On operating the ball mill, the steel balls in it pulverize the raw materials which form a slurry with water. This slurry is passed to silos (storage tanks), where the proportioning of the compounds is adjusted to ensure desired chemical composition. The corrected slurry having about 40 per cent moisture content, is then fed into rotary kiln (Fig. 5.4) where it loses moisture and forms into lumps or nodules. These are finally burned at 1500-1600°C. The nodules change to clinker at this temperature. Clinker is cooled and then ground in tube mills. While grinding the clinker, about 3 per cent gypsum is added. The cement is then stored in silos from where it is supplied. A flow diagram of manufacturing cement by wet process is shown in Fig. 5.7.

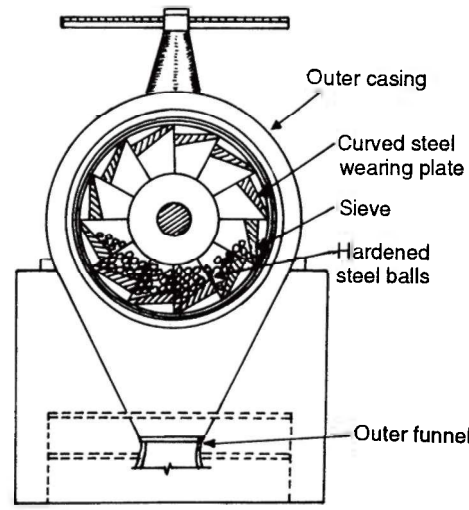


Fig. 5.6 Ball Mill

5.9 TESTING

The cement to be used for engineering purposes must have certain desired qualities in order to play its role effectively. The important physical properties are fineness, setting time, soundness, strength, heat of hydration and specific gravity. To control the quality of cement, the following physical and chemical tests are performed.

Fineness

The degree of fineness of cement is the measure of the mean size of the grains in it. There are three methods for testing fineness: the sieve method — using 90 micron (9 No.) sieve, the air permeability method — Nurse and Blains method, and the sedimentation method — Wagner turbidimeter method. The last two methods measure the surface area, whereas the first measures grain size. Since cement grains are finer than 90 micron, the sieve analysis method does not represent true mean size of cement grains. Also, the tiny cement grains tend to conglomerate into lumps resulting in distortion in the final grain size distribution curves. Considering these demerits, fineness is generally expressed in terms of specific area,

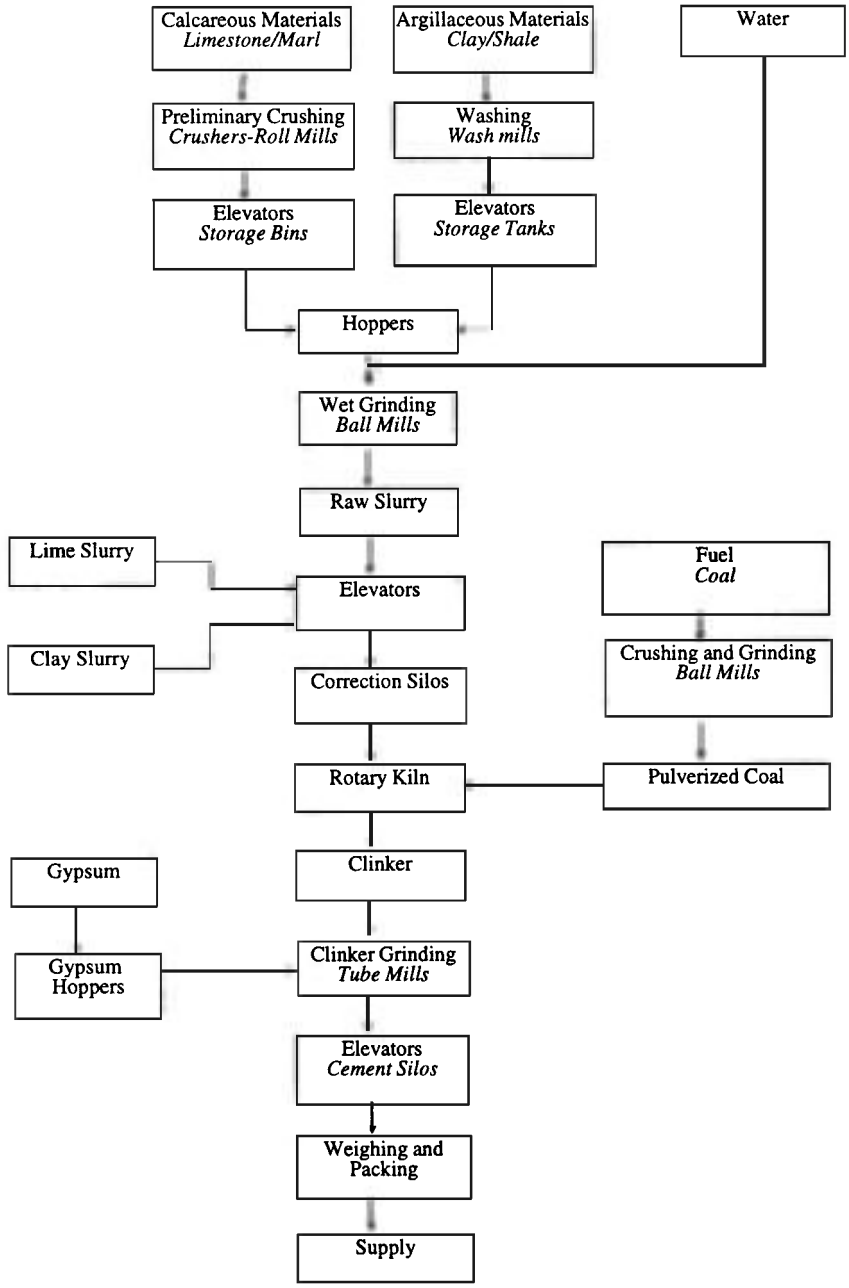


Fig. 5.7 Flow Diagram of Cement Manufacture — Wet Process

which is the total surface area of the particles in unit weight of material.

Conditions Affecting Fineness The chemical composition and the degree of calcination influence the hardness of the clinker and consequently the fineness to which the cement is ground. Clinker, high in iron or silica, is apt to be hard and difficult to grind. The same is true with a hard-burned clinker. Fineness is also influenced by the time of grinding and the character of the pulverizing machinery. It has been found that cement becomes finer with age provided it does not absorb too much moisture. This is probably due to the decrepitation of the coarser grains resulting from the hydration of the embedded lime particles.

Importance Finer the cement, more is the strength since surface area for hydration will be large. With increase in fineness, the early development of strength is enhanced but the ultimate strength is not affected. An increase in the fineness of the cement increases the cohesiveness of the concrete mix and thus reduces the amount of water which separates to the top of a lift (bleeding), particularly while compacting with vibrators. However, if the cement is ground beyond a certain limit, its cementative properties are affected due to the prehydration by atmospheric moisture. Finer cement reacts more strongly in alkali reactive aggregate. Also, the water requirement and workability will be more leading to higher drying shrinkage and cracking.

Sieve Method 100 g of cement sample is taken and air-set lumps, if any, in the sample are broken with fingers. The sample is placed on a 90 micron sieve and continuously sieved for 15 minutes. The residue should not exceed the limits specified below:

Type of cement	Percentage of residue by weight
1. Ordinary Portland Cement (OPC)	10
2. Rapid Hardening Cement (RHC)	5
3. Portland Puzzolana Cement (PPC)	5

Air Permeability Method The fineness of cement is represented by specific surface, i.e. total surface area in cm^2 per gram of cement.

The Lea and Nurse apparatus shown in Fig. 5.8 essentially consists of a permeability test cell — where cement is placed and air pressure is applied, flowmeter — to determine the quantity of air passing per second through its capillary tube per unit difference of pressure, and manometer — to measure the air pressure.

To determine the fineness, a cement sample of 2 cm height is placed on a perforated plate (40 micron perforations) and air pressure is applied. The manometer is connected to the top of the permeability cell and the air is turned on. The lower end of the permeability cell is then slowly connected to the other end of the manometer. The rate of flow is so adjusted that the flowmeter shows a pressure difference (h_2) of 30-50 cm. The reading (h_1) in the manometer is recorded. The

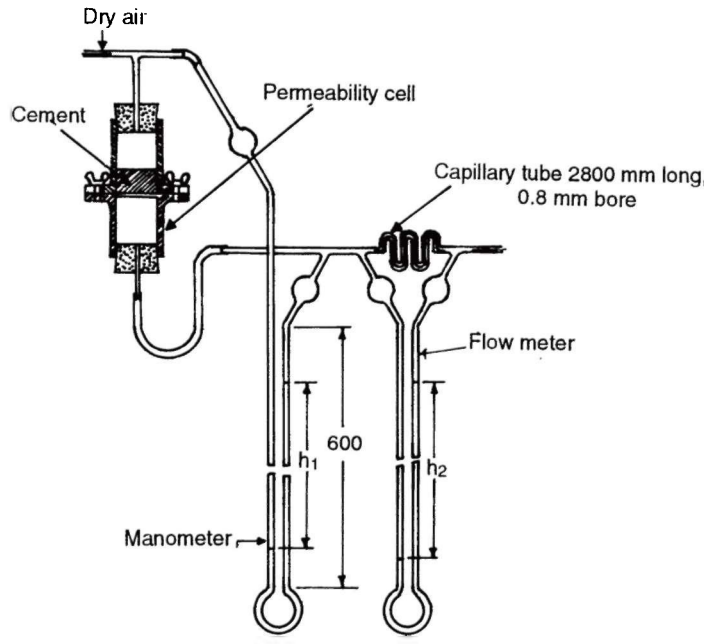


Fig. 5.8 Permeability Apparatus

process is repeated till the ratio h_1/h_2 is constant. The specific surface is given by the expression

$$S = \frac{14}{d\,(1-\psi)} \sqrt{\frac{A\,\psi^2}{K\,L}} \sqrt{\frac{h_1}{h_2}}$$

where L = thickness of cement layer

A = area of cement layer

d = density of cement

ψ = porosity of cement (0.475)

h_2 = flowmeter reading

h_1 = manometer reading

K is the flowmeter constant and is obtained by

$$Q = \frac{K\,h_2\,d_1}{\mu}$$

where μ = viscosity of air

d_1 = density of kerosene

Q = quantity of air passed per second

$$= \frac{V}{t} \frac{P-p}{P}$$

where P = atmospheric pressure

p = vapour pressure of water at room temperature

The minimum specific surface for various cements should be as specified in Table 5.2.

Table 5.2 Minimum Specific Surfaces of Cements

Type of cement		Specific surface not less than 10^2 x mm^2/g
Ordinary Portland Cement	(OPC)	2250
Rapid Hardening Cement	(RHC)	3250
Low Heat Cement	(LHC)	3250
Portland Puzzolana Cement	(PPC)	3000
High Alumina Cement	(HAC)	2250
Super Sulphate Cement	(SSC)	4000

Wagner Turbidimeter Test L.A.Wagner developed a turbidimeter to estimate the surface area of one gram of cement. The cement is dispersed uniformly in a rectangular glass tank filled with kerosene. Then, parallel light rays are passed through the solution which strike the sensitivity plate of a photoelectric cell. The turbidity of the solution at a given instant is measured by taking readings of the current generated by the cell. By recording the readings at regular intervals while the particles are falling in the solution, it is possible to secure information regarding the grading in surface area and in size of particle. Readings are expressed in sq cm per gram.

Consistency

This is a test to estimate the quantity of mixing water to form a paste of normal consistency defined as that percentage water requirement of the cement paste, the viscosity of which will be such that the Vicat's plunger penetrates up to a point 5 to 7 mm from the bottom of the Vicat's mould.

Importance The water requirement for various tests of cement depends upon the normal consistency of the cement, which itself depends upon the compound composition and fineness of the cement.

Test Procedure 300 g of cement is mixed with 25 per cent water. The paste is filled in the mould of Vicat's apparatus (Fig. 5.9) and the surface of the filled paste is smoothened and levelled. A square needle 10 mm × 10 mm attached to the plunger is then lowered gently over the cement paste surface and is released quickly. The plunger pierces the cement paste. The reading on the attached scale is recorded.

When the reading is 5-7 mm from the bottom of the mould, the amount of water added is the correct percentage of water for normal consistency.

Initial and Final Setting Times

When water is added to cement, the resulting paste starts to stiffen and gain strength and lose the consistency simultaneously. Initial and final setting times may be regarded as the two stiffening states of the cement. Vicat's apparatus used for the purpose is shown in Fig. 5.9. The initial setting time may be defined as the time taken by the paste to stiffen to such an extent that the Vicat's needle is not permitted to move down through the paste to within 5 ± 0.5 mm measured from the bottom of the mould. The final setting time is the time after which the paste becomes so hard that the angular attachment to the needle, under standard weight, fails to leave any mark on the hardened concrete. Initial and final setting times are the rheological properties of cement.

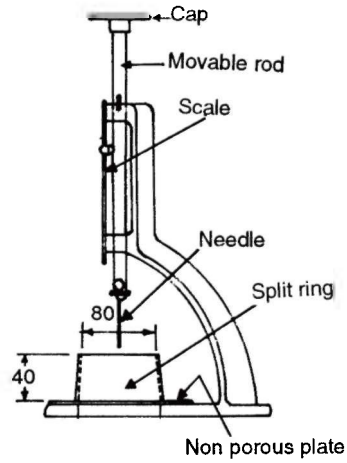


Fig. 5.9 Vicat's Apparatus

Importance It is important to know the initial setting time, because of loss of useful properties of cement if the cement mortar or concrete is placed in moulds after this time. The importance of final setting time lies in the fact that the moulds can be removed after this time.

Conditions Affecting Setting Time The factors influencing the setting properties of cement are its composition, the percentage of retardant, degree of calcination, fineness of grinding, aeration subsequent to grinding clinker, percentage of water used to make cement paste, the temperature of the mixing water, cement and the atmosphere where the cement paste is placed, and the amount of manipulation the paste receives.

The effect of lime, silica and alumina in controlling the set have been discussed in Sec. 5.3. The effect of gypsum is to increase the setting time of freshly ground cement. It is usually mixed with the clinker before final grinding, or just after the clinker has received preliminary grinding. The addition of gypsum before calcination causes it to decompose into lime and sulphur trioxide. Since the latter is liberated in the kiln, there is resulting effect on the setting time. Often, an underlimed cement becomes quick setting after seasoning. This can be avoided by adding to the cement 1 or 2 per cent of hydrated lime or the fraction of a per cent of Plaster of Paris. Setting time of cement is rapid with the increase in the fineness of cement. When the mixing water used in testing cement paste is increased by 1 per cent above that required for normal consistency, an increase of about 30 minutes or more is observed in the initial or final set.

Cements stored in warm rooms will, in general, be quick setting than those stored in cold places. Cold mixing water retards set while warm water accelerates it. Cement exposed to thoroughly saturated atmosphere will set much more slowly than those exposed to a dry atmosphere. If, however, a considerable proportion of moist CO_2 is present in the air, the setting time is found to reduce greatly. By lengthening the time of mixing and by prolonged troweling of the surface mortars, it is also possible to considerably delay the setting time.

Test Procedure: A neat cement paste is prepared by gauging cement with 0.85 times the water required to give a paste of standard consistency. The stop watch is started at the instant water is added to the cement. The mould resting on a nonporous plate is filled completely with cement paste and the surface of filled paste is levelled smooth with the top of the mould. The test is conducted at room temperature of 27± 2°C. The mould with the cement paste is placed in the Vicat's apparatus as shown in Fig. 5.9 and the needle is lowered gently in contact with the test block and is then quickly released. The needle thus penetrates the test block and the reading on the Vicat's apparatus graduated scale is recorded. The procedure is repeated until the needle fails to pierce the block by about 5 mm measured from the bottom of the mould. The stop watch is pushed off and the time is recorded which gives the initial setting time.

The cement is considered to be finally set when upon applying the needle gently to the surface of test block, the needle makes an impression, but the attachment fails to do so.

Soundness

It is essential that the cement concrete does not undergo large change in volume after setting. This is ensured by limiting the quantities of free lime and magnesia which slake slowly causing change in volume of cement (known as unsound). Soundness of cement may be tested by Le-Chatelier method or by autoclave method. For OPC, RHC, LHC and PPC it is limited to 10 mm, whereas for HAC

and SSC it should not exceed 5 mm.

Importance It is a very important test to assure the quality of cement since an unsound cement produces cracks, distortion and disintegration, ultimately leading to failure.

Conditions Affecting Soundness The main cause for unsoundness in Portland cement is the hydration of the uncombined lime encased within the cement particles. Exposed, finely ground, free lime in small percentages, hydrates before the cement sets and produces no injurious effect. The uncombined lime in cement is a result of either underburning the clinker or of excess lime in the raw materials. Freshly ground cement is often unsound due to the presence of uncombined lime. Cement is thus allowed to aerate for two to three weeks to overcome unsoundness.

Fine grinding of the raw material and clinker help to produce a sound cement. By grinding fine the raw materials, it is possible to produce a homogeneous mixture before burning where the lime is uniformly distributed. The coarse grains of cement may imprison minute particles of uncombined lime which do not hydrate. These lime particles on hydration produce disintegration.

Le-chatelier Method The apparatus is shown in Fig. 5.10. The mould is placed on a glass sheet and is filled with neat cement paste formed by gauging 100 g cement with 0.78 times the water required to give a paste of standard consistency. The mould is covered with a glass sheet and a small weight is placed on the covering

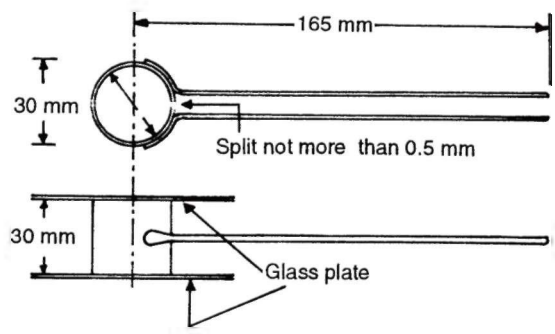


Fig. 5.10 Le-chatelier Apparatus

glass sheet. The mould is then submerged in the water at temperature of 27°-32°C. After 24 hours, the mould is taken out and the distance separating the indicator points is measured. The mould is again submerged in water. The water is now boiled for 3 hours. The mould is removed from water and is cooled down. The distance between the indicator points is measured again. The difference between the two measurements represents the unsoundness of cement.

Autoclave Test The 25 × 25 × 250 mm specimen is made with neat cement paste. After 24 hours the moulded specimen is removed from the moist atmosphere, measured for length, and so placed in an autoclave at room temperature that the four sides of each specimen are at least exposed to saturated steam. The temperature of the autoclave is raised at such a rate that the gauge pressure of the steam rises to 2.1 N/mm^2 in 1 to 1¼ hours from the time the heat is turned on. The pressure is maintained for 3 hours. Then the heat supply is shut off and the autoclave is cooled at such a rate that the pressure is less than $0.1N/mm^2$ at the end of the hour. The autoclave is then opened and the test specimens are placed in water at temperature of 90°C. The temperature is gradually brought down to 27± 2°C in 15 minutes. The specimens are maintained at this temperature for next 15 minutes and are then taken out. The length of the specimen is measured again. The difference in the two measurements gives the unsoundness of the cement.

Strength

Cement hydrates when water is added to it and cohesion and solidity is exhibited. It binds together the aggregates by adhesion. The strength of mortar and concrete depends upon the type and nature of cement. So, it should develop a minimum specified strength if it is to be used in structures. Cement is tested for compressive and tensile strengths.

Conditions Affecting Strength Cement is very strong at early ages if a high lime or high alumina content is there. Gypsum and Plaster of Paris also tend to increase the strength slightly. The effects of the clinker compounds on strength have already been discussed in Sec 5.4. In addition to the effect of composition, the strength of cement is greatly influenced by the degree of burning, the fineness of grinding, and the aeration it receives subsequent to final grinding. An underburnt cement is likely to be deficient in strength. It is found that a well-burned, finely ground cement can carry a greater proportion of sand than a more coarsely ground cement and will be more economical.

Compressive Strength Compressive strength is the basic data required for mix design. By this test, the quality and the quantity can be controlled and the degree of adulteration can be checked.

The test specimens are 70.6 mm cubes having face area of about 5000 sq mm. Large size specimen cubes cannot be made since cement shrinks and cracks may

develop. The temperature of water and test room should be 27°± 2°C. A mixture of cement and standard sand in the proportion 1:3 by weight is mixed dry with a trowel for one minute and then with water until the mixture is of uniform colour. Three specimen cubes are prepared. The material for each cube is mixed separately. The quantities of cement, standard sand and water are 185 g, 555 g and (P/4) + 3.5, where P = percentage of water required to produce a paste of standard consistency. The mould is filled completely with the cement paste and is placed on the vibration table. Vibrations are imparted for about 2 minutes at a speed of 12000± 400 per minute.

The cubes are then removed from the moulds and submerged in clean fresh water and are taken out just prior to testing in a compression testing machine. Compressive strength is taken to be the average of the results of the three cubes. The load is applied starting from zero at a rate of 35 N/sq mm/minute. The compressive strength is calculated from the crushing load and the average area over which the load is applied. The result is expressed in N/mm^2. The minimum specified strength for some of the cements is given in Table 5.3.

Table 5.3 Minimum Specifled Strength in N/mm^2

Type/Days	1 day	3 days	7 days	28 days
Ordinary Portland cement	–	16.0	22.0	31.0
Portland Puzzolana cement	–	–	22.0	31.0
Low heat Portland cement	16.0	27.5	–	–
Rapid hardening cement	–	–	22.0	31.0
High alumina cement	30.0	35.0	–	–

Tensile Strength The tensile strength may be obtained by Briquette test method or by split tensile strength test.

Importance The tensile strength of cement affords quicker indications of defects in the cement than any other test. Also, the test is more conveniently made than the compressive strength test. Moreover, since the flexural strength is directly related to the tensile strength, this test is ideally fitted to give information both with regard to tensile and compressive strengths when the supply for material testing is small.

Briquette Method A mixture of cement and sand is gauged in the proportion of 1:3 by weight. The percentage of water to be used is calculated from the formula (P/5)+ 2.5, where P = percentage of water required to produce a paste of standard consistency. The temperature of the water and the test room should be 27°± 2°C. The mix is filled in the moulds of the shape shown in Fig. 5.11.

After filling the mould, an additional heap of mix is placed on the mould and is pushed down with the standard spatula, until the mixture is level with the top of

the mould. This operation is repeated on the other side of the mould also. The briquettes in the mould are finished by smoothing the surface with the blade of a trowel. They are then kept for 24 hours at a temperature of 27°+ 2°C and in an atmosphere having 90 per cent humidity. The briquettes are then kept in clean fresh water and are taken out before testing. Six briquettes are tested and the average tensile strength is calculated. Load is applied steadily and uniformly, starting from zero and increasing at the rate of 0.7 N/sq mm of section in 12 seconds.

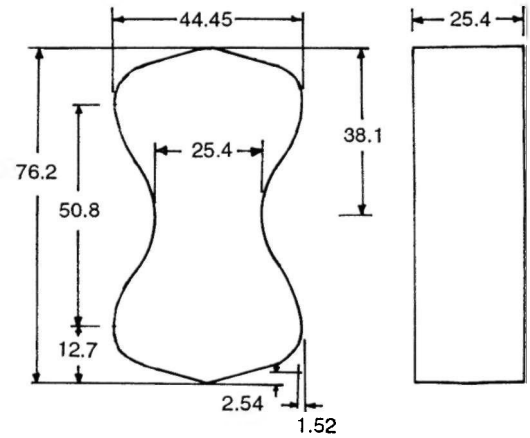


Fig. 5.11 Dimensions of Standard Briquette

Ordinary Portland cement should have a tensile strength of not less than 2.0 N/mm^2 after 3 days and not less than 2.5 N/mm^2 after 7 days.

Notes : (i) In the tension test of cement the load on the briquette should be applied centrally. Since briquettes become brittle with age, the effect of slight eccentricity or any torsional strain is pronounced in long-time tests.

(ii) The strength increases when the loading rate is increased from that specified.

Split Tensile Strength Test Because of difficulties in conducting Briquette test, a number of indirect methods have been developed to determine tensile strength of which splitting tests are most common.

The specimen is made of cylindrical shape with the diameter not less than four times the maximum size of coarse aggregate and not less than 150 mm. The length of cylinder varies from one to two diameters. Normally the test cylinder is 150 mm diameter and 300 mm long. The test consists of applying compressive line loads along the opposite generators of the concrete cylinder placed with its axis horizontal between the platens as shown in Fig. 5.12. The load is applied at a rate so as to produce a tensile splitting stress of about 2.0 N/mm^2/minute until the resistance of the specimen to the increasing load breaks down and no greater load can be sustained. The specimen fails finally by splitting along the loaded diameter. The

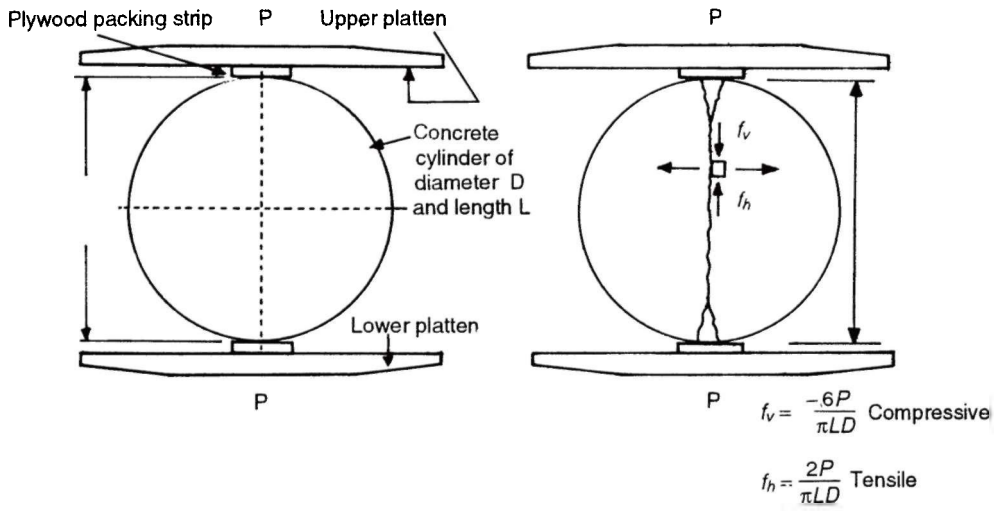


Fig. 5.12 Loading Arrangement of Split Tensile Strength Test

maximum load applied is recorded. The splitting tensile strength is given by

$$T = \frac{2P}{\pi d l} \quad \frac{0.673 P}{d l}$$

where P = maximum load in N applied to the specimen

d = diameter of specimen in mm

l = length of the specimen in mm

The relationship between compressive strength and split tensile strength, and flexural strength and split tensile strength are shown in Fig. 5.13 and 5.14 respectively.

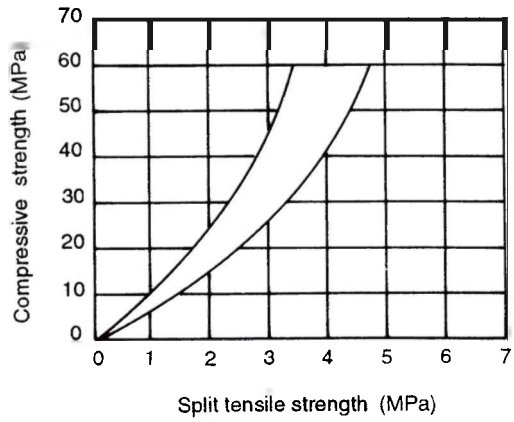


Fig. 5.13 Relationship between Compressive Strength and Split Tensile Strength

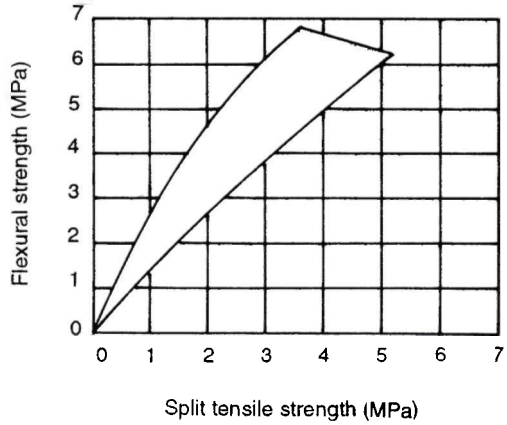


Fig. 5.14 Relationship between Flexural Strength and Split Tensile Strength

Heat of Hydration

Heat is evolved during hydration of cement, the amount being dependent on the relative quantities of the clinker compounds.

Importance The evolution of heat causes an increase in temperature of the concrete, being greatest in mass concreting. Since the cooling of a mass of concrete can only occur from surfaces exposed to atmosphere the temperature of the interior is higher than that at the surface and also there is a rapid increase in strength in the interior than at the surface. Shrinkage cracks may result from stresses, induced by cooling of the surface while the interior of concrete is still at higher temperature. However, in practice, the heat evolution may be taken to its advantage in cold weather provided the concrete is warm at the time of placing and excessive heat loss is prevented by suitable lagging.

Test Procedure The apparatus used to determine the heat of hydration of cement is known as calorimeter and is shown in Fig. 5.15. 60 g of cement and 24 ml of distilled water are mixed for 4 minutes at temperature 15°-25°C. Three specimen glass vials 100 × 20 mm are filled with this mixture, corked and sealed with wax. The vials are then stored with the mixture in a vertical position at 27°± 2°C. The heat of hydration is obtained by subtracting the respective heat of solution of hydrated cement from the heat of solution of unhydrated cement calculated nearest to 0.1 calorie.

For determining the heat of solution of unhydrated cement, weigh a sample of about 3 g. At the same time, weigh out 7.0 g of cement for the loss on ignition. The heat of solution is calculated as

Heat of solution (Cal/g) of unhydrated cement

$$= \frac{\text{Heat capacity} \times \text{corrected temperature rise}}{\text{Weight of sample corrected for ignition loss}} - 0.2(\varphi_0 - \varphi)$$

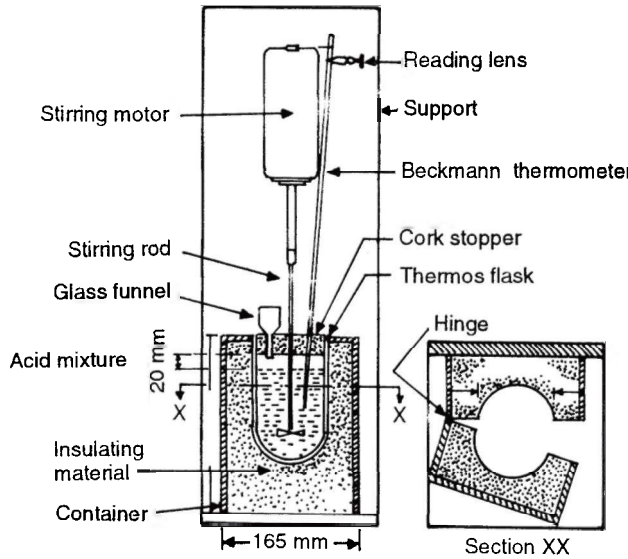


Fig. 5.15 Calorimeter

where 0.2 is the specific heat of unhydrated cement.

For determining heat of solution of the hydrated cement, one of the glass vials is opened and the adherent wax is removed. The cement is ground rapidly, to avoid carbonation, to pass an 850 micron sieve. From this weigh out 4.2 g and 7.0 g of cement samples for heat of solution and loss on ignition.

The heat of solution of hydrated cement (Cal/g ignited weight)

$$= \frac{\text{Heat capacity} \times \text{corrected temperature rise}}{\text{Weight of sample corrected for ignition loss}} - 0.4(\varphi_0 - \varphi)$$

The ignition loss can be obtained by placing the sample in a cool furnance and raising the temperature of the furnance to 900°C over a period of 1hour. The sample is kept at 900°+ 50°C for 3-4 hours and then cooled in a desiccator containing anhydrous calcium chloride. Weigh after half an hour. The difference in the two weighings give the loss on ignition.

To determine the heat capacity sufficient quantity of zinc oxide is ignited for one hour at 900°± 50°C. It is cooled in a desiccator containing anhydrous calcium chloride and ground to pass 250 micron sieve. About 7 g of this ignited oxide is reheated to 900°± 50°C for 5 minutes and then cooled for about 2½ hours (not more than 5 hours). The calorimeter is assembled and temperature reading correct to 0.001°C is recorded to determine the initial heating or cooling correction. The zinc oxide is then introduced. The temperature readings are recorded at one minute

intervals until the solution is complete. The recording of readings is continued for next 5 minutes to determine the final heating or cooling correction. The initial and final heating or cooling rates against the corresponding calorimeter temperature are plotted. The two points thus obtained are joined by a straight line. From this graph the corrections are read off for each temperature reading during the solution period. Heat capacity is calculated from the expression.

$$\text{Heat capacity(cal/°C)} = \frac{\text{Weight of ZnO}}{\text{Corrected temperature rise}} \times [\,256.1 + 0.1\,(\,30.0 - \psi) + 0.1(\,\psi_0 - \psi\,)\,]$$

$$= \frac{\text{Weight of ZnO}\,(\,259.1 - 0.2\,\varphi + 0.1\,\varphi_0\,)}{\text{Corrected temperature rise}}$$

where, 256.1 is the heat of solution of zinc oxide at 30°C and 0.2 the negative temperature coefficient of the heat of solution, φ is the final temperature of the calorimeter, 0.1 is the specific heat of zinc oxide and φ_0 is the room temperature in °C.

Specific Gravity

The specific gravity of hydraulic cement is obtained using Le-Chatelier flask shown in Fig. 5.16.

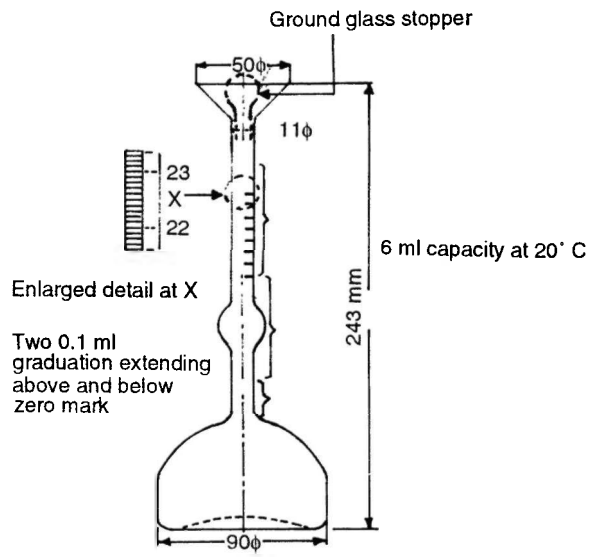


Fig. 5.16 Le-Chatelier Flask for Specific Gravity Test

Conditions Affecting Specific Gravity Long seasoning is the chief cause of a low specific gravity in unadulterated cement. This is because the freshly ground cement when exposed to air rapidly absorbs moisture and carbon dioxide. Cements with high contents of iron oxide have a higher specific gravity. The effect of fineness of grinding upon specific gravity is slight. Very finely ground cements are likely to have lower specific gravities.

Test Procedure The flask is filled with either kerosene free of water, or naphtha having a specific gravity not less than 0.7313 to a point on the stem between zero and 1-ml mark. The flask is immersed in a constant temperature water bath and the reading is recorded. A weighed quantity of cement (about 64 g of Portland cement) is then introduced in small amounts at the same temperature as that of the liquid. After introducing all the cement, the stopper is placed in the flask and the flask rolled in an inclined position, or gently whirled in a horizontal circle, so as to free the cement from air until no further air bubbles rise to the surface of the liquid. The flask is again immersed in the water-bath and the final reading is recorded. The difference between the first and the final reading represents the volume of liquid displaced by the weight of the cement used in the test.

$$\text{Specific gravity} = \frac{\text{Weight of cement in g}}{\text{Displaced volume of liquid in ml}}$$

Chemical Tests

Loss on Ignition: 1.00 g of the sample is heated for 15 minutes in a weighed and covered platinum crucible of 20 to 25 ml capacity by placing it in a muffle furnace at any temperature between 900° and 1000°C. It is then cooled and weighed. Thereafter the loss in weight is checked by a second heating for 5 minutes and reweighing. The loss in the weight is recorded as the *loss on ignition* and the percentage of loss on ignition to the nearest 0.1 is calculated. The percentage loss on ignition should not exceed 4 per cent.

Silica: 0.5 g of the sample is kept in an evaporating dish, moistened with 10 ml of distilled water at room temperature to prevent lumping. To this 5 to 10 ml of hydrochloric acid is added, and digested with the aid of gentle heat and agitation until solution is complete. Dissolution may be aided by light pressure with the flattened end of a glass rod. The solution is evaporated to dryness on a steam bath. Without heating the residue any further, it is treated with 5 to 10 ml of hydrochloric acid and then with an equal amount of water. The dish is covered and digested for 10 minutes on a water bath. The solution with an equal volume of hot water is diluted and is immediately filtered through an ashless filter paper, and the separated silica (SiO_2) is washed thoroughly with hot water and the residue is reserved.

The filtrate is again evaporated to dryness, baking the residue in an oven for one hour at 105°C to 110°C. Then the residue is added with 10 to 15 ml of

hydrochloric acid (1:1) and is heated on a water bath. This solution is then diluted with an equal volume of hot water and the small amount of silica it contains is filtered and washed on another filter paper. The filtrate and washings are reserved for the determination of combined alumina and the ferric oxide.

The papers containing the residues are transferred to a weighed platinum crucible. The papers are dried and ignited, first at a low heat until the carbon of the filter papers is completely consumed without inflaming, and finally at 1100°C to 1200°C until the weight remains constant.

The ignited residue thus obtained, which will contain small amounts of impurities is treated in the crucible with a few drops of distilled water, about 10 ml of hydrofluoric acid and one drop of sulphuric acid and evaporated cautiously to dryness. Finally, the small residue is heated at 1050°C to 1100°C for a minute or two; cooled and weighed. The difference between this weight and the weight of the ignited residue represents the amount of silica (W).

Combined Ferric Oxide and Alumina: 200 ml of the sample from the filtrate reserved in silica test is heated to a boil. A few drops of bromine water or concentrated nitric acid is added during boiling in order to oxidize any ferrous ion to the ferric condition. It is then treated with ammonium hydroxide (1:1), drop by drop, until the solution smells of ammonia. The solution containing the precipitates of aluminium and ferric hydroxides is boiled for one minute. The precipitate is allowed to settle, filtered through an ashless filter paper and washed with two per cent hot ammonium nitrate solution. The filtrate and washings are set aside.

The precipitate and the filter paper is transferred to the same beaker in which the first precipitation was effected. The precipitate is then dissolved in hydrochloric acid (1:3). The solution is diluted to about 100 ml and the hydroxides are re-precipitated. The solution is filtered and precipitated with two 10 ml portions of hot ammonium nitrate solution. The filtrate and washings are then combined with the filtrate set aside and is reserved for the determination of calcium oxide.

The precipitate is placed in a weighed platinum crucible, heated slowly until the papers are charred, and finally ignited to constant weight at 1050°C to 1100°C with care to prevent reduction, and weighed (W_1) as combined alumina and ferric oxide.

If silica is suspected to be carried into the filtrate used for this estimation, the residue in the crucible is treated with a drop of water, about 5 ml of hydrofluoric acid and a drop of sulphuric acid and is evaporated cautiously to dryness. Finally, the crucible is heated at 1050°C to 1100°C for one or two minutes; cooled and weighed (W_2). The difference between this weight and the weight (W_1), represents the amount of residue silica. This amount is subtracted from the weight of ferric oxide and alumina found as W_1 and the same amount is added to the amount of silica (W). The ratio of percentages of alumina to iron oxide should not exceed 0.66.

Ferric Oxide: 40 ml of cold water is added to 1 g of the sample and while the mixture is stirred vigorously, 50 ml of hydrochloric acid is added. If necessary, the solution is heated and cement is ground with flattened end of a glass rod until it is evident that cement is completely decomposed. The solution is heated to a boil and is treated with stannous chloride solution added drop by drop while stirring, until the solution is decolourized. A few drops of stannous chloride solution is added in excess and the solution is cooled to room temperature. Then, 15 ml of a saturated solution of mercuric chloride and 25 ml of manganese sulphate solution are added and titrated with standard solution of potassium permaganate until the permanent pink colour is obtained. Iron as ferric oxide is calculated.

Alumina: The calculated weight of ferric oxide and the small amount of silica is subtracted from the total weight of oxides (W_1). The remainder is the weight of alumina and of small amounts of other oxides reported as alumina.

Calcium Oxide: The combined filtrate reserved in the combined ferric oxide and alumina test is acidified with hydrochloric acid and evaporated to a volume of about 100 ml. 40 ml of saturated bromine water is added to the hot solution and ammonium hydroxide is added until the solution is distinctly alkaline. The solution is boiled for 5 minutes or more, making certain that the solution is at all times distinctly alkaline. Then the precipitate is allowed to settle, filtered and washed with hot water. The beaker and filter is washed once with nitric acid (1:33) and finally with hot water. Any precipitate (of manganese dioxide) that may be left on the funnel is discarded. The filtrate is mixed with hydrochloric acid and boiled until all the bromine is expelled. 25 ml of boiling ammonium oxalate solution is added to the boiling solution. The solution is made alkaline with ammonium hydroxide and brought to boiling, the boiling being continued until the precipitated calcium oxalate assumes a well-defined granular form. The precipitate is allowed to stand for about 20 minutes or until it has settled, filtered and washed moderately with ammonium oxalate solution (one gram per litre). The filtrate and washings (W_3) are set aside for estimating magnesia.

The precipitated lime after ignition and heating at 1100°C-1200°C is weighed.

$$\frac{CaO - 0.7\,SO_3}{2.8\,SiO_2 + 1.2\,Al_2O_3 + 0.65\,Fe_2O_3}$$

in per cent should not be less than 0.66

Magnesia: The filtrate (W_3) is acidified with hydrochloric acid and is concentrated to about 150 ml. To this solution, about 10 ml of ammonium hydrogen phosphate solution (250 g per litre) is added and the solution is cooled by placing in a beaker of ice water. After cooling, ammonium hydroxide is added drop by drop, while stirring constantly, until the crystalline magnesium ammonium phosphate

begins to form, and then the reagent is added in moderate excess (5 to 10 per cent of the volume of the solution), the stirring being continued for several minutes. The solution is set aside for at least 16 hours in a cool atmosphere and then filtered. The precipitate is washed with ammonium nitrate wash solution (100 g of ammonium nitrate dissolved in water, 200 ml of ammonium hydroxide added and diluted to one litre). It is then charred slowly and the resulting carbon is burnt carefully. The precipitate is ignited at 1100°C to 1200°C to constant weight, taking care to avoid bringing the pyrophosphate to melting. From the weight of the magnesium pyrophosphate obtained, the magnesia content of the material taken for the test is calculated. Free magnesia in cement should be less than 4 per cent.

Sulphuric Anhydride: To one gram of the sample, 25 ml of cold water is added and while the mixture is stirred vigorously 5 ml of hydrochloric acid is added. If necessary, the solution is heated and the material is ground with the flattened end of a glass rod until it is evident that the decomposition of cement is complete. The solution is diluted to 50 ml and digested for 15 minutes. The residue is filtered and washed thoroughly with hot water. The filter paper with the residue (W_4) is set aside. The filtrate is diluted to 250 ml and heated to boiling. 10 ml of hot barium chloride (100 g per litre) solution is added drop by drop and the boiling is continued until the precipitate is well formed. The solution is digested on steam bath for 4 hours or preferably overnight. The precipitate is filtered and the precipitate is washed thoroughly. The filter paper and the contents are placed in a weighed platinum or porcelain crucible and slowly the paper is incinerated without inflaming. Then it is ignited at 800°C to 900°C, cooled in a desiccator and the barium sulphate is weighed. From the weight of the barium sulphate obtained, the sulphuric anhydride content of the material taken for the test is calculated. Sulphur in cement should be less than 2.5 per cent.

Insoluble Residue: The filter paper containing the residue (W_4) is digested in 30 ml of hot water and 30 ml of 2 N sodium carbonate solution maintaining constant volume, the solution being held for 10 minutes at a temperature just short of boiling. It is then filtered and washed with dilute hydrochloric acid (1:99) and finally with hot water till free from chlorides. The residue is ignited in a tared crucible at 900°C to 1000°C, cooled in a desiccator and weighed. The insoluble residues should not exceed 1.5 per cent.

5.10 TYPES

Rapid Hardening Portland Cement has high lime content and can be obtained by increasing the C_3S content but is normally obtained from OPC clinker by finer grinding (450 m^2/kg). The basis of application of RHC is hardening properties and heat emission rather than setting rate. This permits addition of a little more gypsum during manufacture to control the rate of setting. It attains

same strength in one day which an ordinary cement may attain in 3 days. However, it is subjected to large shrinkage and water requirement for workability is more. The cost of rapid hardening cement is about 10 per cent more than the ordinary cement. Concrete made with RHC can be safely exposed to frost, since it matures morequickly.

Properties Initial setting time30 minutes
Final setting time 10 hours
Compressive strength
1 day 16.0 N/mm^2
3 day 27.5 N/mm^2

Uses it is suitable for repair of roads and bridges and when load is applied in a short period of time.

Quick Setting Portland Cement The quantity of gypsum is reduced and small percentage of aluminium sulphate is added. It is ground much finer than ordinary Portland cement.

Properties Initial setting time = 5 minutes
Final setting time = 30 minutes

Use It is used when concrete is to be laid under water or in running water.

High Alumina Cement This is not a type of Portland cement and is manufactured by fusing 40 per cent bauxite, 40 per cent lime, 15 per cent iron oxide with a little of iron oxide and silica, magnesia, etc. at a very high temperature. The resultant product is ground finely. The main cement ingredient is monocalcium aluminate CA which interacts with water and forms dicalcium octahydrate hydroaluminate and aluminium oxide hydrate.

$$2(CaO{\cdot}Al_2O_3{\cdot}10H_2O) + H_2O = 2CaO{\cdot}Al_2O_3.8H_2O + 2Al(OH)_2$$

The dicalcium hydroaluminate gel consolidates and the hydration products crystallise. The rate of consolidation and crystallisation is high leading to a rapid gain of strength. Since C_3A is not present, the cement has good sulphate resistance.

Composition	Percentage
Al_2O_3, TiO_2	43.5
Fe_2O_3, FeO, Fe_3O_4	13.1
CaO	37.5
SiO_2	3.8
MgO	0.3
SO_3	0.4
Insoluble material	1.2
Loss on ignition	0.2

Properties It is not quick setting : initial setting time is 30 minutes, even up to 2 hours. It attains strength in 24 hours, high early strength, high heat of hydration

and resistance to chemical attack. Compressive strength after one day is 30.0 N/mm^2 and after 3 days it is 35.0 N/mm^2. After setting and hardening, there is no free hydrated lime as in the case of ordinary Portland cement.

Uses It is resistant to the action of fire, sea water, acidic water and sulphates and is used as refractory concrete, in industries and widely for precasting. It should not be used in places where temperature exceeds 18°C.

Low Heat Portland Cement To limit the heat of hydration of LHC, the tricalcium aluminate component in cement is minimised and a high percentage of dicalcium silicate and tricalcium alumino ferrite is added. The heat of hydration should not be more than 250 and 290 J/g at the end of 7 and 28 days respectively. The rate of development of strength is slow but the ultimate strength is same. To meet this requirement, specific surface of cement is increased to about 3200×10^2 mm^2/g.

Properties Less heat is evolved during setting.

Uses It is most suitable for large mass concrete works such as dams, large raft foundations, etc.

Portland Puzzolana Cement is manufactured by grinding Portland cement clinker and puzzolana, or by intimately and uniformly blending Portland cement and fine puzzolana. Puzzolana (burnt clay, shale, or fly ash) has no cementing value itself but has the property of combining with lime to produce a stable lime-puzzolana compound which has definite cementitious properties. Free lime present in the cement is thus removed. Consequently, the resistance to chemical attack increases making it suitable for marine works. The hardening of Portland puzzolana cement consists in hydration of Portland cement clinker compounds and then in interaction of the puzzolana with calcium hydroxide released during the hardening of clinker. At the same time, calcium hydroxide is bound into a water-soluble calcium hydrosilicate according to the reaction

$$Ca(OH)_2 + SiO_2 + (n - 1)\, H_2O = CaO \cdot SiO_2 \cdot nH_2O$$

with the effect that puzzolana Portland cement acquires greater water-resisting property than ordinary Portland cement.

Properties These have lower rate of development of strength but ultimate strength is comparable with ordinary Portland cement.

Compressive Strength	7 day	22.0 N/mm^2
	28 day	31.0 N/mm^2

Uses It has low heat evolution and is used in the places of mass concrete such as dams and in places of high temperature.

Super Sulphate Portland Cement also known as sulphate resisting Portland cement is a product of finely ground mixture of granulated blast furnance

slag not less than 70 per cent, calcium sulphate and small quantity of Portland cement. In this cement tricalcium aluminate which is susceptible to sulphates is limited to less than 3.5 per cent. Sulphate resisting cement may also be produced by the addition of extra iron oxide before firing; this combines with alumina which would otherwise form C_3A, instead forming C_4AF which is not affected by sulphates. It is used only in places with temperature below 40°C.

Properties It has low heat of hydration and is resistant to chemical attacks and in particular to sulphates. Compressive strength at 3 days is 16.0 N/mm^2 and at 7 days is 22.0 N/mm^2.

Uses RCC pipes in ground water, concrete structures in sulphate bearing soils, sewers carrying industrial effluents, concrete exposed to concentrated sulphates of weak mineral acids.

Air Entraining Cement Vinsol resin or vegetable fats and oils and fatty acids are ground with ordinary cement. These materials have the property to entrain air in the form of fine tiny air bubbles in concrete.

Properties Minute voids are formed while setting of cement which increases resistance against freezing and scaling action of salts. Air entrainment improves workability and water/cement ratio can be reduced which in turn reduces shrinkage, etc.

White and Coloured Portland Cement greyish colour of cement is due to iron oxide. So, it is reduced and limited below 1 per cent. It is manufactured from pure white chalk and clay free from iron oxide. Coloured cements are made by adding 5 to 10 per cent colouring pigments before grinding. These cements have same properties as that of ordinary cement and are nonstaining because of low amount of soluble alkalis. Sodium alumino fluoride is added during burning which acts as a catalyst in place of iron.

Properties Loss on ignition is nil. The compressive and transverse strength of this cement is 90 per cent of that of ordinary cement.

Uses Terrazzo flooring, face plaster of walls (stucco), ornamental works, and casting stones.

Calcium Chloride Cement also known as *extra rapid hardening cement* is made by adding 2 per cent of calcium chloride. Since it is deliquescent, it is stored under dry conditions and should be consumed within a month of its dispatch from the factory.

Property The rate of strength development is accelerated; a higher percentage of calcium chloride causes excessive shrinkage. Strength gained after 1 day is 25 per cent more and after 7 days about 20 per cent more than the ordinary Portland cement.

Uses It is very suitable for cold weathers.

Water Repellent Cement is also called *hydrophobic cement.* A small amount of stearic acid, boric acid or oleic acid is mixed with the ordinary Portland cement during grinding of clinker. These acids form a film around the cement particles which prevent the entry of atmospheric moisture. The film breaks down when the concrete is mixed, and the normal hydration takes place.

Uses It is most suitable for basements and for making water tight concrete.

Water Proof Cement is manufactured by adding strearates of Ca and Al and gypsum treated with tannic acid, etc. at the time of grinding.

Property It is resistant to penetration of water.

Uses Water retaining structures like tanks, reservoirs, retaining walls, swimming pools, bridge piers, etc.

5.11 STORAGE

Portland cement is kept in sacks of 0.035 m^3 (50 kg) capacity for local use. These are stored for short period of time in air tight room avoiding moisture and dampness, at some distance from walls and at some height from floors. The stack should be covered with suitable coverings to avoid circulation of air through and not more than ten bags should be stacked one over another.

5.12 ADMIXTURES

Admixtures are the materials other than the three basic ingredients of cement concrete — cement, aggregate and water — added to the concrete mix before or during mixing to improve certain of its properties in fresh or hardened state. The properties commonly modified are rate of hydration or setting time, workability, dispersion and air entrainment.

Many admixtures affect more than one property of the concrete and although they may enhance some, they may adversely affect some others. An admixture should be employed only after an appropriate evaluation of its effects on concrete. A degree of control must also be exercised to ensure proper quantity of admixture.

Functions

The functions of admixtures are to accelerate the initial set of concrete, i.e. to speed up the rate of development of strength at early ages, retard the initial set, increase the strength of concrete, improve workability, reduce heat of evolution, increase durability of concrete — resistance to freezing and thawing control expansion caused by aggregate-alkali reaction, decrease capillary flow of water and to make

it impermeable, increase the penetration and pumpability of concrete, reduce segregation in grouts, strengthen the bond between old and new concrete surfaces and that between steel reinforcement and concrete, inhibit corrosion of concrete, increase resistance to chemical attack, produce coloured and cellular concrete, produce concrete of fungicidal, germicidal and insecticidal properties, and produce non-skid concrete surfaces.

Classification

Admixtures may be classified as accelerators, retarders, water proofers, workability agents, surface active agents, puzzolanas, etc.

Accelerators normally reduce the setting time, accelerate the rate of hydration of cement and consequently the rate of gain of strength. The examples of accelerators are sulphates with an exception of calcium sulphate, alkali carbonates aluminates and silicates, aluminium chloride, calcium chloride, sodium chloride, sodium and potassium hydroxides, calcium formate, formaldehyde, para formaldehyde, etc.

Some substances may act as accelerators or as retarders according to the proportion added. For example, $CaCl_2$ when added up to 2 per cent by weight of cement acts as accelerator, but on increasing the proportion, it acts as retarder and leads to flash set. Similarly, triethanolamine when added in proportion less than 0.06 per cent by weight of cement acts as an accelerator but acts as retarder if the dosage is increased. $CaCl_2$ and NaCl are very useful to permit concreting in very cold weather (– 23°C). These lower the temperature at which freezing takes place, help to keep the mixture warm by accelerating the generation of heat, and increase the ability of the concrete to resist frost by speeding up the rate of gain of strength.

Retarders normally increase the setting time and thus delay the setting of cement. Since these reduce the rate of hydration, more water is available and better is the workability. Retarders increase the compressive strength under freezing and thawing. Calcium sulphate, sugar, starch, cellulose, ammonium, ferrous and ferric chlorides, sodium hexametaphosphate, lignosulphonic acid and their salts, carbohydrates, hydrocarboxylic acids and their salts are a few examples of retarders. The use of $CaSO_4$ as retarder has already been mentioned in the manufacture of cement where it prevents the flash set. An addition of 0.2 per cent sugar by mass retards the hydration of cement to such an extent that the final set may not take place even for 72 hours. It has also been found that an addition of 0.1 per cent sugar by mass of cement raises the strength of cement at 3 days and increases the 28 days strength by 30 per cent. Retarders are very important in the situations where grouting is to be done for the voids behind the concrete arch, tunnel lining, etc. These also ensure a better bond between successive lifts in concrete constructions. These are very useful, particularly in composite construction where the steel rolled-sections have to carry the load of concrete before the latter is capable of acting as a compression member.

Also, with retarders, the concrete can be mixed by using hot water or injecting steam and it has been found that 28 days strength of concrete is not affected as is the case with normal accelerated curing.

Water Proofers Cement mortar or concrete should be impervious to water under pressure and also should have sufficient resistance to absorption of water. The concrete can be made water resistant with the additives which may be water repellent type or pore filling type. But, the ultimate aim is to produce concrete impervious to water. The examples of water repellent materials such as soda and potash soaps are chemically active, whereas calcium soaps, resin, vegetable oil, fats, waxes and coal tar residue are the examples of chemically inactive materials. The examples of pore filling materials are alkaline silicates and notably silicate of soda, aluminium and zinc sulphate and aluminium and calcium chlorides.

Finely divided workability agents increase the workability by increasing the amount of paste in concrete and hence the cohesiveness. However, if used in excess, the quantity of water has to be increased which causes cracking and loss of strength. Lime, bentonite, kaolin, chalk, diatomaceous earth are a few examples of workability agents.

Bleeding Agents To check bleeding, paraffin wax at about 0.2-0.75 per cent by mass of cement or air entrainment is used. The latter is more effective but requires high degree of control.

Colouring Agents used in concrete work are mainly rawumber (brown), ferrous oxide (black), red oxide (red), and chromium oxide (green).

Air Entraining Agents The air intentionally introduced in the cement during its manufacture or during making concrete is known as entrained air. It is different from entrapped air where the continuous channels are formed, thus increasing the permeability. In the case of entrained air, the voids formed are discontinuous and are less than 0.05 mm in diameter. Air entrainment increases workability, and resistance of concrete to weathering. The possibility of bleeding, segregation and laitance is also reduced. However, there is some loss in the strength of concrete. The air entrainment may be done by surface active agents, chemicals, or by cement dispersing agents.

Surface Active Agents reduce the surface tension and are commonly known as air entraining agents. An addition of 5 per cent of air may increase the compacting factor by 0.07 and a corresponding increase of slump: 12 to 50 mm. Following are some of the examples of air entraining agents:

1. Natural wood resins and their soaps, of which vinsol resin is the best.
2. Animal or vegetable fats and oils such as tallow or olive oil and their fatty acids such as stearic acid and oleic acids and their soaps.
3. Wetting agents such as alkali salts of sulphonated or sulphated organic

compounds. A well known trade material is Darex. Other trade names of this category are N. Tair, Airalon, Orvus, Teepol, Petrosan and Cheecol.

Chemicals The addition of chemicals such as zinc or aluminium powder releases gases. This method is generally not adopted since it requires high control.

Dispersing Agents are surface active chemicals imparting electrostatic charges on the cement particles. This causes cement particles to repel each other and thus prevent coagulation. A small amount of air is also entrained in the concrete and workability is increased. The dispersing agents reduce the strength. The most commonly used dispersing agent is calcium lignosulphonate.

Grouting Agents are classified as follows:

1. Rust generating (expandite)—consisting of finely divided iron and NH_4Cl. Iron rusts and expands, producing non-shrink grouts.
2. Methocel — obtained from Dow chemicals.
3. Hydrogen generating (Nevander) — checks bleeding but does not expand.
4. Chemically expansive (sulphoaluminate) — Denka Tascan.

Superplasticisers are hydrodynamic lubricants which impart high workability by reducing friction between the grains or by reducing the amount of water to be added. They have no harmful effects. Superplasticisers are anionic in nature and impart a negative charge to the cement particles, causing them to repel each other. Once the superplasticiser is added, the concrete should not be agitated as it will lead to an early loss of workability. The workability of the superplasticised concrete decreases more with time than that of the ordinary concrete. The strength, water/cement ratio and creep of concrete with the additive are same as that of concrete before the adding of plasticizer, while shrinkage and surface absorption are reduced slightly and the resistance to thawing and freezing is improved. By addition of superplasticisers it is possible to obtain same strength with a reduced cement content. However, the durability is reduced. The water/cement ratio of the superplasticised concrete may be reduced up to 30 per cent to obtain the initial equality of workability.

In addition to enhancing workability, there are many other advantages of using superplasticisers. Since these are found not to be affected by accelerated curing, they help to release prestressing wires and early demoulding. They can be of assistance in placing concrete under water as the spreading of concrete under water is avoided. They are most advantageous when the concrete is to be pumped. They are not recommended for slabs, the upper surface of which slopes more than 3° or for extruded concrete.

The quantity of the superplasticiser is generally specified by the supplier. In the absence of such data, a dose of 1 to 6 liters per cubic metre of concrete may be

used. If they are used in excess of the specified quantity, the rate of evolution of heat is increased, but the total heat of hydration is not much affected. Superplasticisers are added immediately before use.

Some of the examples of superplasticisers are sulphonated melamine formaldehyde condensates, naphthalene sulphonate formaldehyde condensates, modified lignosulphonate, and mixture of saccharates and acid amines.

Puzzolanas are siliceous materials which are themselves inactive but react, in the presence of water, with lime to form compounds having cementitious properties. The examples of puzzolana are lime, fly ash, burnt clay and blast furnance slag. Puzzolanas react with free lime in cement and so improve the durability of concrete, and reduce the rate of hardening of concrete which is the principal objection to its use. These are dealt in details in Chapter 9.

Expansion Producing Admixtures are used to counteract the drying shrinkage of concrete. Granulated iron and chemicals are most effective.

Bonding Admixtures are used to join the old and the new concrete surfaces or between the successive concrete lifts. The examples are synthetic latex emulsions — made from natural rubber, synthetic rubber, polyvinyl chloride.

Fungicides The examples are arsenic, tin, mercury compounds, Tributyl tin acetate.

Algicides The examples are sodium pentachlorophenate. The usual dosage is 0.2 per cent by weight of cement.

Note : Both of the fungicides and algicides are more effective in the form of paints.

Commercial Names

Some of the commercial admixtures available are

1. *Accoproof, Natson's cement water proofer, Impermo, Sigment* — increase impermeability of concrete.

2. *Trip-L-Seal* —makes the concrete rapid hardening.

3. *Cico* — is water proofer and makes concrete rapid hardening and increases strength.

4. *Feb-Mix-Admix* — is water proofer, increases workability and bond.

5. *Metalcrete, Ferrocrete, Asionate* — are surface hardeners.

EXERCISES

Q.1 (a) What are the ingredients of Portland cement ? State the function and limits of each of them.
(b) What tests would you specify to ensure if the cement supplied at the site is of good quality ?

Q.2 Describe with flow diagrams the dry and wet process of manufacture of cement.

Q.3 (a) Describe the setting and hardening of cement.
(b) Describe how the compounds of clinker affect the properties of cement.

Q.4 (a) When will you recommend high alumina cement in preference to low heat cement?
(b) Describe the properties of blast furnance slag cement and sulphate resisting cement.

Q.5 What is rapid hardening cement ? What is responsible for its high early strength ? How does it differ from ordinary Portland cement ?

Q.6 (a) What are the initial and final setting times of cement ? What is their importance?
(b) What do you mean by normal consistency ? What is its significance ? How is it tested ?

Q.7 (a) What is the effect of grinding on cement ? Describe the method of determining fineness by air permeability method ?
(b) How is the specific gravity of cement determined ?

Q.8 (a) What precautions should be taken while storing cement ?
(b) What is the purpose of adding gypsum while manufacturing cement ?

Q.9 (a) Differentiate between rapid hardening and slow setting cements.
(b) What is the effect of mixing lime in cement ?
(c) Explain how cement gains strength.

Q.10 What are admixtures ? Describe the effect of following admixtures on cement concrete and give three examples of each.
(a) Retarders (b) Water proofer (c) Accelerators

Q.11 Write short notes on
(a) Hydration of cement (b) Clinkering
(c) Grinding of cement (d) Use of gypsum in cement

Q.12 Write short notes on
(a) Compressive strength test of cement
(b) Soundness test of cement
(c) Split-cylinder test of cement

Q.13 State the conditions under which you will recommend the following cements. Give also the reasons.
(a) Puzzolana cement (b) Low heat Portland cement
(c) High alumina cement (d) Rapid hardening cement
(e) Quick setting cement

Q.14 How is the cement classified ? Describe the wet process of manufacturing cement.

Q.15 Discuss the effect of following admixtures on cement

(a) Calcium chloride (b) Sugar

(c) Gypsum (d) Calcium lignosulphonate

(e) Sodium hydroxide

Q.16 What are superplasticisers ? How are these helpful in modifying the properties of cement ?

Chapter

6

MATERIALS FOR MAKING CONCRETE - II AGGREGATES

6.1 INTRODUCTION

Aggregates are the materials basically used as filler with binding material in the production of mortar and concrete. They are derived from igneous, sedimentary and metamorphic rocks or manufactured from blast furnace slag, etc. Aggregates form the body of the concrete, reduce the shrinkage and effect economy. They occupy 70-80 per cent of the volume and have considerable influence on the properties of the concrete. They should be clean, hard, strong, durable and graded in size to achieve utmost economy from the paste. Earlier aggregates were considered to be chemically inert but the latest research has revealed that some of them are chemically active and also that certain types exhibit chemical bond at the interface of aggregates and cement paste. To increase the bulk density of concrete aggregates are used in two markedly different sizes — the bigger ones known to be coarse aggregate (grit) and the smaller ones fine aggregate (sand).

6.2 CLASSIFICATION

On the Basis of Geological Origin

The aggregate may be classified into natural aggregate and artificial aggregate.

Natural Aggregates are obtained by crushing from quarries of igneous, sedimentary or metamorphic rocks. Gravels and sand reduced to their present size by the natural agencies also fall in this category. The most widely used aggregate are from igneous origin.

Artificial Aggregate Broken bricks and blast furnance slag are artificial aggregates. Broken bricks known as *brick bats* are suitable for mass concreting, for example, in foundation bases. They are not used for reinforced concrete works. The blast furnance slag aggregate has good fire resisting properties, but are responsible for corrosion of reinforcement due to sulphur content of slag.

On the Basis of Size

According to size aggregates are classified as coarse aggregate, fine aggregate and all-in-aggregate.

Coarse Aggregate Aggregate retained on 4.75 mm sieve are identified as coarse. They are obtained by natural disintegration or by artificial crushing of rocks. The maximum size of aggregate can be 80 mm. The size is governed by the thickness of section, spacing of reinforcement, clear cover, mixing, handling and placing methods. For economy the maximum size should be as large as possible but not more than one-fourth of the minimum thickness of the member. For reinforced sections the maximum size should be at least 5 mm less than the clear spacing between the reinforcement and also at least 5 mm less than the clear cover. Aggregate more than 20 mm size are seldom used.

Fine Aggregate Aggregate passing through 4.75 mm sieve are defined as fine. They may be natural sand — deposited by rivers, crushed stone sand — obtained by crushing stones and crushed gravel sand. The smallest size of fine aggregate (sand) is 0.06 mm.

All-in-aggregate Naturally available aggregates of different fractions of fine and coarse sizes are known as all-in-aggregate. The deficiency of any particular fraction can be corrected for use in the mix but they are not recommended for quality concrete.

On The Basis of Shape

Aggregates are classified as rounded, irregular, angular, and flaky.

Rounded Aggregates are generally obtained from river or sea shore and produce minimum voids (about 32 per cent) in the concrete. They have minimum ratio of surface area to the volume, and the cement paste required is minimum. Poor

interlocking bond makes it unsuitable for high strength concrete and pavements.

Irregular Aggregates have voids about 36 per cent and require more cement paste as compared to rounded aggregate. Because of irregularity in shape they develop good bond and are suitable for making ordinary concrete.

Angular Aggregate They have sharp, angular and rough particles having maximum voids (about 40 per cent). Angular aggregate provide very good bond than the earlier two, are most suitable for high strength concrete and pavements; the requirement of cement paste is relatively more.

Flaky Aggregates are also known as *elongated* aggregate. The least lateral dimension of flaky aggregate (thickness) should be less than 0.6 times the mean. Flaky aggregate generally orient in one plane with water and air voids underneath. They adversely affect durability and are restricted to maximum of 15 per cent.

Based on Unit Weight

Aggregates are classified as normal-weight, heavy-weight and light-weight aggregate depending on weight and specific gravity as given in Table 6.1

Table 6.1 Classification of Aggregate Based on Unit Weight

Aggregate	Sp. gr.	Unit weight (kN/m^3)	Examples
Normal-weight	2.5-2.7	23-26	Sand, gravel, granite, sandstone, limestone
Heavy-weight	2.8-2.9	25-29	Magnetite (Fe_3O_4) Baryte (Ba_3SO_4), scrap iron
Light-weight		12	Dolomite, pumice, cinder, clay

6.3 CHARACTERISTICS

The properties to be considered while selecting aggregate for concrete are strength, particle shape, specific gravity, bulk density, voids, porosity, moisture content and bulking.

Strength The strength should be at least equal to that of the concrete. Rocks commonly used as aggregates have a compressive strength much higher than the usual range of concrete strength. A typical stress-strain curve for aggregates is shown in Fig. 6.1. The test conducted for strength evaluation are crushing test, impact test and ten per cent fines test. Of these the first one is the most reliable. Generally the specifications prescribe 45 per cent limit for the crushing value. The toughness of aggregate is measured by impact test. The impact value should not exceed 30 per cent for wearing surface and 45 per cent for remaining concretes. Hardness of aggregate is tested by abrasion test. The abrasion value is restricted to 30 per cent for wearing surfaces and 50 per cent for concrete for other purposes.

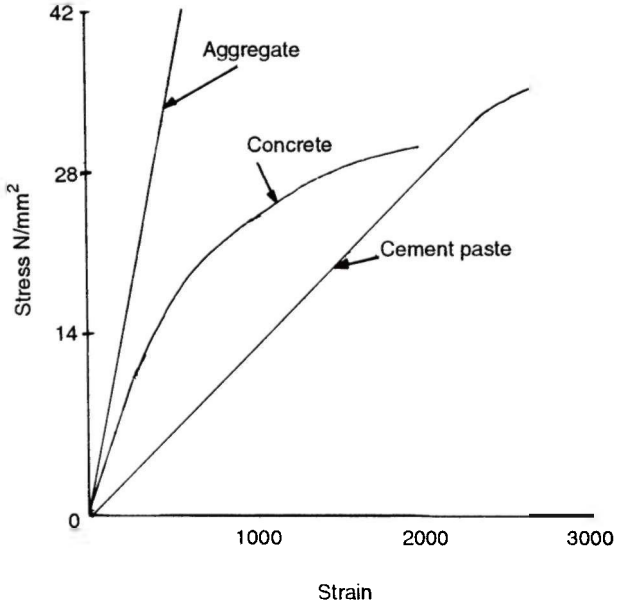


Fig. 6.1 Stress Strain Curves for Aggregate

Stiffness The modulus of elasticity of concrete is approximately equal to the weighted average of the moduli of the cement paste and the aggregates, as such the modulus of the coarse aggregate has an important influence on the stiffness of concrete. A high value reduces the dimensional changes due to creep and shrinkage of cement paste, but at the cost of higher internal stresses. In concrete that is to be subjected to wide variations of temperature and humidity, internal cracking is reduced by the use of a more compressible aggregate, but in practice this effect is rarely of sufficient importance to determine the choice of aggregate.

Bond Strength Due to difference between the coefficients of thermal expansion of paste and aggregate and to the shrinkage of cement paste during hardening, concrete is in a state of internal stress even if no external forces are present. The stresses are likely to be greatest at the paste-aggregate interfaces where minute cracks have been found to exist, even in concrete that has never been loaded. Under increasing external load, these cracks spread along the interfaces before extending into the paste or aggregate particles. The strength of the bond between aggregate and cement paste thus has an important influence on the strength of concrete. There is no standard test for bond, but it is known that the rougher the surface texture of the particles, the better the bond. The role of particle shape is less well understood; the greater specific surface of angular particles should enable greater adhesive forces to be developed, but the angular shape probably causes more severe concentrations of internal stress.

Shape and Texture The shape influences the properties of fresh concrete more than when it has hardened. Rounded aggregates are highly workable but yield low strength concrete. Same is the case with irregular shaped aggregates. Flaky aggregates require more cement paste, produce maximum voids and are not desirable. Angular shape is best. Crushed and uncrushed aggregates generally give essentially the same strength for the same cement content. The shape and surface texture of fine aggregate govern its void ratio and significantly affect the water requirement.

Specific Gravity The specific gravity of most of the natural aggregates lies between 2.6-2.7.

Bulk Density The bulk density depends upon their packing, the particles shape and size, the grading and the moisture content. For coarse aggregate a higher bulk density is an indication of fewer voids to be filled by sand and cement.

Voids The void ratio is calculated as

$$\text{Void ratio} = 1 - \frac{\text{Bulk density}}{\text{Apparent specific gravity}}$$

If the voids in the concrete are more the strength will be low.

Porosity The entrapped air bubbles in the rocks during their formation lead to minute holes or cavities known as *pores*. The porosity of rocks is generally less than 20 per cent; the concrete becomes permeable and ultimately affects the bond between aggregate and cement paste, resistance to freezing and thawing of concrete, resistance to abrasion and specific gravity of aggregate.

Moisture Content The surface moisture expressed as a percentage of the weight of the saturated surface dry aggregate is known as moisture content. A high moisture content increases the effective water/cement ratio to an appreciable extent and may render the concrete weak.

Bulking The increase in the volume of a given mass of fine aggregate caused by the presence of water is known as bulking. The water forms a film over the fine aggregate particles, exerts force of surface tension and pushes them apart increasing the volume. The extent of bulking depends upon the percentage of moisture present in the sand and its fineness. With ordinary sand bulking varies from 15-30 per cent. It increases with moisture content up to a certain point, reaches maximum, the film of water on the sand surface breaks, and then it starts decreasing. Figure 6.2 shows the bulking of sand with moisture content. In preparing concrete mixes if sand is measured by volume and no allowance is made for bulking, the moist sand will occupy considerably larger volume than that prepared by the dry sand and consequently the mix will be richer. Also, there will be chances of segregation, honeycombing and reduced yield of concrete.

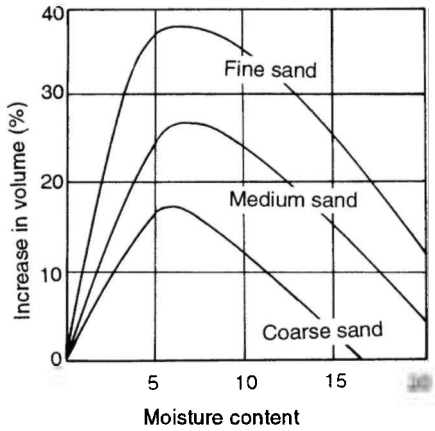


Fig. 6.2 Effect of Moisture Content on Bulking of Sand

6.4 DELETERIOUS SUBSTANCES

Substances such as organic matters, clay, shale, coal, iron pyrites, etc. which are weak, soft, fine or may have harmful physical or chemical effects on the aggregates are considered to be deleterious. They affect the properties of concrete in green as well as in hardened state and are undesirable. They may be classified as those interfering with the process of hydration, i.e. organic matters, coatings such as clay, etc. affecting the development of bond between aggregate and the cement paste, and, unsound particles which are weak or bring about chemical reaction between aggregate and cement paste. The surface coated impurities in aggregate can be removed by adequate washing. However, chemically-bonded stable coatings which cannot be so removed may increase shrinkage cracks. The salts present in the sea-shore sand should be washed out otherwise efflorescence is caused afterwards. Mica, if present in sand, reduces the strength of concrete. Iron pyrites and sulphides produce surface staining and pop-outs.

6.5 SOUNDNESS

Soundness is defined as the ability of aggregate to resist changes in volume as a result of changes in physical conditions. The conditions affecting this property are freezing and thawing, temperature changes, and alternate wetting and drying. Porous and weak aggregates containing undesirable extraneous matter undergo excessive volume changes under favourable conditions. The freeze-thaw resistance of aggregate is related to its porosity, absorption, and pore structure. This may cause local scaling to surface cracking consequently leading to impaired appearance and sometimes structural failure. Aggregates may also be chemically unstable. Some

of the aggregate with certain chemical constituents react with alkalis in cement which may cause abnormal expansion and map cracking of concrete.

6.6 ALKALI-AGGREGATE REACTION

The aggregates were considered to be inert materials till 1940. Considerable trouble has been experienced through extensive pop-outs and cracking in a fairly close pattern, of concrete work probably a year or more after the concrete has been cast. Although this trouble may take a year to become plainly visible the effects can often be observed in petrographic thin sections of the concrete within a few months. The phenomenon is accompanied by extensive expansion and may lead in bad cases to complete disruption and disintegration of the concrete and is known as alkali-aggregate reaction or sometimes *concrete cancer*. The trouble is due to reaction between silica in aggregate and alkalis in the cement. In some cases alkalis, mainly from the cement supplemented by alkalis in the aggregate, react with carbonates in the aggregate to produce similar results. The types of rocks which contain reactive constituents include traps, andesites, rhyolites, siliceous limestone and certain types of sandstones. The reactive components may be in the form of opals, cherts, chalcedony, volcanic glass (excepting basaltic glasses), zeolites, and tridmite.

Mechanism

The precise causes and behaviour of the phenomenon are, however, still a little obscure. A reactive aggregate, if in finely ground state, will inhibit the action. The dividing line between aggregate which will cause trouble and that which will not, appears to be retained on and passing a 150 μm sieve. The precise explanation of this is not quite clear but the action is probably akin to that of lime, the presence of which if fine and thoroughly mixed with the cement has no harmful effect on the concrete, but if present in large lumps it subsequently slakes, if it becomes damp, with disruptive effect.

Reaction between cement and aggregate can be of two types: reaction between the alkalies of the cement and either silicas or carbonates in the aggregate. The former appears to be more common. The alkali aggregate reaction takes place only in the presence of water or water vapour. The water forms strong caustic solute with alkalis of cement. This caustic liquid attacks reactive silica to from alkali-silica-gel of unlimited swelling type. When the conditions are congenial, progressive manifestation of concrete, particularly in thin concrete sections, results cracks and eventual failure of concrete structures. Conspicuous effect may not be notified in mass concrete sections. The formation of pattern cracks result in subsequent loss in strength and elasticity because of stresses induced by the growth of silica gel. Many destructive forces become operative on the concrete disrupted by alkali-ag-

gregate reaction which further hasten the total disintegration of concrete.

The carbonate rocks which are reactive range from pure limestones to pure dolomites and those rocks which have excess of Mg or Ca ions over the ideal proportion are likely to give trouble. Apparently there are several different types of alkali carbonate reactions not all of which are expansive and harmful. The reaction zones are up to 2 mm wide around the aggregate particles and are visible on polished surface in thin petrographic sections.

Factors Affecting Alkali-aggregate Reaction

Reactive Type of Aggregates Reactive material have been found to have serious effects if present in small quantities but not if it constitutes the whole of the aggregate.

High Alkali Content Cement If the cement contains less than 0.4 per cent alkalis (computed as Na_2O) no expansion or disruptive effect is likely even with a quite highly reactive aggregate, but due to difficulties of manufacture it is not usual to specify an alkali content of less than 0.6 per cent.

Availability of Moisture Progress of the alkali-aggregate reaction takes place only in the presence of water. That is why this destructive effect is not observed in the interior of mass concrete.

Temperature Condition The favourable temperature for the reaction is 10-38°C.

Control of Alkali-aggregate Reaction

By Selecting Non-reactive Aggregate Aggregate can be identified by petrographic examination. The mortar bar test and the chemical test are used.

By Using Low Alkali Cement Cements with alkali less than 0.6 per cent should be used.

By Controlling Moisture Old concrete should not be allowed to come in contact with water. The best way is to apply mortar with water proofing agents on concrete surface.

By Puzzolanas The aggregates are found to be reactive when they contain silica in a particular proportion and fineness. When fly-ash or surkhi or crushed stone dust is added this optimum condition of silica being in particular proportion and fineness is disturbed and the aggregates turn to be innocuous.

By Air Entraining Agents The alkali-silica-gel imparts osmotic pressure over the set cement gel and this is mainly responsible for formation of cracks. When air entraining agents are added they absorb the osmotic pressure and control the expansion.

6.7 THERMAL PROPERTIES

The thermal properties of coarse aggregate are specific heat, thermal conductivity and coefficient of expansion. The first two are detrimental in case of mass concrete. Also these properties are of concern in case of light weight concrete used for thermal insulation purposes. The third one affects the concrete in general since the coefficient of thermal expansion of concrete increases with that of coarse aggregate. Any appreciable difference in the coefficients of coarse aggregate and cement paste may break the bond between the two. Freezing and thawing effect may be prominent if the difference in the two is more than 5.4×10^{-6} per °C.

6.8 FINE AGGREGATE

Sand (> 0.07 mm) is used as a fine aggregate in mortar and concrete. It is a granular form of silica. Sand used for mix design is known as standard sand. In India Ennove Sand is standard sand and in U.K. it is Leighton-Burrard Sand. The standard sand should be of quartz, light grey or whitish colour, free from silt and organic impurities and should pass through 850 μm sieve with not more than 10 per cent passing through 600 μm sieve. Sand used in mortars for construction purposes should possess at least 85 per cent of the strength of standard sand mortars of like proportions and consistency. Sand is also used for making mortars.

Classification Sand may be classified on the basis of source, mineralogical composition, size of the particles and particle size distribution. Depending upon the source sand may be classed as natural sand — resulting from natural disintegration of rocks or deposited by streams; crushed stone sand — produced by crushing hard stones and, crushed gravel sand — produced by crushing natural gravel. Based on mineralogical composition, sand is divided into quartz, felspar and carbonaceous varieties. Depending upon its size sand is classified as coarse sand — fineness modulus (F.M.) 2.90-3.20; medium sand — F.M.: 2.60-2.90 and; fine sand — F.M. : 2.20-2.60. Based on particle size distribution fine aggregate have been divided in four grades from grading zone I to grading zone IV as given in Table 6.2.

Table 6.2 Gradings of Fine Aggregate

Sieve Designation	Percentage passing for			
	Grading Zone I	Grading Zone II	Grading Zone III	Grading Zone IV
10 mm	100	100	100	100
4.75 mm	90-100	90-100	90-100	90-100
2.36 mm	60-95	75-100	85-100	95-100
1.18 mm	30-70	55-90	75-100	90-100
600 micron	15-34	35-59	60-79	80-100
300 micron	5-20	8-30	12-40	15-50
150 micron	0-10	0-10	0-10	0-15

Functions of Sand The functions of sand are to achieve economy by its use as adulterant in mortar, prevent shrinkage and development of cracks in mortar, furnish strength to mortar against crushing and, allow carbon dioxide from the atmosphere to penetrate the fat lime mortars necessary for its air hardening.

Effect of Gradation The grading of fine aggregate has a great influence on workability of mortar. Very fine sand and very coarse sand have been found to be unsatisfactory for making mortar and concrete. Very fine sand results in a poor mortar and is uneconomical, whereas very coarse sand produces a harsh mix affecting workability. When well graded (consisting of particles of different sizes) the voids are minimised.

Effect of Impurities The impurities such as clay, dust and organic materials are harmful for mortar and concrete and in any case should not exceed 4 per cent. Of these clay is most harmful since it coats individual sand particles and prevents their bonding with cement consequently diminishing the strength of mortar which is further reduced by the enhanced water requirement of mortar. The clay and dust impurities can be removed by careful washing. Addition of finely ground clay to clean coarse sand may improve its grading and reduce voids. Hence a lean mortar deficient in fines may be improved both in density and workability by addition of small percentages of such clays. The organic matters, shell and vegetables injure the hardening properties of the cement reducing the strength and durability.

Effect by Entraining Air in Concrete The quantity of fine aggregate required for making concrete mix can be reduced by entraining air.

6.9 COARSE AGGREGATE

These may be uncrushed, crushed or partially crushed gravel or stone. They should be hard, strong, dense, durable, clear and free from veins and adherent coatings; and free from injurious amounts of disintegrated pieces, alkali, organic matter and other deleterious substances. Flaky, scoriaceous and elongated aggregate should be avoided.

Functions The functions of coarse aggregate are almost same as that of fine aggregate.

6.10 CINDER AGGREGATES

They are well-burnt furnance residue obtained from furnances using coal as fuel and are used for making lime concrete. They should be clean and free from clay, dirt, wood ash or other deleterious matter. They are classed as A, B and C. Class A is recommended for general purposes, class B for interior work not exposed to damp conditions, and class C for precast blocks.

Sulphate content should not exceed 1 per cent when expressed as sulphur trioxide and loss on ignition 10 per cent for class A, 20 per cent for class B, 25 per cent for class C.

Average grading is as under:

Sieve No.	Percentage passing
10 mm	100
4.75 mm	80
2.36 mm	60
1.18 mm	40
600 micron	30
300 micron	25
150 micron	16

6.11 BROKEN BRICK COARSE AGGREGATE

They are prepared from well-burnt or over-burnt broken bricks free from under-burnt particles, soil and salt and are used in lime concrete.

Water absorption after 24 hours on immersion in water should not exceed 25 per cent and water soluble matter should not exceed 1 per cent. Aggregate impact value should not exceed 50 per cent.

Grading is as under:

Sieve No. (mm)	Percentage passing (by weight)
80	100
40	95-100
20	45-75
4.75	-

6.12 TESTING

The size, shape, grading of aggregate and their surface moisture affect directly the workability and strength of concrete whereas soundness, alkali-aggregate reaction and presence of deleterious substances adversely affect the soundness and durability of concrete. The following tests are conducted to ensure satisfactory performance of aggregate.

Specific Gravity and Water Absorption

Aggregate Larger than 10 mm A sample of 2000 g of the aggregate is used for conducting the test. Aggregates which have been artificially heated should not normally be used.

The sample is thoroughly washed to remove finer particles and dust, drained

and then placed in the wire basket and immersed in distilled water at a temperature between 22°-32°C with a cover of at least 50 mm of water above the top of the basket.

Immediately after immersion the interrupted air is removed from the sample by lifting the basket containing it 25 mm above the base of the tank and allowing it to drop 25 times at the rate of about one drop per second. The basket and aggregate are kept completely immersed during the operation and for a period of 24 ± 1/2 hours afterwards. The basket and the sample are jolted and weighed in water (weight A_1). These are then removed from the water and allowed to drain for a few minutes, after which the aggregates are gently emptied from the basket on to one of the dry clothes, and the empty basket is returned to the water, jolted 25 times and weighed in water (weight A_2).

The aggregates placed on the dry cloth are gently surface dried with the cloth, and are completely surface dried. The aggregates are then weighed (weight B).

The aggregates are thereafter placed in an oven at a temperature of 100°-110°C and maintained at this temperature for 24 ± 1/2 hours. It is then removed from the oven, cooled in the air-tight container and weighed (weight C). The computations are as under

$$\text{Specific gravity} = \frac{C}{B - A}$$

$$\text{Apparent specific gravity} = \frac{C}{C - A}$$

$$\text{Water absorption (per cent of dry weight)} = \frac{100\,(B - A)}{C}$$

where A = the weight in g of the saturated aggregate in water ($A_1 - A_2$)

B = the weight in g of the saturated surface dry aggregate in air

C = the weight in g of oven-dried aggregate in air

Aggregate Between 40 mm and 10 mm A sample of about 100 g of the aggregate is screened on a 10 mm sieve, thoroughly washed to remove fine particles of dust, and immersed in distilled water in a glass vessel at a temperature of 22°C to 32°C for 24± 1/2 hours. Soon after immersion and again at the end of the soaking period, air entrapped in or bubbles on the surface of the aggregate should be removed by gentle agitation.

The vessel is over filled by adding distilled water, dried on the outside and weighed (weight A).

The vessel is then emptied and the aggregate allowed to drain and later refilled with distilled water. It is dried on the outside and weighed (weight B).

The aggregate is placed on a dry cloth and gently surface dried with the cloth.

The aggregate is weighed (weight C) after the surface is completely dried.

The aggregate is then placed in the oven at a temperature of 100°C to 110°C for 24± 1/2 hours and thereafter cooled in airtight container and weighed (weight D).

$$\text{Specific gravity} = \frac{D}{C-(A-B)}$$

$$\text{Apparent specific gravity} = \frac{D}{D-(A-B)}$$

$$\text{Water absorption (per cent of dry weight)} = \frac{(C-D)}{D} \times 100$$

where A = weight in g of vessel containing and filled with distilled water

B = weight in g of vessel filled with distilled water only

C = weight in g of saturated surface-dry sample

D = weight in g of oven-dry sample

A Pycnometer shown in Fig. 6.3 is used for determining specific gravity. A sample about 1000 g for 10 mm to 4.75 mm or 500 g if finer than 4.75 mm, is placed in the tray and covered with distilled water at a temperature of 22°-32°C. Soon after immersion, air entrapped in or bubbles on the surface of the aggregate are removed by gentle agitation with a rod. The sample is kept immersed for 24 ± 1/2 hours.

The water is then carefully drained from the sample through a filter paper, any material retained being returned to the sample. The aggregate including any solid matter retained on the filter paper should be exposed to a gentle current of warm air to evaporate surface moisture and stirred at frequent intervals to insure uniform drying until no free surface moisture can be seen and the material just attains a *free-running* condition.

The aggregate is then placed in the pycnometer which is filled with distilled water. The pycnometer is dried on the outside and weighed (weight B).

The contents of the pycnometer are emptied into the tray. The pycnometer is refilled with distilled water to same level as before,

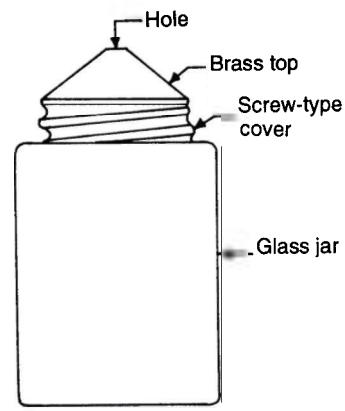


Fig. 6.3 Pyconometer

dried on the outside and weighed (weight C).

The water is then carefully drained from the sample by decantation through a filter paper and any material retained is returned to the sample. The sample is placed in the oven at a temperature of 100°C to 110°C for 24 ± 1/2 hours, during which period it should be stirred occasionally to facilitate drying. It is then cooled in the air-tight container and weighed (weight D).

$$\text{Specific gravity} = \frac{D}{C-(A-B)}$$

$$\text{Apparent specific gravity} = \frac{D}{D-(A-B)}$$

$$\text{Water absorption (per cent of dry weight)} = \frac{(C-D)}{D}\ 100$$

where A = weight in g of saturated surface-dry sample

B = weight in g of pycnometer or gas jar containing sample and filled with distilled water

C = weight in g pycnometer or gas jar filled with distilled water only

D = weight in g of oven-dried sample

Bulk Density and Voids

The bulk density, measured in kilograms per litre is affected by several factors, including the amount of moisture present and the amount of effort introduced in filling the measure. This is laboratory test intended for comparing properties of different aggregates. It is not generally suitable for use as a basis for quoting mix design conversion factors.

The test is carried out on dry material when determining the voids, but when bulking tests are required material with a given percentage of moisture may be used.

The measure is filled with thoroughly mixed aggregate to about one-third and tamped with 25 strokes of the rounded end of the tamping rod. A further similar quantity of aggregate is added and a further tamping of 25 times and the surplus aggregate is struck off, using the tamping rod as a straight edge. The net weight of the aggregate in the measure is determined and the bulk density is calculated.

The measure is then filled to overflowing by means of a shovel or scoop, the aggregate being discharged from a height not exceeding 50 mm above the top of the measure. The surface of the aggregate is then levelled with a straight edge. The net weight of the aggregate in the measure is determined and the bulk density is calculated.

The percentage of voids are calculated as follows:

$$\text{Percentage of voids} = \frac{G_s - \gamma}{G_s} \times 100$$

where G_s = specific gravity of the aggregate

γ = bulk density in kg/litre

Necessary Adjustment for Bulking of fine Aggregate (Field Method)

I Method Sufficient quantity of the sand is put loosely into a container until it is about two-third full. The sand is levelled off and a steel rule is pushed vertically down through the sand at the middle to the bottom and the height is measured (say h mm).

The sand is transferred into another container. The first container is half filled with water and about half the sand is put back and rammed with a steel rod (about 6 mm in diameter) so that its volume is reduced to a minimum. Then the remainder of the sand is added and rammed in the same way. The depth is measured at the middle with the steel rule (say h mm).

The percentage of bulking of the sand due to moisture (say h′ mm) is calculated from the formula:

$$\text{Percentage bulking} = \left(\frac{h}{h'} - 1\right) \times 100$$

II Method The damp sand (consolidated by shaking) is poured in a 250 ml measuring cylinder up to the 200 ml mark. Then the cylinder is filled with water and the sand is stirred well. The sand surface will be found to be below its original level. Supposing the surface is at the mark y ml, the percentage of bulking of the sand due to moisture is calculated as:

$$\text{Percentage bulking} = \left(\frac{200}{y} - 1\right) \times 100$$

Surface Moisture in Fine Aggregate (Field Method)

Determination by Weight The container is filled up to the mark with water and the weight in grams determined. It is emptied. Enough water is placed in the container to cover the sample, after which the sample of fine aggregate is introduced into the container and the entrained air removed. The container is then filled to the original mark and the weight in grams determined. The amount of water displaced by the sample is calculated as:

$$V_s = M_c + M_s - M$$

where V_s = weight in g of water displaced by the sample

M_c = weight in g of container filled up to the mark with water

M_s = weight in g of the sample

M = weight in g of the sample and container filled to the mark with water

Determination by Volume A volume of water sufficient to cover the sample is measured in millilitres and placed in the container. The weighed sample of fine aggregate is then admitted into the container and the contained air removed. The combined volume of the sample and the water is determined by direct reading when a graduated flask is used. Where a pycnometer or volumetric flask of known volume is used, the combined volume of the sample and the water is determined by filling up to the mark with a measured volume of water and subtracting this volume from that of the container. The amount of water displaced by the sample is calculated as:

$$V_s = V_2 - V_1$$

where V_s = volume in ml of water displaced by the sample

V_2 = combined volume in ml of the sample and water

V_1 = volume in ml of water required to cover the sample

The percentage of surface moisture in terms of the saturated surface-dry fine aggregate and in terms of the weight of wet fine aggregate are calculated as:

$$P_1 = \frac{V_s - V_d}{M_s - V_d} \times 100$$

$$P_2 = \frac{V_s - V_d}{M_d - V_s} \times 100$$

where P_1 = percentage surface moisture in terms of saturated surface-dry fine aggregate

V_s = weight in g of water displaced

V_d = the weight of the sample divided by the specific gravity on saturated and surface-dry basis determined as prescribed

M_s = weight in g of the sample

P_2 = percentage surface moisture in terms of the weight of wet fine aggregate

Crushing Value

The material for the test should consist of aggregate passing 12.5 mm sieve and retained on 10 mm sieve. For other sizes, the materials are separated on the appropriate sieves given in Table 6.3.

Table 6.3 Details of Aggregate Crushing Test for Non-standard Sizes of Aggregate

Nominal sizes		Diameter of cylinder to be used	Size of sieve for separating fines
Passing through (mm)	Retained on (mm)	(cm)	
25.00	20.00	15.0	4.75 mm
20.00	12.50	15.0	3.35 mm
10.00	6.30	15.0 or 7.5	1.70 mm
6.3	4.75	15.0 or 7.5	1.18 mm
4.75	3.35	15.0 or 7.5	850 microns
3.35	2.36	15.0 or 7.5	600 microns

Note : About 6500 g of natural aggregate is required to provide the 150 mm test samples for the 150 mm cylinder, or about 1000 g for the 75 mm cylinder.

The aggregate is tested in a surface-dry condition. The weight of material comprising the test sample is determined (weight A).

The cylinder of the test apparatus is positioned on the base-plate and the test sample is added in thirds, each being subjected to 25 strokes from the tamping rod. The surface of the aggregate is carefully levelled and the plunger is inserted so that it rests horizontally on this surface.

The apparatus, with the test sample and plunger in position is then placed between the platens of the testing machine and loaded at an uniform rate as possible so that the total load is reached in 10 minutes. The total load should be 4000 KN.

The load is released and the whole of the material is removed from the cylinder and sieved on a 2.36 mm sieve for the standard test, or on the appropriate sieve given in Table 6.3. The fraction passing the sieve is weighed.

The ratio of the weight of fines formed to the total sample weight in each test is expressed as a percentage, recorded to the first decimal place :

$$\text{Aggregate crushing value} = \frac{B}{A} \times 100$$

where B = weight of fraction passing the appropriate sieve

A = weight of surface-dry sample

Ten Per Cent Fines Test

The *ten per cent fines* value gives a measure of the resistance of an aggregate to crushing, that is, applicable to all aggregates.

The material for the test consists of surface-dry aggregates passing a 12.5 mm sieve and retained on a 10 mm sieve. The weight of material comprising the test sample is determined (weight A).

The cylinder of the test apparatus is put in position on the base-plate and the test sample is added in thirds, each being subjected to 25 strokes from the tamping

rod. The surface of the aggregate is carefully levelled and the plunger inserted so that it rests horizontally on this surface, care being taken to ensure that the plunger does not jam in the cylinder.

The apparatus with the test sample and plunger in position, is then placed in the compression testing machine. The load is applied at a uniform rate so as to cause a total penetration of the plunger in 10 minutes of about:

15.0 mm for rounded or partially rounded aggregate (for example, uncrushed gravels),

20.0 mm for normal crushed aggregate, and

24.0 mm for honeycombed aggregate (for example, expanded shales and slags).

These figures may be varied according to the extent of the rounding or honeycombing.

After reaching the required maximum penetration, the load is released and the whole of the material removed from the cylinder is sieved on a 2.36 mm sieve. The fines passing the sieve are weighed, and expressed as a percentage of the weight of the test sample. Normally, this percentage will fall within the range 7.5 to 12.5, but if it does not, a further test is made at a load adjusted as seems appropriate to bring the percentage fines within the range of 7.5 to 12.5.

The mean percentage fines from the two tests at this load are used in the following formula to calculate the load required to give 10 per cent fines :

$$\text{Load required for 10 per cent fines} = \frac{14\,x}{y+4}$$

where x = load in tonnes

y = mean percentage fines from two tests at x tonnes load.

Aggregate Impact Value

The *aggregate impact value* gives a relative measure of the resistance of an aggregate to sudden shock or impact, which in some aggregate differs from its resistance to a slow compressive load.

The test sample consists of aggregate the whole of which passes a 12.5 mm sieve and is retained on a 10 mm sieve. The aggregate comprising the test sample is dried in an oven for a period of four hours at a temperature of 100°-110°C and cooled.

The measure is filled about one-third full with the aggregate and tamped with 25 strokes of the rounded end of the tamping rod. A further similar quantity of aggregate is added and a further tamping of 25 strokes is given. The measure is finally filled to overflowing, tamped 25 times and the surplus aggregate is struck off, using the tamping rod as a straight-edge. The net weight of aggregate in the

measure is determined to the nearest gram (weight A).

The cup is fixed firmly in position on the base of the machine and the whole of the sample is placed in it and compacted by a single tamping of 25 strokes of the tamping rod.

The hammer is raised until its lower face is 380 mm above the upper surface of the aggregate in the cup, and allowed to fall freely on to the aggregate. The test sample is subjected to a total of 15 such blows each being delivered at an interval of not less than one second.

The crushed aggregate is then removed from the cup and the whole of it is sieved on the 2.36 mm sieve until no further significant amount passes in one minute. The fraction passing the sieve is weighed to an accuracy of 0.1 g (weight B). The fraction retained on the sieve is also weighed (weight C) and, if the total weight (B + C) is less than the initial weight (A) by more than one gram, the result is discarded and a fresh test made. Two tests are made.

The ratio of the weight of fines formed to the total sample weight in each test are expressed as a percentage, recorded to the first decimal place:

$$\text{Aggregate impact value} = \frac{B}{A} \times 100$$

where B = weight of fraction passing 2.36 mm sieve

A = weight of oven-dried sample

Aggregate Abrasion Value

Coarse Aggregate Using Deval Machine

Abrasive Charge The abrasive charge consists of 6 cast iron or steel spheres approximately 48 mm in diameter, each weighing between 390 and 445 g.

An abrasive charge of 6 spheres weighing 25000 ± 10 g is used with each test sample.

The test sample consists of dry coarse aggregate made up of percentages of the various sizes conforming to one of the gradings shown in Table 6.4. The grading used should be that most nearly representing the coarse aggregate furnished for the work.

Table 6.4 Grading of Aggregate for Abrasion Test

Grading	Passing sieve	Retained sieve	Percentage of sample
A	20 mm	12.5 mm	25
	25 mm	20 mm	25
	40 mm	25 mm	25
	50 mm	40 mm	25
B	20 mm	12.5 mm	25
	25 mm	20 mm	25
	40 mm	25 mm	50
C	20 mm	12.5 mm	50
	25 mm	20 mm	50
D	12.5 mm	4.75 mm	50
	20 mm	12.5 mm	50
E	10 mm	4.75 mm	50
	12.5 mm	10 mm	50

The weight of the test sample depends upon its average specific gravity and is as given below.

Range of specific Gravity	Weight of Sample (g)
Over 2.80	5500
2.4 to 2.80	5000
2.2 to 2.39	4500
< 2.20	4000

Procedure The test sample and the abrasive charge are placed in the Devel abrasion testing machine and the machine is rotated for 10000 revolutions at a speed of 30 to 33 rev/min. At the completion of the test, the material is removed from the machine and sieved on a 1.70 mm sieve. The material retained on the sieve is washed, dried and accurately weighed to the nearest gram.

The loss by abrasion is considered as the difference between the original weight of the sample and the weight of the material retained on the 1.70 mm sieve, expressed as percentage of the original weight of the test sample.

In case of crushed gravel, the percentage by weight of crushed fragments is determined, and the permissible percentage or wear is calculated as:

$$W = \frac{AL + (100 - A)L'}{100}$$

where W = permissible percentage of wear

A = percentage of uncrushed fragments

L = maximum percentage of wear permitted by the specifications for gravel consisting entirely of uncrushed fragments

100 – A = percentage of crushed fragments

L′ = maximum percentage of wear permitted by the specifications for gravel consisting entirely of crushed fragments

Coarse Aggregate Using Los Angeles Machine

Abrasive Charge The abrasive charge consists of cast iron spheres or steel spheres approximately 48 mm in diameter and each weighing between 390 and 445 g.

The abrasive charge, depending upon the grading of the test sample should be as given in Table 6.5.

Table 6.5 Abrasive Charge for Los Angeles Test

Grading	Number of Sphere	Weight of charge (g)
A	12	5000 ± 25
B	11	4584 ± 25
C	8	3330 ± 20
D	6	2500 ± 15
E	12	5000 ± 25
F	12	5000 ± 25
G	12	5000 ± 25

The test sample consists of clean aggregate dried in an oven at 105°-110°C to substantially constant weight.

Note : It is recognized that different specification limits may be required for gradings E, F and G than for A, B, C and D. It is urged that investigations be conducted to determine the relationship, if any, which exists between results for these coarse gradings using the 10000 g samples and the finer ones using the 5000 g samples.

The test sample and the abrasive charge is placed in the Los Angeles abrasion testing machine and the machine is rotated at a speed of 20 to 33 rev/min. For gradings A, B, C and D, the machine is rotated for 500 revolutions; for gradings E, F and G, it is rotated for 1000 revolutions. The machine is so driven and so counter-balanced as to maintain a substantially uniform peripheral speed. If an angle is used as the shelf, the machine is rotated in such a direction that the charge is caught on the outside surface of the angle. At the completion of the test, the material is discharged from the machine and a preliminary separation of the sample made on a sieve coarser than the 1.70 mm. The finer portion is then sieved on a 1.70 mm sieve. The material coarser than the 1.70 mm sieve is washed, dried in an oven at 105°-110°C to a substantially constant weight, and accurately weighed to the nearest gram.

EXERCISES

Q.1 (a) What are different types of aggregates for making mortar and concrete?
(b) What are the sources of fine aggregate ? Give the characteristics and uses of sand.
(c) What is bulking of sand ? How does it affect concrete mix ?

Q.2 (a) What is fineness ? How would you find the value of coarse and fine aggregates ?
(b) What are the specifications of good sand for general use in buildings ? From which source is sand preferred and why ?

Q.3 (a) What are the different sources of sand ? Which one of them is the best?
(b) State the disadvantages of sea sand.
(c) What is meant by aggregate ? Briefly describe their classification.

Q.4 (a) Discuss the characteristics of good aggregates.
(b) What are the deleterious substances in aggregates ? What are their harmful effects ?

Q.5 What is alkali-aggregate reaction ? What are the factors which affect this reaction ? How can this reaction be controlled ?

Q.6 Briefly describe the following tests:
(a) Specific gravity test (b) Crushing test
(c) Impact test (d) Ten per cent fines test

Q.7 (a) What is the purpose of adding sand to cement mortar ?
(b) What is meant by all-in-aggregate ?
(c) Write the general specifications for sand to be used in reinforced cement concrete works.

Q.8 Write short notes on:
(a) Effect of moisture on aggregates
(b) Properties of good coarse aggregate
(c) Fineness modulus
(d) Alkali-aggregate reaction.

Chapter

7

MATERIALS FOR MAKING CONCRETE – III WATER

7.1 INTRODUCTION

The purpose of using water with cement is to cause hydration of the cement. Water in excess of that required for hydration acts as a lubricant between coarse and fine aggregates and produces a workable and economical concrete. As discussed later in Chapters 10 and 11, there is a definite optimum water requirement for a particular concrete and mortar. In case of excess water, the cement along with water comes to the surface by capillary action and forms a thin layer over surface known as laitance. This weakens bond between the successive lifts of concrete. The excess water may leak through the form work, resulting in honeycombed concrete and on evaporation makes the concrete porous. On the other hand lesser water makes it difficult to work with concrete and because of nonuniform mixing the resultant concrete is weaker in strength. The amount of water must therefore be limited to produce concrete of the quality required for a job. Water is also used for washing aggregates and curing.

7.2 QUALITY OF MIXING WATER

Almost any natural potable water that has no pronounced taste or odour is acceptable for the concrete mix. Many sources of water unsuitable for drinking may also be used. In case of a doubt, water samples should be tested for suitability.

Excessive impurities may affect setting time, strength, durability and may cause efflorescence, surface discolouration, and corrosion of steel.

The effects of impurities in water are mainly expressed in terms of setting time of Portland cement. The initial setting time of the mixes with impure water and that with the pure water are obtained. Their difference in the initial setting time of ± 30 minutes with initial setting time not less than 30 minutes is supposed to be acceptable. The 7 day and 28 day compressive strengths of the cube/cylinder specimens prepared with impure water should not differ by 10 per cent from that of cubes/cylinders prepared with pure water. The tolerable concentrations of some of the impurities in water are given in Table 7.1.

Table 7.1 Tolerance Concentration of Impurities in Mixing Water

S.No.	Impurity	Tolerable concentration
1.	Silt and suspended particles	2,000 ppm
2. i)	Carbonates and bicarbonates of Na or K	1,000 ppm
ii)	Bicarbonates of Mg	400 ppm
3.	Chlorides	10,000 ppm
4.	Sulphates	20,000 ppm
5.	Sulphuric anhydride	3,000 ppm
6.	Calcium chloride	2 per cent by weight of cement
7.	Sodium sulphide	<100 ppm
8.	Sodium hydroxide	0.5 per cent by weight of cement provided quick set is not induced
9.	Dissolved salts	15,000 ppm
10.	Organic matter	3,000 ppm
11.	pH	6-8
12.	Iron salts	40,000 ppm
13.	Acids (HCl, H_2SO_4)	10,000 ppm
14.	Sugar	500 ppm

Suspended Particles Water containing less than 2000 ppm (parts per million) of dissolved solids can generally be used satisfactorily for making concrete. A higher concentration affects certain cements adversely.

Inorganic Salts The presence of salts of zinc, manganese, tin, copper and lead considerably reduce the concrete strength. Sodium phosphate, sodium borate and sodium iodate act as retarders and cause a marked reduction in the strength of concrete. Sodium sulphide is detrimental to concrete and even a sulphide content of 100 ppm needs testing. Zinc chloride retards the set of concrete and the 3-day strength test cannot be performed. The presence of calcium chloride accelerates setting and hardening of cement. Carbonates of sodium and potassium cause a rapid setting and may reduce the concrete strength. Bicarbonates may accelerate or retard the setting of cement.

Acids and Alkalis Water containing acids or alkalis (industrial waste water) is supposed to be unsuitable for making concrete. Water with pH value between 6-8 should only be used. The limit of acidity is guided by the requirement that the amount of 0.1N NaOH required to neutralise 100 ml sample of water using phenophthalein as indicator should not be more than 1 ml. This acidity is equivalent to 49 ppm of H_2SO_4 or 36 ppm of HCl. The limit of alkalinity is guided by the requirement that the amount of 0.1 N HCl required to neutralize 100 ml of sample should be less than 5 ml. This alkalinity is equivalent to 265 and 420 ppm of carbonates and bicarbonates respectively.

Sugar Sugar up to 0.05 per cent by weight of water is harmless. Sugar up to 0.15 per cent by weight of cement retard the setting time, reduce the early strength and increase the 28 day strength. When used up to 0.2 per cent by weight of cement rapid setting with reduced 28 day strength is resulted.

Oil Contamination Various kinds of oil are occasionally present in the mixing water. Mineral oil (petroleum), not mixed with animal or vegetable oils, probably has less effect on development of strength than other oils. However, mineral oil in concentrations greater than 2 per cent by weight of cement may reduce the concrete strength by more than 20 per cent. The vegetable oils have detrimental effect on concrete strength particularly at later ages.

Algae Algae, present in mixing water or on the surface of aggregate either reduces bond by combining with the cement or reduces strength by entraining a large amount of air in the concrete.

7.3 EFFECT OF MIXING WATER FROM DIFFERENT SOURCES

Ground Water

Natural ground waters seldom contain more than 20 to 30 ppm of iron. However, acid mine waters may carry rather large quantities of iron. Iron salts in concentrations up to 40,00 ppm do not usually affect mortar strengths adversely.

Sea Water

Sea water may be used if suitable fresh water is not available. The sea water generally contains 3.5 per cent of salts with about 75 per cent of sodium chloride, about 15 per cent of chloride and sulphate of magnesium. It has been found to reduce the strength of concrete by 10-20 per cent and slightly accelerate the setting time. Sea water may lead to corrosion of the reinforcement. It has been found that the factors affecting corrosion are permeability of concrete and lack of proper cover. If these are ensured and adequate amount of entrained air is there, the problem of corrosion may be circumvented, or otherwise the reinforcement is likely to be corroded whether it is pure water or sea water but with a difference in the rate of

corrosion. Therefore, sea water may be recommended for concrete without reinforcement. The chlorides in sea water may cause efflorescence restricting it to be used in making mortars for plastering. The use of sea water is not recommended for prestressed concrete because of stress corrosion and the small diameter wires (if corroded may cause disaster).

Industrial Waste Water

Most waters carrying industrial waste have less than 3,000 ppm of total solids. When such water is used as mixing water in concrete, the reduction in compressive strength is generally less than about 10 per cent. Waste waters from paint factories, coke plants, chemical and galvanizing plants may contain harmful impurities. It is advisable to test any waste water that contains even few hundred parts per million of unusual solids before using it for mixing concrete.

One way of using sewage containing large organic matters (say 400 ppm) is to dilute it in a good disposal system to reduce the concentration to about 20 ppm or less, an amount too low to have any significant effect on concrete strength.

7.4 WATER FOR WASHING AGGREGATES

When aggregates are washed with water containing impurities, they get coated with layers of silt, salts and organic matters. These reduce the bond between the aggregates and cement and markedly affect the strength.

7.5 CURING WATER

Water fit for making concrete can be used for curing. Waters containing impurities and leading to stains is objectionable. When concrete is subjected to prolonged wetting, even a very low concentration of iron and organic matter may cause staining. Water containing more than 0.08 ppm of iron is not recommended for curing.

EXERCISES

Q.1 What is the purpose of mixing water in concrete?

Q.2 Enumerate the various impurities in water having deleterious effects on concrete.

Q.3 How will you decide on satisfactory water for making concrete?

Q.4 If water of unknown performance is to be used, explain how to determine its acceptability.

Q.5 What are some of the effects of impurities, in the mixing water, may have on concrete?

Q.6 Sea water should be used in concrete, comment.

Q.7 After what process would sewage water be usable?

Q.8 What effect would the following impurities have if present in mixing water?
(a) Algae (b) Oils (c) Suspended solids

Q.9 Discuss the requirements of water for
(a) Making concrete
(b) Washing aggregates
(c) Curing concrete.

Chapter

8

MATERIALS FOR MAKING CONCRETE - IV LIME

8.1 INTRODUCTION

Until the invention of Portland cement, lime was used as the chief cementing material in the building construction both for mortar and plasters. Usually, lime in free state is not found in nature.

The raw material for the manufacture of lime (CaO) is calcium carbonate which is obtained by the calcination of lime stone. White chalk is a pure limestone whereas kankar is an impure limestone. The varieties of limestone commonly used in the construction industry are tufa, limestone boulders and kankars. Lime can also be obtained by the calcination of shell, coral, chalk and other calcareous substances. Coral and shells are sea animals.

Lime is obtained by burning limestone at a temperature of about 800°C.

$$\underset{\text{Limestone}}{CaCO_3} + 42.52\ \text{Kcal} \xrightarrow[\text{Calcination}]{\text{Heating}} \underset{\text{Quick lime}}{CaO} + CO_2$$

Varieties of Lime

Stone Lime is almost pure lime obtained by calcination of limestone and is used for making lime-sand mortar for superstructures; lime-surkhi mortar for substructures and; lime terracing and flooring. Stone lime has hydraulic properties.

Kankar Lime is an impure lime obtained by calcination of kankars. It is suitable for making lime-sand mortars for substructures.

Shell Lime is very pure lime obtained by calcination of shells of sea animals and corals. It is used for lime punning, white wash and colour wash, soil stabilization and glass production.

Definitions

Quick Lime (CaO) is the lime obtained after the calcination of limestone. It is also called *caustic lime*. It is capable of slaking with water and has no affinity for carbonic acid.

Fat Lime has high calcium oxide component and, sets and hardens by the absorption of CO_2 from atmosphere.

Hydraulic Lime contains small quantities of silica, alumina, iron oxide in chemical combination with calcium oxide component. It has the property to set and harden under water.

Hydrated Lime When quick lime is sprinkled with water, the fine powder obtained is called hydrated lime.

Lump Lime is the quick-lime coming out of the kilns.

Milk Lime is a thin pourable solution of slaked lime in water.

Characteristics of Lime

1. Lime possesses good plasticity and is easy to work with.
2. It stiffens easily and is resistant to moisture.
3. The excellent cementitious properties make it most suitable for masonry work.
4. The shrinkage on drying is small because of its high water retentivity.

Uses: In construction slaked lime is mainly used to make mortar for laying masonry and plastering. When so used quick lime should be completely hydrated by slaking from 3 to 14 days, depending upon the kind of lime, temperature, and slaking conditions. Hydrated lime, although immediately usable, is usually improved by soaking overnight or longer. Hydrated lime is often added to Portland

cement mortar in proportions varying from 5 to 15 per cent of the weight of the cement to increase plasticity and workability. Most of the historical buildings had been plastered in lime. Lime punning — about 3 mm thick shell lime layer to improve the plastered surfaces and to give a shining appearance — is used very commonly now a days in the new structures.

8.2 IMPURITIES IN LIMESTONES

Magnesium Carbonate Limestones contain magnesium carbonate in varying proportions. The magnesium limestones are hard, heavy and compact in texture. In burning limestone, the magnesium carbonate is converted to magnesium oxide at a much lower temperature whereas calcium carbonate is oxidised at a little higher temperature. By the time calcium carbonate is oxidised most of the magnesium oxide formed is over burnt. Magnesium limestones display irregular properties of calcination, slaking and hardening. Up to 5 per cent of magnesium oxide imparts excellent hydraulic properties to the lime.

Clay It is mainly responsible for the hydraulic properties of lime. The percentage of clay to produce hydraulicity in lime stones usually varies from 10 to 30. Limes containing 3-5 per cent of clay do not display any hydraulic property and do not set and harden under water. Whereas, when clay is present as 20-30 per cent of lime, the latter exhibits excellent hydraulic properties and is most suitable for aqueous foundations.

Silica In its free form (sand) has a detrimental effect on the properties of lime. Limes containing high percentage of free silica exhibit poor cementing and hydraulic properties. Limes containing 15-20 per cent of free silica are known as poor limes.

Iron Compounds Iron occurs in small proportions as oxides, carbonates and sulphides. They are converted into Fe_2O_3 at lower temperatures of calcination. At higher temperatures iron combines with lime and silicates and forms complex silicate compounds. Pyrite or iron sulphide is regarded to be highly undesirable. For hydraulic limes 2-5 per cent of iron oxide is necessary.

Carbonaceous Matters Carbonaceous matters in lime are seldom present. Its presence is an indication of the poor quality of lime.

Sulphates Sulphates, if present, slow down the slaking action and increase the setting rate of limes.

Alkalis When pure lime is required the alkalis are undesirable. However, up to 5 per cent of alkalis in hydraulic limes do not have any ill effect.

8.3 CLASSIFICATION

Lime can be classified as lean, hydraulic and pure lime.

Lean or Poor Lime It consists of clayey impurities of about more than 7 per cent in the form of silica, alumina and iron oxide. It sets on absorbing CO_2 from atmosphere.

Characteristics

1. Slaking requires more time and its expansion is less than that of fat lime.
2. It makes thin paste with water.
3. Setting and hardening is very slow.
4. The colour varies from yellow to grey.

Uses It gives poor and inferior mortar and is recommended for less important structure.

Hydraulic Lime It is a product obtained by moderate burning (900°-1100°C) of raw lime stone which contains small proportions of clay (silica and alumina) 5-30 per cent and iron oxide in chemical combination with the calcium oxide content. Depending on the percentage of clay present these are classified further as, feebly, moderately and eminently hydraulic limes. It sets under water.

Feebly Hydraulic Lime has less than 5-10 per cent of silica and alumina and slakes slowly, after few minutes (5 to 15).The setting time is twenty one days. It is used in damp places and for less important structures.

Moderately Hydraulic Lime has 10-20 per cent of impurities, slakes sluggishly after 1-2 hours. The setting time is seven days. It is used in damp places.

Eminently Hydraulic Lime has clayey impurities 20-30 per cent and slakes with difficulty. Its initial setting time is 2 hours and final setting time is 48 hours. It is used in damp places and for all structural purposes.

Pure, Rich or Fat Lime It is soft lime obtained by the calcination of nearly pure limestone, marble, white chalk, oolitic limestone and calcareous tufa. Also known as white washing lime should not have impurities of clay and stones, more than 5 per cent. It sets on absorbing CO_2 from atmosphere.

Characteristics

1. Slaking is vigorous and the volume becomes 2-3 times.
2. It sets slowly in contact with air, and hence is not suitable for thick walls or in wet climate.
3. If kept under water a fat lime paste does not lose its high plasticity and consequently does not set and hard.

Uses Fat lime finds extensive use in making mortar, matrix for concrete, base for distemper and in white wash, manufacturing of cement, and metallurgical industry.

Classification Based on Purpose

Class A – Eminently Hydraulic Lime is used for making mortar and concrete for construction and foundation works.

Characteristics

(i) The colour is grey.

(ii) Calcium oxide and clay are 60-70 and 25 per cent respectively.

(iii) Slakes with difficulty.

(iv) Sets and hardens readily under water with initial setting time 2 hours and final setting time 48 hours.

Class B – Semi Hydraulic Lime is used for masonry mortars, flooring and for concrete in ordinary constructions.

Characteristics

(i) The colour is grey.

(ii) Contains 70 per cent calcium oxide and 15 per cent clay.

(iii) Slakes and sets at slow rate taking about a week to set under water.

Class C – Fat Lime is used for finishing coats in plastering, white washing and with puzzolana in mortars.

Characteristics

(i) The colour is white.

(ii) Slakes vigorously and increases to three times its original volume.

(iii) Contains about 93 per cent calcium oxide and about 5-7 per cent clay.

Class D – Magnesium Lime is used for finishing coat in plastering and white washing.

Characteristics

(i) The colour is white.

(ii) Contains about 85 per cent calcium and magnesium oxides.

(iii) Slakes promptly.

(iv) Sets slowly.

Class E – Kankar Lime is used for making masonry mortars, plastering and white washing.

Characteristics

(i) The colour is grey

(ii) Contains 20 per cent calcium oxide, 5 per cent magnesium oxide and remaining impurities.

(iii) Slakes and sets slowly.

8.4 MANUFACTURE

Fat lime is obtained by burning limestone and hydraulic lime is obtained by burning kankar.

Limestone is usually burned in some form of vertical kiln which may be a tunnel or flare shaped working on continuous (Fig. 8.1) or intermittent (Fig. 8.2) systems. The kilns may also be classified as mixed-feed and separate-feed on the basis of the arrangement of fuel and limestone. In the mixed-feed type, bituminous coal and limestone are fed into the top of the kiln and in alternate layers. In the separate-feed type, the limestone is not brought into contact with the fuel during the burning process: the fuel is burned in a grate which is attached to the sides of the kiln and is so arranged that the heat produced will ascend into the stack. The mixed-feed kiln uses less fuel, but does not produce as high grade product as the separate-feed kiln. Modern furnance fired lime kilns yield about 25-35 cu m of good hydraulic lime per day.

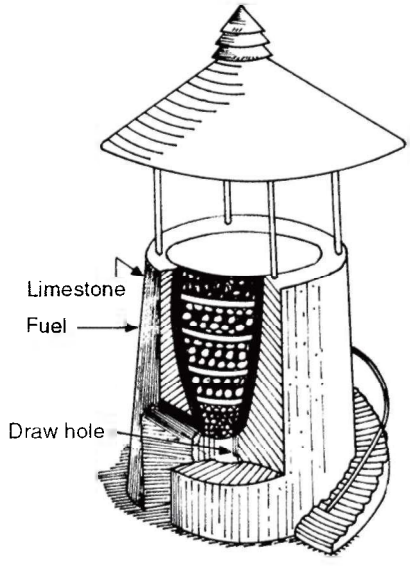


Fig. 8.1 Continuous Kiln

Essentially, the process of making lime consists in heating calcite ($CaCO_3$) or magnesia limestone ($xCaCO_3 + yMgCO_3$), containing 6 to 20 per cent of argillaceous impurities, to a temperature sufficiently high to drive off the carbon dioxide. As burning, seriously injures the setting properties, high-magnesia limes should not be subjected to temperatures above 1000°C and high-calcium limes should be burned at temperatures lower than 1300°C. A part of CaO resulting from the decomposition of calcium carbonate combines in solid state with oxides SiO_2, Al_2O_3 and Fe_2O_3 contained in the clay minerals, to form silicates ($nCaO\ SiO_2$), aluminates ($nCaO\ Al_2O_3$) and calcium ferrites ($nCaO\ Fe_2O_3$) that are capable of hardening not only in the air, but

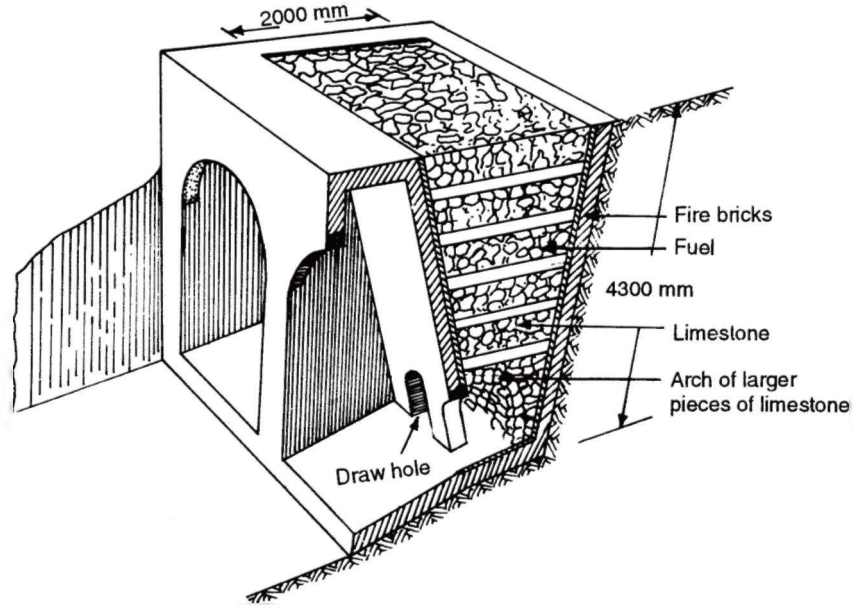


Fig. 8.2 Intermittent Kiln

in water as well.

Lump lime has porous structure on burning. Limestone releases carbon dioxide which constitutes up to 49 per cent of its weight, but the volume of the product decreases only by 10 per cent which means that lump lime has a porous structure. A flow diagram for the manufacture of lime is shown in (Fig. 8.3).

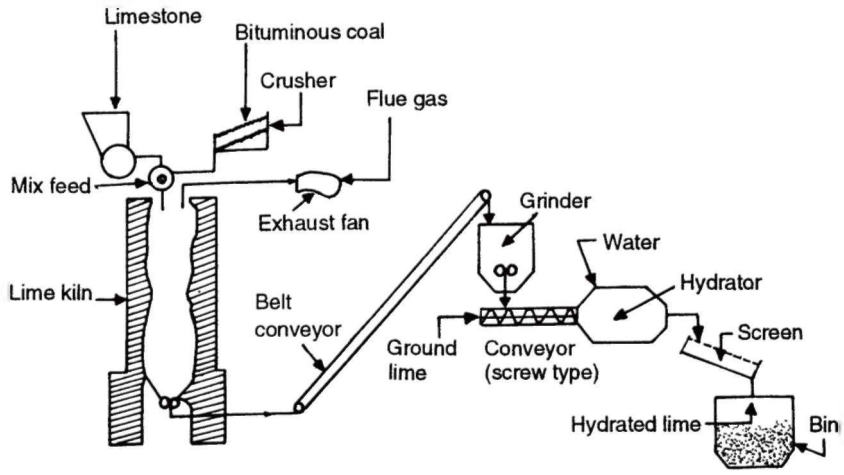


Fig. 8.3 Flow Diagram for Lime Manufacturing

8.5 SLAKING

Quick lime, obtained by burning limestone, when sprinkled with water slakes within 10 minutes and becomes powder. It is then used for various engineering purposes such as white washing, plastering, making mortars and lime putty. The process is also known as hydration of lime.

$$\underset{\text{Quick Lime}}{CaO} + H_2O \xrightarrow{\text{Hydration}} \underset{\text{Slaked Lime}}{Ca(OH)_2} + 15.6 \text{ k cal}$$

In the above reaction high heat of hydration is generated at a temperature of about 350°C. The energy liberated during this reaction causes the lumps of quick lime to split and fall to powder. In hydration of lime the heat of hydration generated is not sufficient to break the lime to powder and therefore, the lime is broken mechanically to a suitable size and sometimes pulverised before hydration.

Theoretically, the requirement of water for slaking of lime is 32 per cent of the weight of CaO. The amount of water used is 2 or even 3 times greater, depending upon composition, degree of burning and slaking methods, because a part of the water used is vapourised by the released heat.

Fat lime slakes in 2-3 hours, whereas hydraulic lime slakes in 12-48 hours. Great care should be exercised to slake the lime completely. The burned lime should be slaked soon after it is drawn from the kiln. The burned lime may also be slaked in the form of paste in slaking tanks (Fig. 8.4) and is termed as putty. Lime, if not slaked immediately, reacts with the carbonic acid from atmosphere in presence of the moisture and becomes air slaked, forming carbonates of lime. Consequently, the lime loses its properties and becomes unsuitable for sound construction. The slaked lime should not be kept in damp places.

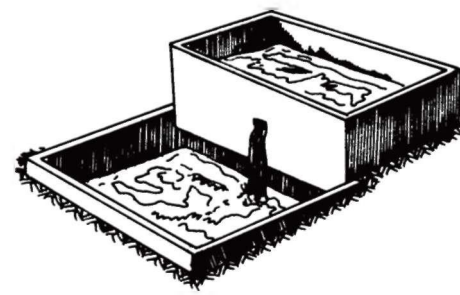


Fig. 8.4 Slaking of Lime to Paste

$$H_2CO_3 \longrightarrow H_2O + CO_2$$

Carbonic acid

$$\underset{\text{Slaked lime}}{Ca(OH)_2} + CO_2 \longrightarrow \underset{\text{Carbonate of lime}}{CaCO_3} + H_2O$$

The hydration of lime is accompanied by an increase in volume which is about 2.5-3 times except for hydraulic lime where it is only 50 per cent.

The process of slaking until recent years was done at the site. But since each type of lime needs different treatment, great skill and knowledge of the type of lime being used is required. Moreover, site slaking requires a fair amount of space, which is not always readily available. Partly for this reason site slaking is being rapidly superseded by factory slaking or hydrating.

8.6 HARDENING

Depending on the kind of lime and its hardening conditions, distinction is made of three patterns of hardening carbonate, hydrate and hydro-silicate.

Carbonate Hardening

Two simultaneous processes take place in lime mortars or concrete from slaked lime.

1. The mixed water evaporates and calcium oxide hydrate crystallises out of its saturated water solution.

2. Calcium carbonate is formed in accordance with the reaction

$$Ca(OH)_2 + CO_2 + nH_2O = CaCO_3 + (n + 1)H_2O$$

The crystallisation process of calcium oxide hydrate is very slow. Evaporation of water causes fine particles of $Ca(OH)_2$ to stick together and form large $Ca(OH)_2$ crystals which in turn grow together and form a carcass that encloses sand particles. The rate of $CaCO_3$ formation is significant only in the presence of moisture. A film of calcium carbonate appearing on the surface of the mortar during the initial period of hardening, prevents the penetration of carbon dioxide into the inside layers, and because of this the carbonisation process, which is very intensive in the presence of a sufficient amount of carbon dioxide stops almost entirely. The more intensive is the evaporation of water, the quicker is the crystallisation of calcium oxide. Therefore, hardening of lime requires an above zero temperature and a low humidity of the surrounding medium.

Pure lime paste cracks as a result of considerable shrinkage during drying; this can be prevented by adding 3.5 parts (by volume) of sand. The introduction of a prescribed amount of aggregate is advisable not only from the economic but also from the engineering stand point, as it improves hardening and reduces drying shrinkage.

The strength of mortar from slaked lime is low: after a month of hardening the compressive strength becomes 0.5-1 N/mm^2, rising to 5-7 N/mm^2 after several decades. This is due not only to greater carbonisation of mortar or concrete, but

also to a certain interaction of silicate and carbonate aggregates with calcium oxide hydrate.

High strength concretes and mortars (30 to 40 N/mm^2) can be obtained by artificial carbonisation. Concretes from ground unslaked lime with addition of up to 0.2 per cent (by weight) of lime which speeds up carbonisation and increases strength are particularly effective.

Hydrate Hardening

It is a gradual conversion of lime mortar and concrete mixes from ground unslaked lime into a rock-like hard body, resulting from the interaction of lime with water and the formation of calcium oxide hydrate. First, lime dissolves in water to give a saturated solution, which over-saturates rapidly because water is absorbed by the remaining unslaked grains. Rapid and strong over-saturation of a mortar, prepared from unslaked lime, results in formation of colloidal masses, which appear because calcium oxide hydrate formed by mixing lime with water consists of particles very close in size to those of the colloids. Colloidal calcium hydrate coagulates quickly into a hydrogel which glues the grains together. As water is partly sucked in by the deeper layers of grains and partly evaporates, the hydrogel thickens and thus increases the strength of the hardening lime. The hydrogel formed in the process of hardening of slaked lime holds much water and its adhesiveness is poor, which is not so for hardening unslaked lime. As slaking lime hardens, crystallisation of calcium oxide hydrate increases its strength. Subsequent carbonisation of calcium oxide hydrate improves the strength of the hardened mortar.

Thus, mixing of ground unslaked lime with water brings about a hydration hardening, which is characteristic of other binding materials as well; it consists of the hydration of calcium oxide and subsequent formation of colloids and crystallisation of the hydration product. Hardening at normal temperature is also affected by the evaporation of free water in the process of drying and natural carbonisation.

The conditions which favour hydration hardening are: rapid and uniform extraction of heat released in the process of hardening, the use of forms to prevent the increase in volume of the hardening mass and the introduction of admixtures to retard hydration. The coagulation structure which appears in the process of hydration hardening is retained and serves as a medium for the crystallisation of new hydrate formation. Should the coagulation structure disintegrate because of a rise of temperature or increase in volume, the new structure will have no time to appear because of a high hydration rate of the lime, and the recrystallisation ends inside non-intergrown particles of lime. Hydration hardening may be improved by uniform burning and grinding of lime.

Hydrosilicate Hardening

When lime-sand mixtures are treated by high-pressure steam (8-16 atm) cor-

responding to temperatures between 175 and 200°C, lime and silica interact in the autoclave and form calcium hydrosilicate which ensures high strength and durability of manufactured items.

In the autoclave method of hardening lime-sand materials, lime does not play the part of a binding material, whose hydration and carbonisation gives rise to a stony body of required strength at usual temperatures. In the given instance, lime is one of the two components that interact and form calcium hydrosilicate which is the chief cementing substance. The required strength results not from the physical cohesion of the binder hydrate formations with the grains of the aggregate, but from chemical interaction between the chief components of the raw materials, lime and quartz sand.

Hardening of autoclave steam-cured lime-silica materials is due to complex physical and chemical processes in three stages:

1. Formation of crystalline nuclei of hydrosilicates, growth of crystals and increase in their number, without any coalescence taking place.
2. Formation of a crystalline concretion.
3. Failure (weakening) of concretion due to recrystallisation contacts among crystals.

New formations, whose number and composition vary continually harden in the process of hydro-thermal curing of items.

8.7 LIME PUTTY AND COARSE STUFF

Lime Putty

It is obtained by adding hydrated lime to water, stirring to the consistency of a thick cream and, allowing it to stand and mature for a period of about 16 hours in the case of non-hydraulic lime before using. The putty so obtained should be protected from drying out.

Coarse Stuff

The hydrated lime is first thoroughly mixed and ground with the required quantity of sand. Then water is added and thorough mixing is done. The mix is kept to mature for about less than 16 hours in the case of hydraulic lime. Coarse stuff should be protected from drying out till it is used.

8.8 TESTING

Visual Inspection

A sample of lime is examined for its colour and lumps:

1. white colour indicates fat or pure lime.
2. lumps of lime indicate quick lime or unburnt lime.

Chemical Analysis

The analysis determines the cementation and hydraulic properties of lime.

$$\text{Cementation value of Lime} = \frac{2.8\,A + 1.1\,B + 0.7\,C}{D + 1.4\,E}$$

where A = Silica oxide content (SiO_2)

B = Aluminium oxide content (Al_2O_3)

C = Ferric oxide content (Fe_2O_3)

D = Calcium oxide content (CaO)

E = Magnesium oxide content (MgO)

Hydraulic Acid Test

The test is carried to know the classification and the carbonate content of lime.

A tea spoon full of lime is put in a test tube containing 10 ml of 50 per cent HCl. Too much of effervescence indicates high percentage of $CaCO_3$. The inert residue at the bottom of tube indicates percentage of inert materials. For eminently hydraulic lime, the gel formed is thick and does not flow. Absence of gel indicates non-hydraulic or fat lime. If gel flows it indicates feebly hydraulic lime.

Soundness Test

The test is done to find the quality, i.e. the unsoundness or disintegration property of lime using the Le-chatelier apparatus. To test hydrated lime, cement, hydrated lime and sand 1: 3 : 12 are mixed in the cylinder of the Le-chatelier apparatus and is covered with a glass sheet and left for an hour. The distance between the indicator pointers is measured. The apparatus is then kept in damp air for 48 hours and is thereafter subjected to steam for 3 hours. The sample is cooled to room temperature and the distance between the pointers is measured again. The difference in the two measurements should not be more than 10 mm.

To determine the soundness of fat lime, pats are prepared by mixing 70 g of hydrated lime, 10 g of Plaster of Paris and 70 ml of water. The pats are subjected to steam and then tested for disintegration, popping and pipping. If any of these occurs the lime is considered to be unsound. The test is known as *Popping and pipping* test.

Workability Test

A handful of mortar is thrown on the surface on which it is to be used. The area covered by the mortar and its quantity is recorded. These data indicate the workability of the lime mortar. It is a very crude field test performed with the actual mortar.

Transverse Strength Test

25 × 25 × 100 mm specimens are cured for 28 days at 90 per cent humidity. They are immersed in water for 30 minutes. They are then taken out and placed on two parallel rollers 80 mm apart and load is applied uniformly starting from zero and increased at a rate of 150 N/minute through a third roller of same size at a point midway between the other two till the specimen breaks.

$$\text{Modulus of rupture of test specimen, } m = \frac{3\,W\,S}{2\,b\,d^2} = 0.0768\ W$$

where m = modulus of rupture of the specimen in N/mm^2

W = Breaking load in N

S = Spacing between the rollers in mm

b, d = The width and depth (each 25 mm) of the specimen in mm

Minimum value of m should be 1.05 N/mm^2 for class-A lime and 0.7 N/mm^2 for class-B lime.

8.9 STORAGE

Lime reacts to the moisture present in the atmosphere and that from the ground. Therefore, it should be stored with utmost care. Following are some of the precautions which should be exercised properly.

1. It should be stored in properly insulated (against moisture) close store rooms in compact heaps to avoid air slaking.

2. When delivered in the form of hydrated lime the material must be kept dry, should be stored under cover and off the ground. When delivered as quick lime for site slaking the material should be used as soon as possible after delivery, positively within a week.

3. Lime putty is stored without any deterioration for many weeks and actually improves by keeping. In case of semi-hydraulic lime, the putty must not be stored for more than 3 days of its preparation. Coarse stuff and putty obtained from hydrated eminently hydraulic lime should be used within 12 hours.

8.10 PRECAUTIONS IN HANDLING

The workers must be provided with goggles and respirators against high heat and dust generated during slaking. Skin protecting cream must be applied as protection against skin-burn.

8.11 LIME VS. CEMENT

A comparison of the binding materials, cement and lime is presented in Table 8.1.

Table 8.1 Comparison of Cement and Lime

Property	Lime	Cement
Colour	White or greyish white	Dark grey or greyish brown
Slaking	Slaking takes place on adding water	Slaking does not take place on adding water
Setting	It sets slowly by taking CO_2 from air or by reacting with water	It sets rapidly by reacting with water
Hardening	Slow	Rapid
Compressive strength	Less	High
Cost	Cheap	Costly
Use	Suitable for ordinary construction works	Suitable for all construction works

EXERCISES

Q.1 Explain the terms
(a) Poor lime (b) Fat lime
(c) Hydraulic lime (d) Quick lime
(e) Slaked lime (f) Punning

Q.2 (a) Describe the different varieties of lime.
(b) Why is it necessary to slake quick lime immediately after burning ?
(c) Why is hydraulic lime unsuitable for plastering ?

Q.3 Describe briefly how lime is manufactured. Distinguish between quick, fat and hydraulic lime.

Q.4 (a) How is hydraulic lime classified ?
(b) State the effects of impurities present in the lime.
(c) What is lime putty and how is it prepared ?

Q.5 (a) Describe the method of burning lime.
(b) How is the lime slaked ? What is the significance of slaking lime ?
(c) Explain briefly the setting of lime.

Q.6 Write short notes on
(a) Use of lime as a building material
(b) Slaking of lime
(c) Storage of lime
(d) Lime putty

Q.7 (a) State the chief impurities in limestones ? How do they affect the properties of lime ?
(b) Describe the various tests performed to assess the suitability of lime as cementing material.

Q.8 Describe the following briefly:
(a) Effect of heat on limestone
(b) Lime mortar
(c) Setting action of fat lime
(d) Transverse strength test of lime
(e) Field tests of lime

Q.9 Enumerate the classification of lime and discuss briefly the main characteristics of each of them.

Q.10 (a) Which lime will you recommend for white washing and plastering ? Give the reasons for the choice.
(b) Describe briefly the manufacture of lime.

Chapter

9

PUZZOLANAS

9.1 INTRODUCTION

The term puzzolana is derived from Puzzouli, a town in Italy on the Bay of Naples near Mount Vesuvious. The sand around this town when mixed with hydrated lime was found to possess hydraulic properties. It is a volcanic dust. Puzzolana is a siliceous material which whilst itself possessing no cementitious properties, either processed or unprocessed and in finely divided form, react in the presence of water with lime at normal temperatures to form compounds of low solubility having cementitious properties. Puzzolanas may be natural or artificial, fly ash being the best known in the latter category. These were used with lime to make concrete before the advent of cement. Currently its principal use is to replace a proportion in cement when making concrete. The advantages gained are economy, improvement in workability of concrete mix with reduction of bleeding and segregation. Other advantages are greater imperviousness, to freezing and thawing and to attack by sulphates and natural waters. In addition the disruptive effects of alkali-aggregate reaction and heat of hydration are reduced. It is generally held that the addition of natural puzzolanas reduce the leaching of soluble compounds from concrete and contributes to the impermeability of the concrete at the later ages.

The main justification for using puzzolanas is the possibility of reducing costs. If they are to reduce costs, they must be obtained locally and it is for this reason that they have not so far been much in use.

9.2 CLASSIFICATION

Puzzolanas are classified as natural and artificial.

Natural Puzzolanas All puzzolanas are rich in silica and alumina and contain only a small quantity of alkalis. Following are some of the naturally occurring puzzolanas:

1. Clays and shales which must be calcined to become active.
2. Diatomaceous earth and opaline cherts and shales which may or may not need calcination (most active).
3. Volcanic tuffs and pumicites. Fine grained ashes form better puzzolana. However, tuffs—solidified volcanic ash—may be ground to desired fineness for use.
4. Rhenish and Bavarian trass.

Artificial Puzzolanas Some of them are:

1. Fly ash
2. Surkhi
3. Rice husk ash
4. Ground blast-furnance slag

9.3 THE ACTIVITY OF PUZZOLANAS

When mixed with cement the silica of the puzzolana combines with the free lime released during the hydration. Silicas of amorphous form react with lime readily than those of crystalline form and this constitutes the difference between active puzzolanas and materials of similar chemical composition which exhibit little puzzolanic activity.

It is commonly thought that lime-silica reaction is the main or the only one that takes place, but recent information indicates that alumina and iron if present also take part in the chemical reaction.

The optimum amount of puzzolana, as replacement for cement, may normally range between 10-30% and may be as low as 4-6 % for natural puzzolanas. It may be somewhat higher for some fly ashes.

9.4 APPLICATIONS

Puzzolana finds its chief application where the reduction effected in the heat of hydration is of great importance and the slower gain in strength is not of much consequence, i.e. where mass concreting is to be done. The examples are dams, retaining walls, wharf walls, breakwaters, harbour works and massive foundations.

The improvement in workability causes a considerable advantage in the lean harsh mixes normally used in the construction of mass concreting. Lime-puzzolana mixtures are used for masonry mortars, plasters and for foundation concrete. Their types and physical requirements are given in Appendix I.

9.5 EFFECTS OF NATURAL PUZZOLANAS

On Heat of Hydration The heat of hydration of a puzzolana is same as that of low heat cement.

On Strength of Concrete When some puzzolanas are used the addition of an air entraining agent may enable a reduction in the amount of water than if the air entraining agent was added to concrete containing cement only. This may lead to an increase in strength and consequently less cement may be permitted for the same strength. At early ages the replacement of cement by a puzzolana usually results in a decrease in the compressive strength, but the difference becomes less and may disappear at ages of 3 months or more.

On Shrinkage and Moisture Movement It is similar to Portland cement.

9.6 FLY ASH

Fly ash or pulverized fuel ash (PFA) is the residue from the combustion of pulverized coal collected by mechanical or electrostatic separators from the flue gases or power plants. It constitutes about 75 per cent of the total ash produced. The properties and composition of fly ash vary widely, not only between different plants but from hour to hour in the same plant. Its composition depends on type of fuel burnt and on the variation of load on the boiler. Fly ash obtained from cyclone separators is comparatively coarse and contains a large proportion of unburnt fuel, whereas that obtained from electrostatic precipitators is relatively fine having a specific surface of about 3500 cm^2/gm or it may be as high as 5000 cm^2/g. Normally it is rather finer than Portland cement. Fly ash consists generally of spherical particles, some of which may be like glass and hollow and of irregularly shaped particles of unburnt fuel or carbon. It may vary in colour from light grey to dark grey or even brown. The principal constituents are normally:

Silicon dioxide + aluminium oxide + iron oxide	$S_1O_2 + Al_2O_3 + Fe_2O_3$	70%
Silicon dioxide	S_1O_2	35%
Aluminium oxide	Al_2O_3	15-30%
Carbon (in the form of unburnt fuel)		up to 30%
Alkalis	Na_2O	1.5%
Magnesium oxide (maximum)	MgO	5%
Sulphur trioxide (maximum)	SO_3	2.75%
Loss on ignition by mass (maximum)		12%

Carbon content is important consideration for use with cement; it should be as low as possible. The fineness of fly ash should be as high as possible. The silica contained in fly ash combines slowly over a very long period with the lime liberated during the hydration of the cement. For this reason silica should be present in finely divided state. Curing at a temperature of 38°C has been found to greatly accelerate its contribution to the strength of concrete. Curing at high pressure and temperature in autoclave is known to promote the reaction between the lime of cement and the silica in the fly ash. This reaction should tend to prevent the release of free lime to reduce efflorescence.

Specifications

Fly ash consists of spherical glassy particles ranging from 1 to 150 μm, most of which passes through a 45 μm sieve. Physical requirements are given in Table 9.1.

Table 9.1 Physical Requirements

S.No.	Characteristics	Requirements	
		Grade I	Grade II
1.	Fineness – Specific surface in m^2/kg, minimum	320	250
2.	Lime reactivity – Average compressive strength N/mm^2, minimum	4.0	3.0
3.	Compressive strength for Portland-puzzolana cement	not less than 80 per cent of the corresponding plain cement mortar cubes	
4.	Drying shrinkage, maximum	0.15	0.10
5.	Soundness – Expansion of specimen, per cent, maximum	0.80	0.80

Effects of Fly ash on Cement Concrete

On Amount of Mixing Water The use of fly ash in limited amounts as a replacement for cement or as an addition to cement requires a little more water for the same slump because of fineness of the fly ash. It is generally agreed that the use of fly ash, particularly as an admixture rather than as a replacement of cement, reduces segregation and bleeding. If the sand is coarse the addition of fly ash should have beneficial results; for fine sands, its addition may increase the water requirement for a given workability.

On Strength in Compression Since the puzzolanic action is very slow, an addition of fly ash up to 30 per cent may result in lower strength at 7 and 28 days, but may be about equal at 3 months and increase at ages greater than 3 months provided curing is continued.

On Modulus of Elasticity It is lower at early ages and higher at later ages.

On Curing Conditions It is similar to Portland cement concrete.

On Shrinkage of Concrete Coarser fly ashes and those having a high carbon

content are more liable to increase drying shrinkage than the finer fly ashes and those having a low carbon content.

On Permeability The permeability of concrete is reduced. 28 days pulverised fly-ash-concrete may be three times as permeable as ordinary concrete but that after 6 months it may be less than one quarter permeable.

On Resistance to Chemical Attack Fly ash slightly improves the resistance of concrete to sulphate attack.

On Heat of Hydration Fly ash reduces the heat of hydration in concrete. A substitution of 30 per cent fly ash may result in a reduction of 50-60% heat of hydration.

On Air Entrainment The presence of fly ash reduces the amount of air entraining agent.

Setting Time A 30 per cent substitution of fly ash may result in an increase of initial setting time up to 2 hours.

9.7 SURKHI

It is one of the artificial puzzolana obtained by burning clay soils at specified predetermined temperatures. In doing so the water molecules are driven off and a quasi-amorphous material, reactive with lime, is obtained. However, in practice, surkhi is manufactured by grinding the brick bats in the grinding mills until an impalpable powder is obtained. This puzzolana is called surkhi in India, semen merah in Indonesia and homra in Egypt.

The best surkhi is obtained by burning clay in field or in a kiln and is classed as grade I whereas that obtained by grinding brick bats is classed as grade II. Soils containing little amount of clay are placed alternately with fuel layers in pit and are fired. The residue obtained from firing is friable and needs no pulverization. In the kiln method of production 50-100 mm clay lumps along with coal fuel are placed in shaft kiln (Fig. 9.1). Coal is fired and the clay is calcined at 700°C. The temperature is regulated by the air blower and feed input.

The clay or clay products used in the manufacture of surkhi must not contain a high percentage of silica. A good surkhi should be clean, cherry red in colour, and free from any foreign matter. It should conform generally to the following chemical requirements on an oven dry basis (at 105°C).

Silica	Not less than 40 per cent
Silica + Alumina + Iron oxide	Not less than 70 per cent
Calcium oxide	Not more than 10 per cent
Magnesium oxide	Not more than 3 per cent
Sulphuric anhydride	Not more than 3 per cent

Soda and potash	Not more than 3 per cent
Water-soluble alkali	Not more than 0.1 per cent
Water-soluble material	Not more than 1 per cent
Loss on ignition	Not more than 10 per cent

The physical requirements are same as that given in Table 9.1 except that for soundness.

Surkhi is extensively used in making mortar and concrete as an adulterant for economy. But its chief function is to impart strength and hydraulic properties to mortar. When mixed with cement to react with lime liberated during the setting and hardening of cement it makes dense, compact and impermeable concrete.

9.8 GROUND BLAST FURNANCE SLAG

Iron ore is smelt in blast furnance. By melting the iron ore at 1400-1600°C pig iron is produced and the floating impurities, containing mainly lime, silica and alumina form the blast furnance slag. By slow cooling of the slag crystalline material is produced, which is used as aggregate. Glassy pallets (> 4 mm) produced on rapid cooling form excellent light weight aggregate and granules (> 4 mm) on grinding possess hydraulic properties.

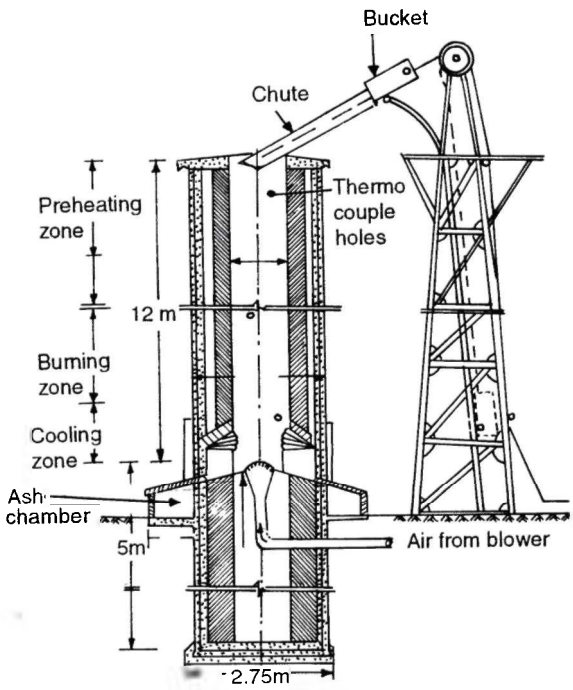


Fig. 9.1 Vertical Shaft Kiln

The ground blast furnance slag exhibits hydraulic action in the presence of calcium hydroxide liberated by Portland cement when hydrated. The ground slag is blended with Portland cement to produce Portland Blast Furnance cement, the proportion of the former not exceeding 65 per cent. The early strength of the cement so produced might be less but the ultimate strength is comparable. Because of low heat of hydration the ground blast furnance slag cement finds its application in mass concreting. The other advantages of addition of blast furnance slag to cement are improved workability, resistance to chemical attack and the protection provided to reinforcement making it suitable for reinforced concrete and prestressed concrete.

9.9 RICE HUSK ASH

The combustion of agricultural residues volatises the organic matters and a silica-rich ash is produced. Of all the agricultural wastes, rice husk yields the largest quantity of ash with about 93 per cent silica which gives its puzzolanic properties.

Burned in the ordinary way rice husks produce a crystalline silica ash but if burned under suitable conditions they give a highly reactive black non-crystalline silica residue having puzzolanic properties. Temperature and duration of combustion are of utmost importance for good quality rice husk ash. The right temperature is 700°C for 2-3 hours.

Rice husk ash when mixed with lime, gives a black cement. It can also be mixed with Portland cement and 28 day strength up to 55 MPa can be obtained. Rice husk ash cements containing not more than 20 per cent of lime are acid-resisting. To improve its reactive properties the rice husk ash should be ground in ball mills for about one hour. It can replace cement in mortars by 30 per cent.

The rice husk mixed with 20-50% hydrated lime is ground in a ball mill to produce ASHMOH, a hydrated binder suitable for masonry, foundation and general concerting. When rice husk is mixed with cement instead of lime, the hydraulic binder is termed as ASHMENT.

Rice husk ash can also be used with lime sludge obtained from sugar refineries. The dried lime sludge is mixed with an equal amount of crushed rice husk and then mixed with water and tennis ball size cakes are prepared and sun-dried. These are fired to produce powder which can be used as a hydraulic binder.

Rice husk ash when mixed with soil (20 per cent), instead of lime sludge, produces excellent binding properties. This binder when used as 30 per cent in mixture with Portland cement gives the properties of Portland puzzolana cement.

EXERCISES

Q.1 What is puzzolana ? How is it classified ?

Q.2 Name different artificial puzzolanas. What are the properties of puzzolana ? State the uses for which different puzzolanas can be considered.

Q.3 Write short notes on

(a) Fly ash (b) Surkhi

(c) Blast furnance slag (d) Rice husk ash

Q.4 Discuss briefly the various effects of adding puzzolana to cement concrete.

Q.5 What are the conditions mainly accentuating the puzzolanas to become active ?

Chapter

10

CONCRETE

10.1 INTRODUCTION

Concrete a composite man-made material, is the most widely used building material in the construction industry. It consists of a rationally chosen mixture of binding material such as lime or cement, well graded fine and coarse aggregates, water and admixtures (to produce concrete with special properties). In a concrete mix, cement and water form a paste or *matrix* which fills the voids of the fine aggregate and binds them (fine and coarse) together. The matrix is usually 22-34% of the total volume. Freshly mixed concrete before set is known as *wet* or *green* concrete whereas after setting and hardening it is known as *set* or *hardened* concrete. The moulded concrete mix after sufficient curing becomes hard like stone due to chemical action between the water and binding material. It would be impossible to discuss all the aspects of this material in few pages and the discussion is confined to the general characteristics and quality tests necessary for its use by

civil engineers and architects.

Most of the ancient structures and historical buildings had been constructed with lime concrete. With the advent of cement, the use of lime concrete has been confined to making bases for concrete foundations and roof terracing. The major factors responsible for wide usage of cement-concrete are mouldability, early hardening, high early compressive strength, development of desired properties with admixtures to be used in adverse situations, suitability for guniting, pumpability and durability. Most of the chapter is devoted to cement concrete because of its versatility. The simple reason for its extensive use in the construction of almost all civil engineering works is that the properties can be controlled within a wide range by using appropriate ingredients and by special mechanical, physical and chemical processing techniques. Buildings — from single storey to multistorey, bridges, piers, dams, weirs, retaining walls, liquid retaining structures, reservoirs chimneys, bins, silos, runways, pavements, shells, arches, railway sleepers are but a few examples of cement concrete applications.

10.2 CLASSIFICATION

Based on Cementing Material Concretes are classified as lime concrete, gypsum concrete and cement concrete.

Based on Perspective Specifications The cement concrete is specified by proportions (by weight) of different ingredients, e.g. 1(cement) : 1½ (fine aggregate) : 3 (coarse aggregate). It is presumed that by adhering to such perspective specifications satisfactory performance may be achieved. The usual mix proportions of cement concrete are given in Table 10.1. Here, M refers to the mix.

Table 10.1 Mix Proportions of Cement Concrete

Grade of concrete	M10	M15	M20	M25
Mix proportion	1:3:6	1:2:4	1:1½ :3	1:1:2
Perspective characteristic Strength	10	15	20	25

Based on Performance Oriented Specifications When the concrete properties such as strength, water/cement ratio, compaction factor, slump, etc. are specified the concrete may be classified as nominal-mix or designed-mix concrete.

Based on Grade of Cement Concrete Depending upon the strength (N/mm^2) of concrete cubes (150 mm side) at 28 days, concrete is classified as given in Table 10.2.

Table 10.2 Grades of Cement Concrete

Grade	M5	M7.5	M10	M20	M25	M30	M35	M40	M45	M50	M55
characteristic strength	5	7.5	10	15	20	25	30	40	45	50	55

Based on Bulk Density On the basis of density, concrete is classified as super heavy (over 25 kN/m^3), dense (18-25 kN/m^3), light weight (5-18 kN/m^3) and extra light weight concrete (below 5 kN/m^3).

Based on Place of Casting When concrete is made and placed in position at the site it is known as *in-situ* concrete and when used as a material for making prefabricated units in a factory is known as *precast* concrete.

10.3 PREPARATION

The preparation of concrete consists in selecting the materials, batching the ingredients and mixing.

Selection of Materials To achieve the desired qualities, the materials for making concrete — cement, fine and coarse aggregates, and water are selected cautiously on the basis of the quality acceptance tests.

Batching of Ingredients Two methods of batching are prevalent — by weight and by volume. The volume batching is commonly used. A convenient method is to make a wooden gauge box (Fig. 10.1) of one cement bag capacity (34.5 litres) and then measure the ingredients with it in the required proportions. In measuring sand due allowance should be made to allow for bulking.

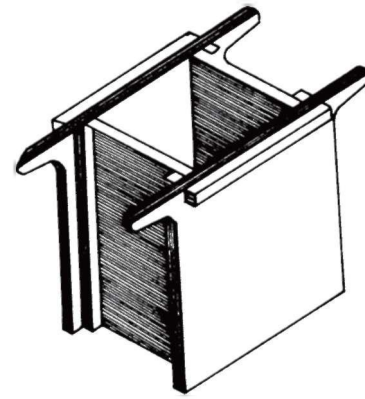


Fig. 10.1 Wooden Box for Gauging Aggregates

Mixing of Concrete Mixing of concrete can be done manually or by mixers, especially for large works. In hand mixing about 10 per cent additional cement is consumed as also more labour and time. For manual mixing a sufficiently large brick platform is made. One bag of cement and required quantity of sand is spread over it and mixed thoroughly till a uniform mix is obtained. The required coarse aggregates are then spread over the platform and over this the cement sand mix is spread. This mixture is then turned over with shovel so as to achieve uniformity. Water is added slowly while the turning on is continued. This process is continued till a uniform mixture is obtained.

When the mixing is to be done by a mechanical mixer (Fig. 10.2), the tilting drum while rotating is charged first with coarse aggregate followed by fine aggregate and cement while the drum is rotating. The measured quantity of water is added on completion of dry mixing. After thorough mixing the drum is stopped, tilted and concrete taken out.

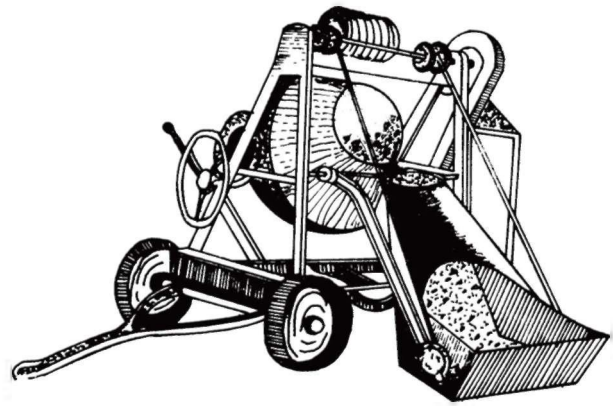
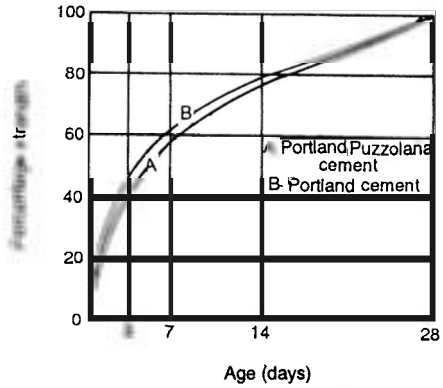


Fig. 10.2 Batch Type Concrete Mixer

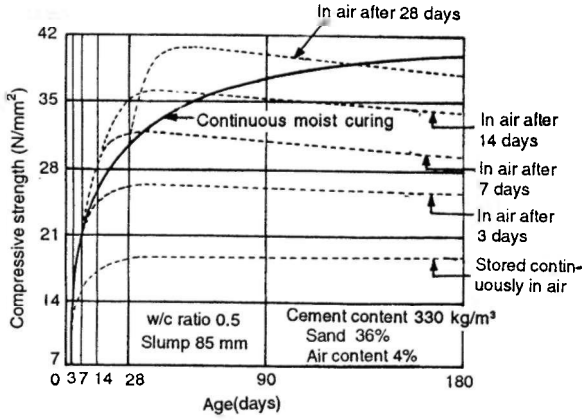
10.4 CURING

Cement gains strength and hardness because of the chemical reaction between cement and water. This chemical reaction requires moisture, favourable temperatures and time referred to as the curing period. The variation of compressive strength with curing period is shown in Fig. 10.3 (a, b). Curing freshly placed concrete is very important for optimum strength and durability. The major part of the strength in the initial period is contributed by the clinker compound C_3S and partly by C_2S, and is completed in about three weeks. The later strength contributed by C_2S is gradual and takes long time. As such sufficient water should be made available to concrete so that it gains full strength. The process of keeping concrete damp for this purpose is known as curing. The object is to prevent the loss of moisture from concrete due to evaporation or any other reason, supply additional moisture or heat and moisture to accelerate the gain of strength. Curing must be done for at least three weeks and in no case for less than ten days.

Approximately 14 litres of water is required to hydrate each bag of cement. Soon after the concrete is placed, the increase in strength is very rapid (3 to 7 days) and continues slowly thereafter for an indefinite period. Concrete moist cured for 7 days is about 50 per cent stronger than that which is exposed to dry air for the



(a) Development of Strength with Curing



(b) Dried in Air after Preliminary Moist Curing

Fig. 10.3 Development of Strength wiith Curing

entire period. If the concrete is kept damp for one month, the strength is about double that of concrete exposed only to dry air.

Methods of Curing

Concrete may be kept moist by a number of ways. They can be classified as (1) supplying additional moisture to concrete, and (2) preventing loss of moisture from concrete by sealing the surface. Following is a discussion of the methods used.

Water Curing is done by covering the concrete surface with gunny bags, sprinkling water over them regularly, or with water proof paper. In membrane curing the surface is coated with a bitumen layer to prevent loss of moisture by evaporation. Other sealing compounds used are rubber latex emulsion, resins, varnish and

wax. The concrete here may not achieve full hydration as in moist curing.

The horizontal surfaces are kept wet by storing water over them (ponding) or by damp gunny bags, straw, etc. Ponding, may, affect the strength if the concrete is flooded too soon. When sprinkling of water is performed at intervals, care must be taken that the concrete does not dry out between applications to prevent the possibility of crazing — the fine cracks that may occur in the surface of new concrete as it hardens.

Steam Curing can be also accomplished by artificial heat while the concrete is maintained in moist condition. Steam curing is also known as *accelerated* curing since an increased rate of strength development can be achieved. The accelerated process of curing has many advantages in the manufacture of precast concrete products; (a) the moulds can be removed within a shorter time; (b) due to shorter period of curing, production is increased and cost reduced as also (c) storage space in the factory. The temperature can be raised by placing the concrete in steam, hot water, or by passing an electric current through the concrete. In the hydration process of cement at higher temperatures, the released calcium hydroxide reacts with finely divided silica, present in the coarse and fine aggregates and forms a strong and fairly insoluble compound which results in higher strengths. Since free calcium hydroxide content is reduced, the leaching and efflorescence are minimised. The hydrating dicalcium silicates and tricalcium alluminates react together at high temperatures to form sulphate-resisting compounds. Consequently autoclaved products show higher resistance to sulphate attack. The initial drying shrinkage and moisture movements are also considerably reduced. However, high-pressure steam-curing reduces the bond strength by about 50 per cent.

The concrete members are heated by steam at 93°C either at low pressure or high pressure. In low pressure steam curing about 70 per cent of the 28 day compressive strength of concrete can be obtained in about 16-24 hours. High pressure steam curing is usually applied to precast concrete members and gives 28 day compressive strength at 24 hours. The effect of curing temperature on compressive strength is shown in Fig. 10.4. It also results in increased resistance to sulphate action and to freezing and thawing. The mixes with low water-cement ratio respond more favourably to steam curing than those with higher water/cement ratio.

An early rise in temperature at the time of setting of concrete may be detrimental because the green concrete may be too weak to resist the air pressure set up in the pores by the increased temperature. The rates of increase or decrease of temperature should not exceed 10 to 20°C per hour to avoid thermal shocks. The higher the water/cement ratio of concrete, the more adverse is the effect of an early rise in temperature. Therefore, to meet the requirement of compressive strength of concrete, the temperature and/or time required for curing can be reduced by having a lower water/cement ratio. While in identical time cycle, the higher the maximum temperature,

greater is the compressive strength. The advantages of curing above 70°C are negated by dilational tendencies due to the expansion of concrete.

Steam curing should be followed by water curing for a period of at least 7 days. This supplementary wet curing is found to increase the later-age strength of steam-cured concrete by 20 to 35 per cent. In most cases, steam curing is employed only for achieving 50 to 70 per cent of specified strength in a short period instead of full treatment for 2 to 3 days required to obtain specified strength.

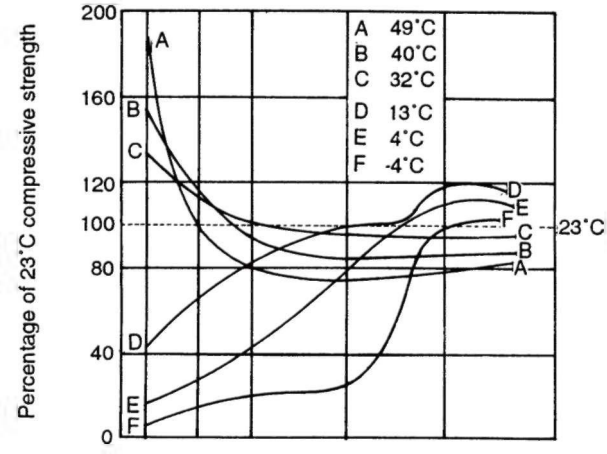


Fig. 10.4 Influence of Curing Temperature on the Strength of Concrete

Low pressure steam curing at atmospheric pressure can be continuous or intermittent. The maximum curing temperature is limited to 85 to 90°C. In the normal steam curing procedure, it is advisable to start the steam a few hours after casting. A delay of two to six hours, called the presteam or presetting period, depending upon the temperature of curing, is usual. The presetting period helps to achieve a 15 to 30 per cent higher 24 hour strength than that obtained when steam curing is resorted to immediately. The rate of initial temperature rise after presetting period is of the order of 10 to 20°C per hour.

In the case of normal steam-curing at atmospheric pressure, the ultimate strength of concrete may be adversely affected if the temperature is raised rapidly. This difficulty can be overcome by employing the steam at a pressure of 8 atmospheres. The process is termed high-pressure steam-curing. The increase in temperature allowed is up to 50°C in the first hour, up to 100°C in second hour and up to 185°C in the third hour. The period of treatment under full pressure depends upon the strength requirements. This period of treatment is 7 to 10 hours for hollow block products and 8 to 10 hours for slab or beam elements; the period may be increased with the thickness of concrete.

Curing by Infra Red Radiation A much more rapid gain of strength can be obtained with the help of infra red radiation than even with steam curing. The rapid initial rise of temperature does not affect the ultimate strength. It is particularly suitable for the manufacture of hollow concrete products in which case the heaters are placed in the hollow spaces of the product. The normal operative temperature is 90°C.

Electrical Curing Concrete products can be cured by passing alternating current of low voltage and high amperage through electrodes in the form of plates covering the entire area of two opposite faces of concrete. Potential difference between 30 and 60 V is generally adopted. Evaporation is prevented by using an impermeable rubber membrane on the top surface of the concrete. By electrical-curing, concrete can attain the normal 28-day strength in a period of 3 days. The technique is expensive.

Chemical Curing Chemical membranes can be sprayed on to cure concrete. Liquid membrane-forming curing compounds such as sodium silicate (water glass) solution retard or prevent evaporation of moisture from concrete. They form a film, fill the pores, seal the surface voids and prevent evaporation. The application should be made immediately after the concreting has been finished. If there is any delay, the concrete should be kept moist until the membrane is applied. Membrane curing compound should not be applied when there is free water on the surface, because this water will be absorbed by the concrete and the membranes broken. Nor should the compound be applied after the concrete has dried out since it will be absorbed into the surface of the concrete and a continuous membrane will not be formed. The correct time to apply the membrane is when the water sheet disappears from the surface of the finished concrete. Adequate and uniform coverage of curing compounds is essential. In most cases two applications are required. Chemical membranes are suitable not only for curing fresh concrete but also for further curing of concrete after removal of forms or after initial moist curing.

10.5 COMPACTION

Entrapped air and segregation during placement of concrete affect the strength of concrete adversely. The process of removal of entrapped air and of uniform placement of concrete to form a homogeneous dense mass is known as compaction. Compaction is necessary

1) for overcoming the friction experienced by ingredients of concrete amongst themselves and between concrete and reinforcement and between concrete and formwork and

2) for reducing the voids to a minimum.

Compaction may be achieved by imparting vibrations with a rod or mechanical

vibrator for cast-in-situ concrete and centrifugation or spinning, or by high pressure or shock for precast units. Practically the vibrations should be stopped as soon as the air bubbles cease to appear and sufficient mortar appears to close the surface interstices. In any case if extra vibration is imparted bleeding, laitance and segregation may be there and consequently the lower layers of concrete will be honeycombed and the surface will lack resistance to abrasion.

10.6 WATER/CEMENT RATIO

The water/cement ratio (w/c) is one of the major factors but not the only one influencing the strength of concrete. It is responsible mainly for the porosity of the hardened cement paste. Water/cement ratio is the water used to the quantum of cement in the mixture by weight. For proper workability the w/c ratio varies from 0.4-0.6. However, maximum strength is derived at w/c = 0.4. When it is decreased to less than 0.4 there is improper consistency and workability of cement and honeycombed structure. However, concrete compacted by vibrator displays higher strength even up to w/c = 0.3 as shown by dotted line in Fig. 10.5. Sometimes cement-water ratio versus strength is plotted (Fig 10.6). Being a straight line it is supposed to be a better mean to interpret the results. At w/c ratio more than 0.4, the expansion of cement on hydration is insufficient to occupy the space previously filled with water. Hence, porosity increases and strength decreases. In arriving at the w/c ratio values it is assumed that aggregates are saturated with the surfaces in dry condition. Suitable adjustments should be made for dry aggregates.

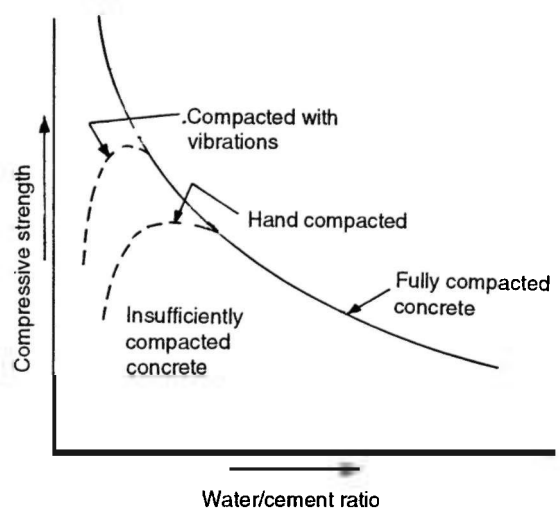


Fig. 10. 5 Relation between Strength and Water/Cement Ratio of Concrete

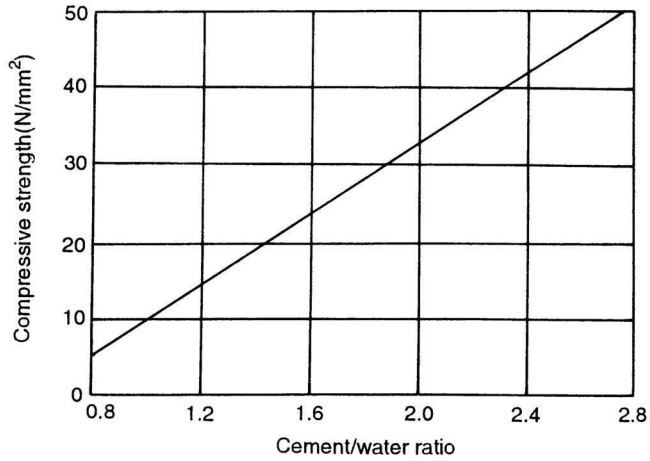


Fig. 10.6 Relation between Strength and Cement/Water Ratio of Concrete

In 1897 Feret proposed a rule defining strength of concrete paste in terms of volume fractions of the constituents as

$$S = K\left[\frac{c}{c+w+a}\right]^2$$

where c = volume of cement

w = volume of water

a = volume of air

K = a constant

In this expression the volume of air is also included, which means the voids in concrete are taken into account in estimating the strength.

Duff Abrahm's Law

Abrahm presented his classic law in 1918 as "For plastic mixtures using neat and clean aggregates the strength of concrete under specified conditions is governed by the net quantity of water mixed per bag of cement". He gave the following equation to estimate the strength of concrete.

$$S = \frac{A}{B^x}$$

where S = strength at 28 days, and constants, A = 98.4 N/mm^2 and B = 7

According to Abrahm's law it is evident that strength of concrete depends only upon w/c ratio provided the mix is workable. Recently some modifications have been suggested by various researchers. However, the truth of statement could not be challenged. The effect of w/c ratio on the composition of cement paste is shown in Fig. 10.7.

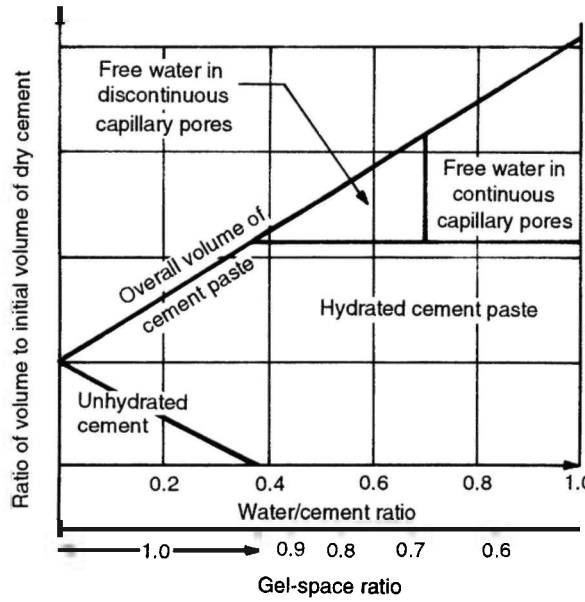


Fig. 10.7 Composition of Portland Cement Paste after Hydration has Ceased

10.7 GEL-SPACE RATIO

Since Abrahm's w/c ratio law has many limitations researchers do not agree to call it a law but they say it to be a rule. Strength at any w/c ratio is a function of following:

1. degree of hydration of cement, its physical and chemical properties.
2. temperature at which hydration takes place.
3. air content in case of air entrained concrete.
4. change in the w/c ratio.
5. formation of cracks due to bleeding and shrinkage.

Some workers feel that the strength can be related better and more correctly to the hydration products than to the space available for the formation of these products.

Gel-space ratio is defined as the ratio of volume of hydrated cement paste to the sum of the volumes of the hydrated cement and that of the capillary pores. Power and Brownyard established the relationship between the strength and gel-space ratio. A typical curve relating gel-space ratio to the compressive strength is shown in Fig. 10.8.

$$S = 240\ x^3$$

where S = strength of concrete

x = gel space ratio

240 = intrinsic strength of gel in N/mm^2 for the type of cement and specimen used

Note: Strength calculated on the basis of gel space ratio is independent of the age, whereas of that calculated on the basis of w/c ratio depends upon the age.

Calculation of Gel Space Ratio

For Complete Hydration

Let C = weight of cement in g, V_c = specific volume of cement ml/g, and W_0 = volume of mixing water in ml.

Assuming 1 ml of cement on hydration produces 2.06 ml of gel.

Volume of gel = $C \times 0.319 \times 2.06 = 0.657C$

Space available = $C \times 0.319 + W_0$

$$\text{Gel-space ratio} = \frac{\text{Volume of gel}}{\text{Space available}} = \frac{0.657\,C}{0.319\,C + W_0}$$

For Partial Hydration

Let α = fraction of cement that has hydrated.

Volume of gel = $C \times \alpha \times 0.319 \times 2.06 = 0.657\,C\alpha$

Space available = $C \times 0.319 \times \alpha + W_0$

$$\text{Gel space ratio} = \frac{0.657\,C\alpha}{0.319\,C\alpha + W_0}$$

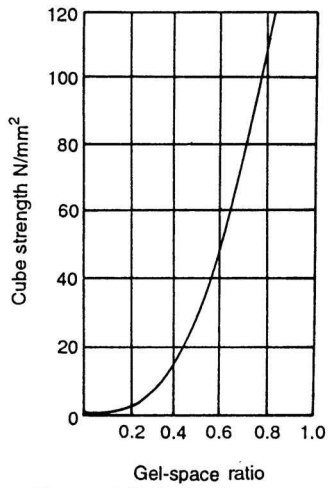


Fig. 10.8 Relation between Compressive Strength of the Mortar and Gel-Space Ratio

The limitation of this theory is that the theoretical strength of concrete is much more than the actual strength of concrete. In the above theory it has been assumed that the concrete is perfectly homogeneous and flawless. But the presence of flaws like cracks, voids, bleeding channels, rupture of bond due to drying shrinkage and temperature stresses reduce the strength. Griffith has done lot of work on this line and his theory is gaining popularity. His work is based on these flaws.

Example 10.1 Calculate the gel space ratio and theoretical strength of a sample of concrete made with 500 g of cement with w/c ratio as 0.55,

1. On full hydration 2. On 75% hydration

Solution

On Full Hydration

$$\text{Gel-space ratio} = \frac{0.657C}{0.319C + W_0} = \frac{0.657\times 500}{0.319\times 500 + 275} = 0.756$$

Theoretical strength of concrete = $240\ (0.756)^3 = 103.72\ \text{N/mm}^2$

On 75 % Hydration

$$\text{Gel-space ratio} = \frac{0.657\ C\ \alpha}{0.319\ C\ \alpha + W_0} = \frac{0.657\times 500\times 0.75}{0.319\times 500\times 0.75 + 275} = 0.6423$$

Theoretical strength of concrete = $240\ (0.6423)^3 = 58.4\ \text{N/mm}^2$

10.8 STRENGTH OF CONCRETE

The most useful property of concrete is its compressive strength. However, it is weak in tension. Till date no relation exists between compressive, tensile, bending, and shear strengths of concrete.

The indicated compressive strength increases as the specimen size is decreased whereas modulus of elasticity decreases. Concrete containing about 6 per cent of entrained air which is weaker in strength is found to be more durable than dense and strong concrete.

Factors Influencing Strength of Concrete

Factors affecting the strength of concrete can be broadly grouped into those depending upon the testing methods and the others independent of the testing methods.

Factors depending on testing methods are size of test specimen, size of specimen relative to maximum size of aggregate, moisture condition of specimen, rate of loading adopted, and type of testing machine used; and those independent of testing method are type of cement and age of cement, type and size of aggregates, degree of compaction, water/cement ratio, aggregate/cement ratio, air-voids, curing method and curing temperature, and type of stress situation that may exist (uniaxial, biaxial and triaxial).

Size of Test Specimen The concrete cubes of side 150 mm, cured for 28 days are tested in the most saturated condition in compression. For materials which rupture on planes inclined more than 45° with the horizontal, the cube is not suitable; since the strength is increased by frictional restraint acting at the surfaces under pressure. Frictional restraint from the platens opposes the lateral expansion of the specimen, and subjects its ends to inward compressive forces. These diminish with distance from the ends, but a cube is so short that their effect extends throughout its volume. A cube is therefore tested under nonuniform triaxial com-

pression. Prisms or cylinders with a height equal to twice the least lateral dimension are more suitable for such materials. End effects have less influence in these specimens, and it is generally agreed that the cylinder strength of concrete is a good estimate of the monoaxial compressive strength. A cube of concrete is expected to have a strength 15 per cent greater than a cylindrical specimen. If height to side ratio is changed the compressive strength of the prisms relative to cube strength changes and is given in Table 10.3. Beyond a height to side ratio of 4 it stabilises. The effect of height to lateral dimension ratio of specimen on compressive strength is shown in Fig. 10.9.

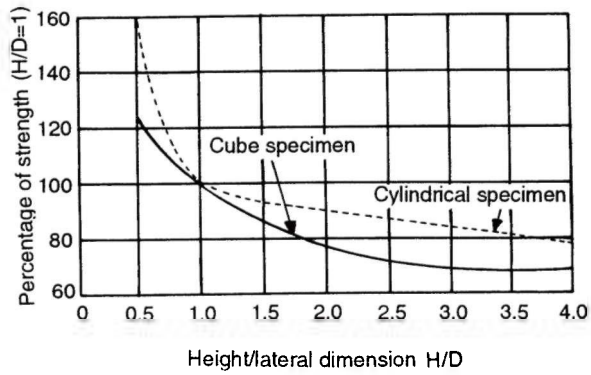


Fig. 10.9 Influence of Ratio of Height to Lateral Dimension on the Compressive Strength

Table 10.3 Relative Strength of Prisms with Different Height to Depth Ratio

Height/side ratio	0.5	1.0	2.0	3.0	4.0	5.5
Relative strength	1.5	1.0	0.8	0.72	0.68	0.6

If size of cube is decreased the compressive strength tends to increase and is given in Table 10.4.

Table 10.4 Relative Strength of Concrete from Cubes of Different Sizes

Cub size (mm)	100	150	200	300
Relative strength to 150 mm cubes	1.05	1.0	0.95	0.87

Size of Specimen Relative to Maximum Size of Aggregate The test specimen, as regards the size and shape, is different in different countries. Generally 150 mm cubes are specified irrespective of size of aggregates. However, for aggregate less than 25 mm in size 100 mm cube is allowed.

Moisture Condition of Specimen Strength of concrete depends upon moisture content at the time of testing. The dry cubes may have drying shrinkage and bond failure leading to smaller strength. The moisture content in concrete provides

lubrication effect and reduces strength. Due to dilation of the cement gel by the absorbed water the force of cohesion between the cement particles is decreased. Probably the decrease in strength on account of this reduction is more than that of the loss of strength due to rupture of gel bond and the dry cubes give higher strength.

Also, the specimen should be tested immediately after taking it out of curing tank. To give uniformity to results as compared to testing of samples which may have dried to different degrees.

Strength of dry sample = (1.1-1.2) × strength of saturated sample

Air Voids These are formed because of the evaporation of the water used in making concrete and by entrained air. If the water used is more than the optimum water required for maximum strength the concrete becomes permeable and susceptible to deterioration. The reduction in strength with an increase in percentage air voids is shown in Fig. 10.10.

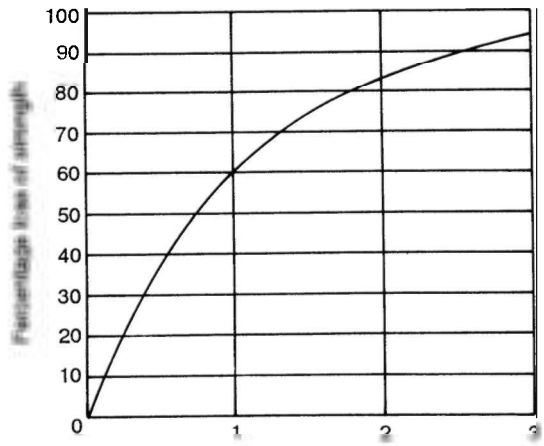


Fig. 10.10 Loss of Strength with the Percentage of Air-Voids

Rate of Loading Strength of concrete increases with that in rate of loading. The influence of rate of application of load on the compressive strength of concrete is shown in Fig. 10.11. Normally in a static loading test, rate is such that the test is completed in 2 to 3 minutes. Within this range, the effect is found to be negligible. At low rates of loading there is more time for creep to occur, so that the increase of strength with rate of loading provides evidence for the theory that failure occurs at limiting values of strain, rather than stress. The relation between observed strength and rate of loading is given by

$$S = S_1 (1 + k \log R)$$

where S = strength at a given

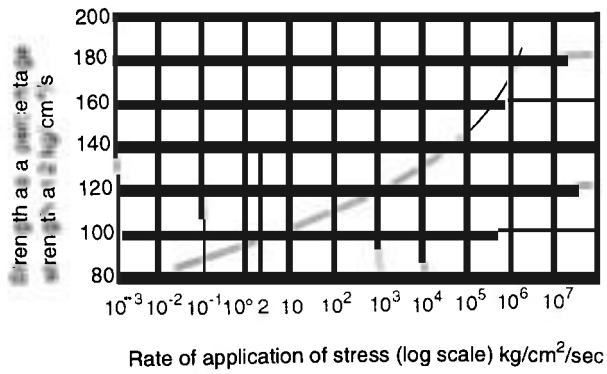


Fig. 10.11 Influence of Rate of Application of Load on Strength of Concrete

rate of loading

R = rate of loading in kg/cm^2/sec

S_1 = strength of concrete at a rate of 1 kg/cm^2/sec

k = a constant = 0.08 for 28 day test

The rate of loading of cube specimen is 140 kg/cm^2/min.

Type of Testing Machine Compressive strength tests of concrete are made in various machines either of the lever-arm type or adoptions of lever presses. Considerable discrepancies have been found to occur between the results of compressive strength test made with different types of machines. It may be up to even 20 per cent. It may be because of errors in centering the cubes, wear of the lower compression plate, friction in the spherical seating of the upper compression plate, and inaccurate calibration of the machine itself.

Type of Stress Situations that may Exist Concrete is tested for uniaxial compression with the line of action of load on a cube specimen at right angles to the axis of cube about which it is cast. However, in actual structure, the concrete at any point is in a complex stress condition and not in a uniaxial compression. Concrete under triaxial state offers more resistance and fails only after considerable deformations, which justifies uniaxial compression testing.

Type and Age of Cement The effect of type of cement on the rate of strength gain is shown in Fig. 10.12. With age the strength of cement reduces since it will

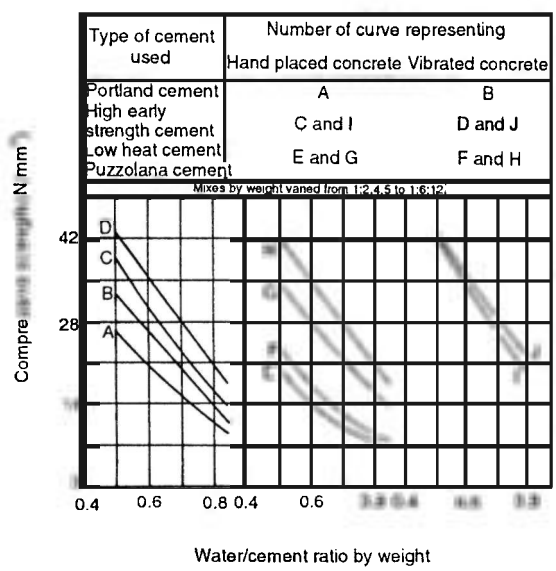


Fig. 10.12 Influence of Different Types of Cement on the Strength of Concrete

set by absorption of moisture from the atmosphere. The effect of storage of cement under different conditions with age is shown in Fig. 10.13.

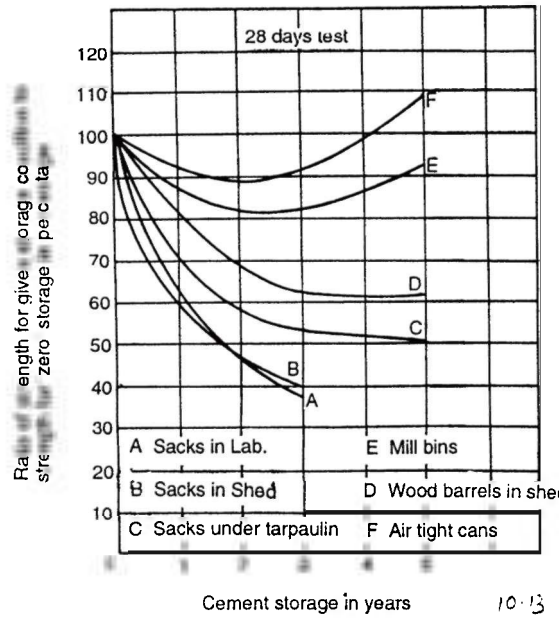


Fig. 10.13 Effect of Storage of Cement on Strength of Concrete

Gain in Strength with Age Concrete gains strength with age. Initially strength developed is more. However, the ratio of gain in strength diminishes with age. It is customary to assume the 28 days strength as full strength of concrete.

Age (Months)	Age factor for low strength concrete
7days	0.65-0.7
1	1.00
3	1.10
6	1.15
12	1.20

Strength at Early Ages 28 day strength is known as characteristic strength of concrete. Sometimes it is required to determine the concrete strength at 1 day or 7 day to accelerate the progress of work. Following relation may be used

$$f_{28} = k_2 (f_7)^{k_1}$$

where f_7, f_{28} are strengths at 7 and 28 days respectively

k_1 = 0.3-0.8 (for different cements)

k_2 = 3-4 (for different curing conditions)

Cement/Aggregate Ratio Provided other factors are kept constant, cement-aggregate will greatly influence concrete strength. With an increase in cement to aggregate ratio the ultimate strength will increase to some extent as shown in Fig. 10.14.

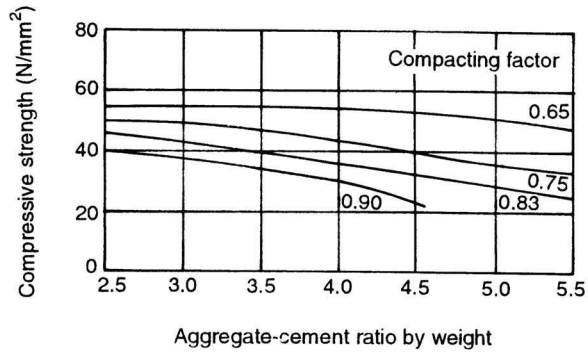


Fig. 10.14 Influence of Aggregate/Cement Ratio on the Strength of Concrete

Effect of Water/Cement Ratio The effect of w/c ratio on the strength of concrete has been discussed in Sec. 10.6 and is shown in Fig. 10.5, at different ages. The aim is generally to use the lowest water/cement ratio which will give a concrete sufficiently plastic to place in position. Approximate relation of strength of concrete with water/cement ratio is given by

$$S = k\left(\frac{c}{w+c+a}\right)^2$$

where S = strength of concrete

w = volume of water

c = volume of cement

a = volume of air

For concrete which is to be compacted by vibrator a lower water cement/ratio may be used.

Type and Size of Aggregate The extent to which an aggregate will pack down and produce a minimum void content is dependent on its particle shape. The crushed stone and gravels give higher strength. A reduction in the void content of the coarse aggregate by better packing, means that the amount of mortar can be reduced and hence sand and cement. Thus the coarse aggregate to sand ratio is increased and although the overall mix may be leaner the mortar may be richer, and by virtue of reduction in water/cement ratio which may thereby be permitted, the strength of concrete may be increased.

A rounded spherical shaped aggregate when compacted contains less voids than an irregular and flaky aggregate of the same nominal size. Therefore, the former gives higher strength.

A common belief has been that the larger the maximum size of aggregate, the denser and stronger will be the concrete. The large aggregates have lower total surface area and require lower water/cement ratio resulting in higher strength. In practice it is not so. The larger aggregates give lower surface area for development of gel bonds leading to lower strength. Also large size aggregates give heterogeneous concrete causing nonuniform distribution of load when stressed.

High strength concrete gives lower strength as compared to lean concrete if a big size aggregate is used. The influence of maximum size of aggregate on compressive strength of concrete with different cement contents is shown in Fig. 10.15, and that with different water/cement ratios is shown in Fig. 10.16. The strength of aggregate does not affect that of concrete greatly as long as it is higher than the design grade of concrete.

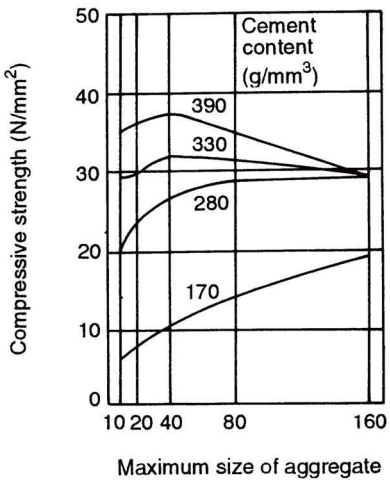


Fig. 10.15 Influence of Maximum Size of Aggregate on 28 Day Strength of Concrete of Different Richness

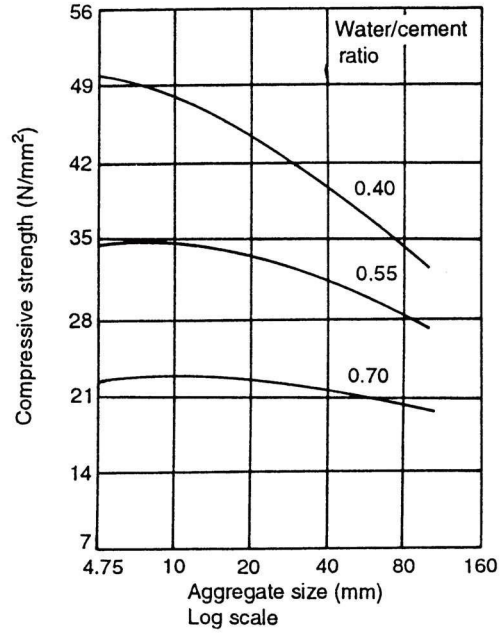


Fig. 10.16 Influence of Maximum Size of Aggregate on the Strength of Concrete

Degree of Compaction Inadequate compaction leading to air void contents of 5 per cent and of 10 per cent result in a loss of strength of 30 per cent and 55 per cent respectively. Following equation may be used to find the variation in strength

$$S = j\left(\frac{C}{1-\rho} - n\right)$$

where S = unit compressive strength

C = volume of cement grains in a unit volume of concrete

ρ = density of concrete

j and n = constants

The effect of degree of compaction on strength is shown in Fig. 10.17.

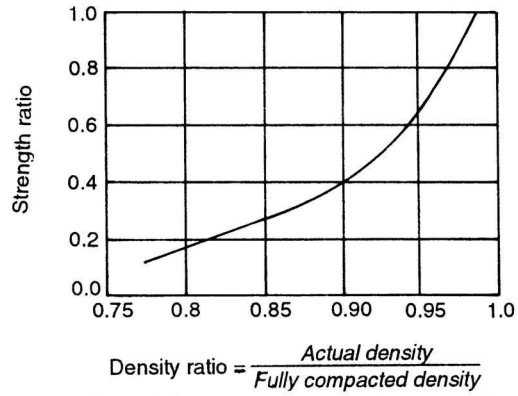


Fig. 10.17 Effect of Compaction on the Strength of Concrete

Mixing Time The strength of concrete increases with increase in time of mixing up to two minutes beyond which no significant improvement is observed. Fig. 10.18 shows the effect of mixing time on strength of concrete.

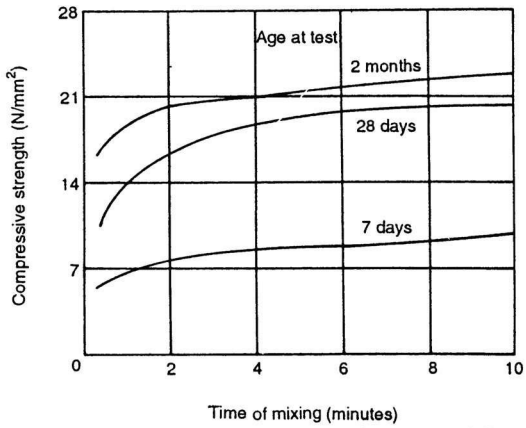


Fig. 10.18 Effect of Mixing Time on Strength of Concrete

Curing Method and Curing Temperature The effect of method of curing on strength has been discussed in Sec. 10.4. The higher the temperature, the greater is the rate of hardening of concrete. 10 hours curing at temperatures of about 90°C, concrete may attain 70 per cent of its 28 day strength.

10.9 MATURITY

The strength of concrete depends upon both the time as well as temperature during the early period of gain in strength. The time factor has already been considered.

The maturity of concrete is defined as the summation of product of time and temperature.

$$\text{Maturity} = \sum (\text{time} \times \text{temperature})$$

Its units are °C hr or °C days.

The temperature is reckoned from – 11°C as origin since hydration continues to take place up to about this temperature.

A sample of concrete cured at 18°C for 28 days is taken to be fully matured which is equal to

$$M_{28\ \text{days}} = 28 \times 24\ [\ 18 - (-\ 11)\ ] = 19488°C\ \text{hr}.$$

The value is 19800°C hr since the datum used as – 11°C is not the exact but the approximate value.

The accurate value can be had by dividing the time into smaller intervals and noting the temperature of each and then obtaining the summation of product of time and temperature. The value obtained without this cumbersome exercise yields a sufficiently accurate value. The relationship between maturity and strength of concrete is shown in Fig 10.19.

The maturity concept is very useful for estimating the strength of concrete at any other maturity as a percentage of strength of concrete of known maturity by using the formula

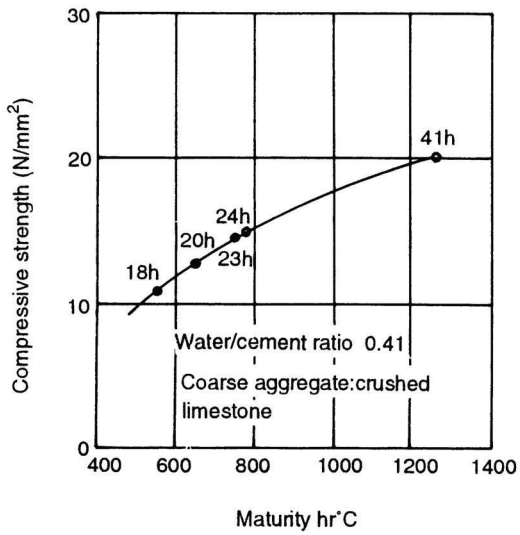


Fig. 10.19 Relationship between Maturity and Compressive Strength

Percentage of strength at maturity of 19800°Ch = $A + B \log_{10} \frac{\text{maturity}}{10^3}$

Plowman has given the following values of constants A and B

28 day strength at 18°C (M = 19800°C hr/Kg/cm^2)	Coefficients A	B
< 175	10	68
175-350	21	61
350-525	32	54
525-700	42	46.5

Example 10.3 The strength of a fully matured concrete sample is found to be 500 Kg/cm^2. Find the strength of identical concrete at age of 7 days when cured at an average temperature of 20°C in day and 10°C in night.

Maturity of concrete at the age of 7 days = $\sum$ (time $\times$ temperature)

$= 7 \times 12 \times [20 - (-11)] + [7 \times 12 \times (10 - (1 - 11)]$

$= 4368$°C hr

Now A = 32 B = 54, thereby

percentage of strength of concrete at maturity of 4368°Ch

$= A + B \log_{10} \frac{4368}{1000} = 66.5$ kg/cm^2

$\therefore$ Strength at 7 days $= 500 \times \frac{66.5}{100} = 331.25$ kg/cm^2

10.10 WORKABILITY

In fresh concrete — concrete in the plastic state, which can be moulded into desired shape — the theoretical w/c ratio to meet the requirements of water for chemical combination with cement, and to occupy the gel-space is about 0.4 for maximum strength. The w/c ratio used at site may vary because of:

a) the presence of free surface moisture in the aggregates, and b) the absorption of moisture by the dry or porous aggregates.

Because of the above limitations another characteristic workability, which is again a reflection of w/c ratio, becomes important.

The theoretical w/c ratio used will not give the maximum strength because of the reasons stated above. 100 per cent compaction of concrete will give maximum strength and this can be obtained by increasing the w/c ratio. The water lubricates the concrete which can be compacted at site with the specified efforts. The lubrication required for handling concrete without segregation, for placing without loss of homogeneity, for compacting with specified effort and for easy finish are

indications of workable concrete.

As per Road Research Laboratory U.K. workability is defined as the property of concrete which determines the amount of useful internal work necessary to produce full compaction. It can also be defined as the ease with which concrete can be compacted 100 per cent with regard to mode of compaction and place of deposition.

Workability is different than consistency. The latter indicates degree of fluidity or mobility. A concrete with high consistency need not be workable for a particular job. For example a concrete workable for foundation may not be workable for slab. Even for slab different workabilities will be required for compaction by hand and that by vibration for the requirement of workability is less.

Factors Affecting Workability

Water Content The fluidity of concrete increases with water content. At site the normal practice is to increase the water content to make the concrete workable which lowers strength. In controled concrete this cannot be resorted and even in uncontrolled concrete this should be the last choice. More water can be added provided cement content is proportionately increased.

Mix Proportions Aggregate-cement ratio influences the workability to a large extent. The higher the ratio leaner will be the concrete. In a lean concrete, paste available for lubrication of per unit surface area of aggregates will be less and hence the workability is reduced.

Aggregate Size For big size aggregate the total surface area to be wetted is less, also less paste is required for lubricating the surface to reduce internal friction. For a given water content big size aggregate give high workability.

Shape of Aggregates For a given water content, round and cubical shape aggregates are more workable than rough, angular or flaky aggregates, because the former requires less cement paste for lubrication as these have less surface area and lesser voids. In case of round aggregates frictional resistance is also small so less lubrication is required. For this reason river sand and gravel provide greater workability than crushed sand and aggregates.

Surface Texture A rough surface aggregate will have more surface area than a smooth round textured aggregate. Hence, latter will be more workable for the reasons discussed above.

Grading of Aggregates Properly graded aggregates are more workable. It is so because such a mix will have least voids and thus excess cement paste will be available as lubricant. This also prevents segregation.

Admixtures Air entrained concrete is more workable. It is so because air forms bubbles, on which the aggregates slide past each other increasing the workability.

Another factor is that air entraining agents are surface active and they reduce the internal friction between the aggregates.

Measurement of Workability

Slump Test This method of test specifies the procedure to be adopted, either in the laboratory or during the progress of work in the field, for determining the consistency of concrete where the nominal maximum size of the aggregate does not exceed 38 mm.

The internal dimensions of the mould for the test specimen shown in Fig. 10.20 are bottom diameter = 200 mm, top diameter = 100 mm, and height = 300 mm.

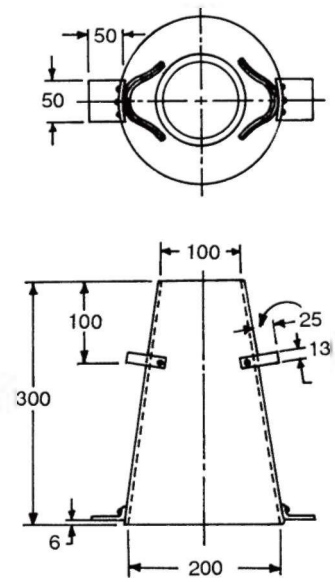


Fig. 10.20 Mould for Slump Test

The mould is filled in with fresh concrete in four layers, each approximately one-quarter of the height and tamped with twenty-five strokes of the rounded end of the tamping rod. The strokes are distributed in a uniform manner over the cross-section and for the second and subsequent layers should penetrate into the underlying layer. The bottom layer is tamped throughout its depth. After the top layer has been rodded, the concrete is struck off level with a trowel or the tamping rod, so that the mould is exactly filled. The mould is removed immediately by raising it slowly and carefully in a vertical direction. This allows the concrete to subside and the slump is measured immediately by determining the difference between the height of the mould and that of the highest point of the specimen being tested (Fig. 10.21). The slump measured is recorded in terms of millimetres of subsidence of the specimen.

Notes : (i) Some indication of the cohesiveness and workability of the mix can be obtained, if after the slump measurement has been completed, the side of the concrete is tapped gently with the tamping rod; a well-proportioned concrete of an appreciable slump will gradually slump further, but if the mix has been badly proportioned, it is likely to fall apart.

(ii) The test is performed with maximum size of aggregate as 38 mm only. However, if the aggregate size is larger the concrete is wet sieved through 38 mm screen to exclude aggregate particles bigger than 38 mm.

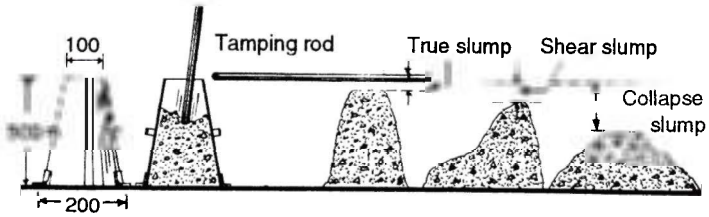


Fig. 10.21 Measuring Slumps

Compacting Factor Test This test is more precise and sensitive than the slump test and is particularly useful for concrete mixes of very low workability as are normally used when concrete is to be compacted by vibration; such concrete may consistently fail to slump. A diagram of the apparatus used in compacting factor test is shown in Fig. 10.22.

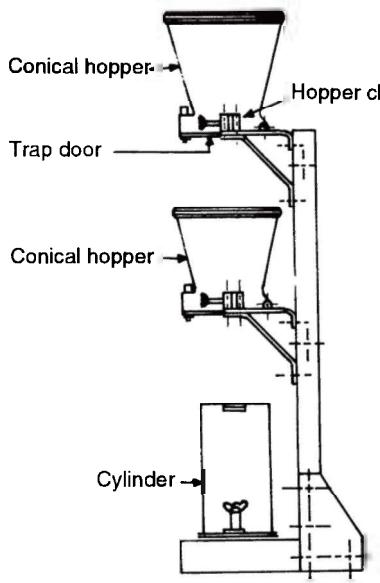


Fig. 1.22 Compacting Factor Apparatus

The sample of concrete to be tested is placed gently in the upper hopper. The hopper is filled level with its brim and the trap-door is opened to allow the concrete to fall into the lower hopper. Certain mixes have a tendency to stick in one or both of the hoppers. If this occurs, the concrete may be helped through by pushing the rod gently into the concrete from the top. During this process, the cylinder should be covered by the trowels. Immediately after the concrete has come to rest, the cylinder is uncovered, the trap-door of the lower hopper is opened, and the concrete is allowed to fall into the cylinder. The excess of concrete remaining above the level of the top of the cylinder is then cut off. The weight of the concrete in the cylinder is then determined to the nearest 10 g as the weight of partially compacted concrete. The cylinder is refilled with concrete from the same sample in layers of approximately 50 mm, the layers being heavily rammed or preferably vibrated so as to obtain full compaction. The top surface of the fully compacted concrete is carefully struck off level with the top of the cylinder. The

compacting factor is defined as the ratio of the weight of partially compacted concrete to the weight of fully compacted concrete. It is normally stated to the nearest second decimal place.

Note : The test is sufficiently sensitive to enable differences in workability arising from the initial process in the hydration of the cement to be measured. Each test, therefore, is carried out at a constant time interval after the mixing is completed if strictly comparable results are to be obtained. A convenient time for releasing the concrete from the upper hopper has been found to be 2 minutes after the completion of mixing.

Vee-Bee Consistometer Method The test determines the time required for transforming, by vibration, a concrete specimen in the shape of a conical frustum into a cylinder.

The apparatus (Fig. 10.23) consists of a vibrator table resting upon elastic supports, a metal pot, a sheet metal cone, open at both ends, and a standard iron rod.

A slump test as described earlier is performed in the cylindrical pot of the consistometer. The glass disc (C) attached to the swivel arm is moved and placed just on the top of the slump cone in the pot and before the cone is lifted up, the position of the concrete cone is noted by adjusting the glass disc attached to the swivel arm. The cone is then lifted up and the slump noted on the graduated rod by lowering the glass disc on top of the concrete cone. The electrical vibrator is switched on and the concrete is allowed to spread out in the pot. The vibration is continued until the whole concrete surface uniformly adheres to the glass disc and the time taken for this to be attained is noted with a stop watch. The consistency of the concrete is expressed in VB-degree which is equal to the recorded time in seconds. The required slump is obtained on the basis of the consistency scale given in Table 10.5. The curve in Fig. 10.24 indicates the relationship between slump in mm and the degrees covered by the consistency scale given in Table 10.5.

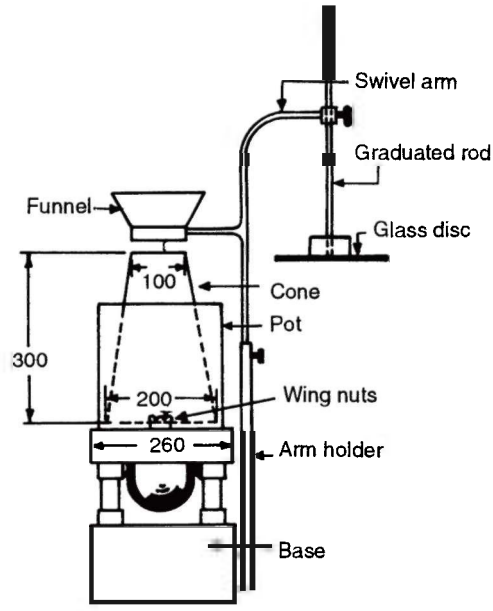


Fig. 10.23 Vee-Bee Consistometer

Table 10.5 Values of Workability for Different Placing Conditions

Degree of workability	Consistency	Slump (mm)	Compacting factor	Vee-Bee degree (sec)	Characteristics	Uses
Extremely low	Moist earth	0	0.65-0.7	> 20	Particles of coarse aggregate in the concrete are adhesive, but concrete does not clot, risk of segregation.	Precast paving slabs
Very low	Very dry	0-25	0.7-0.8		12-20 Concrete has the consistency of very stiff porridge, forms a stiff mound when dumped, and barely tends to shake or roll itself to form an almost horizontal surface when conveyed for a long time in, say, a wheel-barrow.	Roads (power vibrator)
Low	Dry	25-50	0.8-0.85	6-12	Concrete has the consistency of stiff porridge, forms a mound when dumped, and shakes or rolls itself to form a horizontal surface when conveyed for a long time in, say, a wheel-barrow.	Mass concreting, light reinforced section, roads (hand vibrator)
Medium	Plastic	50-100	0.85-0.95	3-6	Concrete can be shaped into a ball between the palms of the hands, and adheres to the skin.	Flat slabs, Heavily reinforced section, RCC sections (manual vibrator)
High	Semi-fluid	100-175	0.95-1	0-3	Concrete cannot be rolled into a ball between the plams of the hands, but spreads out even though slowly and without affecting the cohesion of the constituents so that segregation does not occur.	RCC with congested reinforcement (can not be vibrated)

10.11 DURABILITY

Concrete should be durable. The various factors affecting the durability of concrete used in normal conditions are as follows :

Permeability Almost all forms of deterioration in concrete are due to ingress of water. The ways in which durability of concrete may be affected because of permeability are:

1. The chemicals in liquid form affect the concrete by penetrating it.

2. Frost action, rusting of steel, etc.

Concrete has gel pores and capillary cavities. About 1/3 of gel pores are so small that they hardly pass any water through them. The extent of capillary cavities depends on the w/c ratio. This is the major factor contributing to permeability. The remedies are:

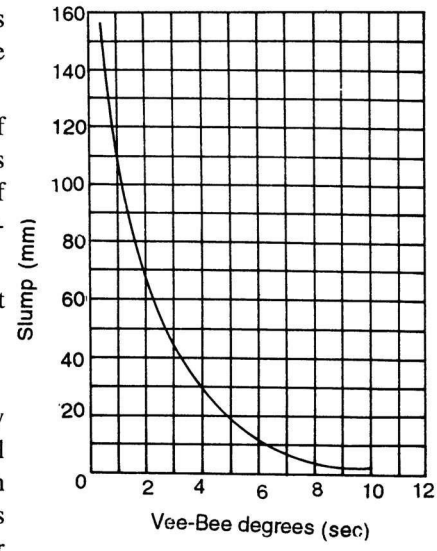


Fig. 10.24 Relation between Slump and Vee-Bee Degrees

1. Use of puzzolanic materials.

2. Air entrainment up to 6 per cent.

3. High pressure steam curing in conjunction with silica.

Frost Action The frost effect may be due to permeable concrete or by temperature below 0°C. The mechanism of attack is attributed to the expansion of absorbed water on freezing. Damage can also result from movement of water within concrete on cooling below 0°C. Ice builds up in large pores causing large expansion in local areas the others being dry cause disintegration. The conditions favouring frost attack are :

1. Horizontal surfaces open to sky absorbing more water in wet conditions and cooling quicker by radiation.

2. Low temperatures increasing the extent of migration of water resulting in freezing to greater depths in the concrete.

3. Repeated freezing and thawing.

4. Use of de-icing salts.

Sulphate Attack denotes an increase in the volume of cement paste due to the chemical action between the products of hydration of cement and solutions containing sulphates. The sulphate solutions react with C_3A forming a chemical

enttringite which expands and causes disruption in concrete. Sulphates occur in three forms — calcium, sodium and magnesium. Calcium has low solubility so that it does not constitute high risk. Of the remaining two magnesium sulphate has the most severe disruptive action because:

a) the reaction product is insoluble, precipitating out of solution and leaving the way clear for further attack, and b) magnesium sulphate reacts with the C_3S hydrate in cement.

A common source of sulphate salts is the soil around the concrete foundation, from the water used in making concrete, and by using unwashed aggregates.

The remedy is to use blast furnance slag cement, sulphate resisting cement, supersulphated cement, and to reduce the permeability.

Mineral Oils Petroleum and its products do not directly affect hardened concrete. To overcome the deteriorating affects of mineral oils on fresh concrete permeability is reduced by surface treatment by applying at least four coats of sodium silicate.

Organic Acids Acetic acid, lactic acid, and butyric acid severely attack concrete. Formic acid is corrosive to concrete.

Vegetables and Animal Oils and Fats Vegetable oils contain small amount of free fatty essence and deteriorate concrete slowly. Fish and cotton seed oils are found to be the most corrosive.

Sugar is a retarding agent and gradually corrodes concrete. The remedy is to coat the concrete surface with sodium silicate solution, tar or asphalt.

Sewage H_2S gas evolved from septic sewage may promote formation of H_2SO_4 affecting the concrete. However, sewers running full are not affected.

Thermal Effects on Concrete Concrete is a heterogeneous material and the ingredients have dissimilar thermal coefficients which affect durability.

Cracks Cracks are inherent in concrete and cannot be completely prevented but can be minimized. Use of unsound materials, high w/c ratio, bad jointing techniques, freezing, thermal effects, etc. lead to cracks and make the concrete less durable.

10.12 DEFECTS

Cracks Cracks in concrete may originate from one or more of the following causes:

Excess Water Water in excess of requirement causes the coarse aggregate to settle more and the water bleeds to top and evaporate leaving voids. This porous, weak concrete will be unable to bear shrinkage stresses without cracking. Concrete

may also shrink down in the forms in the cases of beams and walls.

Early Loss of Water results in shrinkage cracks during or soon after the finishing because of moisture absorption by dry subgrade, dry forms, dry aggregates or hot sunny weather.

Alkali Aggregate Reaction arising out of incorrect selection of coarse aggregate may lead to cracks.

Steel The corrosion of steel bars may cause cracks and rust stains to appear in the concrete.

Freeze and Thaw The cracks because of freeze and thaw are normally observed in concrete with high w/c ratio, producing tiny crevices and voids around the aggregates, allowing the rain water to penetrate into concrete. On freezing, the ice produces tremendous force causing spalls and cracks.

Crazing of concrete products results from differences in shrinkage between the surface and the interior. The cracks rarely exceed 12 mm or so in depth, and are therefore not serious, apart from the unsightliness. The best method to overcome crazing is to be either to use an earth-moist mix, or if a plastic mix is necessary use as low a w/c ratio as is practicable and remove the cement skin to expose the aggregate. Trowelling should be avoided as the surfaces are prone to crazing.

Sulphate Deterioration Sulphate attack is mainly caused by the soil containing sulphates or by sulphate water (Sec. 9.11).

Efflorescence is the appearance of fluffy white patches on the surface of concrete members. It is caused by poorly washed aggregate, salty water used in making concrete the salts being leaching out to the surface by rain water afterwards. As the water evaporates white patches appear on the surface. This defect can be controlled to some extent by coating the surface by a water repellent.

Segregation usually implies separation of: a) coarse aggregate from fine aggregates, b) paste from coarse aggregate, or water from the mix. It can be reduced by increasing small size coarse aggregate, air entrainment, dispersing agents and puzzolana.

The causes of segregation are excess water, dropping concrete from heights, badly designed mixes, concrete carried over long distances — pumping, belt conveyor system etc. over vibrations, and during concrete finishing extra floating and tamping.

Bleeding defined as an autogeneous flow of mixing water within or emergence to the surface from freshly placed concrete is usually due to excessive vibrations imparted to concrete to achieve full compaction. It can be reduced by grinding cement fine, air entraining agents, dispersing agents, puzzolanas and vibration. It is a particular form of segregation in which some of the water comes out on the

surface of concrete. The causes of bleeding are highly wet mix, insufficient mixing, and thin sections (slabs) cast in sunny weather — being more in flaky aggregate and more in the first hours of concreting. The ill effects are reduced bond between aggregate and cement, and between cement and reinforcement.

Bleeding can be checked by the use of puzzolana — by breaking the continuous water channel, or by using — entraining agents, finer cement, alkali cement, and a rich mix.

Laitance defined as cement and water slurry coming on top and setting on the surface is very dangerous since the top surface will weather out fast with larger shrinkage cracks. If laitance is formed in a lift, it should be removed before next lift is placed.

10.13 REVIBRATION

Delayed vibration of concrete, already placed and compacted is known as revibration. When successive top layers are vibrated, some vibration is transferred to bottom layers. It is beneficial as the quality of concrete improves as the entrapped air and water escape and also the rearrangement of particles take place.

10.14 TYPES

Reinforced Cement Concrete

Reinforced cement concrete is a composite material made up of cement concrete and reinforcement in which the concrete resists compression with reinforcement resisting the tension and shear. It is the most versatile building material available and is extensively used in the construction industry ranging from small structural elements such as beams and columns to massive structures like dams and bridges.

Prestressed Concrete

A prestressed concrete may be defined as a concrete in which stresses of suitable magnitude and distribution are introduced to counteract to a desired degree the stresses resulting from external loads. The concrete was first used by Mandl of France in 1896. In prestressed concrete high strength concrete and steel are desirable. The former is required because of following:

1. The smaller cross-section of member results in smaller self weight.
2. High bearing stresses are generated in anchorage zones.
3. The shrinkage cracks are reduced, with higher modulus of elasticity and smaller creep strain.

The loss of prestress at the initial stages is very high and for it high strength steel is required.

Prestressing is achieved by either pretensioning or post-tensioning. In the former the wires or cables are anchored, tensioned and concrete is cast in the moulds. After the concrete has gained strength the wires are released. This sets up compression in concrete which counteracts tension in concrete because of bending in the member. In the post-tensioning the prestressing force is applied to the steel bars or cables, after the concrete has hardened sufficiently. After applying the full prestress the cable passages are grouted.

It is widely used for construction of precast units such as beams, floors, roofing systems, bridges, folded plate roofs, marine structures, towers and railway sleepers.

Polymer Concrete

The strength of concrete is greatly affected by porosity and attempts to reduce it by vibration, pressure application, spinning, etc. They are of little help in reducing the water voids and the inherent porosity of gel which is about 28 per cent. The impregnation of manomer and subsequent polymerisation reduces the inherent porosity of the concrete. Polymers — polyvinyl acetate, homopolymer emulsions and vinyl acetate copolymer emulsions — are added to increase strength, resistance to oil, grease, and abrasion. They also improve bond between new and old concrete and are useful for prefabricated structural elements, prestressed concrete, marine works, nuclear power plants, water proofing and ferrocement products. The disadvantages are that they are very brittle and expensive.

For heavy duty Industrial floor the concrete mix used is 1:2:2. Concrete to PVA emulsion in the ratio 3:1 is then prepared.

For domestic or office floor cement and sand in the ratio of 1:2 is mixed. The cement mortar: PVA emulsion is then made in the ratio 2:1.

Types The available polymer concrete materials available are polymer impregnated concrete (PIC), polymer cement concrete (PCC), polymer concrete (PC) and, partially impregnated and surface coated polymer concrete.

Polymer Impregnated Concrete is a conventional concrete, cured and dried in oven. A low viscosity manomer is then diffused and polymerised by using radiation, heat or by chemical initiation. The manomers used are, methylmethacrylate (MMA), styrene, acrylonitrile, t-butyl styrene, etc.

Polymer Cement Concrete is made by mixing cement, aggregates, water and manomers, such as polyester-styrene, epoxy styrene, furans, venylidene chloride. The plastic mix is moulded, cured, dried and polymerised.

Polymer Concrete In this type of concrete cement is not used and the aggregates are bound with a polymer binder. It is most suitable for structures with a high ratio of live load to dead load and composite construction.

Partially Impregnated and Surface Coated Concrete is made by initially soaking the dried specimens in liquid manomer like methyl methacrylate and then sealing them by keeping under hot water at 70°C to prevent loss due to evaporation. The polymerisation is achieved by adding 3 per cent by weight of benzoyl peroxide to the manomer as catalyst. It finds its application in improving durability of bridge decks.

Fibre Reinforced Concrete

Conventional concrete is modified by random dispersal of short discrete fine fibres of asbestos, steel, sisal, glass, carbon, Poly-propylene, glass, nylon, etc. Asbestos cement fibres so far have proved to be commercially successful. The improvement in structural performance depends on the strength characteristics, volume, spacing, dispersion and orientation, shape and their aspect ratio (ratio of length to diameter) of fibres.

The pull out resistance of fibres depends upon the bond between the fibres and matrix, the number of fibres crossing the crack, and the aspect ratio.

The behaviour of fibre reinforced concrete (FRC) is shown in Fig. 10.25. The tensile cracking strain of cement matrix is about 1/50 of that of yield of steel fibres. Consequently when FRC is loaded, the matrix cracks long before the fibres are fractured. Once the matrix is cracked the composites continue to carry increasing tensile stress, provided the pullout resistance of fibres at the first crack is greater than the load at the first cracking. The bond or the pullout resistance of the fibres depends on the average bond strength between the fibres and the matrix, the number of fibres crossing the crack, and the length and diameter of fibres.

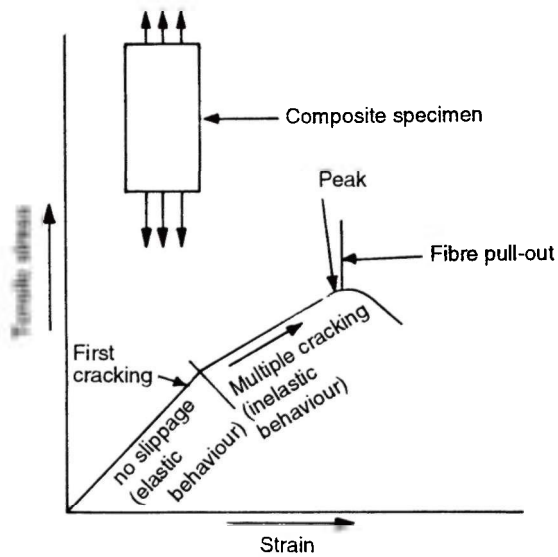


Fig. 10.25 Behaviour of Fibre Reinforced Concrete

The first flexural cracking load on a FRC member increases due to crack arresting mechanism of the closely spaced fibres. After the first crack fibres continue to take load provided the bond is good. Thereafter the fibres, reaching the breaking strain fracture. The neutral axis of the section shifts and the fibres of adjacent layers fracture on reaching the breaking strain. Failure occurs when the concrete in compression reaches

the ultimate strain.

Advantages

1. Strength of concrete increases.
2. Fibres help to reduce cracking and permit the use of thin concrete sections.
3. Mix becomes cohesive and possibilities of segregation are reduced.
4. Ductility, impact resistance, tensile and bending strength are improved.

Disadvantages

1. Fibres reduce the workability of a mix and may cause the entrainment of air.
2. Steel fibres tend to intermesh and form balls during mixing of concrete.

Applications Fibre reinforced concrete is useful in hydraulic structures, airfield pavements, highways, bridge decks, heavy duty floors, and tunnel linings.

Ferrocement

Ferrocement is a composite material in which the filler material, cement mortar, is reinforced with fibres, usually steel mesh dispersed throughout the composite. The fibres impart tensile strength to the mass.

In rationally designed ferrocement structures the reinforcements consist of small diameter wire meshes wherein uniform distribution of reinforcement is made possible throughout the thickness of the element. Because of the distribution of such reinforcement over the entire matrix, high resistance cracking is achieved. Toughness, fatigue resistance, impermeability, etc. are also improved.

The reinforcement may be hexagonal wire mesh (0.5-1.00 mm diameter at 5-25 mm spacing) welded wire mesh (18-19 gauge), woven mesh, expanded metal sheet and Waston mesh. The skeletal steel may be placed 300 mm apart to serve as a spacer rod to the mesh reinforcement. A rich mix of Portland cement and sand usually 1:2 to 1:1.5, is used as mortar. The thickness is kept 10-40 mm, with a clear cover of 1.5-2 mm to reinforcement. No form work is required since the wire mesh and chicken mesh receive the mortar wherein the mortar applied with pressure is held in position by mechanical interlocking.

Steel bars are generally provided to make the formwork of the structure and is known as skeletal steel. The size of the rod varies from 4 to 10 mm and at a spacing of 300 mm apart. In highly stressed structures like boats, barges and tubular sections this spacing is reduced to 75 mm.

Portland cement, rapid hardening Portland cement, sulphate resisting Portland cement or Portland blast-furnance cement may be used.

The advantages of ferrocement are:

1. Easy availability of raw materials.

2. Reduction in weight consequent of thin section.

3. Moulding can be done without any formwork.

4. No machinery or sophistication is required in construction.

Ferrocement acts a homogeneous material in elastic range. Stress-strain curve for ferrocement is linear in elastic range and cracks do not develop. With an increase in stress beyond this limit cracks develop. On further increasing the stress the number of cracks increase rather than the crack widths. Near yield the cracks widen and failure takes place.

The excellent crack control and impermeability characteristics of ferrocement make it suitable for liquid retaining structures, boat building, gas containers, caissons, canal lining, etc. Since it is cheaper than steel and R.C.C. and can be cast in thin sections it is most suitable for low cost roofing, precast units, manhole covers, casings, etc. and is the most appropriate building material for the construction of domes, vaults, shells, grid surfaces, corrugated sheets and folded plates.

Light Weight Concrete

Conventional cement concrete is a heavy building material. For structures such as multistorey buildings it is desirable to reduce the dead loads. Light weight concrete is most suitable for such construction works. It is best produced by entraining air in the cement concrete and can be obtained by anyone of the following methods:

1. By making concrete with cement and coarse aggregate only. Sometimes such a concrete is referred to as *no-fines concrete*. Suitable aggregates are — natural aggregate, blast furnance slag, clinker, foamed slag, etc. Since fine aggregates are not used, voids will be created and the concrete produced will be light weight.

2. By replacing coarse aggregate by porous or cellular aggregate. The concrete produced is known as *cellular concrete* which is further classified in the following:

Based on Manufacturing Method — classified as foam concrete and gas concrete.

Based on Type of Binding Material — classified as gas and foam concrete (Portland cement), gas and foam concrete (lime and sand), gas slag and foam slag concretes (lime and finely divided blast furnance slag or fly ash).

Foam concrete is obtained by mixing cement paste or mortar with stabilized foam. After hardening, the foam cells form concrete of a cellular structure. The foam is obtained by stirring a mixture of resin soap and animal glue. The best foaming agents are alumino sulpho napthene compounds and hydrolysed slaughter blood. This is very suitable for heat insulation purposes.

Gas concrete is also known as *aerated* concrete. It is obtained by expanding the binding material paste by gas forming substances such as aluminium powder. It is

used for same purposes as that the foam concrete. However, it is better than foam concrete.

The basic considerations in choosing the proportion of light weight concrete are economy consistent with placability and adequate strength, and attainment of specified bulk density with the lowest consumption of cement.

Characteristics of Light Weight Concrete

Density The density of L.W.C varies from 300-1200 kg/m^3 (P.C.C 2400 kg/m^3)

Strength It has high compressive strength in relation to density. The tensile strength is about 1/5th of its compressive strength.

Thermal Insulation is about 3-4 times more than that of bricks and about 10 times than that of concrete.

Fire Resistance is excellent.

Sound Insulation is poor.

Durability Aerated concrete is slightly alkaline. Due to its porosity and low alkalinity the reinforcement may be subjected to corrosion and as such, require special treatments.

Reparability Light weight cellular element can be easily sawn, drilled or nailed which makes for easy construction and repairs.

Economy Due to light weight and high strength to mass ratio, the cellular products are quite economical.

Applications of Light Weight Concrete

1. Low density cellular concrete is used for precast floor and roofing units.
2. Load bearing walls using cellular concrete blocks.
3. As insulation cladding to exterior walls of structures.

10.15 PHYSICAL PROPERTIES

Stress-Strain Curve of Concrete

The true elastic curve for concrete in compression (Fig. 10.26) can be plotted by applying and releasing load until the set at zero loads becomes constant. By subtracting the set from the total deformation the elastic deformation for a given load is determined. Since mortar and concrete have no elastic limit, the modulus of elasticity for concrete must be the slope of the stress-deformation curve at zero stress and can be calculated from the formula

$$S_c = \left(1 - \frac{1}{2}q\right) E_c \cdot \varepsilon$$

assuming stress-deformation curve to be parabolic,

where q = ratio of ε (the unit deformation for S_c) to the ultimate unit deformation

E_c = initial modulus

The modulus of elasticity of concrete increases with the density and to some extent with age.

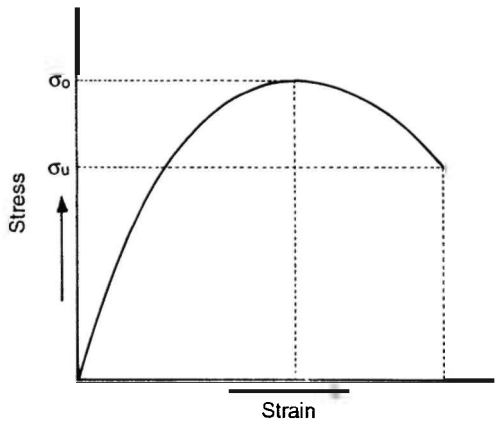


Fig. 10.26 Stress-Strain Curves for Concrete

Poisson's Ratio Under unit compression the unit lateral expansion of concrete is about 1/6th to 1/12th of the unit strain in the direction of the applied forces for the ordinary range of working stress. The ratio increases with the richness of the mix. The value of Poisson's ratio varies between 0.1 to 0.16 for working loads on two month old, 1:2:4 concrete.

Creep The continued deformation with time under applied load is creep. It may be defined as increase of strain in concrete with time under sustained stress. This is also known as *plastic flow* or *time yield*. The rate of creep decrease with time and the creep strains at five years are taken as terminal values. The deformation of hardened concrete is shown in Fig 10.27.

Creep may be due to closer of internal voids, viscous flow of the cement paste and flow of the water out of the cement gel. In reinforced concrete structures it is of advantage since it causes better distribution of stresses. For example in a R.C.C. column there is a reduction of stress in concrete and a corresponding increase of stress in steel due to creep. As another example creep relieves the high stressed portions of concrete in a continuous beam and increases the stress in the adjacent less stressed portion. Creep causes large deformations and deflections and is undesirable.

Creep increases rapidly with the stress, loading at an early age of concrete, broken ballast, soft and porous aggregate, poorly graded and improperly compacted concrete.

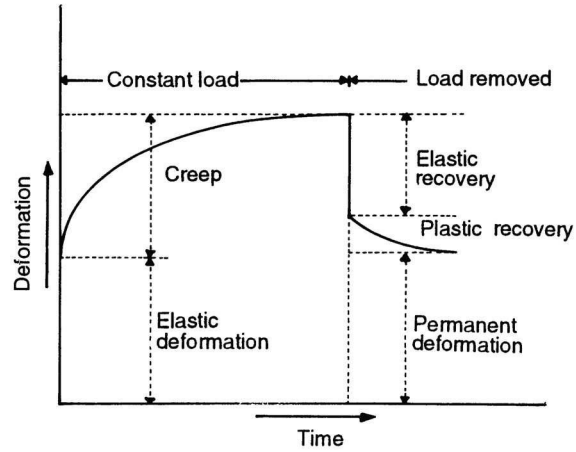


Fig. 10.27 Deformation of Hardened Concrete

Shrinkage Contraction of concrete in the absence of load is known as shrinkage. It may be plastic shrinkage — shrinkage of concrete due to absorption of water by aggregates, evaporation of water and bleeding, or drying shrinkage — the shrinkage taking place after the concrete has set and hardened.

Shrinkage of concrete increases with high w/c ratio and high cement content. Shrinkage can be estimated by using Schorer's formula:

$\varepsilon_s = 0.00125\ (0.90 - h)$

where ε_s is shrinkage strain and h is relative humidity expressed as a fraction.

The rate of shrinkage decreases with time.

10.16 PROPORTIONING

The principle object of proportioning is to achieve requisite strength with desired workability for which due attention should be paid to the selection of cement and aggregates according to the specifications. The additional considerations to be taken note of are:

1. The mix must be workable so that it can be placed and finished without extra effort.
2. Low cement consumption consistent with the attainment of desired properties.
3. High cement content improves strength, impermeability, density and workability.
4. With cement content, ingredients and workability remain constant, strength

and impermeability of concrete increase with the density of mix.

10.17 NON DESTRUCTIVE TESTING

Fresh Concrete

There are two tests, the maturity test and the ultrasonic test.

Maturity Test is based on the principle that concretes having equal maturities will have equal compressive strengths. The maturity of the in-situ concrete at the early ages can be determined with the aid of an instrument known as *maturity meter*. This is used to determine the earliest safe time for removal of formwork. The results are authentic provided the concretes have initial temperatures between 15-26°C and there is no loss of moisture during the period of curing.

Ultrasonic Method Ultrasonic pulses are released from one of the transducers placed in contact with one of the surface of the freshly placed concrete. The pulse is converted into an electric signal by a second electro-acoustical transducer, and the time taken by the pulse to travel is displayed digitally on the instrument. The distance between the transducers being known, the velocity is calculated and strength corresponding to the pulse velocity can be obtained from the calibrated charts supplied by the manufacturers.

Hardened Concrete

Concrete Core Test Concrete cores are drilled from the structure and are tested in compression testing machine. The average equivalent cube strength of the cores is equal to at least 85 per cent of the cube strength of the concrete specified for the corresponding age.

Pullout Test is more authentic than the concrete core test. A special shaped steel rod with one end enlarged is embedded in concrete in the form work. After the concrete hardens the rod is pulled out and in so doing it comes out with a block of concrete. The pullout force determined by a hollow tension ram is related to the compressive strength of concrete.

Ultrasonic Test The ultrasonic pulse velocity method as described for green concrete can also be used to determine the strength of hardened concrete. The flaws, quality of concrete, reinforcement, moisture cement, temperature of concrete materials, etc. affect the pulse velocity and suitable adjustments should be made in evaluating the concrete strength.

Schmidt Test Hammer The hammer is placed on the concrete surface and pressed. The elastic rebound of hammer after impact is measured on a scale as rebound number. A calibration curve relating the compressive strength of concrete with the rebound number supplied by the manufactures of the instrument is used to predict the strength of concrete.

EXERCISES

Q.1 (a) What is concrete and how is it made ?
(b) What is curing ? What is its significance ?
(c) Define water/cement ratio. How does it influence concrete strength ?

Q.2 (a) What are the various types of concrete used in the construction industry?
(b) Describe the procedure of preparing concrete.

Q.3 (a) What are the various methods used for curing ? How 28 day concrete strength can be predicted in one day ?
(b) What is gel-space ratio ?
(c) Describe the factors affecting strength of concrete.

Q.4 What is maturity concept of concrete ?

Q.5 (a) What is concrete ? What are the functions played by its ingredients ?
(b) Discuss the various properties of concrete.

Q.6 (a) What is meant by workability of concrete ? How is it tested in field and in laboratory ?
(b) What are the requirements of good concrete ?
(c) What is polymer concrete ?

Q.7 (a) What are the factors affecting workability of concrete ?
(b) Describe the various defects in concrete. What precautions should be exercised to prevent them ?
(c) Describe the methods of testing fresh concrete.

Q.8 Write short notes on following:
(a) Light weight concrete (b) Fibre reinforced concrete
(c) Ferrocement (d) Air entrained concrete

Q.9 Describe briefly the following:
(a) Vee-Bee Test
(b) Factors affecting durability of concrete
(c) Prestressed concrete
(d) Properties of cement concrete in green and hardened state

Q.10 Write notes on following:
(a) Segregation (b) Bleeding
(c) Laitance (d) Sulphate attack

Q.11 (a) What is meant by M20 grade concrete ?
(b) Describe compaction factor test.
(c) What is crazing ?

Q.12 What concrete mix will you recommend in the following situations:
(a) Beams (b) Columns
(c) Slabs (d) Foundation of a residential building
(e) Water tanks

Q.13 (a) Define creep. What are its advantages and disadvantages ?
(b) What is shrinkage ? What factors promote shrinkage ? What precautions will you take to reduce it ?

Q.14 State the value of slump and compaction factor you will recommend for following works:

(a) Beams (b) Slabs

(c) Foundations (d) Retaining walls

(e) Pavements

Q.15 (a) How is consistency different from workability ?

(b) What are the effects of over compaction and under compaction of concrete ?

(c) How will you judge that compaction is complete ?

Q.16 (a) What are the methods of testing the properties of green concrete.

(b) Describe the methods used to test the hardened concrete ?

Chapter

11

BUILDING MORTARS

11.1 INTRODUCTION

Building mortars are mixtures used for the jointing of bricks, stones, blocks, etc. It may be defined as a paste (capable of setting and hardening) obtained by adding water to a mixture of fine aggregates such as sand and binding material, e.g. gypsum, lime and cement. The pyramids of Egypt have been built with clay-gypsum, gypsum-lime and lime mortar. Indians have used lime mortar for monumental structures such as Taj Mahal and forts. In the years that followed, it was found that burning limestone with clayey substance produced hydraulic lime of high water-resisting properties. Lime with a still higher content of clay led to the manufacture of Roman cement. In 1824 Portland cement appeared; today it is considered to be the strongest binding material for mortar.

The mortar composition is designated by the volume or weight of material in 1 m^3 of mortar or by the relative amount of materials with the amount of binding material taken as unity. For simple mortars composed of one kind of binding material and containing no mineral admixtures (e.g. cement mortar), the composi-

tion will be designated, say 1:4, i.e. one part (by weight or volume) of binding material (cement) and 4 parts of sand. Combined mortar composed of two binding materials or combined mineral admixtures are identified by three figures, e.g. 1:0.4:5 (cement : clay : sand). Some of the important uses of mortars are as follows:

1. In brick and stone masonry — it is used in the vertical joints and is spread over each layer to give an even bed for successive layers of masonry.
2. In plastering and pointing — to cover exposed walls and joints to protect against weathering besides better appearance.
3. As matrix in concrete.

The governing factors in deciding a particular type of mortar for a specific structure depend upon the desired strength of masonry, resistance to penetration of rain water, immediate and long term appearance, hardening temperature, expected working conditions of the building and cost.

11.2 CLASSIFICATION

Mortars are classified on the basis of their bulk density, kind of binding material, applications and, physical and mechanical properties.

On the Basis of Bulk Density

Type of Mortar	Bulk Density (kg/m^3)	Aggregate
Heavy weight	>1500	Heavy quartz or sand
Light weight	<1500	Light porous sand from pumice, tuffa, slags, etc.

On the Basis of Binding Material

For most practical purposes a building mortar will fall in one of the following classes:

Cement Mortars are prepared from Portland cement or its varieties, sand and water.

Lime Mortars are mixtures of air hardening lime or hydraulic lime, sand and water.

Gypsum Mortars are prepared from gypsum or anhydride binding materials.

Mud Mortars are prepared from clay nodules and are used in construction of houses for poor and temporary construction works.

Composite Mortars may be surkhi-mortar (surkhi, lime and water), lime-surkhi-sand mortar, cement-lime mortar and cement-clay mortar.

On the Basis of Application

Brick Laying Mortars are intended for brick work.

Finishing Mortars are intended for arcnitectural or ornamental parts, application of decorative layers on walls and panels.

Special Mortars are intended for specific purposes for acoustics, x-ray shielding, plugging concrete at oil fields, etc.

On the Basis of Physical and Mechanical Properties

The basis of this classification is the strength of concrete which underlies the durability of concrete. Building mortars are subdivided into nine grades on the basis of compressive strength from 0.4 to 30.0 N/mm^2.

11.3 CHARACTERISTICS OF GOOD MORTAR

The chief properties of hardened mortar are strength, resistance to weathering and those of green mortar mixes are mobility, placability and water retention.

Strength

The strength of masonry depends upon both the mortar and the building unit (brick, stone or block). A very strong mortar with weak building units will be of little use. It is also important to consider whether full strength is required within a short time. In cold weather, when the strength of lime or cement mixes develops slowly, this is likely to affect the choice of mix. Strong cement mortars are most likely to lead to shrinkage cracks, and should, therefore be avoided except where high strength is an essential requirement. On the other hand the use of much weaker mortar say, 1:10 cement mortar is not satisfactory since reduction in cement content leads to less workability, less cohesion and will produce porous joints of low frost resistance. Strength of hardened mortar depends on the activity of binding materials, the water/cement ratio, consumption of binding material and the quality of sand. It has been found that :

1. The density and strength of mortars made of the same class of aggregate decrease as the proportion of fine aggregate is increased.
2. It requires about twice as much cement to produce a mortar of given strength when fine sand is used as it does with coarse sand.
3. When the percentage of mixing water is increased beyond that required to form a placeable mix, the density and strength of mortar reduces. The proportionate effect is greatest at the early ages.
4. Even small percentage of mica if present considerably lowers the tensile strength and adversely affects the compressive strength.

5. A replacement of less than 15 per cent of cement by hydrated lime does not affect the tensile strength. There is a loss of compressive strength by the replacement of less than 25 per cent of cement by hydrated lime.
6. The strength of concrete increases with the cement content. A richer concrete requires less water for a definite consistency which may offset the shrinkage. For constant water/cement ratio, an increase in the cement content improves the workability without affecting the strength.

Resistance to Penetration of Rain

The mortar for plastering should protect the masonry joints and units by forming an impermeable sheet. A satisfactory bond between the building units, mortar and plaster should be ensured.

Mobility

Depending on its composition a mortar may have a consistency ranging from stiff to fluid. Mortars for masonry, finishes and other works are made sufficiently mobile. The mobility of mortar mix determines its placability. Mortars prepared from Portland cement alone are frequently deficient in cement paste, stiff and non-placable and plasticizers are added.

Water Retention

It is characterized by the ability of mortar not to stratify during transportation and to retain adequate humidity in a thin layer spread over a porous bed. A mortar mix of low water retention will show the defects after hardening. Mortar may lose so much water that the amount left may be insufficient for its hardening and required strength. Mineral and organic plasticizing agents may be added to enhance water retention.

11.4 FUNCTIONS OF INGREDIENTS

Cement, lime and clay used as binding materials impart adhesive power and strength.

Sand increases the crushing strength of mortar and reduces shrinkage. When used in lime mortar, it assists the hardening of fat lime by allowing air to penetrate providing carbon dioxide for carbonisation.

Surkhi is used for economy and for furnishing hydraulic properties to lime mortar.

Flyash and cinders are used in lime mortar as fine aggregate in place of surkhi.

Molasses or gur is mixed with fat lime mortar; solubility of lime is increased

and it readily crystallises. Consequently the mortar solidifies easily. One part of molasses is used with 80 parts by weight of water used for mixing the fat lime.

Water in mortar lubricates the surfaces of aggregate, spreads the binding material uniformly so that it can fill the pores in the fine aggregate and cause hydration of cement and hydraulic lime. The pH value of water used should not be less than 6.

11.5 CEMENT MORTAR

Cement mortar can be prepared by mixing cement, sand and water in desired proportions. Portland cement and blast furnace slag cement form excellent mortars for walls from bricks, stones and large blocks. Puzzolana Portland cement and sulphate-resisting cement form mortar which are used for constructions exposed to aggressive and waste waters. Cement mortars are used for plastering, rendering smooth finishes and damp proof courses. The mix proportions are given in Table 11.1.

Table 11.1 Mix Proportions

S.No.	Type of Work	Cement	Sand
1.	Masonry	1	4-5
2.	Plastering (a) Interior	1	4
	(b) Exterior	1	5-6
3.	Pointing	1	3
4.	Reinforced brick work	1	3
5.	Foundation	1	3-4

Preparation Small quantities are mixed manually; mechanical mixers may be used for large quantities.

For manual mixing, sand is sieved, cleaned with water to remove dirt and dust and dried. This dry sand is laid uniformly, on a pucca platform, over which cement is uniformly spread. The whole mass is then thoroughly mixed with spades till it becomes uniform in colour. A depression is then made in the middle of the mix and required quantity of water is added. The dry mix from the sides is moved and placed on the edges of the depression formed till the water is completely absorbed by the mix. The wet mix is then worked with spades to give a uniform consistency to the mortar.

For mechanical mixing the calculated quantity of cement, sand and water are fed into the cylindrical container of the mixer. A rota with blades, inside the container, rotates and thoroughly mixes the ingredients. A typical Turbulent mortar mixer is shown in Fig. 11.1.

Precautions Cement mortar should be of uniform and workable consistency and consumed within 30 minutes from the instant of adding water to the mix. The bricks, stones and blocks should be fully saturated in water before laying. The masonry and plastered or pointed surface should be kept completely wet by sprinkling water for at least 7 days.

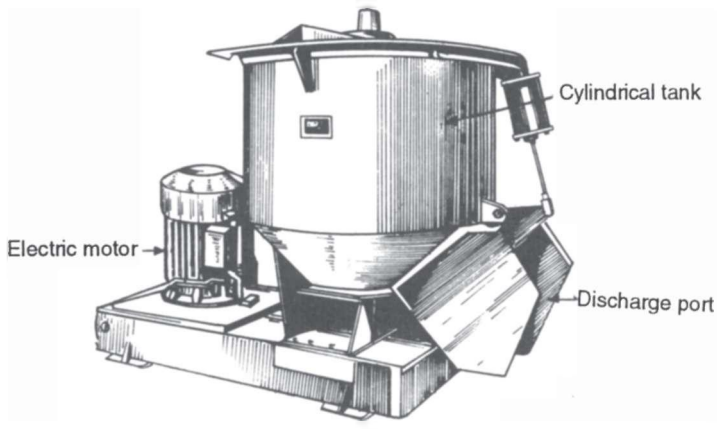


Fig. 11.1 Turbulent Mortar Mixer

Effect of Alkali Waters and Sea Water on Cement Mortar Neat cement may disintegrate by the combined chemical and mechanical action of waters containing salts. The sulphates and chlorides are chemically active and remove lime from the cement. The carbonate of soda alone or in solution with sodium chloride or sodium sulphate withdraws silica. Under the conditions of alternate wetting and drying this process is accelerated. Crystals of large sizes are formed and expansive forces are produced which disintegrate the neat cement paste. This effect is less pronounced in lean mortars.

Effect of Oil and Acids on Cement Mortar Well-cured cement mortars are not affected by oils. Lean mortars may develop less strength after 7 days when partially immersed in oil than when moist-cured for a month prior to immersion. The mortar surfaces soaked with oil show a marked reduction in abrasive resistance. When mineral oils are incorporated in the mixing water they retard the set of cement and reduce strength.

Animal and vegetable oils attack the lime compounds in the cement and form lime soap causing disintegration. Therefore, only mineral oils should be used for lubricating moulds.

For pH value less than 7 water removes the lime from cement in proportion to the decrease in the pH number and consequently the strength is reduced.

Effect of Sugar on Cement Mortar Up to 0.15 per cent of sugar added to cement delays the setting time and destrðys the early strength. However, when added up to 2 per cent, it increases the strength at an age of 2 to 3 months. The action of sugar is attributed to the formation of a soluble calcium saccharate ($C_{12}H_{22}O_{11}\cdot CaO + 2H_2O$).

Effect of Low and High Temperatures on Cement Mortar The rate of setting of cement falls for temperature falling below 4.5°C. When the temperature falls below freezing the particles of cement in unset cement paste separate by the expansion of water. Alterations in freezing and thawing before set break the bond between cement particles and consequently there is loss of power. If binding cement freezes before setting but thaws without refreezing, it achieves half the normal strength under proper curing.

Considerable chemical activity is noticed in neat cement paste when setting at – 18°C. At such low temperatures neat cement paste gains strength at a very slow rate but develops a high proportion of its normal value after several years. Cement paste hardening at room temperature attains higher strength than when allowed to harden for a like period after exposure to freezing temperatures.

Effect of Premixing and Retempering Cement Mortar Only half of the cement grains are hydrated by water in ordinary cement paste. The powder obtained by crushing and grinding neat cement briquettes has cementitious properties, and briquettes made after a second regrinding possess a low strength. The strength is found to reduce in proportion to the increase in water/cement ratio caused by retempering.

11.6 LIME MORTAR

Lime mortar is made by mixing lime, sand and water. Lime used for mortar may be fat lime (quick or hydrated lime) or hydraulic lime. Fat lime has high calcium oxide content. Its hardening depends on loss of water and absorption of carbon dioxide from the atmosphere and possible recrystallisation in due course. Hydrated lime is a dry powder obtained by treating quick lime with just sufficient water to satisfy the chemical affinity of lime for water under the conditions of its hydration. Hydraulic lime contains silica, alumina and iron oxide in small quantities. When mixed with water it forms putty or mortar having the property of setting and hardening under water.

Slaked fat lime is used to prepare mortar for plastering, while hydraulic lime is used for masonry construction and are most suitable for construction of chimneys and lightly loaded superstructure of buildings. The mix proportions of lime mortar for various types of works are given in Table 11.2.

Table 11.2 Mix Proportions

S.No.	Type of lime	Lime	Sand	Fineness modulus of sand	Type of work
1.	Fat Lime	1-2	2-3	2-3	Plastering
		1.5	2-3	2-3	Pointing
2.	Hydraulic	2-3	1.5-2.5	1.5-2.5	Masonry

Note: Sand in lime mortar is an adulterant, and reduces its shrinkage. Lime mortar becomes porous allowing air to penetrate and helps the mortar in hardening.

Lime mortars have high plasticity and placability, good cohesion with other surfacing and little shrinkage. They harden and develop strength very slowly continuously gaining strength over long period. Lime mortars do not set but stiffen only as water is lost by absorption (by masonry units) and evaporation. The gain in strength is a very slow reaction of lime with carbon dioxide absorbed from air.

Preparation

Manual Mixing Lime and sand in required quantities are placed on an impervious floor or in a tank (Fig. 11.2). The constituents are thoroughly mixed dry by turning them up and down with spades. Water is added and mixing is done again with spades till mortar of uniform colour and consistency is obtained.

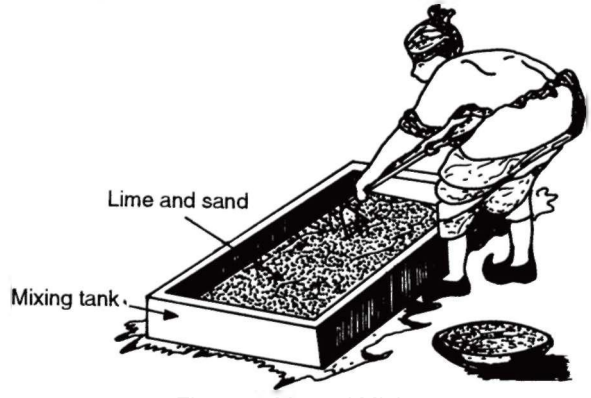


Fig. 11.2 Manual Mixing

Mill Mixing Mills used for preparing lime mortars in undeveloped countries may be a *chakki* or *ghanni* run by bullocks (Fig. 11.3) while a pan mill (Fig. 11.4) is used in developed countries. In the case of ghanni the required quantity of ingredients in the form of putty is put in the trench and grinding for 100 to 200 revolutions is carried out by moving stone roller. The operation takes about 2 to 3 hours for each batch of mix; the time required in a Pan mill is much less.

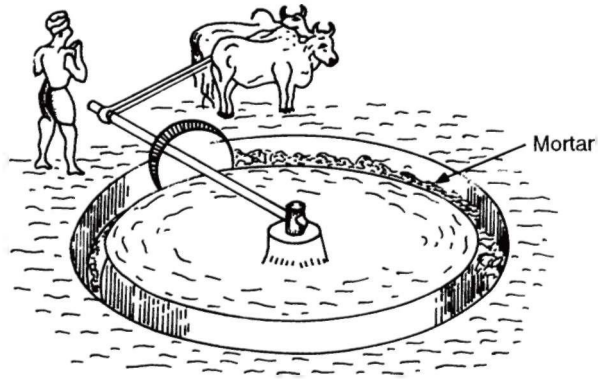


Fig. 11.3 Bullock Driven Motar Mill (Ghanni)

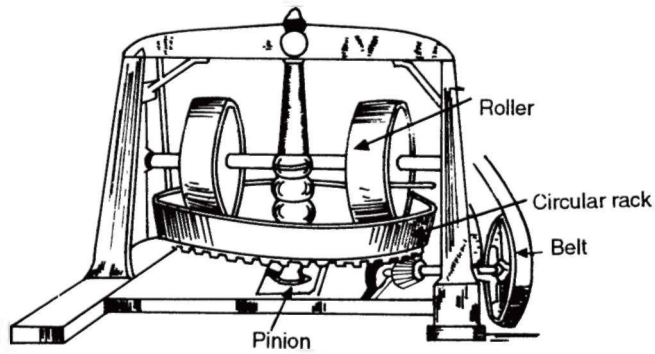


Fig. 11.4 Power Driven Motor Mill (Pan Mill)

Precautions Lime mortar or putty should be kept moist till use and in no case its drying is allowed. The mortar made of hydraulic lime should be consumed within one day and that with fat lime within 2-3 days.

11.7 SURKHI MORTAR

It is prepared in the same way as lime mortar, with surkhi replacing sand. Surkhi should be ground to pass through 4.75 mm sieve and about less than 15 per cent through 150 micron sieve. Sand is also mixed sometimes. The mix proportions are given in Table 11.3.

Table 11.3 Mix Proportions

S.No.	Type of Mortar	Lime	Surkhi	Sand	Type of work
1.	Surkhi	1	2	-	Masonry and foundation
2.	Lime-surkhi	1	1	1	Masonry and foundation

11.8 LIME-CEMENT MORTAR

Also known as *guarded mortar* it is made from cement and lime. The advantages of lime-cement mortar are increased water retentivity, workability, bonding properties and frost resistance. The mortar gives good and smooth plaster finish and is used in buildings.

Preparation For low lime content, cement and sand are first mixed dry. Lime putty is dissolved in water and added to the dry mix. The mix is then worked thoroughly with spades till uniform consistency is obtained. For high lime content lime mortar is made in the mills; lime and sand are first mixed separately in the form of paste for the entire day's requirement. Then cement is mixed with lime mortar in batches to be consumed in an hours time. The mix proportions are given in Table 11.4.

Table 11.4 Mix Proportions

S.No.	Location	Ratio (by volume) Cement	Lime	Sand
1.	Outside wall	1	1	6
		1	2	9
2.	Inside wall	1	2	9
		1	3	12

11.9 MUD MORTAR

They are the cheapest type of mortar prepared with locally available ingredients and are used for masonry works, surfacing floors and plastering wall surfaces in low cost houses. To improve resistance to rain water, the plastered surfaces are sometimes sprayed with bituminous material.

Preparation The top 150 to 200 mm layer of earth is removed and the clay nodules dug from the ground are wetted and allowed to mature for a day or two. Some fibrous material such as cow dung is added which prevents the shrinkage cracks. The ingredients are then kneaded well and mixed thoroughly.

Note : Sometimes clay is added to cement mortar to increase its workability. The grain composition and the water retaining ability of mortar also increases. However, cement-clay proportion should not exceed 1:1. These mortars show high frost resistance and better strength than cement-sand mortar.

11.10 SPECIAL MORTARS

Some of the mortars intended for use under special circumstances are as follows :

Mortars for Filling Joints between Prefabricated Reinforced Concrete Components Prepared with Portland cement and quartz sand with a mobility of 70 to 80 mm the grade of the mortar should be same as that of the concrete and in no case less than M-10.

Cement-sand and cement paste injection mortars intended for filling grooves inside prestressed concrete components should have a grade not less than M-30, usually M-40 grade or more is preferred. Sulphite-alcohol vinasse or naphetene soap is added in amounts up to 0.2 per cent of the weight of cement to reduce viscosity.

Packing Mortars Used for packing oil wells these mortars may be of cement-sand, cement-loam and cement-sand-loam. Slag Portland cement, puzzolana and sulphate resisting cements are used for aggressive water and packing Portland cement when water pressure is expected. These mortars should have high homogeneity, water resistance, predetermined setting time, adequate water yield under pressure and ability to form soil water-proof plugs in cracks and voids of rocks. Cement-sand-loam mortar with 5 per cent calcium chloride is especially suitable for tunnelling.

Damp-proofing Mortars are prepared using high grade sulphate-resisting Portland cement or sulphate-resisting puzzolana cement as binding material and quartz sand or sand from crushed solid rock. An approximate composition of the mortar is 1:2.5 or 1:3.5. Water proof seams and joints are made from damp-proofing mortars prepared with expanding cement.

Sound-absorbing Mortars are prepared with Portland cement, slag cement, lime or gypsum as binding material, caustic magnesite and single-size fraction sand (3.5 mm) from light weight porous materials such as pumice, cinders, ceramsite, etc. They have a bulk density of 6-12 kN/m^3 and are used as sound absorbing plaster to reduce the noise level.

Fire-shielding Mortars are used for setting refractory bricks in the furnace linings where the temperature is too high for ordinary mortars. Aluminous cements and finely powdered fire bricks in the ratio 1:2 give excellent fire resisting mortars. Its trade name is Accoset 50.

X-ray Shielding Mortars Heavy mortars of bulk density over 22 kN/m^3 are required for plastering walls and ceilings of X-ray cabinets. The binding materials are Portland cement and slag cement, and the aggregates are from heavy rocks in the form of sand (up to 1.25 mm) and dust. Admixtures containing light weight elements (hydrogen, lithium, cadmium) are added to enhance the protective properties.

11.11 TESTING

The mortars are tested for their quality by the crushing strength, soundness initial and final setting time tests as discussed in Sec. 5.9 and Sec. 10.7. The crushing strength of some of the mortars is given in Table 11.5.

Table 11.5 Permissible strength of Brick Masonry

S.No.	Type of Mortar	Mix proportion (N/mm^2)	Permissible strength
1.	Cement	1 : 3	0.75
2.	Cement	1 : 6	0.45
3.	Lime	1 : 3	0.45
4.	Cement-Lime	1 ; 1 ; 6 or 1 : 1 : 9	0.50

11.12 GROUT

Cement mortar of fluid consistency used to fill the voids and joints in masonry and to repair the cracks is known as grout. Also used to increase the bearing capacity of soil by injection. Grout finds extensive use in dams — to fill the cracks formed after the concrete sets and hardens; spaces between tunnel walls and the surrounding earth — to spread the earth stresses uniformly over the structures and; hollow concrete blocks — to develop bond between steel reinforcement and concrete.

Grout differs from mortar in its fluidity as it is to be poured and not spread into place with trowel. It is essentially composed of cement, fine or coarse sand, water, and a small amount (if any) of grouting admixture. The water/cement ratio should be kept as low as possible to increase the strength and reduce the shrinkage. This may necessitate use of admixtures, e.g. accelerators, retarders, gas forming and workability agents. Accelerators such as calcium chloride or triethanolamine are used to reduce the setting time in situations where plugging effect is desired. When the grout is to be pumped, the retarders or gas forming agents like mucic acid, gypsum are used. Gas forming agents, e.g. aluminium powder is used while grouting in confined areas as under the base of a machine. Workability agents like flyash, bentonite clay, diatomaceous earth, etc. are used as water reducing admixtures.

For wide cracks the grout is poured under pressure or pumped in the cracks. After the crack is filled, pressure is maintained for a few minutes to ensure satisfactory penetration. For finer cracks, chemical grouts are used. These consist of solution of two or more chemicals forming a gel or precipitate and can be successfully used even in the moist environment. The properties of cement grout are given as follows:

1. Compressive strength — 20-70 N/mm^2
2. Elastic modulus (compression) — 20-30 GPa

3. Tensile strength	15-35 N/mm^2
4. Flexural strength	2-5 N/mm^2
5. Linear coefficient of thermal expansion	(7-12) x 10^{-6} /°C
6. Water absorption (7 days)	5-12 %
7. Development of strength	7-28 days

11.13 GUNITING

The application of mortar or concrete under pneumatic pressure through a cement gun is known as guniting; concrete becomes extremely strong and a high bond is achieved.

The gunite may be defined as mortar comprising cement and sand conveyed through an equipment known as gun. It is pneumatically forced, on a backing surface, through a nozzle where water is added at a high velocity. The mix leaving the nozzle at a high velocity strikes the surface to be repaired or protected. In the process the coarser particles rebound from the surface and leave an excellent bond coat of fine grout in intimate contact with the backing surface. In the process a thin layer of grout builds up and acts like a cushion reducing the percentage rebound in the successive layers. The composition of the material deposited on the backing surface has been found to be different from that of the mix leaving the gun because of more of the coarse materials in the rebound material. Table 11.6 gives the proportions in place for various mixes for optimum nozzle velocity.

Table 11.6 Proportion of gunite mixes

Nominal mix placed in the gun Cement : Sand	Mix in place Cement : Sand
1 : 3	1 : 2.0
1 : 3.5	1 : 2.8
1 : 4.0	1 : 3.1
1 : 4.5	1 : 3.3
1 : 5.0	1 : 3.6
1 : 6.0	1 : 4.1

In the application of gunite rebound becomes the most important consideration as it affects the economy. Approximate values of rebound for different working conditions are listed below.

Basements	30%
Vertical walls	40%
Beam sides and bottoms	55%
Overhead slabs	50%
Columns	65%

The impact caused by the jet force compacts the material. A comparatively dry mix is preferred for guniting as the material will support itself without sagging even for vertical and overhead applications. The guniting is done in layers of 40-50 mm. After the first layer is applied and has set initially, all the loose material and laitance is removed by brooming, sand blasting or water jetting. The surface is then sounded by hammer to locate dummy areas resulting from lack of bond or rebound pockets. These pockets are cut and replaced during placing of the next layer. A good well compacted gunite cured for 28 days gives a compressive strength as high as 42 N/mm^2. The average unit weight of gunite is 23 N/m^3. Curing is done for seven days.

Uses : Gunite can be employed for construction of thin sections, e.g. folded plates, shells and thin walls; linings for tunnels and swimming pools; repairing of deteriorated concrete damaged by fire, earthquake, chemicals and in hydraulic structures; strengthening buildings, bridges and jetties; stabilizing rocks and earth slopes; protective coatings over prestressing wires and steel pipes and; to furnish rough surface texture from architectural point of view. Pneumatic guniting is also used for refractory castables.

Precautions

1. If the air or water pressure fluctuates a certain amount of a too dry or a too wet mix will be applied leaving a spotty appearance. The water pressure should be kept 0.45– 0.675 N/mm^2 higher than air pressure.
2. The backing surface should be thoroughly cleaned. For concrete and masonry surfaces cleaning is followed by wetting and damp drying.
3. The guniting should start from the bottom for walls. The first gunite layer should embed the reinforcement completely. The distance of the nozzle from the backing surface should be 0.6-1.5 m.
4. The nozzle velocity should not be more than 140 m/s. At higher velocities the material particles in the nozzle interfere with rebound material and result in a porous mass of lower strength.
5. The thickness of gunite should not be less than 40 mm for repairing of structures.
6. The rebound material should not be reused.

11.14 PLASTERING

Plastering mortars are prepared with cement, lime, cement-lime, gypsum and gypsum-lime as binding materials. Also known as *finishing* mortars. They are applied over the masonry and concrete surfaces to hide the manufacturing and construction defects besides improved appearance. Plastering mortars should have adequate mobility, good

cohesiveness with the surface over which applied and small volumetric variations to avoid cracking. High mobility can be obtained by using organic plasticizers. Gypsum mortars set and harden rapidly which is overcome by the use of retarders.

The surface to be plastered is brushed and broomed. To provide a key to the plaster all the masonry joints are raked when the applied mortar is still not set. The surface to be plastered is wetted before the application of mortar except for mud mortar.

11.15 POINTING

Sometimes the masonry surface is not plastered from architectural considerations and the joints are raked out to a depth of 12.5 mm with a rich mortar. The ratio of cement sand mortar used is 1:1. Some of the types of pointed joints are shown in Fig.11.5.

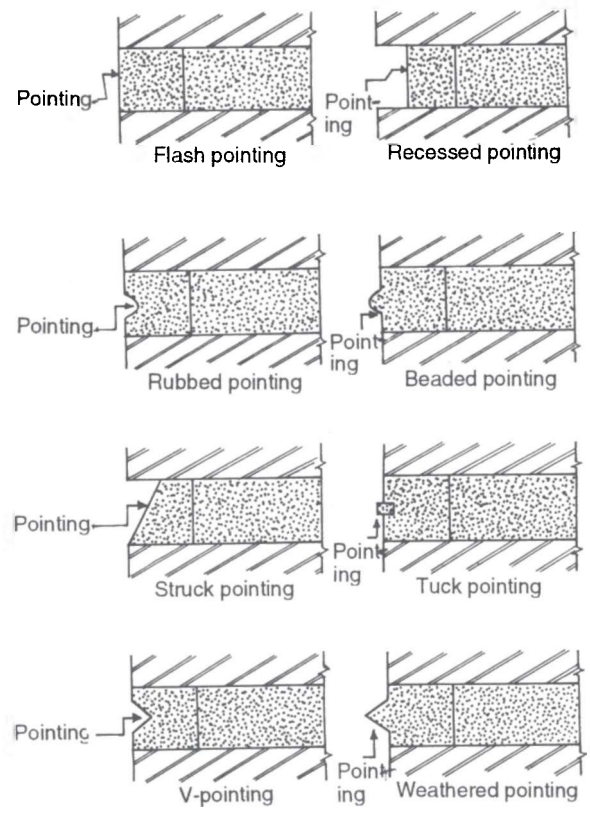


Fig. 11.5 Types of Pointings

EXERCISES

Q.1 What is mortar ? Briefly describe the various types of mortars.

Q.2 (a) Describe the process of making lime mortar.
(b) State the functions of sand in mortar.
(c) What proportions of mortar will you recommend in the following cases:
1. Lime concrete in foundation, 2. Brick work in foundation.

Q.3 (a) What are the functions of sand, surkhi and water in mortar ?
(b) Under what conditions will you recommend cement mortar over lime mortar for masonry.
(c) What is the effect of clay in mortar ?

Q.4 (a) Describe briefly the method of preparing lime mortar.
(b) Why are lime mortars ground and why cement mortars are not ground ?
(c) How can mortar be made water proof ?

Q.5 What are the different types of mortars used for engineering works ? State the composition and function of each.

Q.6 (a) What are the advantages of adding surkhi to lime mortar ?
(b) Describe the procedure of preparing cement mortar.
(c) What are the precautions to be exercised while using mortars ?

Q.7 What do you understand by
(a) Grout (b) Gauged mortar
(c) Guniting (d) Pointing

Q.8 Give the reasons:
(a)Why are bricks and stones soaked with water before they are laid in cement mortar ?
(b) Why are molasses used in mortar ?
(c) Why is sand added to mortar ?
(d) Why is puzzolana added to mortar ?
(e) Why is it necessary to cure mortar ?

Q.9 Write short notes on:
(a) Lime mortar (b) Lime-surkhi mortar (c) Cement mortar

Q.10 (a) What are the essential properties of lime mortar ?
(b) How and why the grinding of lime mortar is done ?
(c) State the tests conducted for quality acceptance of mortars.

Q.11 What types of mortars will you recommend under the following situations? Give reasons for your selection. Also write the proportions of the ingredients:
(a) Masonry in foundation (b) Plastering interior of a house
(c) Foundation work (d) Pointing

Q12. What is pointing ? What are the various types ? Which type of pointing will you recommend for following works ?
(a) Exposed brick work of your college building.
(b) Exposed stone work of a residential building.

Chapter

12

FERROUS METALS

12.1 INTRODUCTION

Metals are aiming the most useful building materials. They exist in nature as compounds like oxides, carbonates, sulphides and phosphates and are known as ores. Metals are derived from ores by removing the impurities. Those used for engineering purposes are classified as ferrous metals, with iron as the main constituent, e.g. cast iron, wrought iron and steel and others like aluminium, copper, zinc, lead and tin in which the main constituent is not iron as non ferrous metals.

12.2 STRUCTURES OF FERROUS METAL

Iron is a pure element occurring in four different allotropic structures as alpha, beta, delta, and gamma iron. Of these the common commercial forms are gamma iron with its fcc (face-centered cubic) structure (formed at temperatures from 1394°C to 912°C), and alpha iron which has bcc (body-centered cubic) structure (formed at temperatures from 912°C to 273°C). The delta form is commercially unimportant.

Gamma iron containing carbon, is called austenitic and alpha iron containing carbon, is called ferritic. The other steel alloys having same gamma structures are also called austenitic. Similarly alloys having alpha structure are called ferritic.

Even the closed-packed metallic structures contain empty spaces (holes),

assume atoms to be spherical. About 26 per cent of the volume is empty in the fcc metallic structures and about 29 per cent of the bcc volume is empty. The holes in the gamma iron are nearly half the diameter of the carbon atom, causing the solubility of carbon to be practically zero in austenite iron. However, in alpha iron the holes are comparable to the size of carbon atom, allowing an interstitial solubility of about 2 per cent carbon austenite iron. Thus the number of available spaces and the relative size of carbon atom limits the amount of latter to dissolve in the solid solutions and form the useful kinds of carbon alloys.

12.3 IRON

Iron does not freely occur in nature. The iron content of the main ores are as follows:

Magnetite (Fe_3O_4) — 70-75%,

Haematite (Fe_2O_3) — 70% ,

Limonite ($2Fe_2O_3 \cdot 3H_2O$) — 60%, it is hydrated haematite,

Iron pyrite (FeS_3) — 47%, and

Siderite ($FeCO_3$) — 40%

12.4 PIG IRON

The iron ore is dressed by crushing it to about 50 mm cubes. The impurities are knocked off and the ore is then calcined to drive off moisture. The calcined ore is smelted in blast furnance (Fig. 12.1). The iron is deoxidised and a part of sulphur is also removed. Then limestone, which acts as flux*, is added to finally remove the sulphur. The molten metal is tapped from the furnance and is cast in the form of pigs.

Classification

Pig iron is classified as Bessemer pig, foundry pig, forge pig, and mottled pig.

Bessemer pig derives its name because of its use in the manufacture of steel by Bessemer process using haematite ore. Impurities such as sulphur, phosphorus and copper are not desirable in the Bessemer pig. Foundry pig, also known as grey *pig*, contains sufficient quantity of free carbon and is produced when the furnace is provided with sufficient fuel. When fuel provided is insufficient and if sufficient sulphur is present in the ore forge pig is produced. This is also known as *white* pig.

** Flux is a mineral substance charged into blast furnance to lower the melting point of the ore and to remove impurities such as ash, sulphur, etc. It combines with the ashes of the fuel and the impurities of the ore to form fusible products which separate from the metal as slag.*

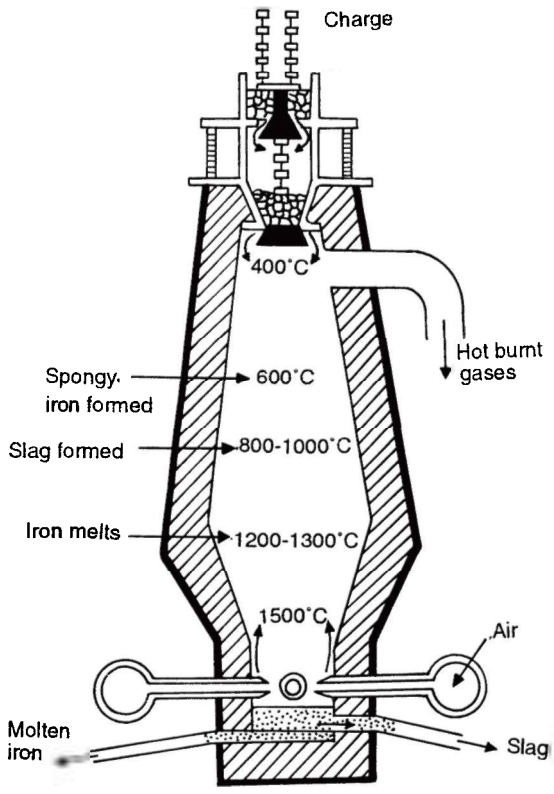


Fig. 12.1 Blast Furnance for the Manufacture of Pig Iron

Mottled pig is in between the grey and white varieties. They exhibit mottled fracture.

Composition

Pig iron contains 3-4% carbon, 0.5-3.5% silicon, 0.5-2% manganese, 0.02-0.1% sulphur and 0.03-1% phosphorous.

Properties

Pig iron is hard and brittle with fusion temperature of 1200°C and melts easily. It can be hardened but cannot be tempered and magnetised. Its compressive strength is high but is weak in tension and shear. Pig iron does not rust and cannot be riveted or welded.

Uses

Pig iron is most suitable for making columns, base plates, door brackets, etc.

12.5 CAST IRON

Pig iron is remelted with limestone (flux) and coke and refined in Cupola furnance (Fig. 12.2). It is then poured into moulds of desired size and shape. The product is known as cast iron containing about 2-4% of carbon in two forms, i.e. as the compound cementite — in a state of chemical combination, and as free carbon — in a state of mechanical mixture. Carbon in the first form is called combined carbon, and graphite in the latter form. The quality of cast iron thus depends upon the state in which carbon exists in it.

Methods of Casting

Sand Casting The most common casting procedure involves pouring molten metal into a cavity in a mass of packed sand. Wooden patterns are used for moulds which are removed when the sand has dried. Each mould has a hole for casting through which the molten iron is poured. Air and hot gases escape through another hole. Cast material is taken out by breaking the mould after iron cools down.

Hollow Casting is used for making columns and piles. For hollow casting of the objects a solid core is placed where the hollow is to be maintained. After casting the core and mould are taken out. Cast material becomes hollow due to the core.

Vertical Sand Casting The mould box and the solid core is kept in vertical position. After cooling the core is taken out by crane. Good quality pipes can be obtained by this method.

Centrifugal Casting Many blow holes are left in ordinary casting because of little control over temperature and the sand mould. The problem is overcome by centrifugal casting. Molten material is poured in a revolving metallic cylindrical mould in a controlled manner, rotating at the rate of 10,000 revolutions per minute. Large diameter pipes, gun barrels, etc. are cast by this method. The castings are dense and have a fine-grained structure with uniform and high physical properties. They are least subjected to directional variations on properties than static castings.

Die Casting Die casting is cheap for commercial production. Casting is done under pressure, which may be as high as 140 MN/mm^2, into a split die cavity. Since the die is water cooled, the molten metal solidifies quickly, permitting early removal of the casting.

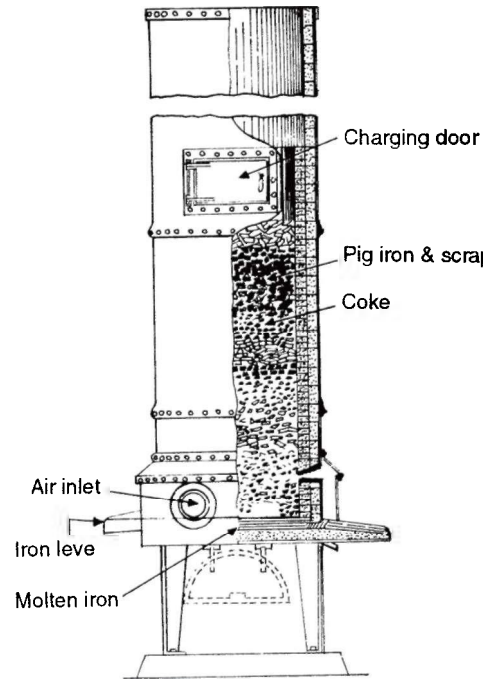


Fig. 12.2 Cupola Furnace for Manufacture of Cast Iron

Classification

Cast iron is classified as grey, white, malleable, mottled, chilled and toughened, and is described in Table 12.1.

12.1 Classification of Cast Iron

Type	Properties	Composition (%)		Uses
Grey	Obtained from foundry pig Good machinability Low melting point (1200°C) Rusts easily in air Readily acted upon by acids Grey in colour	Carbon Silicon Manganese Sulphur Phosphorous	2.50-3.75 1.0-2.0 0.40-1.0 0.06-0.12 0.10-1.00	Pipes, fittings, locomotive wheels, machinebeds
White	Hard and brittle Can hardly be machined White slivery colour	Carbon (C) Silicon (Si) Manganese (Mn) Phosphorous (P) Sulphur (S)	1.75-2.3 0.5-0.9 0.15-0.5 0.20-0.70 0.15-0.25	In the manufacture of malleable iron, wrought iron
Malleable	Obtained by partial removal of carbon, silicon, phosphorus, sulphu and manganese from cast iron. Soft and strong Available as white hearth and back hearth varieties	White Hearth C 3.2-3.6 Si 0.4-0.9 P 0.1	Black Hearth 2.2-2.8 0.7-1.1 0.1	Automobile, agricultural equipments, rail-road engineering
Mottled	Made by heating cast iron with powdered haematite to redness, High toughness Fractured surface shows grey and white patches			Small castings
Chilled	Made by cooling cast iron rapidly causing the outer layer of the product to become hard			Roller mills, grinding mills, cylinders, pistons, spoked wheels for railways, guide rails, crossings in railways
Toughened	Produced by melting cast iron with ¼-½ of its weight of wrought iron scrap.			

Properties

Cast iron is hard and brittle. It can neither be riveted nor welded. It is strong in compression (600 N/mm^2) but weak in tension (150 N/mm^2) and shear. Its specific gravity is 7.50. It has low melting point (1200°C) and is affected by sea water. It cannot be magnetized and is not suitable for forging. Iron containing large amounts of manganese and chromium are likely to be permanently white, while those having a high silicon content are grey. With proper adjustment in composition, cast iron may be rendered white by cooling rapidly or grey by cooling slowly from the molten state.

Effect of Impurities

Carbon The proportion of carbon and its form more or less influence most of the physical and mechanical properties of cast iron. The melting temperature of cast iron is reduced as the carbon content or the percentage of combined carbon is increased. Consequently white cast iron has a lower melting point than grey cast iron. Shrinkage varies inversely as the carbon content.

Silicon In small percentages silicon increases the fluidity of the molten iron, decreases blow holes and increases the density of castings. It also reduces the solubility of carbon in iron and shrinkage. When silicon is increased up to 6 per cent the iron becomes hard and has a mirror-like fracture.

Sulphur Sulphur is an undesirable element in cast iron and is limited to less than 0.1 per cent. It combines with manganese to form the sulphide (MnS) or, if the manganese is very low and not sufficient to satisfy the sulphur. Since these sulphides solidify at considerably lower temperatures, than cast iron, they tend to make castings brittle and weak at higher temperatures. High sulphur content also increases shrinkage and causes hard, brittle iron. These may be neutralized by proper additions of silicon.

Phosphorus When phosphorus is less than 0.5 per cent, it has no marked effect on cast iron. If more than 2 per cent, the iron is embrittled and strength diminished. High phosphorus irons are much more fluid and shrink less, which make them suitable for ornamental castings.

Manganese When present in range of 0.4-1.2%, manganese combines with sulphur, and — having satisfied sulphur — with carbon to form manganese carbide. Manganese increases the solubility of carbon in iron and opposes the liberation of graphite. High percentage of manganese increases shrinkage and hardness. Thus in grey iron which is to be machined manganese should be kept low.

Uses

Cast iron is used to make ornamental castings such as wall brackets, lamp posts; bath room fittings such as cisterns, water pipes, sewers, manhole covers, sanitary

fittings and; rail chairs, carriage wheels and machine parts subjected to shocks. It is used as basic material for manufacturing wrought iron and mild steel.

Defects

Checks, segregation, blow holes and coarse grain originate the cooling of the castings. Irons with high sulphur content are liable to have small cracks running transverse to longitudinal axis, called *checks*, due to greater shrinkage and lack of strength. Segregation is pronounced in high phosphorous iron. Carbon and silicon sometimes segregate in such manner that interior portions of the metal are white and exterior parts are grey rendering it difficult to machine the casting. *Blow holes* are caused due to improper venting of the mould or to a high proportion of sulphur. A *coarse* or *open grain* in the iron is caused by too slow cooling, or it may be due to a very high phosphorous content. *Spongy spots* (the exaggerated forms of open grains) and *cold shuts* — faults planes in the metal produced by the solidification of part of the casting before the remaining molten metal was run into place — result from lack of fluidity in the iron or from improper grating.

12.6 WROUGHT IRON

Wrought iron considered to be pure iron, is produced by removing the impurities of cast iron. The total impurities are limited to 0.5 per cent with a maximum percentage of carbon as 0.15, silicon 0.15-0.2%, phosphorous 0.12-0.16%, sulphur 0.02- 0.03% and manganese 0.03-0.1%. It is manufactured in reverberatory or puddling furnance (Fig. 12.3) by Astor's process. The molten iron is first refined by blasting air in the furnance. The metal is cooled and poured into moulds. The metal becomes brittle. It is then melted in reverberatory furnance where iron melts due to burning of gas. After melting, puddle balls are produced which are sent for shingling. Here the balls are formed as bloom. The bloom is sent to grooved rollers to form flat bars. The process is repeated several times to remove the impurities.

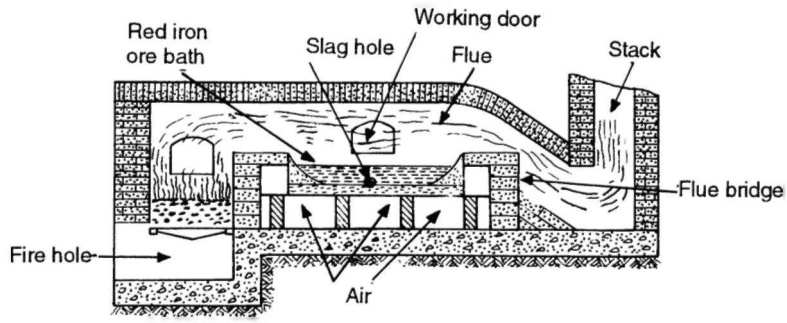


Fig. 12.3 Puddling Furnace for Manufacture of Wrought Iron

Properties

Wrought iron is ductile, malleable, tough and moderately elastic. Its ultimate crushing strength is 200 N/mm^2 and ultimate tensile strength is 40 N/mm^2. Transverse to the direction of the rolling the tensile strength ranges from 60 to 85 per cent of its strength parallel to this direction. The modulus of elasticity of wrought iron is 1.86×10^5 N/mm^2. The melting point of wrought iron is 1500°C and sp. gr. about 7.80. It can be forged and welded. Wrought iron effectively resists corrosion. It is tough and withstands shocks and can neither be hardened nor tempered. At about 900°C wrought iron becomes so soft that its two pieces can be jointed by hammering.

Uses

Roof coverings, rivets, chains, ornamental iron works such as gates, etc. are made of wrought iron.

Defects

The harmful effects of sulphur and phosphorus appear to be less pronounced in wrought iron than in steel because of less opportunity for segregation in the puddling process. Furthermore, much of the impurities in wrought iron are affiliated with the slag rather than iron. However, a very high sulphur content (0.3-0.5%) is likely to cause the wrought iron to crumble or exhibit red shortness (Section 12.7 – Sulphur) in forging or welding. Sections rolled from red short wrought iron are likely to have rough edges. A phosphorus content of 0.4-0.5% causes the wrought iron to be cold short (iron becomes brittle at cold temperatures). Such wrought iron cannot be refined by heat treatment. Spilly places, the defect due to burning of portions of the iron in puddling, are often found as spongy spots in wrought iron sheets and plates. Blisters are also found on plates and sheets of inferior wrought iron due to the oxidation of carbon in the iron by the oxide of iron in the slag.

12.7 STEEL

Steel is the most suitable building material and is classified on the basis of carbon content as under

Type of steel	Carbon content (%)
Mild steel	0.15-0.3
Dead mild steel	< 0.15
Medium carbon steel	0.3-0.8
High carbon steel	0.8-1.5
	(> 1 is also called cast steel or tool steel)

Manufacturing Methods

The methods are :

1. Bessemer process
2. Cementation process
3. Crucible process
4. Open Hearth process
5. Electric Smelting process
6. Duplex process
7. Lintz and Donawitz (L.D.) process

The basic method is the Bessemer process. The pig iron is first melted in Cupola furnance and sent to Bessemer converter (Fig. 12.4). Blast of hot air is given to oxidize the carbon. Depending upon the requirement, some carbon and manganese is added to the converter and hot air is blasted once again. Then the molten material is poured into moulds to form ingots. L.D. process is modification of the Bessemer process in which there in no control over temperature. By this method steel can be made in hardly 25 minutes. In Open-hearth process also known as Siemen's-Martin process, the steel produced by this process is more homogeneous than by Bessemer's. The electric process is costly but no ash or smoke is produced. The Crucible process involves melting of blister steel or bars of wrought iron in fire clay crucibles. Cast steel so obtained is very hard and is used for making surgical equipments. The Duplex process is a combination of Acid Bessemer process and Basic Open-Hearth process.

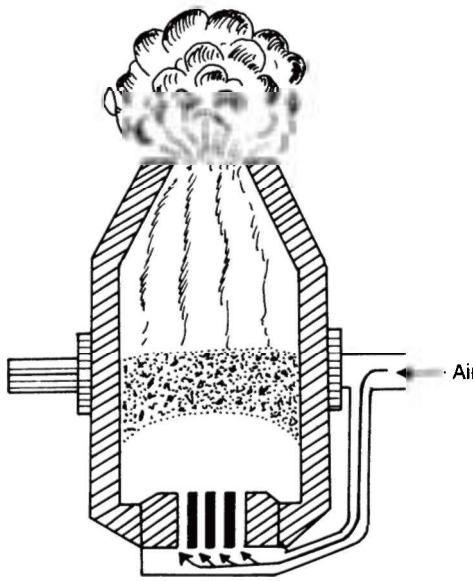


Fig. 12.4 Bessemer Converter for the Manufacture of Steel

Properties and Uses

Mild Steel Also known as low carbon or soft steel. It is ductile, malleable; tougher and more elastic than wrought iron. Mild steel can be forged and welded, difficult to temper and harden. It rusts quickly and can be permanently

magnetised. The properties are: sp. gr. = 7.30, ultimate compressive and tensile strengths 800-1200 N/mm^2 and 600-800 N/mm^2.

Mild steel is used in the form of rolled sections, reinforcing bars, roof coverings and sheet piles and in railway tracks.

High Carbon Steel The carbon content in high carbon steel varies from 0.55 to 1.50%. It is tougher and more elastic than mild steel. It can be forged and welded with difficulty. Its ultimate compressive and tensile strengths are 1350 N/mm^2 1400-2000 N/mm^2. Its sp. gr. is 7.90.

High carbon steel is used for reinforcing cement concrete and prestressed concrete members. It can take shocks and vibrations and is used for making tools and machine parts.

Properties of Steel

The factors influencing the properties of steel are chemical composition, heat treatment, and mechanical work.

Chemical Composition

The presence of carbon in steel gives high degree of hardness and strength. The addition of carbon to iron decreases the malleability and ductility of the metal, and reduces its permeability to magnetic forces.

The tensile strength of hot rolled steel bars is between 1.0 and 1.2 per cent carbon. The elastic limit and the ultimate strength of steel increase with carbon content but at a lower rate. The compressive strength of steel increases directly with carbon content up to 1.0 per cent. The shear strength of steel also increases with the carbon content. The modulus of elasticity is nearly same for tension and compression and is practically independent of the carbon content.

The ductility of steel decreases markedly as the carbon content increases. The resistance of steel to heavy shocks or blows decreases with increase of carbon content.

Effects of Principal Impurities on Steel It is not feasible to entirely remove impurities in making either iron or steel. The final product always contains small percentages of the metallic impurities like silicon, manganese, sulphur, and phosphorus besides iron and carbon. Occasionally small percentages of copper and arsenic are also present. In well made steel these impurities generally range between 0.2 and 1.0 per cent and their resultant effect on the constitution of steel is often small. Of the common impurities, phosphorous cannot be eliminated in the process of manufacture, whereas most of the silicon and manganese are introduced to improve the metal.

Silicon is often added to molten metal to remove oxygen and diminish blow holes. In structural steel it rarely exceeds 0.25 per cent. Silicon up to 1.75 per cent

appears to increase both ultimate strength and elastic limit without decreasing ductility.

Phosphorus is considered to promote enlargement of the grains and thus produce brittleness. The ductility of low-carbon steel decreases slightly by the presence of 0.3-0.5 per cent phosphorus. However, yield point, ultimate strength and hardness of steel are increased. Resistance to shock is also reduced by 0.1 per cent phosphorus and the metal is rendered cold short. A decrease in toughness appears to be more pronounced in high-carbon than in low-carbon steels. The maximum limits for phosphorus are : for inferior grades of structural steel 0.1, for best grades of structural steel 0.05, and 0.02 per cent for tool steels.

Sulphur Sulphur readily combines with iron to form iron sulphide (FeS) which, when present in iron or steel, has a tendency to segregate and form brittle networks at the grain boundaries. On account of its low melting point, iron sulphide causes lack of cohesion between adjacent grains when heated above a red heat. Such brittleness at high temperature is termed as *red shortness* which makes steel or iron hard to roll or forge. Manganese sulphide has a much higher melting point than iron sulphide and does not render ferrous metals red short. Therefore, inasmuch as manganese has a very powerful affinity for sulphur, it is possible to relieve red shortness by adding sufficient quantity of manganese to the molten metal to combine with sulphur. Theoretically the ratio of manganese to sulphur should be 1.70 to 1.0 in order to form manganese sulphide and completely satisfy sulphur. Less than 0.15 per cent sulphur content hardly exercises any appreciable effect on the mechanical properties of steel.

Manganese has strong affinity for oxygen and sulphur and acts as a cleanser of the molten metal by withdrawing much of the undesirable impurities into the slag. When more manganese is present than required for sulphur and oxygen the excess manganese forms carbide and acts as hardener.

Copper increases resistance to corrosion when present in small percentage.

Arsenic has a tendency to raise the strength and brittleness.

Non-metallic Impurities are mechanically suspended in the metal and are often called *slag inclusions* causing brittleness.

Heat Treatment

Heat treatment influences the solubility relations of the constituents, changes the crystallisation either with respect to form or degree of aggregation and introduces or relieves internal stresses in the metal.

Mechanical Work

Mechanical work may be hot or cold. It alters the form of the crystalline aggregate and introduces internal stresses. Cold rolling increases the tensile elastic limit from

15 to 97 per cent and tensile strength from 20 to 45 per cent. In elastic resilience the cold-rolled metal is superior to the hot-rolled, whereas in energy of rupture it is inferior to the hot-rolled metal. The modulus of elasticity is slightly increased by cold rolling.

12.8 DEFORMED STEEL BARS

Concrete being extremely weak in tension requires reinforcement which may be bamboo, fibres or steel. Steel reinforcement is available in the form of bars of specific diameters with different chemical composition — mild steel and high tensile steel, and surface characteristics — plain or deformed.

Plain mild steel bars have yield strength of 250 N/mm^2 and are designated as Fe 250. For bars up to 20 mm diameter the permissible tensile strength is 140 N/mm^2 and that for over 20 mm diameter is 130 N/mm^2.

The deformed bars are mild steel bars with surface lugs or ribs as shown in Fig. 12.5. The deformed surfaces ensure better bond between concrete and reinforcement. In addition when twisted hot or cold they result in a considerable increase in yield, tensile and bond strength. They are also known as high yield strength deformed (HYSD) bars. Yield stress and permissible tensile strength of HYSD bars are 415 N/mm^2 and 230 N/mm^2 respectively and are designated as Fe 415 HYSD For still higher tensile strength another form designated as Fe 500 HYSD has been developed having yield stress of 500 N/mm^2 and permissible tensile strength of 275 N/mm^2. The bond strength of HYSD bars is about 40 per cent more than that of plain mild steel bars.

Fig. 12.5 Deformed Bars

12.9 ALLOY STEEL

In general, the properties desired in a metal to be used as building material are not present to the best advantage in any single metal. To develop specific properties a combination of metals or metallic substances is done and are classed as alloys. Some of the alloys are listed in Table 12.2 along with their composition and suitability.

Table 12.2 Properties and Uses of Alloy Steels

S.No.	Alloy steel	Composition	Properties	Uses
1.	Stainless steel	Chromium 16%	Very hard and tough High elastic and ultimate strength Acid and rust proof	Ball bearings, dies, crushing machines, razors.
2.	Nickle steel	Nickel 3.5%	More elastic Higher tensile strength Lesser brittle than mild steel. Improved hardness and ductility	Automobile and airplane parts
3.	Invar steel	Nickel 30-40%	Low coefficient of thermal expansion	Delicate instruments
4.	Vanadium steel	Vanadium 0.1-2%	High tensile and yield strength It has resistance to softening at high temperatures	High speed tools, locomotive castings, autoparts, chessis
5.	Tungsten steel	Tungsten 14-20%	High cutting hardness Resistant to abrasion	Drilling machines,High speed tools
6.	Manganese steel	Manganese 12-15%	Hard, tough and strong Difficult to machine High electrical resistance	Points and crossing in railways, rollers, jaws of crushers, Heavy earth and mining equipments
7.	Molybdenum steel	Molybdenum 0.2-0.3%	Maintains tensile strength at high temperature	Gears, axles, shafts

EXERCISES

Q.1 (a) Name the ores required for making steel.
(b) What is pig iron? Describe how it is manufactured from iron ore.
(c) Describe briefly the manufacture of steel by open hearth process.

Q.2 (a) State the differences between mild steel, wrought iron, cast iron and cast steel.
(b) Give the properties and uses of stainless steel and high carbon steel.
(c) What are the different methods of castings? State their advantages and disadvantages ?

Q.3 What is the effect of carbon, sulphur, phosphorous and silicon on
(a) Steel (b) Cast iron (c) Wrought iron

Q.4 (a) Specify some important uses of cast iron, wrought iron and mild steel.
(b) What are the factors controlling composition and quality of steel ?
(c) What is alloy? Describe the properties and uses of some of the steel alloys.

Q.5 (a) What is meant by cold short and red short irons?
(b) What are the effects of different types of impurities in iron on its physical and mechanical properties?
(c) Briefly describe the defects of cast iron.

Q.6 What type of steel would you recommend in the following cases :
(a) Reinforcement in prestressed concrete and cement concrete.
(b) Cables of suspension bridge
(c) Bridge girder
(d) Springs
(e) Hammer

Q.7 Write short notes on the following:
(a) Puddling (b) Red shortness
(c) Grey cast iron (d) Bessemer pig iron

Q.8 State the carbon contents and uses of the following metals:
(a) Pig iron (b) Cast iron
(c) Wrought iron (d) Low-carbon steel

Q.9 (a) What is the difference between ferrous and non-ferrous metals?
(b) Name the various steel alloys and describe their properties and uses.

Q.10 (a) What are the various methods used for the manufacture of steel? Give the merits and demerits of each of them.
(b) Describe briefly the defects in steel.

Chapter

13

NON-FERROUS METALS

13.1 INTRODUCTION

Aluminium, copper, tin, zinc, lead and manganese are the chief constituents of non-ferrous alloys.

13.2 ALUMINIUM

The principal constituents of bauxite ($Al_2O_3 \cdot 2H_2O$) which yield aluminium on a commercial scale are hydrated oxides of aluminium and iron with some silica. Some of the other aluminium ores are corundum, kaolin or china clay, and kryolite. The ore is purified by Bayer's process and is reduced to aluminium by Hall Hiroult's process in two stages. In the first stage bauxite is converted into alumina by roasting, grinding, heating (with sodium hydrate) and filtering. Then it is agitated for several hours to precipitate the hydrate, which is separated, washed and calcined at 1000°C. In the next stage aluminium is extracted by electrolysis of alumina in a molten bath (Fig. 13.1) of crystolite (a fluoride of alumina and sodium). A flow diagram for extraction of aluminium is shown in Fig. 13.2.

Properties Aluminium is silver white in colour with a brittle metallic lustre on freshly broken surface. It is malleable, less ductile than copper but excels zinc, tin, and lead. Aluminium is harder than tin. Aluminium is very light, soft, strong and durable, has low thermal conductivity but is a good conductor of electricity. Aluminium can be riveted and welded, but cannot be soldered. It can be tempered at 350°C. The melting point is 657°C, tensile strength is 117.2 N/mm^2 in the cast form and 241.3 N/mm^2 when drawn into wires. Aluminium is found to be resistant

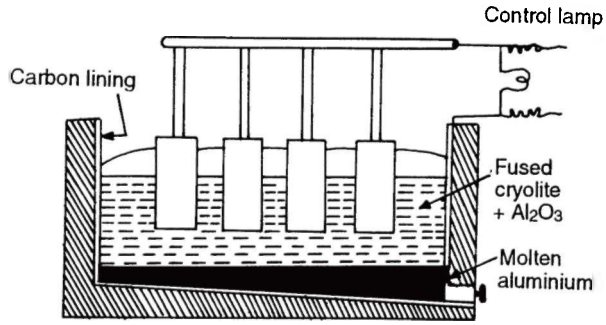


Fig. 13.1(a) Extraction of Aluminium by Electrolysis

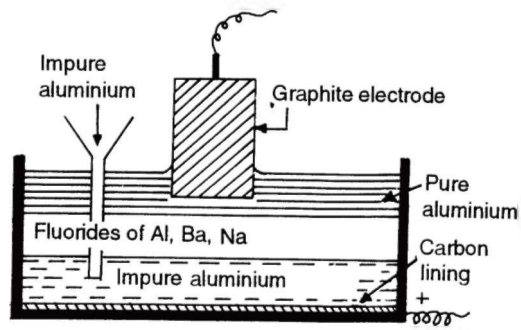


Fig. 13.1(b) Hoope's Cell for Refining Aluminium

to the attack of nitric acid, dissolves slowly in concentrated sulphuric acid and is soluble in hydrochloric acid. At normal temperature it is not affected by sulphur, carbonic acid, carbonic oxide, vinegar, sea water, etc. but is rapidly corroded by caustic alkalis.

Uses Pure aluminium is very soft and is unsuitable for structural purposes. Satisfactory properties are derived by alloying copper, manganese, zinc, silicon, nickel with aluminium. It is most suitable for making doors, window frames, railings of shops and corrugated sheets for roofing system. Aluminium sheets are used over doors in bathrooms to protect them from getting rot and for stamping into a variety of shapes. Aluminium powder is used for making paint. Aluminium is extensively used in making parts of internal combustion engine, airplanes, utensils and packings for medicines, chocolates, etc.

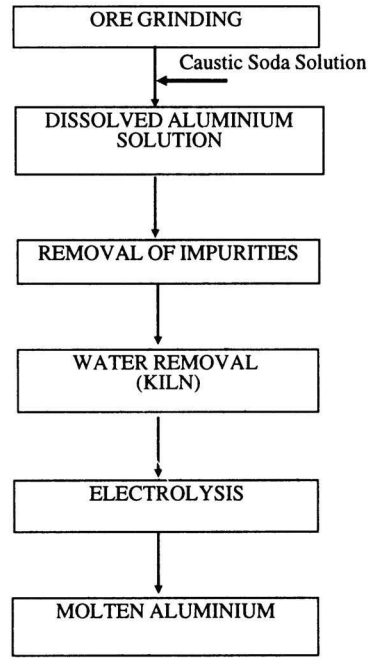


Fig. 13.2 Flow Diagram for Extraction of Aluminium

Alloys

Aluminium is commonly alloyed with copper or zinc to improve its mechanical properties. Following are some of the aluminium alloys.

Duralumin contains 3-5% copper, 0.5-1% magnesium and 0-0.07% manganese. 0.3-0.6% iron and 0.3%-0.6% silica are present as impurities. The relative density is 2.80, which is quite low as compared to that of mild steel. However, when rolled and heat treated tensile strength equals that of mild steel. Its yield point is 206.85 N/mm^2. It is highly resistant to corrosion. Wire and sheets are drawn from duralumin. It is fabricated into different structural shapes for construction.

Magnalium is an alloy of aluminium and magnesium (6 per cent). It has got very good mechanical properties and is a little lighter than pure aluminium. It is easy to work, exceptionally strong, and ductile and is widely used as deoxidizers in copper smelting operations.

Aldural When a coating of aluminium is given to duralumin it is known as aldural and has better corrosion resisting properties.

Y-alloy invented during World War II contains 4 per cent copper, 20 per cent nickel and 1.5 per cent magnesium. Toughness and hardness are achieved by heating it to 500°C for six hours and then cooling it down in boiled water. Its relative density is 2.80 and resists corrosion better than duralumin. Y-alloy has good thermal conductivity and can sustain high temperature. It is used for making pistons of I.C. engines, cylinder head, connecting rod and propeller blades.

Aluminium Bronze contains less than 11 per cent of aluminium and is rather inappropriately named. It is highly ductile when aluminium is less than 7.3 per cent. As the aluminium increases, ductility decreases and at 12 per cent the alloy is very brittle.

Bronzes containing less than 7.3 per cent aluminium are highly resistant to torsional stress, readily rolled, forged, cold drawn, exhibit toughness under impact and resistance to alternate bending stress.

The input of 1 per cent of manganese into 10 per cent aluminium bronze increases the yield point and ductility without change in strength or endurance under reversal of stress. The modulus of elasticity of aluminium bronze is about 1.03425×10^5 N/mm^2. These are almost incorrodible in sea water and in this respect are superior to Muntz metal or naval brass.

Light Alloy contains 3 per cent copper and 12 per cent zinc. It is used for castings such as crank and gear housings.

Aluminium Copper Alloy contains copper up to 4 per cent. Less liable to burning the alloy produces light castings that are stronger and tougher than that made from aluminium. It is mainly used in automobile industry for casting.

Aluminium Zinc Alloy contains zinc up to 15 per cent and is used for light casting which can be easily machined or forged into desired form. These are very sensitive to high temperatures in melting and in solid form exhibit low strength and brittleness when heated above 50°C. Alloys containing 15 to 25 per cent zinc are harder, stronger, but less ductile and more difficult to roll or draw. If percentage of zinc is increased above 25 the alloy suffers decrease in strength when excessively worked, either hot or cold. Aluminium zinc alloys have well defined yield points.

13.3 COPPER

Copper is extracted from ores, e.g. copper pyrite, such as, chalcopyrite ($CuFeS_2$, 34.5 per cent copper), malachite ($CuCO_3 + Cu(OH)_2$, 57.3 per cent copper) and copper glance (Cu_2S, 79.8 per cent copper). Nearly all the copper is extracted by smelting. After calcining the ore it is mixed with silica and coke. Then it is oxidized in Bessemer converter where removal of major portion of iron and sulphur compounds is effected. The crude copper thus produced is known as *blister copper* which is cast into small pigs. The blister copper contains many impurities and is

refined in the reverberatory furnance (Fig. 13.3) or by electrolysis.

In reverberatory furnance the sulphides are oxidized and the cuprous oxide exerts cleansing action on the base metals in the crude copper. A larger excess or a deficiency of cuprous oxide in the copper makes it weak and brittle which make it necessary to remove any excess which remains after the impurities have been skimmed off. This is achieved by the addition of charcoal and green wood to the bath. Fire refining imparts malleability, toughness and ductility. Electrolytic refining is used when pure grade copper is required for electrical purposes, and where there is a considerable quantity of gold or silver associated with the crude copper.

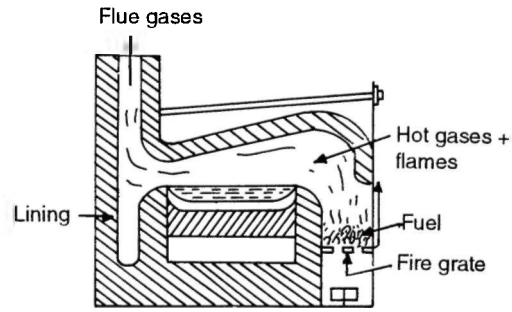


Fig. 13.3 Roasting of Copper-Pyrite Ore in Reverberatory Furnance

Properties Copper is a bright shining metal of reddish colour which turns greenish on exposure to weather. Copper is malleable and ductile and can be worked in hot and cold conditions. It is not weldable, except on red heat. It is soft and good conductor of heat and electricity. The electrical resistivity of copper having less than 0.1 per cent non-metallic impurities lies between 0.155-0.159 ohm per metre gram at 20°C. The resistivity increases with the content of impurities and with amount of wire drawing. Its tensile strength is high.

Uses Copper is extensively used for electrical purposes, tubes for condensers and for other conductors which must withstand corrosion. In buildings copper is used for roofing, sheeting and damp proofing. Its use is restricted in the appliances and connections used for water supplies in houses.

Alloys

Some of the important alloys made with copper are brass and bronze.

Brass is an alloy 60-90% copper and 10-40% zinc. The colour is silvery-white for low content of copper and copper-red for higher copper content.

Brass may be either cast or wrought. Brass for castings usually contains 30-40% zinc. Tin (2-3%) when added increases hardness but decreases ductility. An addition of about 2 per cent lead renders brass easy to turn, file and polish but ductility and strength are reduced. Aluminium (1-6%) when added raises the strength but decreases the ductility. Cast brasses are stronger and more ductile than either of their components, copper and zinc. Compared to copper its electrical conductivity is quite low.

The zinc content is 37-45% for brasses suitable for forging, rolling or extruding and hot working. Brasses used for extruding contain 2-4% lead to make them flow easily through dies. Lead, however, lessens the amount of reduction in working, which these alloys will withstand without cracking, makes the metal more susceptible to burning during melting. The brasses wrought into shape by cold working have copper to zinc ratio 2:1 and 3:1, the former being used for making sheets, wires and stamped and drawn articles.

Brasses with copper to zinc ratio 1:1 are used for brazing brass goods. They have a very high crushing strength but are too brittle for mechanical working.

Alloys containing 57-63% copper are called Muntz metals also known as yellow metals. Brasses are used for making bolts, rods, tubes and extruded shapes. Alloys having 70-75% copper are used for making cartridge cases, condenser tubes and spinning operations. With 80-85% copper the brasses take a good polish resembling gold and are used for making medals and artificial jewellry.

Manganese Bronze contains small percentage of tin (0.5-1.5%), iron (0.5-1.0%), manganese (< 0.5 per cent) and lead (< 0.2 per cent). On account of its high strength (551.6 N/mm^2 in tension), the facility with which it can be rolled or forged, and its resistance to salt water, manganese bronze is extensively used in marine engine, propeller blades and condenser tubes.

Naval Brass has same composition as that of manganese bronze except it does not contain manganese and iron. It is slightly weaker but more ductile than manganese bronze.

Sterro Metal is brass containing 38 per cent zinc and 1.5-2.0% iron and copper, used for hydraulic cylinders working under heavy pressure.

Delta Metal contains 50-65% copper, 50-30% zinc, 0.1-5% iron and 0.1-1% tin and is as strong as mild steel having a tensile strength of 413.7-551.6 N/mm^2.

Bronze is an alloy of copper and tin with one or more additional metal. When copper (95 per cent) is alloyed with tin (5 per cent) the bronze is known as *coinage bronze* used for making coins. Copper (88 per cent), tin (10 per cent) and zinc (2 per cent) results in *Gun metal* used for making valves and bearings. *Bell metal* is produced by alloying copper (65-45%) to zinc (35-20%) and nickel (5-35%). It is used for making utensils, fittings and electric goods.

Zinc Bronze It contains 59 per cent copper, 39 per cent zinc and 2 per cent tin. The tensile strength of such a casting is 413.7 N/mm^2. It is too brittle, however, to be of much value.

Phosphor Bronze is an alloy of copper and tin with phosphorus as a deoxidizer. For malleability tin and phosphorous should not exceed 4 per cent and 0.1 per cent respectively. Phosphorous up to 4 per cent increases hardness and brittleness. If added in excess the product becomes useless.

Lead Bronze contain copper, tin, phosphorous (< 1.0 per cent) and lead (< 3.0 per cent). It is most suitable for making bearings. When lead is more than 4 per cent, bronze, segregates, forming soft spots in the hard matrix which rapidly wears and forms cavities for the lubricant.

13.4 ZINC

The main source of zinc is the sulphide ore zinc blende or black jack (ZnS, 67 per cent zinc). The other ores for extraction of zinc are zinc carbonate, calamine ($ZnCO_3$, 52 per cent zinc) and zinc silicates — hemimorphite and willemite. The sulphide ore is finely ground and calcined in reverberatory furnaces until nearly all the sulphur is expelled. Carbonate ores and silicate ores are often calcined in shaft furnaces before being distilled. Ore containing impurities of iron is broken to small pieces and calcined to powder and iron is removed by electromagnet. Zinc is extracted either by distillation or by electrolysis. The ore is mixed with coal or coke and kept in retort (Fig. 13.4). By carefully controlling the temperature of the retorts to white heat, carbon monoxide is produced and the zinc is relieved of its oxygen. Zinc is collected and cooled to liquid form in condensers. From time to time molten zinc is tapped from condensers, skimmed and poured into moulds. The zinc so cast is known as *spelter*.

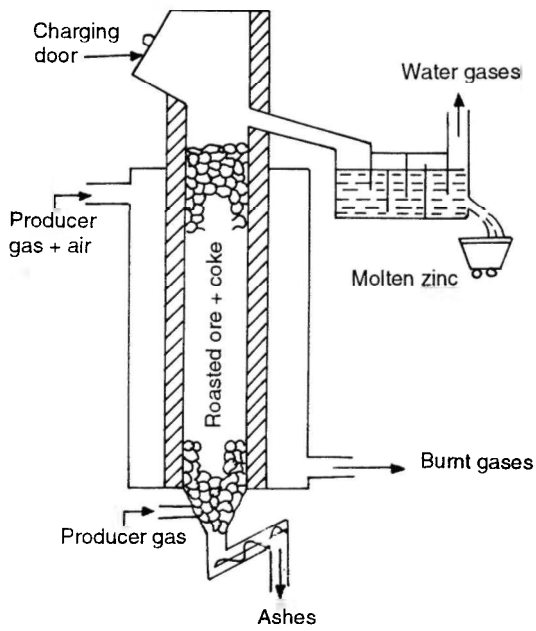


Fig. 13.4 Vertical Retort Furnace for Extraction of Zinc

Properties The most important property of zinc is its resistance to atmospheric corrosion. Ductility is good and it can be deformed into desired shapes. Lead (< 0.1 per cent) makes the spelter roll easier, however, it softens, weakens and ductility is reduced. Iron and cadmium embrittle and harden zinc and are, therefore, a detriment in spelter which is to be rolled or used for galvanising. They should not exceed 0.02 per cent. Zinc, either rolled or cast, shows no well defined yield point.

Uses It is used to produce brass, German silver, some of the bronzes, as a protective coating on iron and steel, boiler tubes, fruit jar covers, cans for resisting corrosion and for negative pole pieces of batteries.

13.5 LEAD

Mainly used in its pure form, lead is the densest, softest and the weakest metal. The principal ore is lead sulphide, galena (PbS, 86.6 per cent lead). Lead is extracted by reducing the sulphur content by roasting the raw ore in pots or sintering it in shallow pallets (Fig. 13.5). It is then smelt in a blast furnace (Fig. 13.6) along with flux and coke. Lead, zinc, copper, arsenic, etc. are taken out of the blast furnace and separated alternately on the basis of their different melting points.

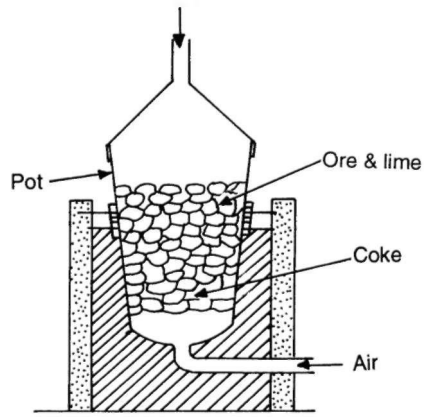


Fig. 13.5 Roasting of Lead Ore in Sinterer

Properties Pure lead can be scratched even with finger nail, highly malleable and can be rolled, into thin foils. It has a blue grey colour and dull metallic lusture when freshly fractured. When exposed to moist air it loses lusture due to oxidation. Its relative density is 11.34 and melting temperature is 327°C. The softness and

specific gravity of lead are reduced because of the impurities such as antimony, arsenic, zinc and copper. Magnesia (2 per cent) raises the hardness abruptly.

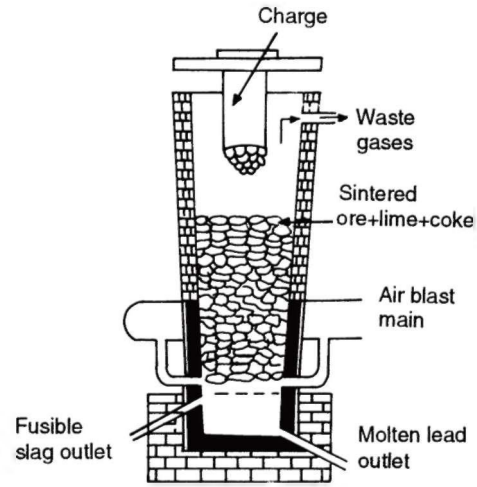


Fig. 13.6 Smelting of Galena in Blast Furnace

Uses It finds its principal use in paints as base, lead pipes and joints in sanitary fittings and in batteries.

Alloys

Some of the important lead alloys are as follows:

High Lead Alloy is made by alloying 15-20% antimony with lead. The hard lead so produced is used for making bearings. *Mangolia metal* containing 78 per cent lead, 16 per cent antimony and 6 per cent tin is one of the most common bearing metal.

Lead Tin Alloys are used in making solder and toys. By adding tin to lead the strength and hardness are considerably increased. The alloy carrying more than 50 per cent lead remains pasty over a considerable range of temperature before solidifying. It is suitable for plumbers solder.

Lead Antimony Alloys containing 12-17% antimony are inexpensive and are used for light loaded bearings. The useful per cent of antimony in the alloy is 10-25%. More of lead makes the alloy soft while more antimony makes it very brittle.

13.6 TIN

It is extracted from black oxide of tin, cassiterite (SnO_2, 78.6 per cent tin). Tin is extracted from the ore by crushing, roasting and melting to a temperature of about 1000°C in a way similar to that of copper.

Properties Tin is a silvery-white, lustrous, and extremely malleable metal. It is so soft that it can be cut by a knife. Its specific gravity is 7.3 and it melts at 232°C. It is harder, more ductile and stronger than lead. Tin is as ductile as soft steel. It is highly resistant to corrosion and has low tensile strength.

Uses Sheets coated with tin are used to make cans, utensils and furnance pipes. Sheets coated with lead-tin alloy are used for roofing. It is used for making bronze and other alloys.

Alloys

The important tin alloys are solder, babbitt metal, white metal, and pewter.

Solder It is obtained by alloying tin with antimony (0.5-3%), lead (5-40%) and tin (40-95%). These have low melting points.

Babbitt Metals These are alloys with tin base containing small proportions of copper and antimony. These are used for making bearings.

White Metal It is an alloy of tin, lead and antimony with copper in varying proportions. It is used for making bearings. This bearing metal accommodates itself for any defect in the alignment of bearings.

Pewter It is an alloy of tin 75 per cent and lead 20-25%. It has high corrosion resistance.

13.7 NICKEL

Nickel is generally extracted from pyrite or silicate ores.

Properties A brittle metal approaching silver in colour, nickel takes good polish and at ordinary temperatures does not tarnish or corrode in dry air. It has specific gravity 8.30, when cast and 8.70, when rolled. Its melting point is 1500°C. It is almost as hard as soft steel far more malleable, and when rolled and annealed, is somewhat stronger and almost as ductile. Nickel resists alkaline corrosion, but gets readily dissolved in nitric acid and aquaregia. The presence of carbon, arsenic, sulphur leads to brittleness. Small amounts of magnesium render it more ductile whereas iron makes it hard.

Uses Nickel is used in making nickel steels, coin, German silver, wires, plating, as catalyst and for moisture-proof packings.

EXERCISES

Q.1 Describe manufacture, properties and uses of:
(a) Copper (b) Aluminium (c) Lead

Q.2 Give the properties and uses of following:
(a) Tin (b) Nickel (c) Zinc

Q.3 Describe the extraction, properties and uses of any three non-ferrous metals. Describe also their alloys and uses.

Q.4 Discuss the use of non-ferrous metals as building materials.

Q.5 What is the difference between ferrous and non-ferrous metals? Give two examples of each type and state their properties and uses.

Q.6 Write notes on:
(a) Brazing (b) Soldering (c) Annealing

Q.7 What is an alloy? Describe the properties and uses of brass and bronze.

Q.8 Describe the following:
(a) Gun metal (b) Monel metal
(c) White metal (d) Yellow metal
(e) German silver (f) Pewter

Chapter

14

CERAMIC MATERIALS

14.1 INTRODUCTION

Ceramics refer to polycrystalline materials and products formed by baking natural clays and mineral admixtures at a high temperature and also by sintering oxides of various metals and inorganic substances having high melting point. The word is of Greek origin and derives its name from *Keromos* meaning potter's earth or clay. But, nowadays the term ceramic is applied to a wide range of silicates, metallic oxides and their combinations. Carbon, boron, silicon, certain carbides, silicates, refractory hydrides and sulphides are also considered to be ceramics. As a building material, ceramics, may include brick, stone, concrete, glass, abrasives, porcelain, high temperature refractories, etc. Clay is the most common example of ceramic materials. Magnesium oxide can withstand high temperatures (1650-2500°) without melting and is used extensively as a refractory.

Ceramics are usually hard and brittle and are in the form of amorphous (non-crystalline) or glassy solids. The bond in these materials is mixed ionic and covalent and while these can be made in single crystal forms, their more common structure is glassy. Because of covalent ionic bond the electrons are not free which makes the ceramics, thermal and electrical insulators. At low temperatures, ceramics behave elastically. However, under proper conditions of stress and temperature these deform by viscous flow.

14.2 CLASSIFICATION OF CERAMIC

On the basis of their internal structure the ceramics are classified as clay products, refractories and glasses. Clay products have been dealt in detail in Chapter 2. Refractories and glasses are described in the sections to follow.

14.3 REFRACTORIES

These materials are capable of withstanding high temperature in different industrial processes. They have high dimensional and chemical stability and do not lose their physical shape and chemical composition. Refractories confine the heat and prevent the heat loss to the atmosphere from the outside walls of furnances. The ability of a material to withstand prolonged action of high temperature (1580°C and onwards) without appreciable deformation or softening under service condition is known as *refractoriness* expressed in degrees C. It is generally measured by the softening or the melting point of the material and is determined by the pyromeric cone method, with the aid of tetrahedral cones or elongated pyramids, made of the same material to be tested, the size being 20 mm base and 40 mm height. They are heated until they soften and bend to touch the base. These cones are then compared with the standard *Segar cone* of known refractoriness, kept under same thermal load. The value is known as Polymeric Cone Equivalent (PCE). Fire-clay and high alumina clay soften gradually over a range of temperature, whereas, others silica softens over a relatively narrow range.

Classification

On the Basis of Chemical Behaviour

Acid refractories combine readily with bases. Their chief constituent is silica: quartz, sand, ganister and silica bricks.

Basic refractories consist mainly of basic oxides: magnesite and dolomite.

Neutral refractories consist of materials which do not combine with either basic or acidic oxides: silicon carbide, chromite and carbon.

On the Basis of Use

Siliceous Refractories containing not less than 93 per cent SiO_2 are used for roof, metallurgical furnances and glass tanks.

Alumo-silicate Refractories may be semi-acid type containing silica (over 65 per cent), chamotte with 30-45 % alumina are used in brickwork, lining of furnances; alumina (less than 35 per cent) or high-alumina variety with more than 45 per cent alumina are used in glass industry for furnance brickwork. Alumino-silicate items are used to line cupolas, coke ovens etc.

Magnesian Refractories consist chiefly of MgO (80-85 %) and their

refractoriness may be as high as 2000°C.

Chromous Refractories are obtained from chromous iron ore blended with magnesia and alumina. Their refractoriness is 1800-2000°C and they withstand attack by iron ore slags. They are used in steel making furnances.

Carbonaceous Refractories are manufactured from graphite or coke. These have refractoriness above 1700°C and are resistant to attack by molten slags.

Properties

Refractories are capable of withstanding high temperatures, thermal shocks and rough usage. The expansion and contraction of these materials is minimum. They are chemically inactive at high temperatures and are resistant to the fluxing action of slags and corrosive action of gases. Refractories are good thermal insulators and have low electrical conductivity.

14.4 GLASS

Glass is an amorphous substance having homogeneous texture. It is a hard, brittle, transparent or translucent material. It is the most common material glazed into frames for doors, windows and curtain walls. The most common types used in building construction are sheet, plate, laminated, insulating, tempered, wired and patterned glass. Most ordinary colourless glasses are alkali-lime silicate and alkali-lead silicate with tensile and compressive strengths of about 30-60 N/mm^2 and 700-1000 N/mm^2 respectively and modulus of elasticity in the range 0.45×10^5 to 0.8×10^5 N/mm^2. The strength is very much affected by internal defects, cords and foreign intrusions.

Constituents

The raw materials used in manufacturing glass are sand, lime (chalks) and soda or potash which are fused over 1000°C. Oxides of iron, lead and borax are added to modify hardness, brilliance and colour. The functions of the various ingredients are as below.

Silica is used in the form of pure quartz, crushed sandstone and pulverised flint; should be free from iron contents for best quality glass. Since it melts at very high temperatures (1710°C) carbonates of sodium or potassium are added to lower down the fusing temperature to about 800°C. These also make liquid silica more viscous and workable.

Lime is used in the form of limestone, chalk or pure marble and sometimes marl. The addition of lime makes the glass fluid and suitable for blowing, drawing, rolling, pressing or spinning. It also imparts durability and toughness to glass. Excess of lime makes the molten mass too thin for fabrication.

Soda acts as an accelerator for the fusion of glass and an excess of it is harmful.

Potash renders glass infusible and makes glass fire resistant.

Lead Oxide imparts colour, brightness and shine. When 15-30 % of it added to substitute lime it lowers the melting point, imparts good workability, while its transparency is lost with the glass becoming brittle and crystalline.

Cullets are broken glasses added to act as a flux to prevent loss of alkali by volatisation during the process of forming glass and also to lower the fusion temperature. However, flux may reduce the resistance of glass to chemical attack, render it water-soluble or make it subject to partial or complete devitrification (crystallisation) on cooling. These crystalline areas are extremely weak and brittle. Stabilizers are added to overcome these defects.

Titanic acid, oxides of Nickel and Cobalt are used for chromatic neutralisation.

Note : Iron is not desirable as a constituent. However, when present it imparts a bottle green colour to the glass. To overcome this manganese dioxide known as glass maker's soap is added which washes the liquid glass and removes the colour.

Manufacture

Glass is manufactured in the following four steps:

Melting The raw materials — lime, soda and sand — separately cleaned, ground, sieved (called 'Batch') in definite proportion and mixed with water are fused in a continuous type (tank) furnace or batch-type (pot) furnace. The charge in the first stage melts, forming a bubbly, sticky mass, and as the temperature is raised (1100°C-1200°C) it turns to a more watery liquid and the bubbles rise to the surface. The melting process in case of ordinary soda-glass involves the following series of reactions.

$$CaCO_3 + SiO_2 \rightarrow CaSiO_3 + CO_2\uparrow$$

$$Na_2CO_3 + SiO_2 \rightarrow Na_2SiO_3 + CO_2\uparrow$$

When all the carbon dioxide has escaped out of the molten mass, decolourisers such as MnO_2 or nitre are added to do away with ferrous compounds and carbon. The colouring salts are added at this stage. Heating is continued till the molten mass is free from bubbles and glass balls. As the glass cools (8002°C), it is ready to be drawn or floated to its desired thickness and size at the other end of the furnace as shown by a flow diagram in Fig. 14.1 (1100°C- 1200°C).

Forming and Shaping The molten glass can be fabricated to desired shapes by any one of the following methods:

Blowing A 2 m long and 12 mm diameter blow pipe is dipped in the molten glass and taken out. It is held vertically and is vigorously blown by the operator. The sticking molten glass takes the shape of a hollow ball. On cooling it is reheated and the blowing operation repeated a number of times till the desired articles are ready.

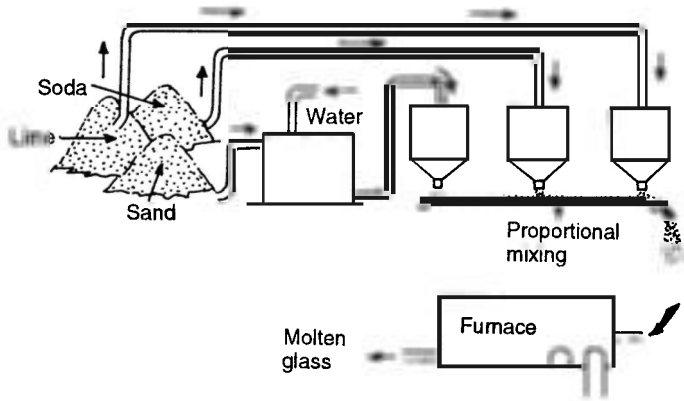


Fig. 14.1 Glass Manufacturing Process

Flat Drawing The process of drawing the glass up into a sheet begins when an iron grille (bait) is lowered into the glass in the kiln. In a short time the liquid molten glass adheres to the bait, and as the bait is slowly lifted it draws a sheet of glass. The bait and the drawn sheet of glass are then drawn through rollers, the bait is cracked off and a continuous sheet of glass is drawn up. This sheet is then slowly cooled in a chamber and annealed for cutting into proper size. A machine for vertical drawing of glass is shown in Fig. 14.2.

Compression Moulding In this process moulds are used to obtain the ar-

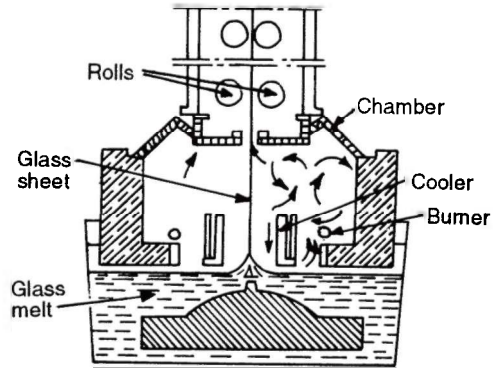


Fig. 14.2 Machine for Vertical Drawing of Glass

ticles of desired shapes.

Spinning A machine is used to spin the molten glass. The fibres so produced are very fine and are used for heat and sound insulation.

Annealing Glass articles are then allowed to cool under room temperature by

passing through different chambers with descending temperature. If cooled rapidly, the glass being bad conductor of heat, the superficial layer cools down first and strain develops in the interior portions, which causes unequal expansion and the articles are likely to crack.

Finishing After annealing the glass articles are cleaned, ground, polished, cut and sand blasted.

Classification

Depending upon the constituents glasses are classified as soda-lime glass, lead glass and boro-silicate glass.

Soda-lime Glass is also known as soda-ash glass, soda glass or soft glass. Soda-lime glass is obtained by fusing a mixture of silica, lime and soda. The quality of this glass can be improved by adding alumina and magnesium oxide and the glass is then called *crown* glass. This is the most common type of glass used in doors, windows and for making glass wares such as bottles.

Lead Glass also known as *flint* glass is obtained by fusing a mixture of silica, lead and potash. It is free from iron impurities and is colourless. Lead glass has high shining appearance and can take polish. It is not affected by temperature. Electric bulbs, optical glasses, cut glass, ornamental glass works and radio valves are some of the articles made from it.

Boro-silicate Glass is obtained by fusing a mixture of silica, borax, lime and felspar. The examples are *pyrex* glass and *heat resisting* glass. Boro-silicate glass can withstand high temperatures and is most suitable for making laboratory equipments and cooking utensils.

Commercial Forms

Sheet Glass is used for glazing doors, windows and partitions and is obtained by blowing the molten glass into the shape of a cylinder. The ends of the cylinder so produced are cut away and the cylinder is flattened over a plane tray. It is available in thicknesses of 2, 2.5, 3, 4, 5, 5.5 and 6.5 mm and up to 1750 × 1100 mm size and is classified as

Type	Uses
Ordinary glazing quality	General engineering purpose
Selected glazing quality	Class works
Special selected quality	Superior quality works such as show cases and cabinets etc.

Plate glass is used for all engineering purposes and is superior to sheet glass. A plate glass differs from a sheet glass in that it has a parallel, distortion-free surface obtained by grinding or floating process. It is produced by pouring the molten glass on casting tables and levelling it to an uniform thickness. Both the glass surfaces

are then ground, smoothened and polished. Glass so produced is clear and contains unblemished true plane surfaces and is available in thicknesses of 3 to 32 mm and sizes up to 2750 × 900 mm. It is classified as

Type	Uses
Ground glass quality	Showcases, cabinets, counters, shop fronts, etc.
Selected glazing quality	Making mirrors
Special selected quality	High class works wind screen of vehicles

Tempered Glass is made from plate glass by reheating and sudden cooling and is 3 to 5 times stronger. Although not unbreakable, it resists bending stress better than plate glass and, when broken, the pieces are relatively small in size. It is used extensively in sports arenas, sliding doors and curtain walls.

Wired Glass is produced by embedding wire nets 0.46 to 0.56 mm into the centre of sheet glass during casing. The minimum thickness of wired glass is 6 mm. When broken it does not fall into pieces. It has higher melting point than ordinary glass. Wired glass is used for fire resisting doors and windows, for sky lights and roofs. A special example of this is wired-refrax glass which transmits 100 per cent more light than the other glasses.

Obscured Glass is made comparatively opaque to sunlight. Also known as *patterned* glass. They are classified as frosted, rolled and ribbed.

Frosted glass is produced by subjecting the polished face of the glass to a sand blast which grinds off the surface. It can also be produced by etching on glass by hydrofluoric acid.

Rolled glass has a series of waves of desired pattern on the surface and is also known as *figured* rolled glass.

Ribbed glass A series of triangular ribs are produced in the glass during casting.

Laminated Glass is made by sandwiching a layer of polyvinyl butyral between two or more layers of plate or sheet glass. Also known as *safety* glasses. The examples are heat proof glass, sound proof glass and bullet proof glass.

Heat and sound proof glasses Two or more glass plates are sandwiched by a tinted plastic inner layer. It provides high resistance to heat and glare. By increasing the thickness of plastic layer the glass can be made more sound resistant.

Bullet Proof Glass is produced by placing vinyl plastic and glass in several alternate layers and pressing them with outer layers of glass. It is used in banks, Jewellry stores and display windows.

Insulating Glass is composed of two glass plates into which a layer of 6-13 mm thick dehydrated air is sealed . The round edges are formed by fusing together

the two glass plates. These reduce the heat transmission by 30-60 per cent.

Heat absorbing Glass is bluish green in colour and cuts ultra violet rays of sun. The example is *calorex*. It is used in railway carriages, factories, hospitals, health clubs and kitchens.

Ground Glass In this type one face of plate or sheet glass is made rough by grinding. It is used for maintaining privacy by obstructing vision and at the same time allowing light and is used for bedrooms, toilets and for making black boards.

Block Glass is hollow sealed made by fastening together two halves of pressed glass. It is used for making partitions.

Coloured Glass is produced by adding oxides of metals to molten glass:

Types of glasses	*Metal oxide*
Ruby red glass	Lead glass, 1 per cent of cupric oxide and 1 per cent of magnetic oxide of iron
Ruby rose glass	Gold chloride is used as colouring agent. Brownish red colour is obtained by adding oxide of iron, bluish red shade is obtained by adding 2 per cent MnO_2 and 4 per cent nitre (KnO_3).
Blue glass	0.1 per cent of cobalt oxide in ordinary glass.
Yellow glass	
(a) Uranium glass (greenish yellow)	2-3 % of alkali uranate.
(b) Selenium glass (orange)	Selenite and a reducing agent or add ferric oxide and MnO_2.
Green glass (emerald green)	Oxide chromium Cr_2O_7.
Violet glass (violet)	MnO_2
Black glass	Oxide of Co and Mn.

Opal Glass is also known as *milk* glass. It is produced by adding bone ash, oxide of tin and white arsenic to vitreosil (99.5% silica glass known as clear silica glass). The composition is 10 parts of sand, 4 parts cryolite and 1 part zinc oxide.

Enamel Glass is produced by adding calcined lead and tin oxide to the ordinary glass. The composition is 10 parts sand, 20 per cent lead and tin oxide and 8 parts potash.

Optical Glass contains phosphorus, lead silicate and a little cerium oxide, the latter capable of absorbing ultra-violet light injurious to eyes. They are used for making lenses.

14.5 GLASS WOOL

When silicate rock or flint is melted (1650°C) with a small quantity of calcareous matter and the liquid is blown by steam jet (Fig. 14.3), it splashes out in the form of small globules which are hurled in a large container at a great speed to cause them to be drawn into very fine, soft and flexible fibres. The source material is glass bottle waste melted at 1300-1400°C temperature. Also known as *rock wool* it can be packed into small pads or formed into (5-6 μ) boards or blankets. The fibres are chemically inert and have small bulk densities (150-750 g/mm^3) and a low coefficient of heat conductivity (0.04 to 0.17 Kcal/mh°C). Glass wool has high tensile strength and chemical resistance and, low sound and heat conductivities. They contain air in the pores forming a useful filter media for air conditioners and an insulating material for heat and sound. Glass wool may also be used as an aggregate in the manufacture of asbestos-cement items and as a fine aggregate for plastering and finishing mortars. Glass wool is also used to produce glass plastics by mixing it with polymers.

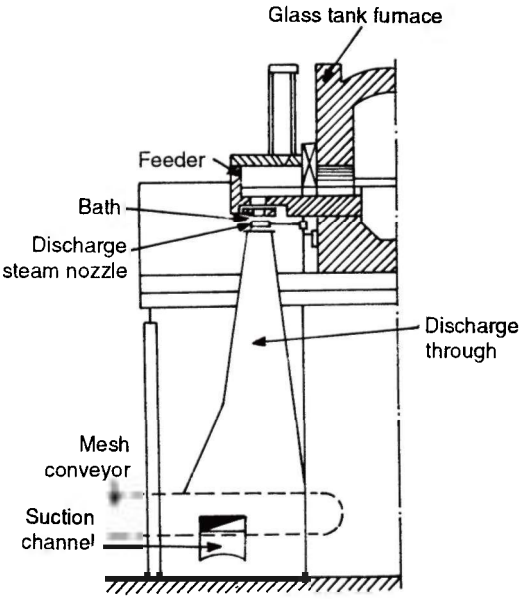


Fig. 14.3 Manufacturing of Glass Wool by Blowing

14.6 POLYMORPHISM IN CERAMIC MATERIALS

The main constituent of ceramic materials is silicate: Portland cement, glass, tiles, vitreous enamels, reinforcing glass fibres, etc. The primary unit of silicates is the SiO_4 tetrahedron, in which one silicon atom fits between four oxygen atoms with either ionic or covalent bond mechanism.

The tetrahedral units of silica are arranged in a hexagonal pattern at room temperature. But at 875°C the stable arrangement of silica-tetrahedral breaks to a new structure of a hexagonal pattern. Above 1940°C a third stable solid arrangement of tetrahedral in cubic pattern is formed. These three modifications are named as quartz — the low temperature mineral; tridymite — the intermediate temperature mineral and cristobalite — the high temperature mineral. However, quartz may exist as metastable phase at high temperature and tridymite and cristobalite may remain as metastable phases at room temperature.

A second type of inversion which may occur in silica is shown in Fig. 14.4. At 573°C the straightening of bonds across the oxygen takes place. This change which is rapid and spontaneous produces instantaneous volume expansion. As the quartz cools the process is reversed. Fig. 14.4 represents thermal expansion of quartz. Tridymite shows two such changes in its metastable range, one at 117°C and the other at 163°C, whereas cristobalite undergoes a change similar to that of quartz at 200°C.

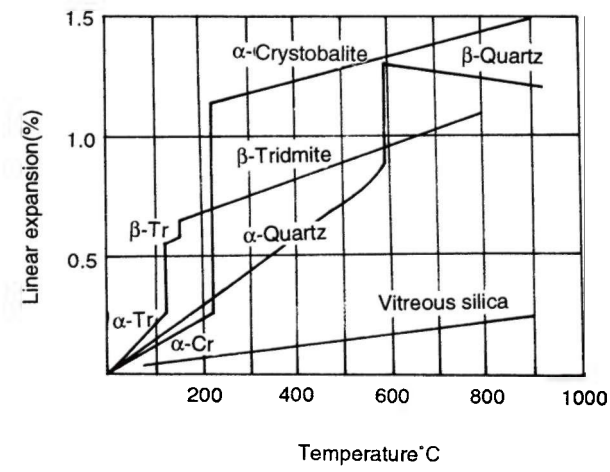


Fig. 14.4 Thermal Expansion of SiO_4 Phase

These three inversions affect the use of silica as a refractory material under conditions of rapid temperature changes where it may produce cracking or spalling.

14.7 MECHANICAL PROPERTIES OF CERAMIC PHASES

Tensile Strength Theoretically the tensile strength of ceramics is very high but in practice it is quite low. Tensile failures of ceramics are attributed to the stress concentrations at the pores and micro-cracks at grain corners. The modulus of elasticity 7×10^{10} to 42×10^{10} N/m^2. Glass fibres have tensile strength of the order of 700 MN/m^2.

Compressive Strength The compressive strength is high and it is usual to use ceramics like clay, cement and glass products in compression.

Shear Strength Ceramics have very high shear strength with resistance to failing in a brittle manner.

Transverse Strength is difficult to ascertain and ceramics are not used in the

places where such strength is the criteria.

14.8 THERMAL PROPERTIES OF CERAMIC PHASES

Thermal capacity, conductivity and resistance to shocks need to be considered while using a ceramic. The specific heat of fire-clay bricks is 0.250 at 1000°C and 0.297 at 1400°C, whereas for carbon bricks it is about 0.812 at 200°C and 0.412 at 1000°C. The specific heat for refractories to be used in regenerator chambers should be more. The heat in ceramics is conducted by phonon conductivity and by the interaction of lattice vibration. The ceramic materials do not have enough free electrons to bring out electronic thermal conductivity. At high temperatures, conduction takes place by transfer of radiant energy. The thermal conductivity of refractories should be minimum for linings and maximum for crucibles and retorts.

Thermal shocks are developed primarily because of expansion and contraction of ceramics. Lithium compounds are used in ceramics to improve the shock resistance. Hot pressed silicon nitride has the best thermal shock resistance whereas steatite is the most poor.

14.9 ELECTRICAL PROPERTIES OF CERAMIC PHASES

Ceramic materials have no free electrons so they have low electrical conductivity. However, at high temperatures the ionic diffusion is accelerated. For example glass is an electrical insulator, but in the glass melting furnace, its conductivity becomes quite high. Clay displays a very high dielectric content — a property of material related to its behaviour when located within an electric field between two electrodes — under static conditions. However, for alternating current, the dielectric constant in clay arises from ion and electron movement.

EXERCISES

Q.1 a) What are the ceramic materials ? What are their properties ?
b) Give the classification of ceramic materials.
c) Describe the mechanical properties of ceramics.

Q.2 a) What are refractories and their types? Give examples of each of them.
b) Describe the thermal and electrical properties of ceramics.
c) Describe the polymerisation of ceramics.

Q.3 a) Describe the manufacturing process of glass.
b) What are the constituents of glass? Give the functions of each of them.
c)Describe the classification of glass.

Q.4 How are the following glasses obtained ?
a) Obscured glass (b) Milk glass
c) Laminated glass (d) Enamel glass
e) Flint glass (f) Tempered glass

Q.5 a) What is glass wool ?
b) What is refractoriness and how is it measured ?
c) Describe briefly the use of glass as a building material.

Chapter

15

POLYMERIC MATERIALS

15.1 INTRODUCTION

High polymers, also known as macromolecules, are large molecules of colloidal dimensions (10^{-3} to 10^{-6} mm in diameter) have high molecular weight (10,000 to millions). Small molecules called monomers undergo polymerisation reaction and form macromolecules. The examples of polymeric materials are resins, plastics and rubbers.

15.2 POLYMERISATION MECHANISM

Polymerisation may be defined as the union of two smaller molecules of similar or different types with or without elimination of water resulting in the formation of new C-C linkages. The mechanism by which polymerisation takes place may be addition or condensation.

A monomer for polymerisation should be bi- or polyfunctional, i.e. it must contain two or more functional groups. Some of the other functional groups are hydroxyl acid, amino acid, di-amino acid, di-acids, di-or polyalcohols.

The structures depend on the functionability of monomers. In case of a bi-functional monomer there will be two reactive groups at its ends. These groups may align side by side to form a straight chain like molecule as shown in Fig. 15.1. The monomer units

are linked by primary covalent bonds and the different chains are held together by secondary force of molecular attraction. However, during the chain growth side chains may also develop leading to branched chain molecules as shown in Fig. 15.2.

In case of poly-functional groups the monomer molecules are connected to each other by covalent bonds and form a three-dimensional network (Fig. 15.3).

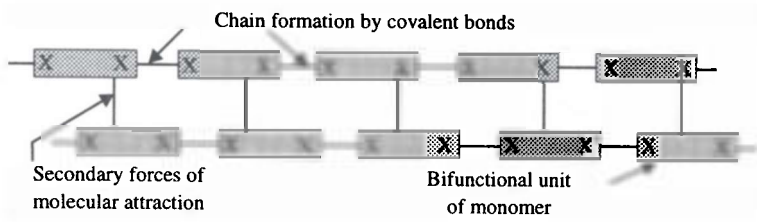


Fig. 15.1 Linear Chain Polymer Formation by a Reaction of bi-functional Molecule

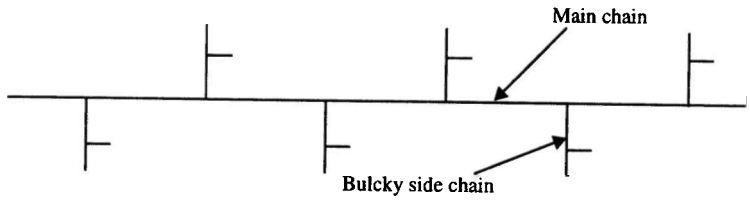


Fig. 15.2 Branched-Chain Polymer

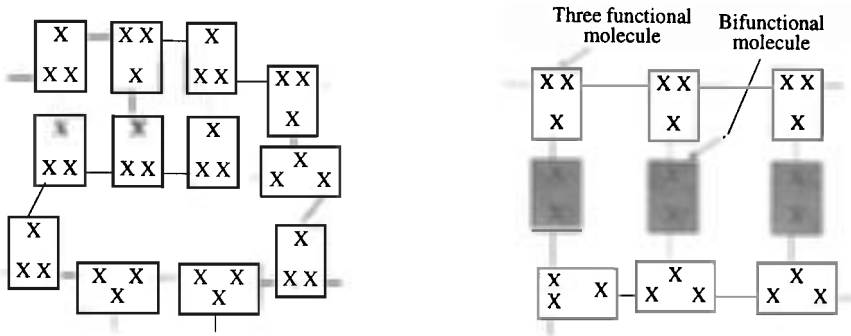


Fig. 15.3 Formation of a Three-Dimensional Network Ploymer
(a) Reaction of Three-Functional Molecule
(b) Reaction between Two and Three-Dimensional Molecules

Addition Polymerisation

It may be defined as a reaction that yields a product which is an exact multiple of the original monomeric molecule. Such a monomeric molecule usually contains one or more double bonds, which by intermolecular rearrangement may make the molecule bi-functional.

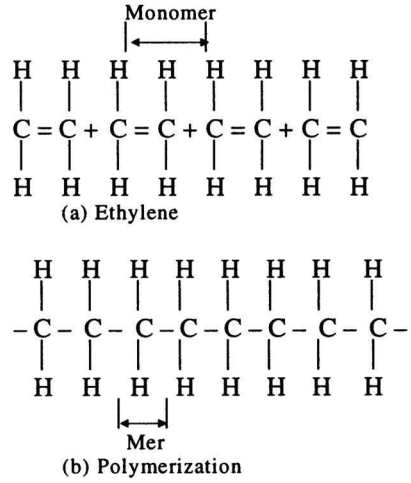


Fig. 15.4 (a) Each Step Involves the Breaking of a Double Bond and the Formation of Two Single Bonds

Fig.15.4 (a) shows ethylene polymerisation. One of its double bond is transferred to form a bond with the adjacent monomer and the resultant product is polyethylene which serves the prototype for addition polymerisation. It is commonly used in the manufacture of flexible films and squeeze bottles. Some of the other examples are shown in Fig 15.4 (b, c).

The addition polymerisation reactions can take place only by the application of heat, light, pressure, or catalyst.

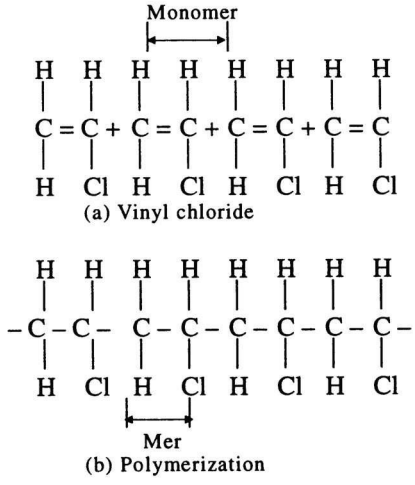


Fig. 15.4 (b) Double Bonds are Necessary as with Polyethylene

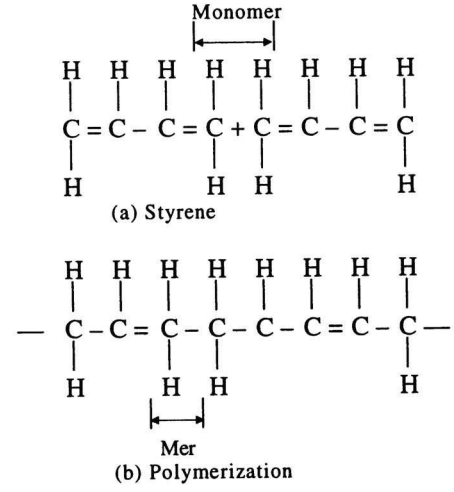


Fig. 15.4 (c) Hydrogens are not Shown on the Benzene Ring in (b)

The thermal initiators are most commonly used to generate radicals to imitate polymerisation. Peroxide compounds (containing O-O bonds) like acetyl peroxide (Ac_2O_2), benzoyl peroxide (Bz_2O_2) and azO compounds also used as initiators. The initiated polymerisation process does not last indefinitely because the molecules must be available in the immediate vicinity at the ends of the chains.

Co-polymerisation is a type of addition polymerisation where simultaneous polymerisation of two or more chemically different monomers takes place resulting in the formation of a polymer containing both monomers linked in one chain. An example is shown in Fig. 15.5.

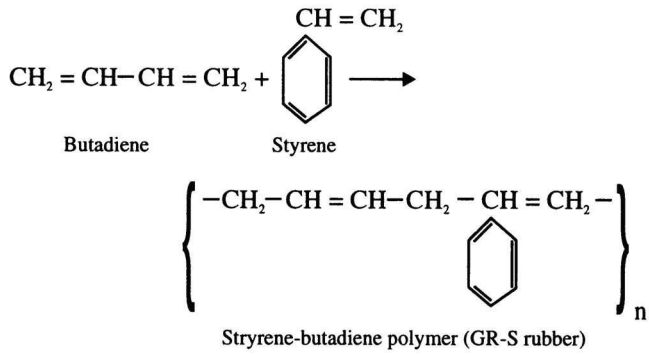


Fig.15.5 Styrene-Butadiene Polymer (GR-S Rubber)

Condensation Polymerisation

It may be defined as the reaction between functional monomer molecules leading to the formation of a polymer with the elimination of some small molecules such as water, HCl, etc. The most common is Nylon formed from hexamethylene diamine and adipic acid (Fig. 15.6(a)). Phenol formaldehyde resin (Bakelite) shown in Fig. 15.6 (b) is another example.

15.3 DEPOLYMERISATION

Also known as degradation, depolymerisation may occur when used for extended period of time with steam as in the case of urea-formaldehyde plastic or due to thermal variations disrupting the intramolecular bonds within the molecules of plastic formed at high temperatures.

Depolymerisation is used to its advantage for cracking petroleum into highly combustible products, light molecules charring of carbohydrates (toast) and of cellulose (charcoal).

$HN_2 - (CH_2)_6 - NH$ (Hexamethylene diamine) $\boxed{H + HO}$ $OC - (CH_2)_4 - COH$ (Apidic acid)

$H_2O + NH_2 - (CH_2)_6 - NHCO(CH_2)_4COOH$

$HO \quad OC - (CH_2)_4 - CO$ (Apidic acid) $\boxed{OH + H}$ $NH - (CH_2)_6 - NH -$

$- CO(CH_2)_4CO \boxed{OH + H} NH - (CH_2)_6 - HN|H -$ (Hexamethylene diamine)

$- OC\ (CH_2)_4\ CONH(CH_2)_6NHCO(CH_2)_4CONH(CH_2)_6NH -$

$[- OC(CH_2)_4CONH(CH_2)_6NH -]_n$

Fig.15.6(a) Polyhexmethylene Adipamide (Nylon 6:6)

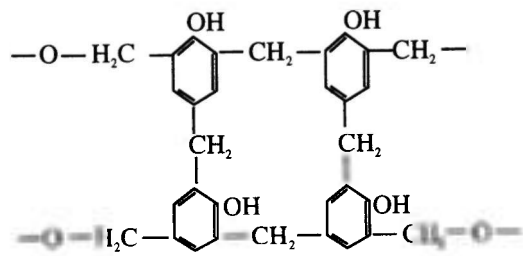


Fig. 15.6(b) Bakelite Plastic

15.4 RUBBERS

Rubbers also known as elastomers, are high polymers having the unique property of undergoing large deformations under load and returning to their original shape and dimension on its removal owing to lengthening and shortening of the springs of polymeric chains (elastomer molecule is not straight chained but in the form of coil) as shown in Fig. 15.7.

The unstretched rubber molecule is amorphous. In stretching, the macromolecules in it get partially aligned with respect to one another causing crystallisation. Consequently the material gets stiffened due to increased attractive forces between the molecules. On releasing the stress the chain regains its original coiled state and the material again becomes amorphous.

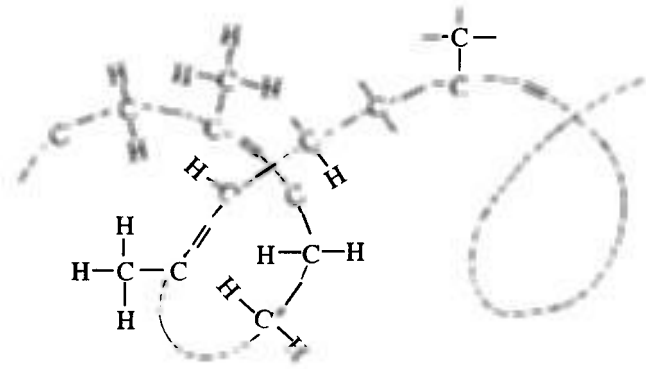


Fig. 15.7 Schematic Representation of Coiled Elastometer Chain of Natural Rubber (Polyisoperene)

Classification

Rubber can be classified as natural, synthetic and rubber like plastic.

Natural Rubber consists of basic material latex, dispersion of isoprene, which polymerises to form long coiled chain of polysoperene (Fig. 15.8). It is made from the sap occurring in cells of the various parts of the plants such as havea brasiliansis and gauyile.

The latex is obtained by making incisions in the bark of the rubber tree, allowing

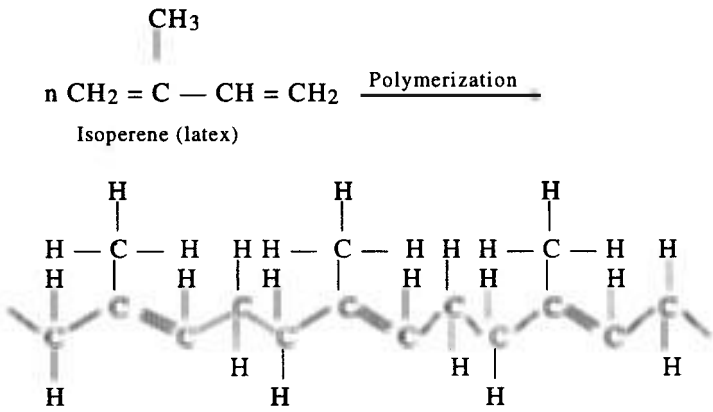


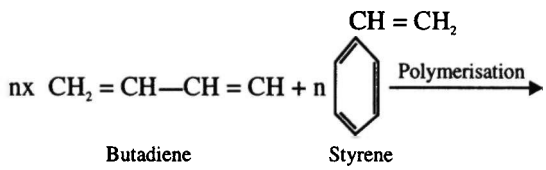
Fig. 15.8 Polyisoperene (Natural Rubber)

the sap to flow out. It is collected and diluted to contain 15-20% of rubber and then strained to remove any dirt. Thereafter the rubber is coagulated by adding acetic or formic acid. The coagulated rubber is then treated to produce crude rubber known as *crepe rubber* and *smoked rubber* which is further processed, milled and vulcanized to produce commercial rubber.

Crepe Rubber is produced by coagulating rubber in the presence of retarder like sodium bisulphite. Then it is passed between the rollers of creping machine where most of the serum is squeezed out and a sheet resembling crepe paper is formed.

Smoked Rubber is prepared by pouring diluted latex into tanks having sides with vertical grooves. Diluted formic or acetic acid is added and stirred. The partition plates are inserted in the grooves and left for about 16 hours. The slabs so formed are removed and passed through series of rollers with decreasing clearances. The sheets are kept for four days in a smoke house having a temperature of 40-50°C.

Synthetic Rubber is based on the model of natural rubber and thermo-plastic vinyl high polymers. The possible number of synthetic rubbers are unlimited. It is so because all straight-chain polymers can be made to specific requirements to produce rubber like properties. However, the cheap price and easy availability of natural rubber has suppressed the demand of synthetic rubber. Some of the synthetic rubbers are shown in Fig 15.9.



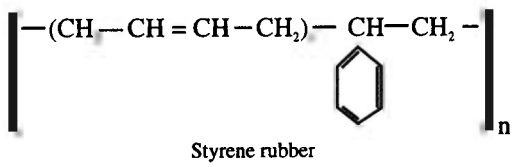


Fig. 15.9(a) Styrene Rubber

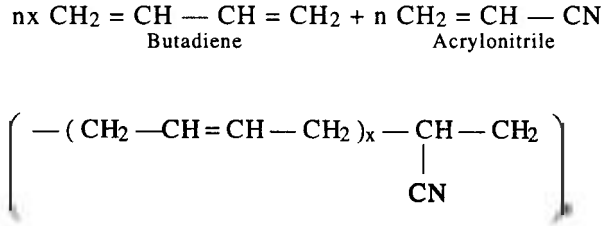


Fig. 15.9(b) Nitril Rubber

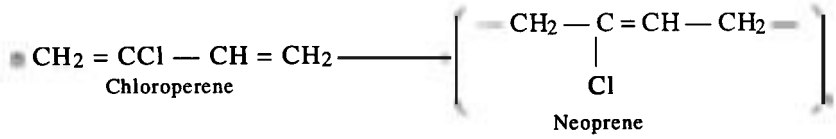


Fig. 15.9(c) Neoprene

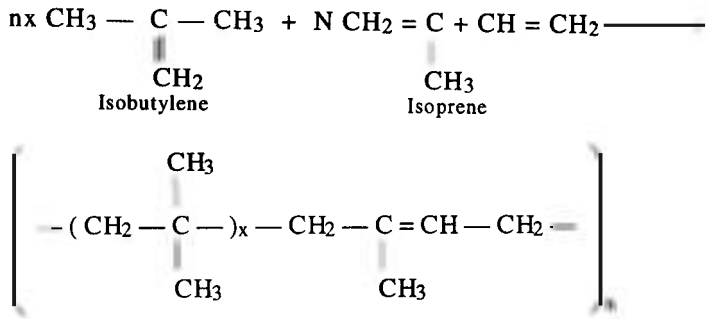


Fig. 15.9(d) Butyl Rubber

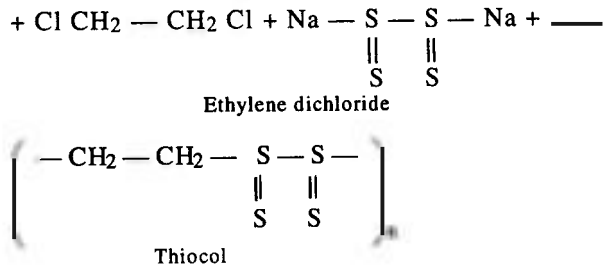


Fig. 15.9(e) Thiocol

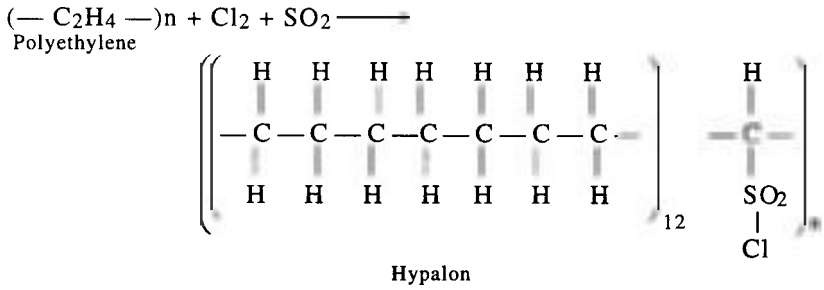


Fig. 15.9(f) Hypalon

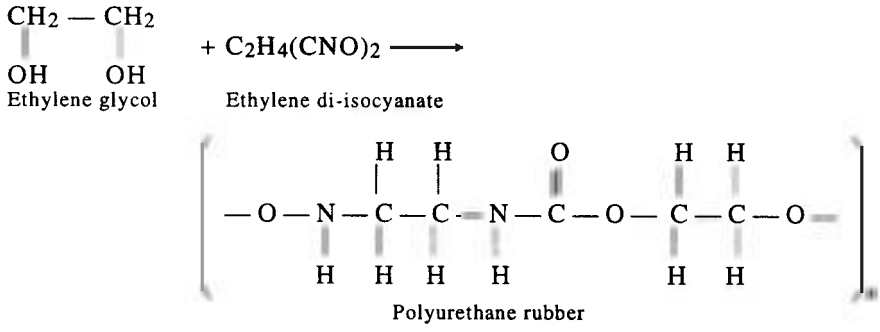


Fig. 15.9(g) Polyurethane Rubber

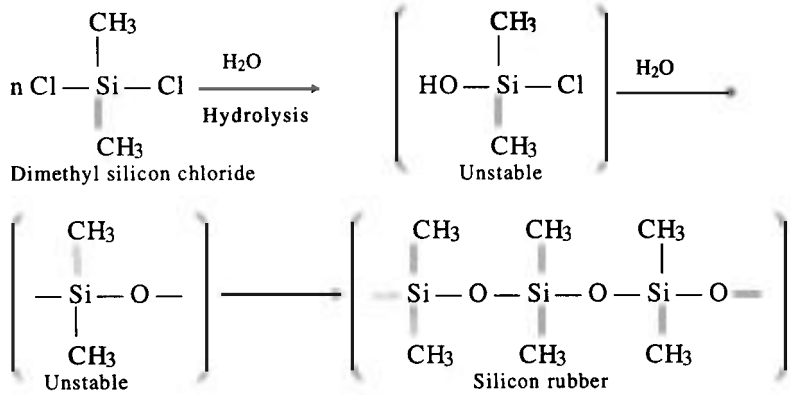


Fig. 15.9(h) Silicon Rubber

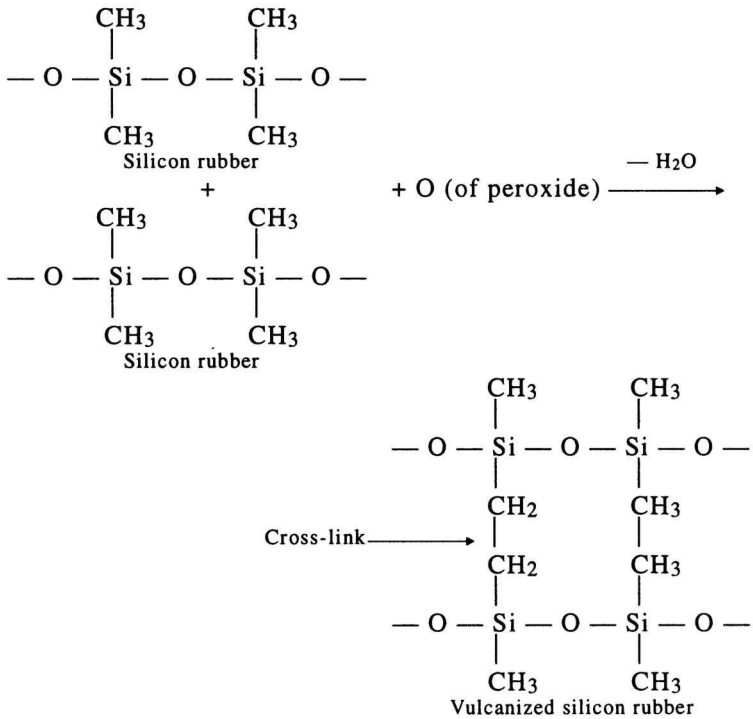


Fig. 15.9(i) Vulcanized Silicon Rubber

Compounding of Rubber

Softeners and plasticisers such as vegetable oils, wax and rosin oil are added to natural or synthetic rubber to enhance tenacity and adhesion; vulcanizing agents such as sulphur (0.15-32%) which combines chemically at the double bonds of different rubber springs (Fig. 15.10) and thus enhancing stiffness. A vulcanized rubber tyre may contain 3-5% of sulphur whereas a battery case rubber contains as much as 30 per cent; accelerators like benzthiozole shorten the time required for vulcanization; antioxidants like complex amines are added to check the tendency of natural rubber to perish due to oxidation; reinforcing fillers such as carbon black are added to give strength and rigidity to the tyres.

Uses

Rubber is the most suitable material for conveyer belts, linings, types, gaskets, mountings, hoses, insulating coatings and toys, phenolaldehyde resin with waste rubber is used to make flooring tiles. Like cyclised rubber chlorinated rubber, is a

modified form of natural rubber, most widely used in the production of protective coatings and adhesives. Rubber hydrochloride, on processing can produce thin films of wrapping and packages.

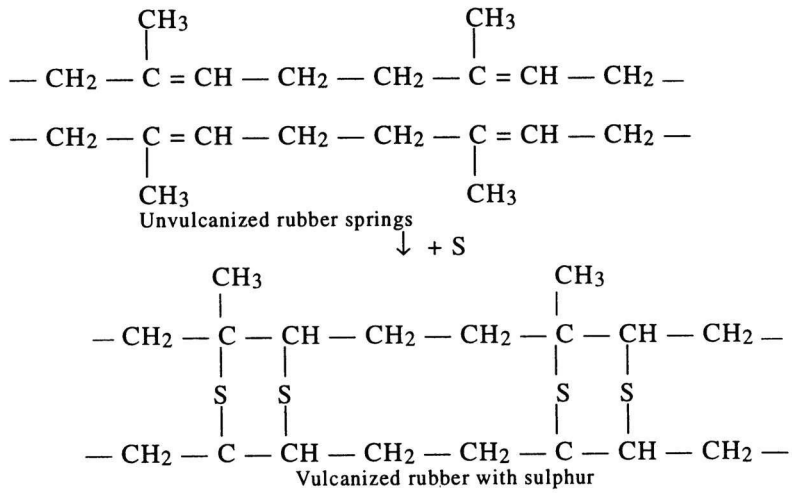


Fig. 15.10 Vulcanization of Natural Rubber with Sulphur

15.5 PLASTICS

Plastics are made from resin with or without fillers, plasticisers and pigments. These are organic materials of high molecular weight which can be moulded to any desired form when subjected to heat and pressure in the presence of a catalyst. Schonbein invented a plastic named cellulose in 1846. Later John Wesley Hyatt in 1890 developed cellulose, and Adolph spitter invented casein plastics. Bakelite was developed in 1909 by Dr. Bakeland. Since then a variety of plastics have been developed. These are natural (shellac and resin) or synthetic in origin.

Plastics are replacing glass, ceramics and other building materials for their low cost and easy availability. Plastics are classified as thermoplastic, and thermosetting.

The thermoplastic variety softens on heating and hardens on cooling, i.e. their hardness is a temporary property subjected to change with rise or fall of temperature. These are formed by addition polymerisation and have long chain molecular structure. They can be remoulded, for use, as many times as required. Examples

are material resins — rosin, kopal, amber, shellac; cellulose derivatives — cellulose acetate, cellulose nitrate, nitrocellulose or celluloid, cellulose acetate-butyrate; polythenic or vinyl resin — polyethylene, polyvinyl chloride, polyvinyl acetate, vinyl chloride-vinyl acetate, poly vinylidene chloride, polystyrene, polymethyl methyacrylate or lucite or plexiglass and polytetrafluoroethylene; polyamides — Nylon 6:6, Nylon 6 and Nylon 11. Some of the uses of the plastics are given in Table 15.1.

Table 15.1 Principal Uses of Plastics

S. No.	Uses	Name of plastic
1.	As a substitute of glass for doors and windows	Acrylic (Trade name Perspex), better than glass.
2.	Insulation of electric cables, light fittings, hand rails	Cellulose acetate
3.	Set squares, slide rules, fountain pens	Cellulose nitrate
4.	Electric insulation, kitchenware, toys, sheets for packing	Polyethylene
5.	Electric equipments, refrigerator parts, food containers, toys, as a rigid form for packing	Polystyrene
6.	Drainage pipes, floor finishes, emulsion paints	Polyvinyl chloride (PVC) Polyvinyl acetate (PVA)

Thermosetting plastic cannot be reused. They require great pressure and momentary heat during moulding and finally get hardened on cooling. The chemical reaction in this process cannot be reversed. Once solidified they cannot be softened. The thermosetting plastics acquire three-dimensional cross-linked structure with predominantly strong covalent bonds during polymerisation retaining strength even on heating; under prolonged heating they fail by charring. Compared to thermoplastics, they are hard, strong and more brittle. The important thermosetting resins are phenolic resins or phenoplasts (bakelite), amino resins, polyester resins, epoxy resins and silicon resins. The principal uses are in electrical equipments, plugs, sockets, switches, ash trays, knobs, handles, etc.

Properties

1. Can be moulded to any desired shape or size and have high tensile and compressive strengths.
2. Easy to work upon.
3. Light in weight and a few varieties are glossy like glass.
4. Not attacked by insects and fungi.

5. Available in desired colour and texture.
6. Require a little maintenance.
7. Good electrical insulators and have low thermal conductivity.
8. Shock absorbing material.
9. Can be sawn, drilled and punched and welded easily.
10. High strength to weight ratio.
11. High resistance to weathering conditions.
12. Corrosion resistance.
13. Decorative surface effect — painting or polishing of the surface is not required.
14. High refractive index.
15. Some varieties are as hard as steel.
16. Withstands moisture, oil and grease well.
17. Inflammable.
18. High coefficient of thermal expansion (about ten times of steel).
19. Deterioration under prolonged exposure to sun's ultra-violet rays.
20. Low manufacturing cost, hence cheap.

15.6 CONSTITUENTS OF PLASTICS

The constituents of plastics are resin, plasticizer, filler, pigment and dye, lubricant and catalyst.

Resin acts as binder for holding different constituents together. Thermosetting resins are usually supplied as linear polymer of a comparatively low molecular weight being fusible and mouldable.

Plasticiser is supposed to neutralize a part of the intermolecular force of attraction between macromolecules of resins. Consequently the polymeric macromolecules of resin move with greater freedom, thereby increasing the plasticity and flexibility of the compounded material. However, tensile strength and chemical resistance is reduced. Some of the examples of plasticisers are vegetable oils (non-drying type), camphor, esters of stearic and oleic acids, tricresyl phosphate, tributyl phosphate, tetrabutyl phosphate and triphenyl phosphate.

Filler is added up to 50 per cent of the moulding mixture to increase the hardness, tensile strength, bond, opacity, finish and workability besides reducing the cost, shrinkage on setting, and brittleness of the final product. Some of the fillers are wood floor, asbestos fibres, saw dust, ground cork, paper pulp, corn husk, carbon

black, cotton fibre, metallic oxides, metal powder (Al, Cu, Pb). Carborundum, quartz are found to be most suitable for extra hardness. Mica is used to improve electrical properties. Barium salts when added to plastics make them impervious to X-rays. Asbestos is used to make plastics heat resistant.

Pigment is added to achieve desired colour of the plastic and should be resistant to the action of sunlight.

Lubricant is used to make the moulding of plastic easier to prevent sticking of materials to the mould for a flawless finish. The examples are stearates, oleates and soaps.

Catalyst is added only in the case of thermosetting plastics to accelerate the polymerisation of fusible resin during moulding operation into cross-linked in-fusible form.

Blowing Agent Sodium bicarbonate and ammonium carbonate are sometimes added to plastics to produce porous articles.

15.7 FABRICATION OF COMMERCIAL ARTICLES

The method used for fabrication of commercial articles from plastics depends primarily on the type, resin used, shape, size and thickness of the articles. Following are the commonly used fabrication methods.

Moulding

Compression Moulding can be employed both for the thermoplastics and thermosetting plastics. The fluidised material is filled in the mould cavity by hydraulic pressure (Fig. 15.11). There is an arrangement to heat the plastic if desired. Temperature and pressure is applied till the chemical reaction is complete. Finally curing is done by heating (thermosetting plastics) or by cooling (thermo-

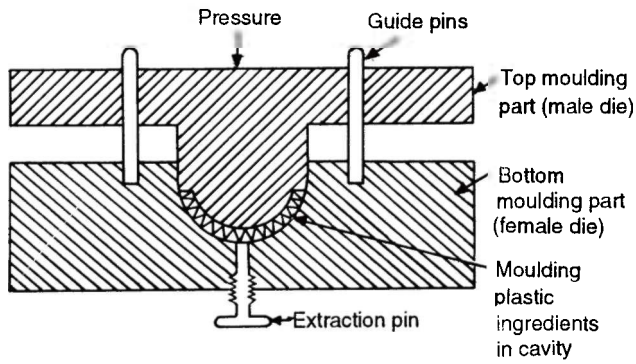


Fig.15.11 Compression Moulding of Plastic

plastics). After curing is complete, mould is opened and moulded material is taken out.

Injection Moulding is best suited for the moulding of thermoplastic materials. The plastic powder is fed into a cylinder from a hopper where it is heated. When the mould opens, a screw (Fig. 15.12) or a plunger allows the material to go inside the cylinder from the hopper. The resin melts in the heating zone from where it is sent to the mould cavity through nozzle. The mould is kept cold to allow the hot plastic to cure and acquire the shape. Half of the mould is opened to cause ejection of the finished article.

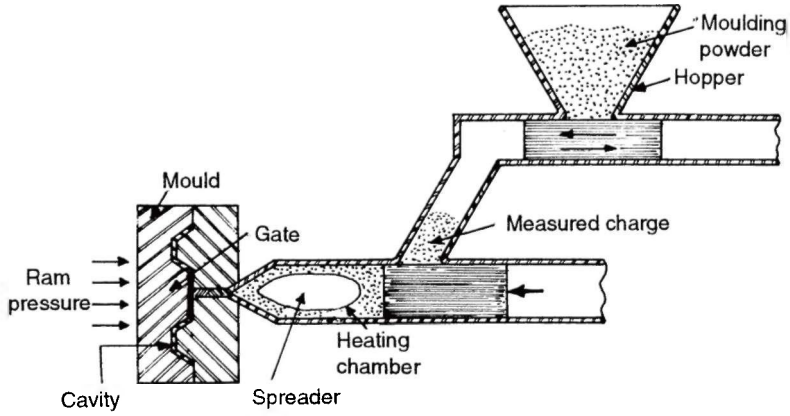


Fig.15.12 Injection Moulding

Transfer Moulding uses the principle of injection moulding for thermosetting materials. Intricate machine parts are moulded by this method. The thermosetting material powder is heated to become just plastic and injected through an orifice, as shown in Fig. 15.13, into the mould by the plunger working at high pressure. The temperature of the material rises because of the friction at the orifice and the powder becomes almost liquid which flows into the mould and in turn is heated to curing temperature.

Extrusion Moulding is used for continuous moulding of thermoplastic materials into articles of uniform cross-section such as tubes, rods, strips, electric cables, etc. The thermoplastic material is heated to plastic state and is pushed to a die by a screw conveyer (Fig. 15.14 and Fig. 15.15). As the extruder rotates it has a mixing, smearing, and frictional heating action which changes the dry granular charge into a soft plastic mass before it reaches the end of the screw. Here the plastic mass is cooled by air jets.

Blow Moulding Air pressure or vacuum are employed in this method of moulding to force the softened plastic powder into the mould.

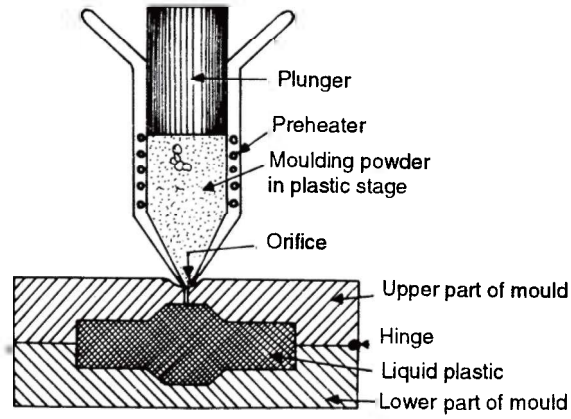


Fig. 15.13 Transfer Moulding of Plastic

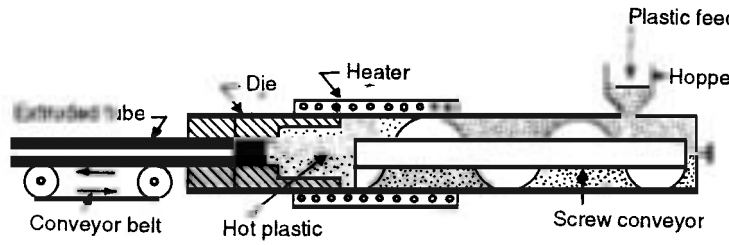


Fig. 15.14 Moulding of Tube by Horizontal Extrusion Moulding

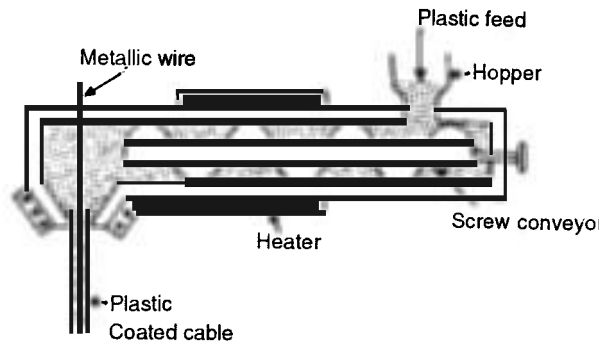


Fig. 15.15 Moulding of Cable by Vertical Extrusion Moulding

Casting

The plastics are moulded without application of pressure. The resin is melted and poured into mould. The casting of plastics is similar to that of cast iron. Since the cast plastic is not so smooth just after casting, they are polished. This method is most suited to the plastics formed from cellulose acetate and cellulose nitrate.

Lamination

Thin sheets of cloth or paper asbestos are impregnated with thermosetting resin. These lamins are then pressed by a hydraulic press. Under temperature and pressure the lamins are bonded together to form one sheet. The laminated plastics exhibit improved mechanical and electrical properties. The thickness of laminated plastics ranges between 0.13 mm-15 mm. Vinyl resin is most suitable for lamination.

15.8 APPLICATIONS OF PLASTIC

Plastics have innumerable applications either to substitute or protect other building materials, or to improve the comfort conditions. However, because of relatively low stiffness they are not used as primary load bearing materials. Some of the uses of plastics are as follows.

Wall Facing tiles Polystyrene tiles have excellent water proofing properties and are used for bathrooms, kitchens, lavatories, swimming pools and facing tiles.

Flooring Tiles Polyvinyl chloride synthetic resins used for floor tiles are non-absorbent, resistant to abrasion, wear and tear.

Flooring Sheets Mastics, prepared from synthetic resins such as polyvinyl acetate with suitable plasticisers form decorative linoleum floor coverings.

Water-proofing Membranes Polythene and polyvinyl resins with suitable fillers and plasticisers, oils and antipyrene compounds are used to make films which have high elastic strength, rupture value and acid resisting properties. These films are used for damp proofing courses, covering of concrete for curing, temporary protection from rain and wind.

Pipes and Sanitary Appliances Polythene, polypropylene and polyvinyl chloride are used for making pipes and sanitary wares and fittings.

15.9 PROPERTIES OF PLASTICS

The great diversity of plastic materials, modified by fillers, plasticisers, laminating sheets, etc. leads to a wide range of mechanical and physical properties.

Stress-Strain Relationships Typical tensile stress-strain curves for various types of plastics are shown in Fig. 15.16. Curve A of Fig. 15.16 is typical of hard,

strong, but unyielding plastics like moulded thermosetting materials and paper laminates. Curve B relates to materials like cellulose acetate, cellulose acetate butyrate, and some fabric materials. Curve C is typical of a large number of plastics.

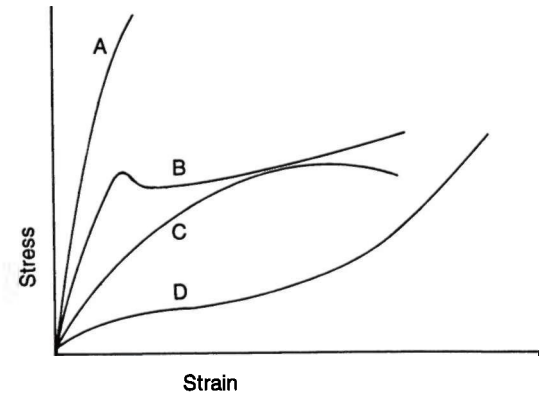


Fig. 15.16 Tensile Stress-Strain Curves for Various Types of Plastics

Curve D relates to some highly extensible plastics. Rubbers behave similarly. The stress-strain curves for cellulose acetate sheet at various temperatures is shown in Fig. 15.17.

Creep, Relaxation, Memory

When a load is applied to a plastic specimen it quickly deforms and the load is sustained, the specimen continues to deform at a decreasing rate. If, after creep has occurred for a period of time, the load is released, a quick partial recovery takes place immediately, followed by slow recovery which may or may not completely restore the specimen to its original size and shape (Fig. 15.18(a)).

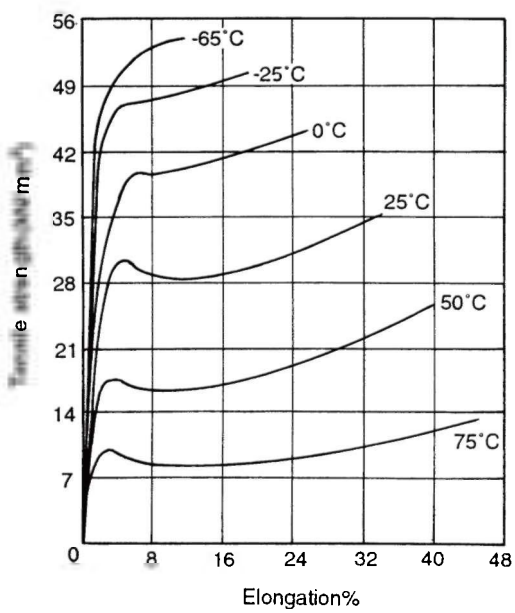


Fig. 15.17 Stress-Strain Curve for Cellulose Acetate Sheet at Various Temperatures

If the deformation caused by a load is held constant, the load decreases. The phenomena is known as relaxation (Fig. 15.18(b)). Memory means that the behaviour of a plastic specimen under stress may be influenced by its previous stress history. As shown in Fig. 15.18(c), the specimen is subjected to a succession of loads of varying intensities, directions, and durations. There may not be time for normal creep recovery before a reversal of load occurs. The final deformation may, therefore, experience a reversal.

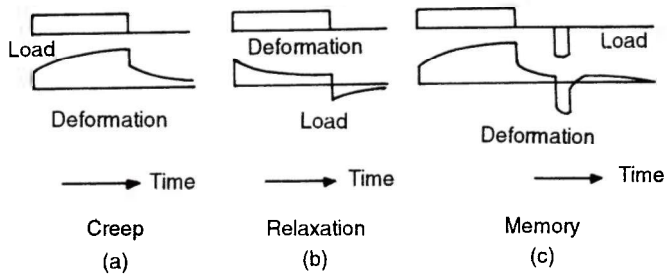


Fig. 15.18 Diagrammatic Representation of Creep, Relaxation, and Memory

15.10 EFFECT OF TEMPERATURE ON MECHANICAL PROPERTIES

Mechanical properties of all plastics are sensitive to changes in temperatures. Figure 15.19(a) and Fig. 15.19(b) show the respective effects of temperatures on

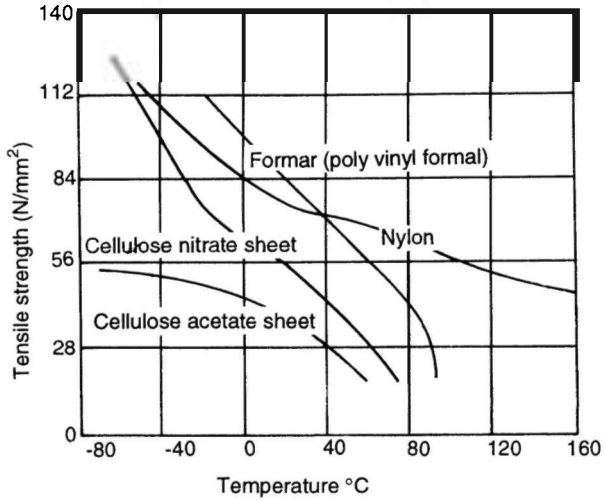


Fig. 15.19(a) Effect of Temperature on Tensile Strength of Thermoplastics

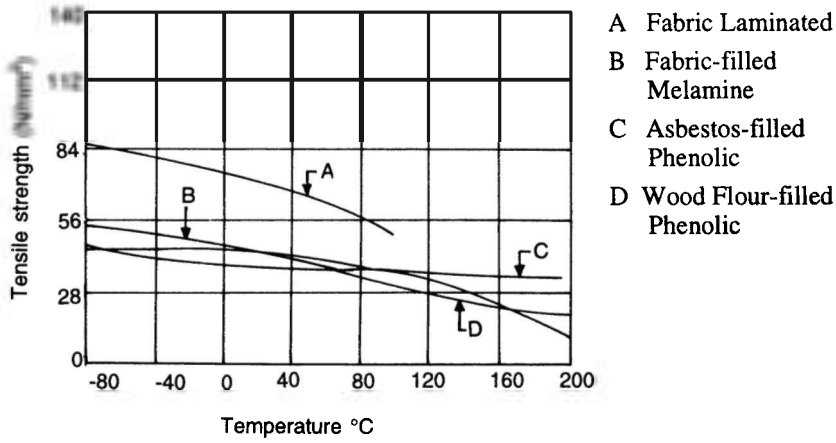


Fig. 15.19(b) Effect of Temperature on Tensile Strength of Thermosetting Plastics

thermoplastics and thermosetting plastics. The effect on ultimate elongation of thermoplastics is shown in Fig. 15.20.

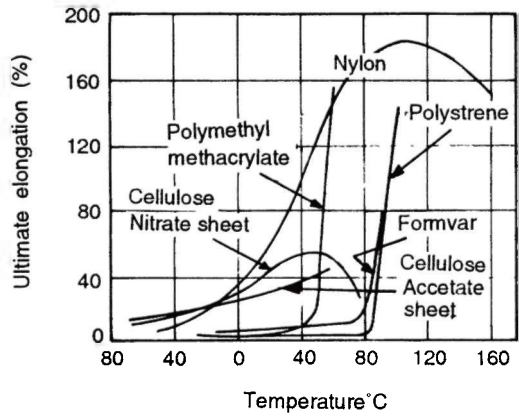


Fig. 15.20 Effect of Ultimate Elongation on Thermoplastics

EXERCISES

Q.1 (a) What do you understand by polymerisation ? Explain the mechanism of polymerisation.
(b) Differentiate between addition and condensation polymerisations.

Q.2 (a) Explain the following terms:
Co-polymerisation, condensation, smoked rubber.
(b) Why are the plasticisers added to polymers.

Q.3 (a) What is a rubber and how is it classified ?
(b) State the reasons for compounding rubber.
(c) What is artificial rubber ?

Q.4 Differentiate between following:
(a) Thermoplastic and thermosetting plastic.
(b) Addition and condensation polymerisations.
(c) Rubber and Plastic.
(d) Injection and compression mouldings of plastics.

Q.5 (a) What is vulcanization of rubber and how is it affected ?
(b) Give the important characteristics of plastics.
(c) Describe the moulding of plastics.

Q.6 (a) Give the typical uses of plastics obtained from different moulding processes.
(b) What are the various ingredients of the plastics ? Give their specific uses.

Q.7 (a) Describe the characteristics of PVC.
(b) Write a note on Bakelite.
(c) Describe briefly the fabrication of plastics.

Q.8 (a) How are plastics classified ? State the role of plastic as a building material.
(b) Differentiate between crepe rubber and smoked rubber.
(c) Explain what is meant by depolymerisation. Is it harmful ?

Q.9 (a) State the properties of plastics.
(b) What are the advantages of plastics over the other suitable building materials ?
(c) Describe briefly use of plastics as building material.

Q.10 Discuss:
(a) Stress-Strain curve for plastics.
(b) Creep and relaxation in plastics.
(c) Effect of temperature on ultimate elongation of plastics.

Chapter

16

PAINTS, ENAMELS AND VARNISHES

16.1 INTRODUCTION

Paint is a liquid surface coating. On drying it forms a thin film (60-150μ) on the painted surface. Paints are classified as oil paints, water paints, cement paints, bituminous paints and special paints such as fire proof paints, luminous paints, chlorinated rubber paints (for protecting objects against acid fumes), etc.

The functions of the paints are: to protect the coated surface against possible stresses — mechanical or chemical; deterioration — physical or environmental; decorate the structure by giving smooth and colourful finish; check penetration of water through R.C.C; check the formation of bacteria and fungus, which are unhygienic and give ugly look to the walls; check the corrosion of the metal structures; check the decay of wood work and to varnish the surface to display it to better advantage.

16.2 COMPOSITION OF OIL PAINT

Base The base, usually a metallic oxide, is the principal constituent of the paint. It makes the paint film opaque and possesses binding properties which reduce the shrinkage cracks in the film on drying. Some of the examples of base are white lead, red lead, zinc white, aluminium powder, iron oxide, etc. Lead based paints are in general affected by atmosphere and are not recommended for final coats. Zinc white is weather resistant. For inferior works Lithophone (barium sulphate chemically combined with zinc sulphide) is used for inside work. Aluminium powder is used as base for all aluminium paints.

Vehicle Also known as *binder*, vehicle is an oil to which the base is mixed. It holds the constituents of paint in suspension and helps spread it over the surface to be painted, imparts durability, toughness and water proofness to the paint film and resistance to weathering and gloss to the painted surface and forms the body of the paint. The examples are natural drying oils such as linseed oil, nut oil, poppy oil and tung oil; animal, plant, artificial and synthetic glues in glue paints and air slaking lime and polymer in lime water colours and polymer paints respectively.

The natural drying oils (glycerides of the unsaturated fatty acids) harden in thin layers to form strong and elastic surface coats. These are available in oxidized and polymerised varieties. The former being (obtained by blowing air through linseed oil heated to about 160°C and by introducing a manganese-lead-cobalt drier) the latter is obtained by polymerising linseed oil by heating it to about 275°C and introducing a manganese-lead-cobalt siccative. Linseed oil is the most widely used vehicle. It contains acid which reacts readily with oxygen and hardens by forming a thin film known as *linoxyn*. A priming coat of pure linseed oil induces corrosion which is greatly retarded by the presence of pigments. For this reason priming coat should contain little oil. Raw linseed oil has slow drying rate as such pale boiled linseed oil having better drying properties is used. The best results are obtained by using double boiled linseed oil.

Pigments are used to hide the surface imperfections and to impart the desired colour. They protect the paint film by reflecting the destructive ultra violet light, which acts as a catalytic agent for the destructive oxidation of the film. They also improve the impermeability of the paint film and enhance its resistance to weathering, affect the flow characteristics making it possible to paint vertical and uneven surfaces smoothly. Pigments are finely ground mineral, organic substances or metal powders; their size in organic coatings ranges from 0.1 to 5.0 microns in diameter. Their general properties are covering power, colouring capacity, fineness, fire resistance, chemical stability and weather resistance. The fine particles of the pigments have a reinforcing effect on the thin paint film.

The common pigments are classified as natural and artificial. The former used for preparing limestone and glue paints, putties and coloured building mortars,

include ground natural white chalk, mastics, grey graphite, dry yellow ochre (a clay containing over 15 per cent of iron oxide), etc. Artificial mineral pigments, obtained by chemical processing of raw mineral materials, include titanium dioxide, zinc white, lead white ($2\ PbCO_3 \cdot Pb(OH)_2$), lithophone ($BaSO_4 + ZnS$), chrome oxide, red lead, gas black soot, etc. metal powders such as aluminium powder, metallic powders, gold dust, etc. synthetic substances of organic origin, possessing high dyeing capacity. Some of the examples of pigments used to produce the desired colours are lamp black and ivory black (Black), Prussian blue, indigo (Blue), chrome yellow, yellow orchre (Yellow), burnt umber, burnt siena (Brown), vermilion, red lead (Red) and copper sulphate (Green).

Solvents are the oils used to thin the paints, increase the spread, and are also known as *thinners*. They make the paint of workable consistency and evaporate during drying of the film. The common thinning agents used are petroleum, spirit, naptha and turpentine oil—a mixture of the various terpens, obtained from the steam distillation of the resinous exudations of the pine tree, leaving resin as a by-product. Turpentine is used extensively because of high solvent power, excellent flattening properties and ideal rate of evaporation.

Driers also known as plasticizers, are chemicals added to paint for specific purposes, e.g. as catalyst (accelerate the drying of the vehicle) for the oxidation, polymerisation and condensation of the vehicle in paint. The quantity of drier is limited to 8 per cent, excess of it affects the elasticity of paint leading to flaking failure. Some of the examples of driers are letharge (oxidized lead, PbO), lead acetate, red lead (Pb_3O_4), manganese dioxide and cobalt, zinc and lead chromate. Red lead is the best for primary coat over steel and metal work; it produces an extremely hard and tough film, almost impervious to air and moisture, adheres firmly to the metal and is extremely effective in protecting steel from corrosion. The cost of zinc and lead chromates is high.

Adultrants bring down the overall cost, reduce the weight and increase the durability. Adultrants also help to reduce cracking of dry paint and sometimes help to keep the pigment in suspension. Barium sulphate, calcium carbonate, magnesium silicate and silica are but a few examples. The best adultrant is barium sulphate. Silica is used only in the undercoats so as to take the advantage of its roughness in development of bond with the next coat.

16.3 CHARACTERISTICS OF AN IDEAL PAINT

The requirements are uniform spread as a thin film, high coverage, good workability and durability, sufficient elasticity to remain unaffected by expansion or contraction of the surface to be painted or by weathering action of atmosphere. The paints should also be: impervious to air and water, cheap and economical to

form a hard surface.

16.4 PREPARATION OF PAINT

The base is ground in a vehicle to the consistency of paste in a stone pestle known as *muller*, linseed oil, is intermittently added to the paste in small quantities and the mixture is stirred with a wooden puddle. In case of coloured paints, the pigment is mixed with linseed oil separately and the paste is formed as explained above. Driers are also ground separately in linseed oil. The three pastes so prepared are mixed and a little linseed oil is added further to soften the paste. The mixture is continuously stirred till a consistency of cream is obtained. The mixture is thereafter strained through fine canvas or a sieve. The paint is now ready for use. The paint so prepared can be used by adding oil or a thinner to make it of workable consistency before application.

For commercial manufacturing of paints a four-storey building is used to have gravitational flow of materials. Pigments, oil, thinner, plasticizer, drier, etc. are stored on the fourth floor and are fed by means of chutes in proper proportions, to the grinding mill placed on the third floor and are ground. The thoroughly ground materials are then sent to storage tanks on the second floor. The charge in the tanks is kept in motion by agitation mechanism so that settling of materials does not take place. An additional quantity of vehicle is added here to get the desired composition. The batch is then tested for quality control. The paint material is then strained and sent to first floor, where it is packed in containers. Finally the packed material in containers is sent to the ground floor. A flow diagram of paint manufacture is shown in Fig. 16.1.

The factors affecting the quality of paint so prepared are quality of ingredients, grinding, intimate mixing and proportioning, straining, packing, etc. Ready mixed paints are also available in the market with different trade names, e.g. Ducco, Shalimar, Jenson and Nicholson, Solignum, etc.

16.5 COVERING POWER OF PAINTS

The covering power is the capacity, of a given quantity of the paint of the suitable consistency for application, to cover the extant of area.

The covering power, also known as *spreading capacity* of paints and varnish depends upon the type of paint and its constituents, type of surface to be painted,

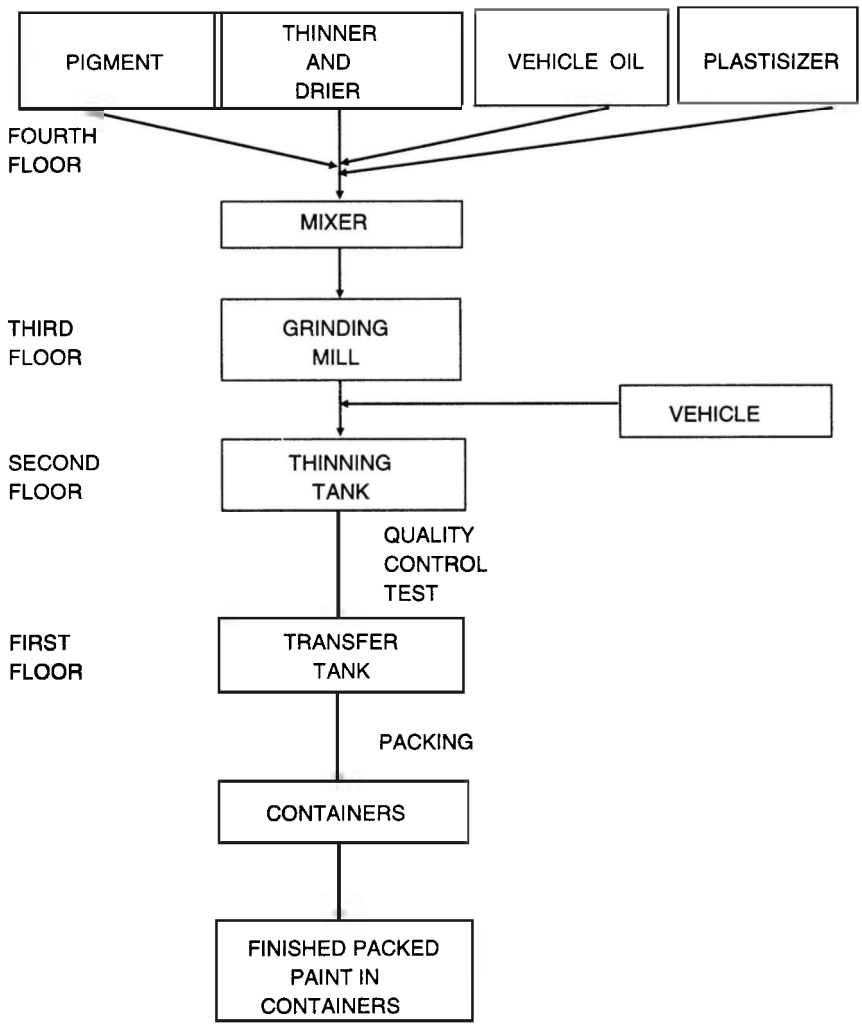


Fig.16.1 Flow Diagram of Paint Manufacture

and number of coats to be applied. The area covered by different paints is given in Table 16.1.

Table 16.1 Covering Capacities of Paints

S.No.	Type of paint or varnish	Type of surface	Area covered in sq.m/litre
1.	Lead priming coat	Wood work	10
		Metal work	11
2.	Under coat	Flat surface	11
3.	Gloss paint	Flat surface	11
4.	Enamel	Flat surface	11
5.	Varnish (first coat)	Flat surface	12
6.	Varnish (second coat)	Flat surface	15

16.6 PIGMENT VOLUME CONCENTRATION (P.V.C.)

It is the concentration by volume of the pigments expressed as a percentage of the total of the volume of non-volatile constituents of the paint.

$$\text{P. V. C.} = \frac{\text{Volume of pigment in paint}}{\text{Total volume of nonvolatile constituents of the paint}}$$

$$= \frac{\text{Volume of pigment in paint}}{\text{Volume of (pigment + nonvolatile vehicle constituents) in paint}}$$

Importance of P.V.C. The pigment volume concentration largely controls such factors as gloss, washability, adhesion and durability. With increase of P.V.C. the gloss decreases until paint becomes flat and the different type of finish or gloss of paints is found by experience, the relative quantity of binder decreases; and, as such the film formed looses cohesion and durability, the washability of paint film decreases.

Extenders, when added to a paint, amounts to increase in P.V.C. and thus decrease the gloss, washability, durability, and adhesion. So, if a pigment is costly and its covering power is high, a portion of the pigment may be economically replaced by extenders without sacrificing efficiency in covering power of pigment. Opacity of a white paint is created by the difference in the refractive indices of the pigment and vehicle. It is also influenced by the size of the dispersed pigment particles and by P.V.C.

Table 16.2 Different Types of Paints and P.V.C.

S.No.	Type of paint	P.V.C.
1.	Flat	50-75
2.	Semi-gloss	35-45
3.	Gloss	25-35

16.7 PAINTING PLASTERED SURFACES

Painting a New Surface

The operations are as follows:

Surface Preparation Paint cannot take care of construction defects. Before applying the paint it is ensured that the surface is free from dust, dirt, loose matter, grease etc. and is rubbed with an emery paper, to provide a mechanical key between surface and paint for satisfactory adhesion.

Sequence of Painting The primer (first coat) is applied with brush or spray on the prepared surface, it should be thinned with water or thinner in the recommended manner and proportion. After drying it is rubbed with emery paper.

Dents and cracks, if any, are filled with putty using a knife applicator. Putty should not be applied thick. If the required thickness is large, it should be applied in two coats. After the putty has dried, the whole surface is rubbed down well in order to smoothen the putty and provide a mechanical key to the finished coats.

Two or three finish coats are applied. Each coat is allowed to dry before the application of next coat.

Painting Old Surfaces

The procedure depends on the state of the existing coating. If any of the defects discussed below is very much pronounced it is completely removed and the surface is painted as a new surface.

Chalking Clean the surface, rub with an emery paper so that the chalk is removed. Apply one or two finish coats.

Efflorescence, Blistering, Cracking and Flaking Scrap off the old paint from affected areas. Touch up with primer and apply one or two finish coats on affected areas. Rub the entire surface and apply the finish coats.

Glossy surface Remove all gloss by rubbing with emery paper and then apply the finish coats.

Fungus growth Remove the growth. Apply fungicidal solution liberally and observe for further growth. If there is none apply the desired paint.

16.8 PAINTING WOOD SURFACES

Painting of woodwork should be done with great care. Normally 3-4 coats are sufficient for wood work.

New Wood Work

Surface Preparation The wood should be well seasoned, dried, cleaned and

the surface made smooth with an emery paper. Nails, if any, should be driven down the surface by at least 3 mm.

Knotting Knots in the wood create lot of problems. These excrete resin which causes the cracking, peeling and brown discolouration. Knotting is done so that resin cannot exude from the knots. Any of the following methods may be used suitably.

Ordinary Knotting This is also known as *size knotting*. The knot is treated with a coat of hot red lead ground with a strong glue size in water. Then a coat of red lead ground in boiled linseed oil is applied.

Lime Knotting The knot is covered with hot lime for 24 hours after which it is scrapped off. Thereafter, the process described in ordinary knotting is followed.

Patent Knotting Two coats of varnish or shelac are applied.

Priming Coat The main function of priming coat or primer is to form the base for subsequent ones. After knotting priming coat is applied over the entire surface to fill all the pores. A second priming coat is applied after first has dried. In general the ingredients are same as those of the subsequent coats but with a difference in proportion. A typical composition of primer may be

Ingredient	Primer	
	Exterior work	Interior work
Red lead	0.03 Kg	0.12 Kg
White lead	4.5 Kg	3.6 Kg
Boiled linseed oil		0.57 litres
Raw linseed oil	2.27 litres	0.57 litres
Litharge	0.06 Kg	0.45 Kg

Stopping After the priming coat putty is applied to fill the pores of the surface. Then it is rubbed smooth. Colouring pigment is also added to it to match the shade of the finished coat. On drying, the selected paint is applied with brushes to bring smoothness and uniformity in colour. After painting the surface in one direction, the brush is worked in the perpendicular direction to eliminate brush marks. This is known as *crossing*. All the successive coats are applied after drying and slight rubbing of previous coats for proper bond.

Old Wood Work

The old paint is removed with a sharp glass piece, sand paper, paint remover or with a blow lamp. Any smoky or greasy substance should be washed with lime and subsequently rubbed with pumice stone. The surface is then washed with soap and water and dried completely. Then two coats of paints are applied in a way similar to that described in painting new surfaces.

Paints for Wood Work

A mixed pigment paint provides better protection; white lead combined with zinc oxide and a moderate amount of filler such as barytes or silica gives good results. Tinted paints have proved to be satisfactory for maintaining colour and durability. Generally enamel paints are used to give high gloss surface. When the wood is of superior quality and if the grains are to be highlighted the only choice is the varnish forming a transparent or translucent film.

16.9 PAINTING METAL SURFACES

New Iron Work

The surface should be free from scales, rust and grease. Scales and rust are cleaned by hard wire brush. Grease is removed by using petroleum or by hot alkaline solution of Na_2CO_3 or NaOH, benzene, and lime water. A priming coat of red lead with barytes and raw linseed oil is then applied over the prepared surface. After drying of the priming coat, one or more undercoats with desired paint are applied. The second coat is given only after the first has dried. The finishing coat is applied carefully to produce a smooth fine surface.

Old Iron Work

The surface is prepared by scraping properly all the scales and rust with emery paper. The greasy substances are removed with lime water. The old paint may be burned with a blow lamp or by suitable solvents. After this the surface is brushed with hot linseed oil and painted as for new iron work.

Paints for Structural Steel Work

The major problem to overcome in painting iron and steel is corrosion due to electrolysis caused by the presence of air and moisture. Red lead is considered to be the best priming coat; it produces a tough elastic film, impervious to air and moisture. Pure linseed oil priming coat is detrimental in that it stimulates corrosion. The linseed oil film is rendered more impervious by the use of spar varnish. Graphite paint used for black colour, is very durable and is not affected by sulphur films, ammonia or chlorine gases. Silica-graphite paints are best; they do not crack and blister in course of time. Aluminium paint is also gaining popularity because of its shining and contrast properties and heat and chemical resistance. Bituminous paints may be very well adopted to paint inside of pipes, iron under waters, piles, ships and boats; they are unsatisfactory when exposed to sunlight. Lead or zinc paint should never be applied directly over the iron surface as it encourages galvanic action destroying the paint.

16.10 DEFECTS

A painted building with full colour effects gives complete satisfaction. But the appearance of defects, becomes a ready source of complaint. Unfortunately painting defects are by no means uncommon. They may arise from a variety of causes but the principal reasons behind them are incorrect choice of paint in relation to backing materials, application of paint to a damp surface or one to which moisture may have access and; poor workmanship.

Effects of Background

The factors affecting durability are dampness, cleanliness, movements, chemical reactions, etc.

Dampness The traditional construction in brick, cement, etc. involve the use of wet procedures. If paint is applied on an insufficiently dry background the moisture is trapped and in the process of subsequent drying the adhesion of the paint breaks down. Emulsion paints are somewhat better in this respect.

Cleanliness Paint will not adhere to the surface if it is not cleaned of dirt or dust.

Movements The painting processes can be delayed for proper results for movements caused by shrinkage and special paints should be used for thermal movements.

Chemical Reactions between backing material and paint film may push the paint off the backing material, lead to softening or discolourise the paint. This effect generally occurs only if moisture is present and is noticeable in oil paints over materials containing cement or lime. The breakdown of bond is because of the crystallisation of salts below the paint film and the discolouration is usually due to action of free lime on the pigments.

Effect of Weather

The paint film is subjected to chemical attack of atmosphere, sunlight and heat, all deteriorating it. Special chemical resistant paints should be applied in industrial areas. Alkali resistant paints weather well in coastal areas. Blue and green colours tend to fade when exposed to bright light. In addition the fierce heat of sun may breakdown the paint film because of the disintegration of the material itself and also because of the thermal movement.

The most common defects noticed after painting are as follows:

Blistering and Peeling are swelling of the paint film and can be defined as localised loss of adhesion between one or more coatings or between primer and parent surface. When swelling is because of oil or grease on the surface it is known as *blistering* and in case of moisture it is called *peeling*. It occurs in nonporous coatings such as oil based paints and enamels. A special heat-resisting type of paint

should be used for hot surfaces such as radiators.

Causes It is brought about by moist air, oily or greasy surface, or imprisoned gases between the painted surface and the paint film, which expand under the influence of heat.

Cure Emulsion paints provide a porous coating and allow the moisture to pass through.

Checking is a mild form of cracking. If hair cracks produced enclose small area it is known as *crazing*. In case the enclosed area is large the defect is called *crocodiling*.

Causes · It is caused when the paint film lacks in tensile strength and occurs when paint is applied during very cold weather or because of insufficient drying of undercoat.

Cure When cracks are very small and do not enlarge with time, the top coating is flattened with emery paper and a fresh coat of paint is applied.

Cracking The cracks extend throughout the entire paint system extending right down to the original surface.

Causes

1. Cracks in the plaster or masonry do not let the paint to remain intact.
2. Paint applied on glossy surface.
3. Premature application of top coat before the previous coat has completely dried.
4. Painting improperly seasoned wood.

Cure The causes of cracking should be attended to.

Flaking is detachment of paint film from the surface.

Cause The moisture penetrates through the cracks on the coatings and the bond between surface and paint film is lost.

Cure

1. Use of plastic emulsion paints.
2. Surface should be rubbed with emery paper before applying a fresh coat.
3. All dirt or dust on surface to be removed prior to painting.

Chalking Paint film becomes powder due to insufficient oil in primer.

Alligatoring One layer of paint film sliding over the other one, when a hard paint is applied over a soft one or vice versa.

Wrinkling or *crawling* appears when the paint film is quite thick or the oil in the paint is more than required. The lower portion of the paint does not dry due to

greater thickness of the paint film which shrinks due to drying in course of time.

Running and Sagging Paints applied over smooth and glossy surface do not stick and flow back or toward on the unpainted area. This is known as *running* and *sagging*. The surface to be painted should, therefore, be rubbed with an emery paper before painting.

Mildew Mildew thrives in warm, moist and dark places. Zinc oxide and phenol mercury oleate are very useful to check its growth.

Bloom is identified as dull patches on the finished, polished or painted surface due to defect in the quality of paint or poor ventilation.

Flashing is characterized by the appearance of certain glossy patches on the painted surface. The reasons attributed to this defect are weathering actions, use of cheap paint, and poor workmanship.

Grinning is due to the imperfect opacity of the paint film even after the final coat. The background and its defects can be clearly visible in such a case.

16.11 ENAMELS

It this type bases like zinc oxide, etc. are ground in varnish. If desired colouring pigments may be added. They dry quickly and furnish a hard glossy surface. It can be used for internal as well as external works and are generally recommended for application on wood work. These are acid resistant, not affected by alkalis, gases and, are waterproof.

Process of application The surface of the wood work is rubbed with a sand paper and cleaned. A primer coat consisting of titanium white in pale linseed oil is followed by two to three coats of enamel paint.

16.12 DISTEMPER

The base is white chalk and the thinner is water. Some colouring pigments and glue are added. They are available in powder and paste forms and are substantially cheaper than paints. They are most suitable for plastered surfaces as well as whitewashed surfaces of interior walls. Oil bound washable distemper, washable oil free distemper, and nonwashable distemper or emulsion paints are some of the types of distemper. In the oil bound distemper, the drying oil is rendered mixable with water. While using they are tinned by adding water. On drying, the oil content in distemper hardens and yields a comparatively durable coating.

Characteristics

1. The coatings are thick and more brittle compared to paints.
2. They are workable easy in application but less durable.

3. The film being porous can be applied on even newly plastered surface.

Distempering

Distempers are applied in the following manner:

Preparation of Surface The surface is thoroughly rubbed and cleaned. In case of a new plastered surface, the surface is kept exposed, to weather, for drying before the application of distemper. If an existing (old) distempered surface is to be redone, surface is cleaned with profuse watering. The efflorescence and patches, if any, should be wiped out by a clean cloth. Cracks, etc. if any, should be filled with putty.

Priming coat A priming coat as recommended by the manufacturer is applied on the prepared surface.

Final Coat Two or three coats of distemper are applied. Each coat should be applied only after the previous coat has dried.

16.13 WATER WASH AND COLOUR WASH

Fresh lime slaked with water is mixed thoroughly with water in a tub and then screened through a fine, clean cloth. Thereafter glue, dissolved in water, is added to it. The surface is cleaned and the white wash is applied with jute brushes. A white wash when mixed with colouring pigment such as yellow earth is called *colour wash.*

Characteristics

1. Lime is toxic for germs, for which white wash is good from hygiene considerations.
2. A bright surface is provided at very low cost.

Uses

They are generally recommended for low and medium class houses; ceilings are white washed and walls are colour washed.

16.14 VARNISH

Varnish is a nearly homogeneous solution of resin in oil, alcohol or turpentine. The type of solvent depends upon the type of resin used and is given in Table 16.3. The oil dries with time and the other solvents evaporate leaving behind a solid transparent resin film over the surface. For rapid drying, driers such as letharage, lead accetate, etc. are used.

Table 16.3 Materials for Making Varnishes

S. No.	Resin	Solvent
1.	Amber, copal, gum anime	Boiled linseed oil
2.	Common resin, gum dammer, mastic	Turpentine
3.	Lac, shellac, sandarch	Methylated spirit
4.	Raw copal, cheaper types of resins	Wood naptha

Varnishes provide a protected coating and gloss to the surface and intensify the wood grains.

Varnishing

Varnish is applied as under:

Preparation of Surface The wood work is made smooth by rubbing it with sand paper and the surface is cleaned.

Knotting is the process of covering the knots in the wood work, using any of the following methods may be used.

Size knotting A coat of red lead ground in water mixed with glue size is applied. After it dries another coat of red lead ground in oil and thinned by boiled turpentine oil is applied.

Patent knotting Two coats of varnish prepared by dissolving shellac in methylated sprit or wine, is used.

Stopping The surface of the wood work is then rubbed again and cleaned. Before rubbing, the surface is applied with size of hot, weak glue.

Varnish coat Varnish is then applied in two coats. The second coat is applied after the first has dried.

Types of Varnishes

Varnishes are classified as oil, spar, flat, spirit and asphalt varnishes.

Oil Varnish uses linseed oil and takes about 24 hours to dry. It is suitable both for interior and external works.

Spar Varnish derives its name from its use on spars and other parts of ships. It gives sticky effect in warm weather and is not used indoors.

Flat Varnish Materials such as wax, metallic soap or finally divided silica when added to varnish produce a dull appearance on drying known as flat varnish.

Spirit Varnish is resin dissolved in spirit. The examples are French polish, lacquer and shellac varnish. It dries very quickly.

Asphalt Varnish is made by dissolving melted hard asphalt in linseed oil with a thinner such as turpentine or petroleum spirit. It is used over shop fabricated steel works.

16.15 FRENCH POLISH

It is a type of spirit varnish, prepared by dissolving resin in methylated spirit at room temperature for use on hardwood substances to hide the grain defects. The surface is made smooth by rubbing. A filler mixed with desired colour is prepared to the consistency of a paste applied to the cracks, pores, etc. The surface is rubbed after drying and dusted off. Two coats of polish are then applied. The filler material is prepared by mixing 2 kg of whiting in 1.5 litres of methylated spirit or by mixing Plaster of Paris, red ochre and linseed oil.

16.16 WAX POLISH

It consists of bees wax dissolved in turpentine and is used for highlighting the grain over wooden surfaces. The polish is rubbed over the surface with rag until a bright appearance is obtained. Generally two coats are applied. However, it is also used over marble with 1 part of wax dissolved in 4 parts of hot turpentine or by mixing wax, linseed oil, turpentine and varnish in the ratio 2 : 1.5 : 1 : 0.5, by weight.

16.17 MISCELLANEOUS PAINTS

Aluminium Paints consist of aluminium powder (as base) held in suspension by varnish. They are highly heat reflective and resistant to acid fumes. Aluminium paints are used for painting metal roofs, silos, machinery, poles, towers and storage tanks. It provides a very attractive appearance to the surface and the painted surface is visible even in darkness. Aluminium paints have high dispersive property—over 200 m^2/litre.

Anticorrosive Paints Linseed oil is used as vehicle with dry red lead, sublimed blue lead, zinc oxide and iron oxide and zinc chromate as pigments. They are used for preservation of structural steel work against acid fumes and adverse weather conditions. The anticorrosive paints impede or obstruct the flow of corrosion current by reducing the direct access of air and water to the metal. These paints should have quick drying and hardening properties.

Asbestos Paints The main constituent is fibrous asbestos. It is used for stopping leakage in metal roofs, painting of spouts, gutters, etc. and sometimes on the outer surface of basement wall to prevent dampness. It is also called *fire proof paint*.

Bituminous Paints are made of asphalt bitumen dissolved in mineral spirit or nephtha. They are black in colour, but suitable colouring pigments may be added for desired colour. They are alkali resistant and are used to paint exterior brick work, concrete and plastered surfaces and to reduce the moisture permeability. It is also used over iron works under water. When exposed to sunlight they deteriorate very fast.

Bronze Paint Generally a pigment, aluminium or copper powder is used with a vehicle like nitrocellulose lacquer. It is highly reflective and is applied over radiators.

Cellulose Paint are made by celluloid sheets, amyl-acetate substitute or nitro-cotton dissolved in petroleum. Also known as *lacquers*, they are colloidal dispersion of cellulose derivative, resin and plasticisers in solvent and dilutents. Castor oil is also added to improve adhesion, toughness and smoothness of the paint film. A cellulose paint hardens by evaporation of the thinning agent, whereas an ordinary paint hardness by oxidation. Being very costly its use is restricted to painting cars, ships and airplanes. The trade names are spray paint, Ducco etc. Cellulose paints are not affected by adverse weather conditions.

Casein Paints Casein, a protein substance extracted from milk, curds, is mixed with a base like whiting and lithopone. They are available in powder or paste form. They are used over new plaster surface, walls and ceilings. A drying varnish is added when used over exterior surfaces of buildings. Casein paints can be tinted in any colour.

Cement Based Paints White or coloured Portland cement (70 per cent) forms the base. They are thinned with water during application. Proper curing is necessary for strength and durability. Cement paints are durable, strong and display better water-proofing qualities and are used on exterior surfaces of buildings. Mixed with boiled linseed oil they are also used over corrugated iron sheets. To get good results, an aqueous solution of sodium silicate and zinc sulphate is applied as primary coat on the surface to be painted.

Rubber Base Paints Rubber treated with chlorine gas is dissolved in solvent and desired pigment is added. They are resistant to acid, alkalis and dampness. They are used over concrete and cement plastered surfaces.

Emulsion Paints are essentially a dispersion of rubber-like resin polyesterene, and polyvinyl acetate in water and are prepared by grinding suitable pigments (titanium dioxide) in an emulsion of water (vehicle) and film forming drier, e.g. Co and Mn. Sometimes oil is used as vehicle. In the former case the emulsifying agents are sodium or ammonium soaps whereas in the latter case metallic soaps of magnesium or zinc are used. Stabilizers such as proteins (dextrin, starch, casein) are added to impart chemical resistance to the emulsion. Moreover, protein provides body thereby improving brushing. Antifoaming agents such as pine oil and kerosene are added to check any excessive foam formation by the agitation of emulsion paint during its manufacture. These paints dry and harden within 2 hours and are alkali resistant. These are useful in porous and/or wet surface. The emulsion coats are less odorous, non-inflammable, quick drying and easier to apply than other paints.

Plastic Paints have plastics as base with water as thinner. They have high covering capacity and give a neat, decorative and pleasing appearance to the surface. Owing to their high cost they are mainly used for interiors of auditoriums, showrooms and offices.

EXERCISES

Q.1 Describe briefly how the followings are prepared:
(a) Oil Paint (b) French Paint (c) Enamel
(d) Wax Polish (e) Aluminium Paint (f) Cement paint

Q.2 (a) What are the various ingredients of paints ? State the functions of each of them.
(b) What are the characteristics of good oil paints ?
(c) Why are steel structures painted ? Describe the procedure of painting an old steel structure.

Q.3 (a) What is the function of adulterant in a paint ?
(b) Discuss the reasons for the causes of defects in painting work.
(c) What precautions should be exercised while painting ?

Q.4 (a) How painting of new wood work is done ?
(b) Describe in details the types of defects in painted work.
(c) What are the differences between paints, varnishes and distemper ?

Q.5 Name and describe the properties of:
(a) Bases (b) Driers (c) Thinners (d) Adulterants

Q.6 Write short notes on
(a) Ingredients of paints (b) Defects in painted work
(c) French Polish (d) Enamels
(e) Colour wash (f) Distemper

Q.7 (a) What are the ingredients of varnish ?
(b) Classify different types of varnish and briefly describe them.
(c) What qualities a good varnish has ?

Q.8 (a) How would you judge the quality of an oil paint ?
(b) What is distempering ? How is it done ?

Q.9 (a) What is meant by spreading capacity of paint ?
(b) Describe briefly how an oil paint is prepared.

Q.10 (a) What are the objects of varnishing a surface ? Where will you prefer a varnish to a paint ?
(b) Give the requirements of paints suitable for:
(a) Wood (b) Iron (c) Cement concrete

Q.11 Write short notes on
(a) Aluminium paint (b) Asbestos paint (c) Bituminous paint
(d) Fire proof paint (e) Anti corrosive paint (f) Graphite paint

Q.12 (a) What are the different types of paints used for protecting steel structures in coastal regions ?
(b) What preparatory work should be done before repainting an old painted surface?

Q.13 (a) Describe the procedure of following :
(a) Painting of new wood work (b) Painting of an old iron work
(c) Painting of a plastered surface (d) Distempering
(e) Varnishing

Chapter

17

TAR, BITUMEN AND ASPHALT

17.1 INTRODUCTION

Bitumens are being extensively used in damp proofing the basements, floors, roofs, damp proof courses; painting timber and steel structural elements; as adhesives and tars are used in road work.

Bitumens are mainly composed of a mixture of high-molecular hydrocarbons, methane, napthene and other aromatic series and their oxygen or sulphur derivatives. Tar and asphalt are the two varieties of bituminous materials. Tars are bituminous condensates obtained in the process of destructive distillation of coal, petroleum, wood and other organic materials at high temperature without access of air. They are composed of hydrocarbons and their sulphurous, nitrous and oxygen derivatives. Asphalt is a combination of an inorganic mineral matter either calcareous or siliceous and an organic matter — a chemical compound of carbon and hydrogen known as bitumen.

17.2 BITUMEN

Bitumen is a noncrystalline solid or viscous material derived from petroleum, by natural or refinery process and substantially soluble in carbon disulphide. It is asphalt in solid state and mineral tar in semifluid state. Bitumen is brown or black in colour.

The main constituent is petrolene — a yellowish oily substance, an excess of which makes bitumen to melt at low temperature and, asphaltene — hard black substance, an excess of which makes bitumen brittle and non-plastic. Its composi-

tion is carbon 87 per cent, hydrogen 11 per cent and oxygen 2 per cent.

The properties of bitumen are modified by blowing air through it under pressure at a high temperature and the variety is called *blown bitumen.* When a volatile dilutent (kerosene, naphtha, or gasoline) is added, its viscosity is reduced and the product is called *bitumen cut-back,* mainly used in road construction and soil stabilization (2-4% bitumen). Bitumen is further classified as rapid curing (RC), medium curing and, slow curing (SC). Finely divided bitumen held in suspension in an aqueous medium is called *bitumen emulsion* and is used for soil stabilization. Bitumen distilled to a definite viscosity of penetration without further treatment is known as *straight run bitumen.*

Bitumen is not affected by light, air or water individually, but in combination they can make it brittle, porous and susceptible to oxidation forming blisters and cracks. It becomes soft at temperatures between 30°-100°C (no sharp melting point), and therefore must be protected from exposure to heat. It is insoluble in water and fairly resistant to most acids. Although bitumen is combustible, composite products, such as mastic asphalt, are not readily ignited. Physical and chemical requirements of bitumen for use in buildings is given in Appendix II.

Classification

Based on Source Bitumens are classed as natural and petroleum bitumens.

Based on Consistency (at 18° C) These are classified as solid, semi-solid and liquid bitumens.

Based on Application Bitumens are classified as road construction bitumen, building bitumen and roofing bitumen.

Natural Bitumen Pure natural bitumen occurs rarely. Limestones, sandstones and soils impregnated with bitumen are frequently found. It originates from the accumulation of petroleum in the top layers of earth crust through migration, filling pores and cavities of rocks, under the action of high temperature and pressure.

The natural bitumen is dark-brown in colour which on heating gradually softens and passes to liquid state and on cooling solidifies. It is insoluble in water but dissolves in carbon disulphide, chloroform, benzene and very little in gasoline. Natural bitumen may by extracted from bituminous rocks by blowing in kettles or dissolving in organic solvents (extraction).

Petroleum Bitumens are product of processing crude petroleum and its resinous residues. These are classified as residual asphaltums, oxidized, cracked and extracted bitumens.

Residual Asphaltums are black or dark-brown solid substances at normal temperatures, obtained by atmospheric-vacuum distillation of high-resin petroleum after topping of gasoline, kerosene and fractions.

Oxidized Bitumen are produced by blowing air through petroleum residues. Oxygen from air combines with hydrogen of the residues to give water vapour. The petroleum residues thicken because of polymerisation and condensation.

Cracked Bitumen are obtained by the cracking — high temperature decomposition — of petroleum and petroleum oils allowing high yield of gasoline. Blowing of air through residues gives oxidized cracked bitumens.

Uses Bitumen is used for manufacture of roofing and damp proofing felts, plastic bitumen for leak stops, waterproof packing paper, pipe asphalt, joint filler, bituminous filling compounds for cable boxes for sealing accumulators and batteries. It is also used for fixing of roofing felts, damp proofing felts and for heat insulation materials for buildings, refrigeration and cold storage equipments.

Properties of Bitumen

The various properties are viscosity, ductility and softening point.

Viscosity depends greatly on temperature. At lower temperature, bitumen has great viscosity and acquires the properties of a solid body, while with increase in temperature the viscosity of bitumen decreases and it passes into liquid state.

Ductility depends upon temperature, group composition and nature of structure. Viscous bitumens, containing solid paraffins at low temperatures are very ductile.

Softening Point is related to viscosity. Bitumen needs sufficient fluidity before specific application.

Bituminous Sheets

These are manufactured by running refined bitumen on to paper of different thicknesses and qualities. These sheets are used for damp proof courses. These can be bent without cracking. A lead sheet sandwiched between two layers of refined bitumen makes the sheet acid-proof.

Fluxed Bitumen

When bitumen is used in hot applications, the process is known as *hot mopping* in which case a suitable flux is added. Fluxing is essentially a softening process. The flux is usually a heavy oil added primarily to control the final setting hardness, but may also serve to reduce the temperature at which a hot applied bitumen becomes workable.

17.3 TAR

It is a dark (deep black) viscous liquid. Depending upon the source of origin it is classified as coal tar, wood tar and mineral tar.

Coal Tar is obtained, as a byproduct in the destructive distillation of coal, or in

the manufacture of coal gas. It is heavy, strong smelling and black. On the further distillation of coal tar (from coal gas) coal naphtha, creosote oil, dyes, etc. are obtained. Coal tars for road works are obtained by coking coal or melting together coal pitch with oils or dehydrated raw tar.

Composition A typical composition of coal tar from coke oven plant is true pitch 72 per cent, heavy oils 15 per cent, medium oil 6 per cent, light oil 6 per cent, moisture and ash 1 per cent.

Uses For coating of wooden poles, sleepers, iron-poles, latrine walls, etc.

Wood Tar is obtained by the distillation of resinous wood (pine, etc.). It contains creosote and as such is a very strong preservative. On further distillation wood tar produces wood creosote. Compared to coal tar creosote, it is an inferior preservative for wood. The residue left after the distillation is known as *pitch.*

Mineral Tar is obtained by the distillation of bituminous shales. Some examples are tarmac, tar paving and tar macadam.

Tarmac is ironstone slag impregnated with tar oils. It is impervious to water and used in road pavement.

Tar Paving is a composition of limestone and coal tar. It is heated before use.

Tar Macadam is used for road pavement. Soft rock materials such as lime stones, blast furnance cinder, etc. are heated in a furnance and then mixed with boiling coaltar, pitch and creosote oil. The mix is applied in road soon after cooling and rolled.

Road Tar

It is prepared from crude tar as a byproduct of high temperature carbonisation of coal in coke ovens or in retorts. There are five grades of road tars:

RT-1 :	For surface painting under exceptionally cold weather conditions, hill roads at very high elevations.
RT-2 :	For standard surface painting under normal climatic conditions.
RT-3 :	For surface painting and renewal coats and is also used for premixing chips in top courses.
RT-4 :	For premixing tar macadam (base course).
RT-5 :	For grouting.

Coal Tar Pitch

It is obtained either as the residue of the direct distillation of crude tar produced by the high temperature carbonisation of coal, or is obtained by fluxing back such

pitch residues with high boiling coal tar distillates to give products of desired softening points.

Coal tar pitch is classified on the basis of softening point into four grades as given in Table 17.1..

Table 17.1 Requirements for Coal Tar Pitch

Grade	Softening point	Sp. gr.	Distillate per cent by wt. below 270°C (Max.)	300°C (Max.)	Matter insoluble in toluene % by weight (Max.)	Ash, % by weight
Soft pitch	45-55°	1.20-1.30	4	8	25	0.50
Soft medium pitch	58-68°	1.22-1.32	4	8	28	0.50
Hard medium pitch	70-80°	1.22-1.32	3	4	30	0.75
Hard pitch	82-92°	1.28-1.38	-	-	35	0.80

Composition

Carbon	75%
Hydrogen	8%
Oxygen	16%
Nitrogen	1%
Ash and sulphur	Little

Uses Pitch is extensively used as ingredient in a number of water proofing, protective and binding compounds in masonry, timber and steel structures. It is also used in the manufacture of tar felt and flooring mastics, and as a base for coal tar paints designed mainly for cold applications. The pitch paints set by drying of the solvent.

17.4 ASPHALT

Asphalt or asphaltum is a native mixture of hydro carbons — a product of decomposition of animal and vegetable substances. It is black or brownish black in colour. At temperature between 50-100°C it is in liquid state whereas at temperature less than this it remains in solid state.

Natural Asphalt is also known as native asphalt. When obtained from lakes it is termed as *lake asphalt.* It is used for making pavements, for water proofing of structures, stopping vibrations in machine foundations, tunnels and subways, in manufacture of marine glue, and in lining trenches.

Rock Asphalt is a naturally occurring rock formation, usually limestone or sandstone intimately impregnated throughout its mass with 6-14% bitumen.

Refined Asphalt is obtained by heating pitch to drive off the water and to draw off the mineral matter by segregating the impurities.

Composition

Bitumen	52 %
Inorganic matter	38 %
Organic matter	10 %

Mastic Asphalt is manufactured by adding pulverized natural rock gradually to molten refined bitumen, agitating the mixture for about 5 hours (200-250°C) and placing it into moulds for cooling. The mass consolidates into hard elastic blocks which can be remelted when used for pavements. It is tough, durable, nonabsorbent, damp proof, noninflammable, and noiseless.

Liquid Asphalt is the viscous residue obtained by the distillation of asphaltic base crude oil to 425°C.

Cut-back Asphalt is derived by distillation of asphalt in a volatile solvent.

Artificial Asphalt is the pitch residue obtained by evaporation of the volatile constituent of coal tar. It is formed of an admixture of coaltar, pitch, ground iron slag, sawdust, chalk, etc.

Composition :

Bitumen	12%
Minerals and sand	87%
Organic matter	1%

Asphaltic Cement is prepared by oxidizing asphalt at a high temperature and is used for flooring and water proofing.

A comparison of tar and asphalt is given in Table 17.2.

Table 17.2 Properties of Tar and Bitumen

S.No.	Property	Asphalt	Tar
1.	Colour	Brownish-black	Brownish-black
2.	Viscosity	Viscous	Viscous
3.	Sp. gr.	0.92-1.02	1.08-1.24
4.	Manufacture	Fractional distillation of crude petroleum	Fractional distillation of organic material
5.	Affinity to water	Does not weather well in presence of water	Greater surface tension and the tar coatings remain intact even in the presence of water
6.	Temperature changes	Has a wider range of temperature for hardening and softening	More susceptible to temperature changes
7.	Durability	High	Loose volatile matter very fast
8.	Hardening	Slow	Quicker
9.	Toxicity	Not	Toxic and used as preservative
10.	Solubility	Soluble in CS_2	Insoluble in CS_2

17.5 TESTING

Bituminous cements are tested for consistency, heat, solubility and composition, ductility, specific gravity and adhesion.

Consistency Test

Furol viscosity test, Engler viscosity test, penetration test, or softening point test may be performed for the purpose.

Viscometer Consistency Test is conducted in Fural viscometer shown in Fig. 17.1. It consists of a cylindrical vessel with a standard orifice at the bottom. The vessel is filled with the bitumen sample and time taken, in seconds, for 50 ml of bitumen sample to flow out through the standard orifice denotes its viscosity.

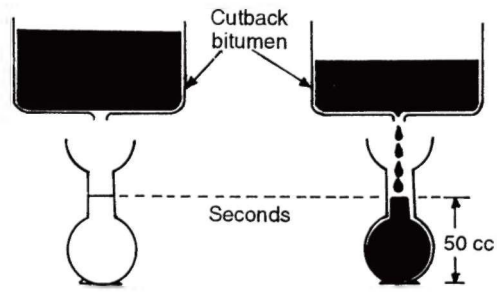


Fig. 17.1 Furol Viscometer

Engler Specific Test In this method the time taken for a 50 cc of the tar sample is divided by the time taken, in seconds, by an equal quantity of water. The quotient gives the specific viscosity of the sample.

Penetration Test determines the hardness of the bituminous materials by measuring the depth in millimetre to which a standard needle penetrates vertically under specified conditions of load, time and temperature. The needle consists of a 1.00 to 1.02 mm diameter rod tapered between 8°40′ to 9°40′. A truncated cone is formed at the pointed end, with the diameter of the smaller base: 0.14 to 0.16 mm. The test is normally conducted at a temperature of 25°C by loading the needle for 5 seconds with a weight of 100 g, and allowing it to penetrate into the sample placed in a small cup below. The apparatus used are standard penetrometer (Fig. 17.2), sample cup, water bath, thermometer, benzene solution, bitumen sample, etc.

Procedure The bitumen sample is softened to a pouring consistency and is then poured into the cup to a depth at least 15 mm in excess of the expected penetration. The sample is placed in a temperature controlled water bath and maintained for one hour at 25°C. The sample container is taken out of bath and is

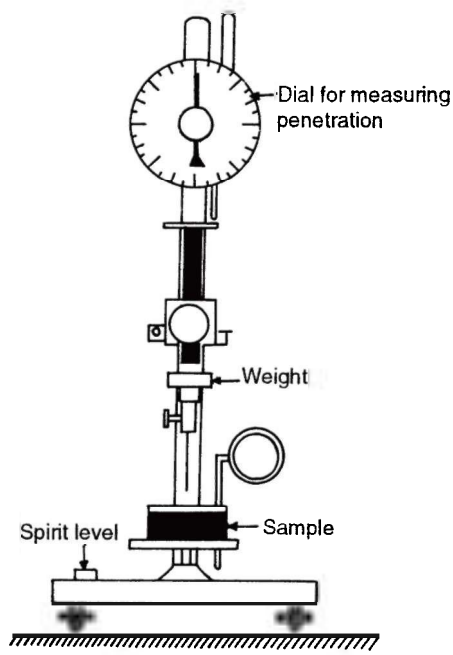


Fig. 17.2 Penetrometer

placed on penetrometer table under needle. The needle is kept touching the surface of the bitumen with the dial set zero and the initial reading is recorded.

The needle is then released for 5 seconds. It will penetrate into the bitumen. The needle, is locked and the final reading is recorded. The needle is taken out from bitumen, washed with benzene solution and the process is repeated. Penetration value will be the average of the three results.

Significance The penetration test measures the consistency of bitumen binders so that they can be classified into standard grades but on its own has no relation to binder quality. However, bitumens are known to reduce in penetration with age and to develop cracking tendencies. Penetration values below 20 have been associated with bad cracking of road surfacings, while cracking rarely occurs when penetration exceeds 30. Penetration tests carried out at different temperatures, can also determine the temperature susceptibility of a bitumen. Where resistance to flow is important, e.g. when bitumen is used to fill cracks in concrete road slabs, a small change in temperature is desirable.

Softening Point Test The Ring and Ball softening point test is extensively used to evaluate the consistency of bituminous binders. The test consists of placing a 9.5 mm diameter steel ball on a binder sample placed in a steel ring (Fig. 17.3) and its temperature is raised until a value is reached when the test sample is sufficiently soft to allow the ball enveloped in binder, to fall through a height of 25 mm. The water temperature at which this occurs is read to nearest 0.5°C and is called the softening point of the bituminous binder.

Procedure The sample binder is heated approximately between 75°-100°C above softening point and it is ensured that the sample is completely fluid, free from

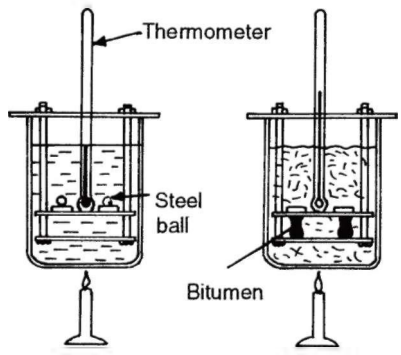


Fig. 17.3 Softening Point Test (Ring & Ball Apparatus)

water and air bubbles. If necessary it is filtered. The brass rings are also heated to a temperature approximately equal to that of molten binder and are placed on a metal plate coated with mercury or a mixture of glycerin and dextrine. The brass rings are filled with molten binder slightly above the level of ring. After cooling for about 30 minutes in air, the excess bitumen is removed with a warm sharp knife. The apparatus is assembled with the rings, thermometer and ball guides in position, and the water bath is filled to a height of 50 mm above the upper surface of the rings with freshly boiled distilled water at a temperature of 5°C for 15 minutes. A ball, previously cooled to 5°C is placed in each ball guide. The bath is then heated and the liquid is stirred so that the temperature rises at a rate of 5°± 0.5°C per minute. The temperature, for each ring and ball is recorded at the instant the binder surrounding the ball touches the bottom plate of the support, if any, or bottom of the bath. The process is repeated. The mean of the two determinations gives the softening point.

Significance Bitumen does not suddenly change from solid to liquid state,. but as the temperature increases it gradually becomes softer until it flows readily. All semi-solid state bitumen grades need sufficient fluidity before they are used for application with the aggregate mix. For this purpose bitumen is sometimes cutback with a solvent like kerosene. The common procedure, however, is to liquefy the bitumen by heating. The softening point is the temperature at which the substance attains a particular degree of softening under specified condition of test. Softening point is found to be related with viscosity. The ring and ball test results with tars are approximately 20°C lower than equiviscous temperatures. Bitumen with higher softening point is also sometimes used to specify hard bitumens and pitches. The range of softening point is from 30°-55°C.

Viscosity Test

Viscosity defined as inverse of fluidity defines the fluid property of bituminous material. It is measured by determining the time taken by a specified quantity of binder to flow from a cup through specified orifice at a given temperature. Because of the great variation of this time for different binders, it is not practicable to determine the viscosity of all binders under same conditions of temperature, heat and flow. So

different viscometers are in use. A typical tar viscometer is shown in Fig. 17.4. The time taken in seconds by 50 ml of binder to flow from a cup through a 10 mm (or 4 mm) orifice under an initial head and at known test temperature is measured. The flow times should lie between 10-140 sec, so that temperatures for tars are chosen to ensure these conditions. With cutback bitumens the 10 mm orifice cup is used at 25°C for materials whose viscosities at that temperature and in that cup exceeds 10 seconds, and at 40°C for materials whose viscosities at 25°C exceeds 75 seconds. The 4 mm cup at a temperature of 25°C is used for cutbacks whose viscosities are less than 10 seconds in the 10 mm cup at 25°C.

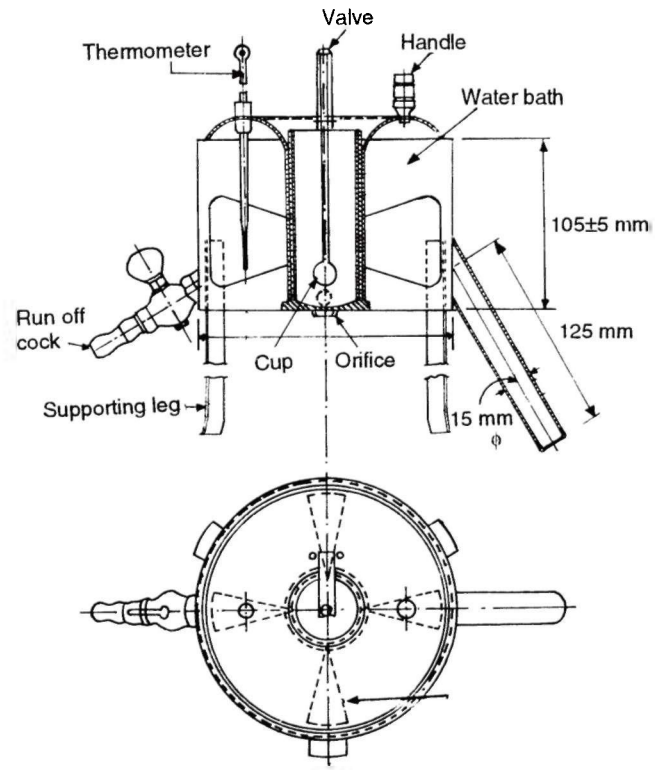


Fig. 17.4 Tar Viscometer

The tar cup is levelled with the help of a bubble level. The cup is immersed in the water bath up to little above the peg mark. The water is heated to the test temperature specified and is maintained throughout the test. The binder is heated to 20°C above the test temperature and allowed to cool. The tar is poured into the cup (when it is slightly above the test temperature). The receiver is cleaned and soft soap solution (1 per cent soap by weight) up to 20 ml mark is poured. The

receiver is placed under the orifice. When the binder reaches the test temperature the valve is opened. The stop watch is started when the receiver records 25 ml and is stopped when the receiver records 75 ml. The time elapsed is recorded in seconds. The observations are repeated 3 times and the mean of three values is taken as the viscosity of the given binder.

Significance Viscosity measurements are useful not only ensuring that material with the desired properties has been obtained, but also as a means of selecting binders for specific uses. If a binder with too low viscosity is premixed with an aggregate, it may flow off the stone while en route from the mixing plant. Conversely, if the viscosity is too high, the mixture may be unworkable by the time it reaches the site. If too low viscosity is used for surface dressing purposes, the result may be bleeding or loss of chipping under the traffic. With low viscosity binders, application temperatures can be kept lower and aggregates are more easily coated. The test results are very useful in classifying the grade of tars and cut-backs.

Heat Tests The complete tests comprise flash and fire point test, loss on heat test, distillation test and water content test.

Flash and Fire Point Test Flash point is the lowest temperature at which the vapour of a substance can be ignited in air by a flame under specified conditions of test. The substance itself does not continue to burn.

The sample is filled in an open metal cup suspended in air as shown in Fig. 17.5. It is heated at a uniform rate and an open flame is passed over its surface to determine the temperature at which the volatile vapours are given off and catch fire. The significance of the test is that in practice the bitumen should be heated 10°C below the flash point from safety point of view.

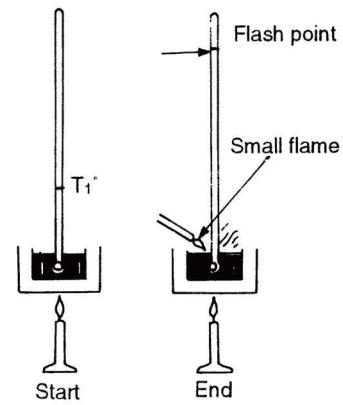


Fig. 17.5 Flash Point Test

Fire point is the lowest temperature at which the material gets ignited and burns under specified conditions. The name of the test is Pensky-Marten test (Fig. 17.6).

Loss on Heat Test The significance of the test is that the bitumen should contain just sufficient oil to impart consistency necessary for processing and blending. Also the

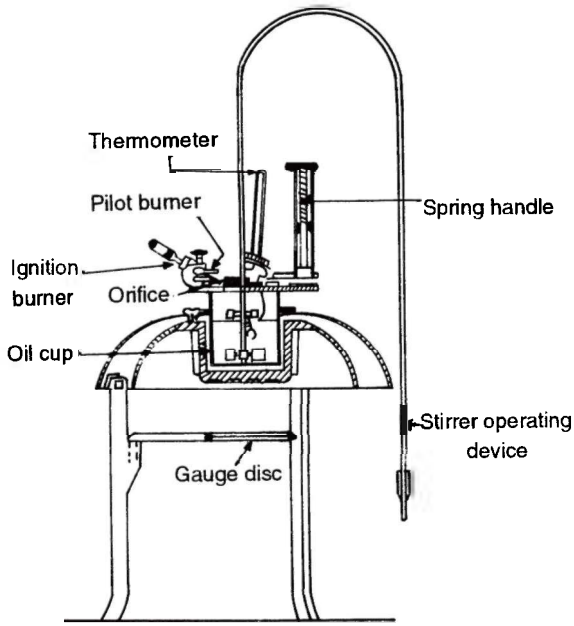


Fig. 17.6 Pensky-Marten Test

loss of weight in the test is an indication of the hardening that bitumen undergoes when heated.

A bituminous sample of 50 g is heated for 5 hours in a flat-bottom cylindrical container. It should not undergo more than 1 per cent loss in weight.

Distillation Test In this test the quantities of the various volatile oils added to bitumens fluxing or for cutting-back are determined. The residue left behind in the test indicates the actual bitumen quantity.

Water Quantity Test Foaming occurs when water is in excess of the specified amount. In this test water-free petroleum distillate is added to the sample and heated. Then the distillate is condensed and the quantity of water collected at the bottom is expressed as percentage by weight of the sample. It should not exceed 1 per cent.

Solubility Test

This test indicates the purity of bituminous binders by finding the quantity of bitumen in binder. Insoluble impurities like free carbon, mineral salts, dusts, etc. are found by this test. The sample consists of 2 to 5 g of bitumen in 100 g of carbon-disulphate or carbon tetrachloride.

Sulphonation Index Test

This test is performed to find the presence of paraffin, naphthalene, benzene, etc. which produce greasy effect and fail to hold the aggregate. Moreover, binder does not set in the presence of these impurities.

The tar sample is treated with sulphuric acid and the volume of unsulphonated residue is expressed in millimetre per 100 g to tar. The number denotes the index value of the sample.

Ductility Test

All bituminous materials must have some specified ductility so that when placed in the

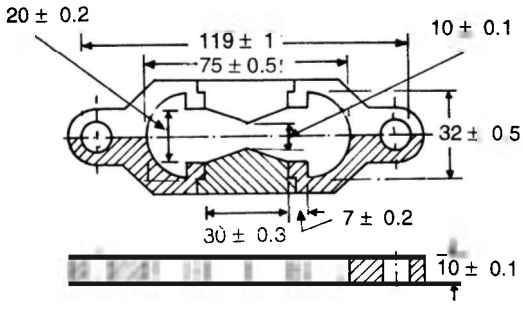


Fig. 17.7 Briquette Mould

pavement, they will distort rather than crack. The test consists of stretching the bitumen binder (in the form of a standard briquette shown in Fig. 17.7) at a standard temperature of 27°C at a standard rate of 5 cm per minute till the thread breaks. The ductility is expressed as the distance stretched in centimetres.

Procedure The binder is heated slowly to a pouring consistency between 75°C to 100°C above the approximate softening point. The mould is placed on a brass plate and coated with a mixture of equal parts of glycerin and dextrine. The fluid bitumen is poured into the mould more than level full and is allowed to cool. The whole assembly is placed for 30 minutes in a water bath maintained at 27°C. The moulds are taken out and the excess bitumen removed by means of a hot sharp knife. The assembly is placed again in bath and kept their for 85 to 95 minutes at 27°C. The sides of the mould are removed and the clips are hooked on to the ductility machine. The pointer is set to read zero. Load is applied and the reading on the scale recorded when the bitumen thread just breaks (Fig. 17.8).

The average distance (of two normal tests) in centimetres through which the pointer has travelled to produce rupture is reported. In a normal test the material between two clips pulls to a thread and rupture occurs where the cross-section is minimum. The water cover, both below and above the specimen, must remain at least 10 mm throughout the test.

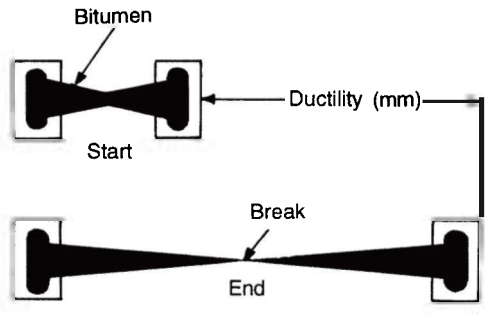


Fig. 17.8 Ductility Test Set-up

Significance This test indicates the cohesive property of the bitumen and its ability to form a thin, continuous film around the aggregate. It is also an indication of the binding strength and ability to withstand shocks. In the flexible pavement construc-

tion bitumen binders should form thin ductile film around the aggregate. The binder material which does not possess sufficient ductility would crack resulting in damping effect.

The ductility values of bitumen vary from 5 to over 100 cm. Often minimum value of 50 cm is specified for bituminous pavement construction.

Specific Gravity Test

Specific gravity is defined as the ratio of the mass of a given volume of the substance to the mass of an equal volume of water at 27°± 0.1°C.

Procedure In the Pycnometer method the specific gravity bottle is cleaned, dried and weighed along with the stopper. It is then filled with fresh distilled water and kept in water container for half an hour at temperature 27°± 0.1°C. The bottle is removed and cleaned from outside. The bottle containing distilled water is now weighed. The bitumen is heated to a pouring temperature and is poured in the empty bottle. The material is filled up to half and inclusion of air is prevented. To permit an escape of air bubbles, the sample bottle is allowed to stand for half an hour at a suitable temperature, then cooled to 27°C before weighing.

In the Balance method the test specimen is 12 mm cube prepared by pouring the liquefied sample in brass mould. The sample is weighed in air and is then weighed in distilled water, maintained at 27°± 0.1°C, to the nearest 0.1 mg.

The specific gravity of the bitumen material is calculated as follows :

Pyncnometer Method

$$\text{Specific gravity} = \frac{(c-a)}{(b-a)-(d-c)}$$

where a = weight of the specific gravity bottle

b = weight of the specific gravity bottle filled with distilled water

c = weight of the specific gravity bottle about half filled with material

d = weight of the specific gravity bottle about half filled with the material and the rest distilled water

Balance Method

$$\text{Specific gravity} = \frac{a}{a-b}$$

where a = weight of the dry specimen

b = weight of the specimen immersed in distilled water

Significance Density of bitumen is a fundamental property frequently used in classifying the binders for use in paving jobs. In most applications, the bitumen is weighed, but finally in use with aggregate system, the bitumen content is

converted on volume basis. Thus an accurate density value is required for conversion of weight to volume.

Adhesion Test

It is also known as *aggregate bitumen affinity* test. From the point of view of behaviour of aggregates towards bituminous binders, aggregates are classified into hydrophilic (which lose bituminous coating in the presence of water) and hydrophobic (which retain its bituminous coating). A number of tests have been developed to test the affinity of aggregate towards bituminous binder. The static immersion test is the simplest. The principle is immersing aggregates coated with binder in water, and estimating the degree of stripping, i.e. the ratio of the uncovered area observed visually to the total area of aggregates expressed as a percentage.

Procedure 200 g of dry and clean aggregates passing 20 mm sieve are heated and retained on 12.5 mm sieve up to 150°C when the binder is bitumen and up to 100°C in case of tar. Then the binder, 5 per cent by weight, is heated up to 10°C more than the aggregate separately. The heated aggregates and binder are mixed thoroughly. The mixture is transferred to a 500 ml beaker and cooled at room temperature for about two hours. The coated aggregates are immersed in distilled water to cover the beaker and then kept in a water bath maintained at 40°C, taking care that level of water in bath is at least half the height of the beaker. The beaker is taken out from the water bath after 24 hours and cooled at room temperature. The percentage of stripping is estimated visually keeping the specimen still under water. The average of the three results (rounded of to nearest whole number) is reported as stripping value of the tested aggregates.

Significance Besides selecting road aggregates of suitable physical strength and exercising normal quality control, it is necessary to foresee the adhesion behaviour of aggregate with bitumen as otherwise road is likely to fail due to disintegration of road components under stresses of traffic. Prior knowledge of the adhesion behaviour of available road metal with bitumen helps the highway engineer to decide on the suitability of available road metal for bituminous construction. The stripping value for aggregates in bituminous constructions should not be more than 25 per cent.

EXERCISES

Q.1 (a) Define bitumen, asphalt and tar and how do they differ ?
(b) What are the various types of bitumen and what are their uses ?
(c) What is meant by flash point and fire point of bitumen ?

Q.2 Describe briefly the classification of tar and the specifications of bitumen as a building material.

Q.3 (a) Describe Penskey-Marten's test of bitumen.
(b) What are the properties of bitumen and asphalt ?
(c) What do you understand by the following terms
Cut-back bitumen, Straight-run bitumen, Blown bitumen ?

Q.4 (a) Describe briefly the classification of bitumen.
(b) How bitumen is tested for ductility ?
(c) Give the comparison of tar and asphalt in a tabular form.

Q.5 Describe the tests for
(a) Penetration (b) Flash point and fire point
(c) Ductility (d) Softening point

Q.6 Write short notes on:
(a) Rock asphalt (b) Cut-back asphalt
(c) Bituminous felt (d) Coal tar
(e) Tar-macadam (f) Coal tar pitch

Q.7 Discuss the significance of following tests:
(a) Stripping value test (b) Ductility tests
(c) Ring and ball test (d) Viscosity test

Chapter

18

GYPSUM

18.1 INTRODUCTION

Gypsum is a non-hydraulic binder occurring naturally as a soft crystalline rock or sand. Pure gypsum is a white translucent crystalline mineral and is so soft that it can be scratched by a finger nail. When heated to 205°C, pure gypsum loses its lustre and its specific gravity is increased from 2.3 to 2.95 due to the loss of water of crystallisation.

There are two commercial varieties of crude gypsum, rock gypsum and gypsum earth or gypsite used for the manufacture of gypsum binding material. These substances consist principally of a hydrous sulphate of lime ($CaSO_4 + 2H_2O$), with varying percentages of silica, carbonate of lime, carbonate of magnesia, and iron oxide. Building gypsum is an air-setting binder composed mainly of semihydrate gypsum and obtained by processing gypsum at temperatures 150°C-160°C.

Gypsum items have a number of valuable properties like relatively small bulk density, incombustibility, good sound absorbing capacity, good fire resistance, rapid drying and hardening with negligible shrinkage, superior surface finish, resistance to insects and rodents and low energy input during burning to produce gypsum plaster. The major shortcomings are its poor strength in wet state and high creep under load. Gypsum-based items should be used only in dry state and in

premises of not more than 60 per cent relative air humidity.

Gypsum plasters, e.g. Plaster of Paris, wall plaster, stucco, and hard finish plaster are extensively used in wall construction. Flooring plaster, made by calcining gypsum at a high temperature has been considerably used. In all of these powders, gypsum in a more or less dehydrated state is the essential element. Gypsum has a unique property of moulding. When heated it gives up combined water and easily turns into powder. On adding water to the powder it can easily be shaped and moulded, and in a short time it hardens again and becomes similar to what it was in its natural state. When water is added the gypsum forms interlocking crystals. As the gypsum hardens it is this crystallisation that makes it such an effective fire resisting material.

18.2 EFFECT OF HEAT AND MOISTURE

The water of crystallisation in the gypsum ($CaSO_4 \cdot 2H_2O$) is not held firmly by the mineral. Therefore, when it is heated to about 160°C it loses a part of water of crystallisation and is known as *half-hydrate gypsum.*

$$\underset{\text{Gypsum}}{2CaSO_4 \cdot 2H_2O} \xrightarrow{150^\circ C} \underset{\text{Plaster of Paris}}{2CaSO_4 \cdot \frac{1}{2} H_2O} + 3H_2O$$

At still higher temperatures (about 200°C), gypsum loses all its water of crystallisation and turns out into anhydrate gypsum.

$$CaSO_4 \cdot 2H_2O \xrightarrow{200^\circ C} CaSO_4$$

The lost water of crystallisation can be regained under favourable damp or moist conditions.

$$2CaSO_4 \cdot \frac{1}{2} H_2O + 3H_2O \xrightarrow{\text{Hydration}} 2CaSO_4 \cdot 2H_2O$$

$$CaSO_4 + 2H_2O \longrightarrow CaSO_4 \cdot 2H_2O$$

18.3 SETTING AND HARDENING

The setting and strengthening of gypsum are due to intergrowth of very fine and poorly soluble crystals of dehydrated gypsum as they precipitate from a solution which remains oversaturated as long as the hydration of gypsum proceeds.

According to the crystallisation theory proposed by Le-chatelier when water is added to gypsum, the latter dissolves forming a saturated solution of dehydrate gypsum. Since the solubility of semihydrate gypsum is about 3.5 times more than that of dehydrated gypsum, the solution that is saturated with respect to the

semihydrate gypsum causes dehydrated gypsum to crystallise. In this process the concentration of semihydrate gypsum is reduced causing more of it to dissolve until again the solution is oversaturated and consequently again yielding crystals of dehydrate gypsum. This process continues until all the semihydrate gypsum is hydrated and crystallised.

According to colloidal theory when water is added to gypsum, the semihydrate gypsum goes into solution until the latter is saturated. In an oversaturated solution, the interaction of water with the solid semihydrate continues on their surface due to high mutual chemical affinity. The resultant dehydrated gypsum fails to dissolve further and precipitates as an unstable disperse colloid mass in the form of gel, the process being accompanied by the setting of the mass. The resultant crystals grow both in number and size, while orienting randomly and interwining, convert the jelly like mass into a crystalline growth. The resultant $CaSO_4 \cdot 2H_2O$ crystals grow into a single crystalline concretion which on drying becomes very strong.

Gypsum sets within 20 minutes and it is difficult to use it for some purposes. Suitable setting retarders like lime-kerat in glue and sulphite-alcohol vinasse may be used.

18.4 CLASSIFICATION

Gypsum binders are classified as low and high burning varieties. The low burning variety is manufactured by heating dehydrated gypsum to a temperature of about 160°C. The examples of low burning variety are building and extra strong gypsums. The high burning (anhydrite) variety is obtained by burning dehydrated gypsum at 700°C-1000°C, when the chemically bound water is lost totally. Gypsum may also be classified as low strength gypsum — obtained by heating natural gypsum rock at normal pressure, the resultant gypsum (β-modification) is very hygroscopic (60-65%) and porous (40%), and extra strong gypsum — obtained by heating gypsum at pressure of 2-3 atm followed by drying at 160°C-180°C (α-modification). The extra strong gypsum is used in metallurgical industries for manufacture of moulds.

18.5 MANUFACTURE

A 75 per cent dehydrated gypsum is referred to as Plaster of Paris. The pulverized Plaster of Paris is the basic material used to make many of the gypsum building materials. For refined grade of Plaster of Paris the oven, kettle and rotary processes are used. Hard finish plaster is made in kilns similar to that used in calcining lime.

The excavated raw materials are crushed, and if the kettle process is used, ground until about 60 per cent pass a No.100 sieve. In the rotary process the final

pulverization is omitted until calcination is completed.

The kettles employed for calcination are 2.5 or 3 m in diameter and about 2 m high. The pulverised material is chuted into the kettle and temperature raised gradually so as to drive off the mechanically held water. At about 100°C the whole mass bubbles up violently and then sinks. At 150°C the combined water begins to boil out and between 170° and 200°C the process is stopped. The kettle process, requires about 2 to 3 hours to calcine a charge yielding 5 or 6 tonnes. The calcined product is then cooled partially in a vat and is sent to the screens. Residues from the screen are ground; the fines are stored in bins.

In the rotary process the raw material is crushed to pass through 25 mm mesh and is then fed into a rotating cylinder inclined to the horizontal. Calcination is accomplished with the introduction of hot furnance gases. The roasted material is conveyed to calcining vats in which further changes are brought about by the heat within the material. The product is then ground screened and stored.

In case of Plaster of Paris or stucco the time of setting is delayed by adding fraction of one per cent of retardant like glue, saw dust or blood after the plaster has cooled to increase the handling time. Cattle hair or wood fibre is introduced for cohesiveness of plastics. Wall plasters made from pure raw materials are adulterated with 15-20 % of hydrated lime, the addition is not required for the raw materials containing considerable amount of clay. If instead of using moderate heating the gypsum is heated sufficiently to drive off all the water, the product no longer combines readily with water to form a useful plastering material. If small quantity of accelerating salts is added to it, a useful range of materials is again formed. These are known as anhydrous gypsum plasters or hard burnt plasters.

18.6 PLASTER OF PARIS OR STUCCO

It is produced by incompletely dehydrating pure finely ground gypsum at a temperature somewhat lower than 185°C. Most plasters theoretically approach — $CaSO_4 + \frac{1}{2} H_2O$ — which contains about 6.2 per cent of water.

The setting of Plaster of Paris is attributed to the formation of gypsum crystals from a supersaturated aqueous solution. When substances of colloidal nature (for example glue) are mixed with the plaster the formation of crystals is hindered and the time of set retarded. In hardening, Plaster of Paris first shrinks then expands. The latter property makes the material suitable for making casts, since a sharp impression of the mould can be secured. For the same reason it forms an excellent material for filling cracks, holes in the plastered surfaces and also on the wooden surfaces before painting/polishing.

Owing to the rapidity of set and difficulty in working, its use in structures is

limited to ornamental works. Being unstable in water it should be used for indoor works only.

Properties

1. White in colour.
2. Setting time is 5 to 10 minutes.
3. Specific gravity is 2.57.

18.7 GYPSUM WALL PLASTERS

Gypsum wall plasters gain one-half of their one-month strength in a day. Plaster and sand mortars of 1:1 proportions may be expected to develop 80 per cent of the neat strength at corresponding ages, while those of 1:2 proportion generally possess one-half to two-third of the neat strength.

The gypsum neat plaster to sand in proportion of 1:3 should set in 2 to 32 hours and in 1.5 to 8 hours when mixed with wood fibres. The dry set density of gypsum wall plaster is 8.5-10.4 kN/m^3, and compressive strength of 1:2 gypsum wall plaster is 0.93 to 1.0 N/mm^2.

Gypsum wall plasters are divided into following four categories.

Gypsum Neat Plaster 60.5 per cent or more of calcined gypsum (Plaster of Paris) with material added to control workability, time of set and cohesiveness.

Gypsum Wood Fibre Plaster 60.5 per cent or more of calcined gypsum and, wood fibre 1.0 per cent or more to increase cohesiveness, and the remaining material to control workability and time of set.

Calcined Gypsum Used for finishing coat, it may or may not carry a retardant. Calcined gypsum may be white or grey.

Gypsum Ready Sanded Plaster consists of cementing material, predominantly calcined gypsum, which has been mixed at the mill with the proper proportions of sand and other desirable constituents. It is prepared for use simply by adding water. There are two grades of Gypsum Ready Sanded Plaster, the scratch or first coat, and the browning or second coat.

The scratch coat contains 2 sand to 1 cementing material by weight. The Browning coat contains 3 sand to 1 cementing material by weight. The cementing material carries at least 60.5 per cent by weight of calcined gypsum and other ingredients to control set and workability. Some of the properties of gypsum plasters are given in Table 18.1

Table 18.1 Properties of Gypsum Plasters

Setting time (minutes) Neat	Sand mixed	Type	SO_3 %	CaO %	Magnesium salts (%)	Sodium salts(%)
20-40	120-900	i) Plaster of Paris	35	23.5	0.3	0.3
60-180	120-900	ii) Retarded Semihydrated gypsum plaster *Type I Under coat :* Browning plaster, and Metal lathing plaster *Type II Final coat :* Finish plaster, and Board finish plaster	35	23.5	0.3	0.3
20-360		iii) Anhydrous gypsum plaster (for finishing only)	40	27	0.3	0.3
20-360		iv) Knee's plaster (for finishing only)	47	31.5	0.3	0.3

18.8 HARD FINISH PLASTER

When gypsum is burnt at considerably high temperature than that for calcining of cement plaster, and treated with certain solutions like alum and Glauber's salt (Na_2SO_4), the plasters so produced show slow setting but ultimately become very hard. Such plasters may be polished to form a smooth surface and make a very satisfactory finish for interior walls. Often walls of these plasters are marked to imitate tiling with pleasing effects. Two commercial hard finish plaster cements are available.

Keene's Cement is made by burning a very pure rock gypsum at a red heat (700°C), cooling, and then adding 1.0 per cent of potassium and aluminium sulphates to accelerate the set. Subsequently the material is ground so that 90 per cent or more passes a No.100 sieve. It is pure $CaSO_4$ of pure white colour. Keene's cement is not injured by storage and mortars of it may be retempered. Set occurs between 1 to 4 hours. At 7 days the tensile strength is 3.16 N/mm^2. It is used where a greater resistance to moisture and surface abrasion is required.

Mack's Cement is made by burning gypsum at a very high temperature and adding about 0.4 per cent of burnt Glauber's salt or potassium sulphate. It is said to form unusually hard, dense and durable surface which will take paint very well.

18.9 GYPSUM PLASTER BOARDS

It is a gypsum product of recent origin made of thin layers of card board or wood cemented together with wall plaster, used for lining walls and ceiling of buildings.

The boards may be strengthened by incorporating fibres as fibrous gypsum plaster boards. Sissal or coconut fibres are generally used. The weight of plaster in the later variety is 10^4 g/m^2 of board and that of fibre is 250 g/m^2 of board. They are very light weight and have high fire resisting properties. Gypsum plaster boards can be sawn to desired size and shape. They are available in widths 400, 600, 800, 900, 1200 mm; in length 1200, 1500, 1800 to 3600 mm in steps of 100 mm and; in thickness 9.5 to 15 mm. They are classified as

The breaking load of the boards are given in Table 18.2.

Table 18.2 Breaking Load of Gypsum Plaster Boards

Type	Thickness (mm)	Transverse (N)	Longitudinal (N)
Plaster board	9.5	140	340
	12	180	500
	15	220	650
Base board	9.5	125	180
	12	165	235

Note : For fibrous boards the deflection should not exceed 19 mm when subjected to a proof load of 340 N.

Gypsum wall boards	It has a face to which decoration may be applied.
Gypsum wall board with reduced water absorption rate	These boards have additives in the core and/or the paper liners to reduce water absorption rate.
Gypsum wall boards with improved core cohesion at high temperature	These boards have mineral fibres and/or other additives in the gypsum core to improve core cohesion at high temperature. These have a face suitable for direct direction.
Gypsum plaster base board	These boards have a face suitable to receive gypsum plaster and may be perforated during primary manufacturing.
Gypsum plaster base board with improved cohesion at high temperature	It is a combination of the above two.
Fire resistant gypsum wall boards	These boards have cores containing special mineral materials.

18.10 NON-LOAD BEARING GYPSUM PARTITION BLOCKS

These can be solid or hollow, rectangular with straight and square edges and true surfaces.

The compressive strength of these partition blocks should not be less than 50 N/m^2 on gross area.

Length (mm)	Height (mm)	Breadth (mm)	Hollow blocks	
			Circular holes (mm)	Elliptical or rectangular holes (mm)
700 maximum in step of 100 mm	300 maximum	75	15	20
		100	20	20
		125	25	30
		150	15	20

18.11 PYROCELL

It is finely ground powder containing an admixture, forms a gas on being mixed with water and expands the mixture to 3 or 4 times its volume. This inflated paste hardens into a light, cellular, fire resistant mass possessing good acoustical and insulating properties.

EXERCISES

Q.1 (a) What is gypsum ?
(b) How is gypsum classified ?
(c) What is Keene's cement ?

Q.2 (a) What is Plaster of Paris ? What are its uses ?
(b) What are the various types of gypsum wall plasters ?
(c) Briefly describe the effect of heat and moisture on gypsum.

Q.3 Write notes on:
(a) Stucco (b) Hard finish plaster (c) Pyrocell

Q.4 (a) Describe setting and hardening of gypsum.
(b) Give the salient features of Keene's and Mack's cements.
(c) How is Plaster of Paris manufactured ?

Chapter

19

MISCELLANEOUS MATERIALS

19.1 ADHESIVES

Adhesives are natural or synthetic binders used for surface coatings. Natural binders like plant juices, glues, etc. have been in use since prehistoric age but have gradually lost their social acceptance and have been replaced by synthetic binders derived from plant minerals or mineral oil. These may be applied hot, or as an emulsion, or with a solvent. High load bearing adhesives have been developed for engineering applications. Structural adhesives are based on specially cured rubber-toughened epoxies, acrylics and silanes. Silane resins are used to prevent moisture penetration.

Advantages

Adhesives have an advantage over rivets and bolts by distributing stress over larger areas of a joint. This reduces galvanic corrosion between dissimilar metals and provides the ability to cement together extremely thin sheets. The process of bonding with adhesives is economical.

Disadvantages

Adhesives lose stability at high temperatures and the resistance to peeling is poor. Special care is to be exercised in their application. They need lot of time for bond to form.

Properties

Adhesives should have high tensile strength. The important physical properties of adhesives are cohesive strength, adherence, fluidity, and wettability of the substrate.

Cohesive Strength Adhesives should have more cohesive strength than either of the surfaces being held together. Usually the adhesion becomes more brittle as its cohesive strength is increased.

Adherence For an adhesive to hold two surfaces together, the former should form a strong bond at each of the interfaces between the surface and the adhesive, and the adhesive must have strong cohesive strength. Since adhesive failure occurs in the weakest bond, failure can occur at either interface, as also for cohesive failure. Failure may also occur inside the adhesive itself. In practice the bond failure at the interface is rare. Regardless of the quality of the adhesive clean surfaces are necessary to get the best results.

Fluidity When the liquids are stirred, they become temporarily more fluid because of alignment of their tiny crystals. The fluid thickens as soon as stirring is stopped. This property, called thixotropy of adhesives and paints helps to prevent a sag or run when these coatings are applied on vertical surfaces. If the viscosity of a liquid increases with the shear stress of stirring, it is called *dilatency*. Since the viscosity decreases with increase in temperature, an adhesive should be applied while hot.

Wettability Adhesive must wet the surface thoroughly as it spreads. It must be able to flow into the surface crevices displacing dirt, moisture, and trapped air. For this purpose the surface tension of adhesive can be lowered by adding a surfactant wetting agent.

Types of Adhesives

Following are the types of adhesives in use.

Organic Solvent Thinned Adhesives are applied to each of the two surfaces and the solvent is allowed to escape before the two surfaces are put together. Solvents are classified as active and nonpolar, e.g. ethyl acetate, methyl ketone, and poor and polar such as aliphatic paint thinner.

Latex Adhesives are natural or synthetic rubber or vinyl copolymers. These water-dispersed or latex adhesives contain, elastomeric film former, emulsifiers, thickeners, and antifoaming agents. The examples of synthetic rubber-based adhesives are styrene butadiene and neoprene.

Water-dispersed Adhesives depend on natural materials for bonding. The bond of these can be destroyed by soaking in water. The examples are glue made by hydrolysis of collagen extracted from skin and bones of fish and animals. Natural

adhesives are casein and soybean used in wood working industry. Dextrin adhesives are made from starch for use with paper products.

Two-package Adhesives In this type of adhesive solvent is not required. The examples are epoxy adhesives. These are made by using a low-molecular-weight partially polymerised polymer.

19.2 ASBESTOS

It is a silky, fine fibrous mineral made into a fabric, paper, insulating cement and insulating board. It occurs in the veins of metamorphosed volcanic rocks. The original source of asbestos is the mineral antinolite. However, the fibres of chrysotile have replaced antinolite because of their high tensile strength (550-1370 N/mm^2) and melting point (1520°C). Asbestos fibres are used to make sheets and boards which are economical, durable, workable and fire resistant.

Uses

Asbestos is used to make sheets and boards for roofing, false-ceilings, paneling, partitions, wall linings, door panels, window panes, sign boards, wardrobes, etc. In the form of pipes it is used to drain rain water, soil water, etc. It is also used for making paints.

19.3 LINOLEUM

It is a plastic material obtained by oxidizing linseed oil into a rubber like substance mixed with ground cork, wood flour and pigments. The resulting material is pressed upon a backing of burlap.

Linoleum is classified as plain, printed and inlaid. It is available in the form of tiles and rolls. The plain linoleum of a uniform colour is available in thickness 2-4.5 mm. The printed linoleum has a pattern printed on it in oil paints. Its thickness ranges from 1.25-2 mm. The inlaid linoleum has small units of linoleum in different colours and shapes patterned and pressed on a burlap back.

Uses

This is most suitable decorative floor covering for wood and concrete floors.

Properties

Linoleum floors are durable, resilient, quiet and comfortable. They are cheap easy to install and maintain.

19.4 THERMOCOLE

Thermocole is a light and cellular plastic material used for sound and heat insulation

of ceilings, walls, refrigerators and for air conditioning of the buildings.

It is soft, light, strong and durable having compressive strength in 11.7 to 14.4 N/mm^2 range. It has excellent heat, sound and electric insulating properties.

19.5 HEAT INSULATING MATERIALS

The purpose of thermal insulation is to restrict the heat transfer from warmer to cooler areas.

The commonly used heat insulating materials work on principle of air spaces formed between structural components, surface insulation and, internal insulation. Well known products are aerated concrete, gypsum boards, fibre boards, asbestos cement boards, chip boards, cork boards, foam plastic, aluminium foil, reflecting paints, expanded blast furnance slag, vermiculite, fibre glass, glass wool, etc. Cavity wall, though costly, provides good insulation.

Properties

A good heat insulating material should be impermeable to water, fire proof, resists insect attacks, have low thermal conductivity (0.0228 $kCals \cdot cm/m^2{}^\circ C$). Since a good heat insulating material has porous structure the strength is lowered affecting its stability.

19.6 SOUND INSULATING MATERIALS

A well designed building should incorporate sound insulation to restrain noise level. High noise conditions result in uncomfortable living conditions, mental strain, fatigue and may even lead to nervous break down or temporary deafness. Adequate insulation can be achieved by using sound absorbing or sound repellent materials.

The commonly used sound insulating materials are cellular concrete, asbestos, rock wool, glass wool, glass silk, mineral wool boards, cane fibre and porous tiles. Acoustic plastics such as gypsum plaster is very effective in sound insulation.

Properties

A good sound insulator should have low density, porous texture, resistance to moisture, pleasing look. It should be incombustible, light in weight and easy to handle and fix, resistant to attacks of vermins, insects, termite and dry rot.

19.7 GEOSYNTHETICS

Geosynthetics are made of polypropylene, nylon, PVC and other synthetic materials. These are being used for a variety of innovating usage in civil engineer-

ing construction works (Table 19.1). Some of the popular usages are for reinforcement, separation, drainage, filtration and moisture barrier, seepage control, foundations and pavements. The success and increasing popularity of geosynthetic applications in various civil engineering works can be attributed to a number of advantages associated with its usage, some of which are :

1. They can be good replacement for scarce and costly conventional construction materials like cement and steel for several types of applications.

2. They may be very useful, or perhaps the only alternative, at some of the poor site conditions.

3. They can be used and installed rapidly and have proved economical in mass usage.

4. Compared to other reinforcing materials (e.g. steel) they are better resistant to atmospheric weathering action.

5. They have added advantage of being useful in environment protection works.

Geosynthetics have been classified as Geotextiles, Geogrids, Geomembranes and Geocomposites.

Geotextiles are any permeable textile material used with foundation, soil, rock, earth or any other geotechnical engineering related material, as an integral part of man-made project, structure or system. These are generally synthetic polymeric materials and consist of either woven or non-woven fabrics and are generally used for separation, drainage, filtration and reinforcement.

Geogrids are relatively stiff materials with large apertures of sufficient size (10 to 50 mm) to allow interlocking with surrounding soil, rock, earth or any other geotechnical material. They are also characterised by high dimensional stability and tensile modulus at very low elongation. Because of the large openings, they cannot be used in filtration and as moisture barriers but are quite useful for the purpose of separation and reinforcement. They can be used in road pavements, or in improvement of bearing capacity.

Geomembranes are a continuous membrane type linear and barrier composed of asphaltic, polymeric or a combination thereof materials with sufficiently low permeability so as to control fluid migration in a geotechnical engineering-related man made project, structure or system.

Geocomposites consist of combinations of geotexites, geogrids, geomembranes and/or other materials. In geocomposites best features of different types of geosynthetics are incorporated in such a way that the joint action of the materials provide optimal performance in a particular situation.

Table 19.1 Functions of fabrics in various Civil Engineering Applications

APPLICATION	FUNCTION			
	Separation	Filtration	Drainage in the plane	Reinforcement
Roads, Railways and Area Sub-grade Stabilization				
Drainage				
Wet Fill Enbankments				
Coastal and River Protection				
Land Reclamation				
Asphalt Reinforcement				
Earth Reinforcement				

Dominant Function | Secondary Function | Not Important

LIME-PUZZOLANA MIXTURES

APPENDIX - I

1. **Scope** - Requirements for lime-puzzolana mixture for use in construction works.

2. **Type** - LP40 - For masonry mortars and plasters of grade 3.0 to 5.0 N/mm^2 and for foundation concrete.
LP20 - For masonry mortars and plasters of grade 1.5 to 3.0 N/mm^2 and for foundation concrete.
LP7 - For masonry mortars and plasters of grade 0.7 to 1.5 N/mm^2

3. **Requirements** - See Table A

Table A - Requirements of Lime-Puzzonala Mixtures

Sl. NO.	Characterstic	Requirements		
		Type LP40	Type LP20	Type LP7
(i)	Free moisture, per cent, *Max*	5	5	5
(ii)	Loss on ignition, per cent, *Max*	20	20	20
(iii)	Fineness, per cent, retained on 150-micron sieve	10	10	-
(iv)	Setting time (by Vicat apparatus), hours: (a) Initial, *Min* (b) Final, *Max*	 2 24	 2 36	 2 48
(v)	Compressive Strength: Average compressive strength of not less than 3 mortar cubes of size 50 mm composed of one part of lime puzzolana mixture and 3 part of standard sand volume, N/mm^2: (a) 7 days, *Min* (b) 28 days, *Min*	 2.0 4.0	 1.0 2.0	 0.3 0.7
(vi)	Water retension-flow after suction of mortar composed of one part of lime-puzzolana mixture and 3 parts of standard sand by volume, per cent of original flow, *Min*	70	70	70

INDUSTRIAL BITUMEN FOR USE IN BUILDINGS

APPENDIX - II

1. **Scope** - Physical and chemical requirements of industrial bitumen for use in buildings and for other industrial purposes.

2. Industrial bitumen either fully blown or semiblown shall be of the following ten grades:

75/15, 65/25, 75/30, 85/25, 85/40, 90/15, 105/20, 115/15, 135/10, 155/6

The two figures given in the grade denote approximate values of softening point and penetration in that order; for example, 85/25 means that industrial bitumen corresponding to this grade has approximately a softening point of 85°C and a penetration of 25.

3. **Requirements** - See Table B

Table B - Requirements of Industrial Bitumen

Sl. NO.	Characteristic	Limit for Grade									
		75/15	65/25	75/30	85/25	85/40	90/15	105/20	115/15	135/10	155/6
(i)	Specific Gravity at 27°C	1.00 to 1.05	1.00 to 1.05	1.00 to 1.05	1.00 to 1.05	1.00 to 1.05	1.01 to 1.06	1.01 to 1.06	1.01 to 1.06	1.01 to 1.06	1.01 to 1.06
(ii)	Flash point, Pensky-Martens Closed Type °C, *Min*	200	200	200	200	200	200	200	200	200	200
(iii)	Softening point, °C	65 to 80	55 to 70	70 to 80	80 to 90	80 to 90	85 to 100	95 to 115	110 to 120	110 to 140	110 to 160
(iv)	Penetration, at 25°C, 100 g, 5 seconds in 1/100 cm	10 to 20	20 to 30	25 to 35	20 to 30	35 to 45	10 to 20	15 to 25	8 to 20	7 to 12	2 to 10
(v)	Ductility, at 27°C, in cm, *Min*	2.5	10	3	3	3	2	2	2	1	0
(vi)	Loss on heating, per cent by weight, *Max*	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
(vii)	Matter soluble in carbon disulphide, per cent by weight, *Min*	99	99	99	99	99	99	99	99	99	99

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